BIS Department for Business Innovation & Skills

ECONOMIC IMPACTS OF THE UK RESEARCH COUNCIL SYSTEM: AN OVERVIEW

Science and Innovation Analysis (SIA)

MAY 2010

CONTENTS

Summary

- The UK system of funding for Science and Research is managed under a dual structure, combining block grants to Universities and project grants allocated by seven Research Councils. This report assesses the economic impacts of the stream of funding managed by the Research Councils. It is based on the quantitative and qualitative data returned by Councils under the ‘Economic Impact Reporting Framework’, which is part of the monitoring structure that governs the relations between the seven Councils and the Department for Business, Innovation and Skills.
- It is sometimes argued that the economic impacts of science and research are most visible after commercialisation of research-based discoveries. This report takes a broader view of Research as a problem-solving activity with impacts at different levels of maturity. In the introductory section of the report we illustrate and describe how the outcomes and outputs of science and research add to the creation, the diffusion or the maintenance of knowledge.
- Research Councils activities are accounted for with a mixture of qualitative and quantitative evidence, on the following aspects of performance:
    - *Overall Impacts*
    - *Innovation Outcomes and Outputs*
    - *Knowledge generation*
    - *Investments in the research base*
    - *Public Engagement*

- The sections on Overall Impacts and Innovation Outcomes and Outputs demonstrate how Research Councils fund activities at the forefront of innovation in technologically advanced sectors, bringing to the market new drugs and new products and services with estimated substantial monetary returns.
- Albeit more difficult to value in monetary terms, Research Councils make a sizeable contribution to the quantity and quality of publications contributed by the UK to global knowledge. Taken together Councils fund a minimum of[1] 8,000 PhDs a year, adding significantly to the accumulation of specific and technical human capital within the UK.
- Research Councils advocate actively for engagement with users and the public. Knowledge exchange activities are an increasingly important source of complementary funding while public engagement is now embedded in strategic agendas as a means to exploit synergies

[1] Some Councils report on fully funded PhDs only, hence this is at best a lower bound.

between the researchers and the parsimonious users of research outputs.

- This report is by no means a definitive account of the impacts of Research Councils, but the evidence suggests continuing and growing effects of Research Council activity on UK innovation and economic performance.

1. Introduction

This report evaluates the economic impact public funds for Science and Research managed through the seven Research Councils in the UK. The Councils are organised either along broad disciplinary lines (such as physical or social sciences) or around particular key functions (such as environmental issues or the management of research facilities). In alphabetical order the Councils are:

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

The Councils are funded through the Department of Business, Innovation and Skills (BIS), and disburse research funds to a wide range of institutions with complex final objectives. Both the Government and the Councils seek to monitor the impacts of the activities they fund[2]. This ambition is embedded in the Government's commitment to Science and Research articulated in the 10 Year Science and Innovation Framework. The Economic Impact Group, led by Mr Peter Warry, published recommendations on how the Research Councils could deliver and demonstrate they are delivering economic impacts in 2006. The current monitoring structure largely follows from those recommendations.

Two complementary reports on impact are returned by Councils annually. The 'Baseline Reporting Framework' reports in a general qualitative way on outcomes of research council activity. The 'Economic Impact Reporting Framework' (EIRF), is more quantitative in character and seeks, where possible, to develop data on inputs as well as outputs. The performance of Research Councils in this report is assessed against information returned under the Economic Impact Reporting Framework, all of which together with the Baseline Reports are available in the relevant Council website.[3]

1.1 Research Councils in the UK innovation system

[2] The Warry Report http://www.dti.gov.uk/files/file32802.pdf.
[3] Corresponding websites: http://www.ahrc.ac.uk; http://www.bbsrc.ac.uk; http://www.esrc.ac.uk; http://www.epsrc.ac.uk; http://www.mrc.ac.uk; http://www.nerc.ac.uk; http://www.stfc.ac.uk.

An important feature of the UK innovation system is a substantial Science and Research Base[4], largely though not exclusively funded by Government. The UK Science and Research System has two main components - Universities (where research is performed in departments or in problem-focused research centres), and Research Council Institutes.

Public sector funding for Science and Research is organised via the Dual Support System into two main channels: firstly there are block research grants to Universities distributed by HEFCE and linked to quality research performance over 5 years as portrayed in the Research Assessment Exercise (RAE)[5]. Universities have discretion over the in-house allocation of these resources. Secondly, there is project or programme based funding managed by the Research Councils providing resources to both Universities and Research Council Institutes. Here the Research Councils define strategic priorities and allocate funds to research performers via peer review of research proposals. The funds under the Councils stream may go to individual projects or large-scale programmes of work around priority topics, as well as funding Research Council Institutes.

1.2 Governance and strategic decision-making

Public research funding in the UK operates under the long-standing 'Haldane principle', according to which the Government identifies strategic priorities, and the scientific community selects projects within relevant fields on the basis of scientific merit, as assessed by peer review. The Research Councils are a central mechanism for the operation of this principle.

The Director General for Science and Research is responsible for advising Ministers on strategic priorities. In advance of major decisions on allocations he consults key stakeholders who are either themselves science funders (such as charities and foundations), learned societies, the Chief Scientific Advisor, Department Chief Scientists and major science users and funders (such as businesses).
The Research Councils then develop strategic plans in close collaboration with stakeholders, and organise decision-making on specific research proposals. These plans are then agreed by BIS. The resulting structure of funding indicates that strategic decisions are indeed made – funding is not dispersed widely across the system, but tends to be concentrated in key fields and institutions.

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[4] In this report the terms "Science" and "Research" may at times be used interchangeably to identify the whole Ecosystem of Science and Research.
[5] This performance related reward system is under review and a new Research Excellence Framework (REF) is undergoing consultation. http://www.hefce.ac.uk/Research/ref

1.3 Mechanisms of economic impact

The UK Government does not fund scientific research only for economic purposes. Significant parts of the UK research effort relate to issues to do with population wellbeing (such as research into public health problems), or defence, or cultural issues, or better understanding of social dynamics. Nevertheless – as shown below – such research may have important economic spin-offs. Even where research may ultimately have economic implications, the returns may be long-term and indirect.
Traditionally, the research sector, comprising universities and research institutes, has been where most new scientific and technological principles are discovered. Nevertheless, the benefits of investment in research are fully reaped when these discoveries transform into innovations. This view of the research sector leads to an emphasis on commercialisation as the central mechanism of economic impact, and hence to a policy focus on intellectual property rights, patenting, and technology transfer.

Notwithstanding the fundamental role of research in the process of innovation, it is important to bear in mind that the outcomes and outputs of research are not limited to specific discoveries, and that many great innovations were achieved by chance. There are many ways of grouping the multiple routes through which research generates economic impact. Delivering skilled people and generating new knowledge are primary outcomes as well as the creation of new businesses and helping improve the performance of existing business. Moreover a good research base serves as a focal point of attraction for foreign investment for research and innovation complementing domestic efforts from public and private sectors.

In order to avoid too narrow a focus when accounting for the impacts of science and research it is convenient to structure them in terms of knowledge generation and diffusion. The OCED[6] identifies four broad ways in which the research sector contributes to the creation and use of knowledge in both economic and social life. These are:

- the building of technology-relevant knowledge bases (primarily through research),
- the creation of technological capabilities in people and organisations (through teaching and post-graduate training and through the domestic and foreign investment in research infrastructure);
- the diffusion of knowledge (through interactions with knowledge users, expanding the supply of businesses but also fostering the demand for new knowledge in existing ones), and

[6] Tertiary Education for the Knowledge Society. Volume 1. OECD Report (2008)

- the maintenance of knowledge (inter-generational storage and transmission of knowledge through codification, libraries, databases, etc).

Each of these in turn conceal complex interactions across producers and users knowledge (op. cit.)

1.3.1 Building knowledge-bases

The research sector is the primary producer of scientific knowledge albeit not the only one. Companies also produce and apply scientific knowledge, mostly in response to specific problems but also to remain “plugged in” to the external scientific network (Cockburn and Henderson, 1998). Nevertheless, the central piece of the science system is the publicly funded research sector (Colyvas et al, 2002: 61-2)[7]. Universities and Research Institutes build knowledge bases through research and associated activities, but not exclusively in the form of ‘blue-sky’ science. Knowledge breakthroughs may often happen by chance but in effect they result from past knowledge accumulation, through incremental research, testing, improved measurement, better instrumentation or new uses of research technologies. Much research involves continuous monitoring and observation of for example natural phenomena over long periods of time, or the combination of existing knowledge in new ways. The research effort also links diverse areas of knowledge, creating wider and more complex multi-disciplinary knowledge bases. Research is a problem-solving activity that expands the pool of usable knowledge, and knowledge is the primary means to achieve ground breaking discoveries of social and economic importance.

1.3.2 Developing human capital

A natural extension of its role as a maker of knowledge bases is the research sector’s fundamental part in the process of human capital formation. As with other roles, this is not exclusive to public research sector since informal learning at work, firm- and sector-specific skills and on-the-job training also contribute to the accumulation of human capital. Formal education and learning at the higher level, however, take place predominantly within the science and research system. Despite the fact that teaching is often held to be closely linked to research, it is arguably quite separate from it (Nelson, 1986: 187)[8]. To the extent that science is a problem solving activity, the contribution of formal education to the accumulation of higher level human capital takes place through two channels. The human capital generated by teaching and learning works through the inter-generational transmission of

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[7] Colyvas, J., Crow, M., Gelijns, A., Mazzoleni, R., Nelson, R. R., Rosenberg, N., and Sampat, B. N. 2002. How Do University Inventions Get Into Practice?. *Management Science.* 48, 1 (Jan. 2002), 61-72

[8] Richard R. Nelson (1986), Institutions Supporting Technical Advance in Industry *The American Economic Review*, Vol. 76, No. 2, (May, 1986), pp. 186-189

specific forms of knowledge, through formal and informal training, some of which may lead to qualifications. However there is a subtler and fundamental aide to human capital engendered within the science system which is developing problem-solving capabilities of a more general character. The latter is particularly important since the dynamics of knowledge imply a need for continual updating and retraining.

1.3.3 Knowledge diffusion

The transmission of knowledge from where it is conceived across the research sector and beyond it is a necessary condition for knowledge to result in visible economic and social benefits. Because of the multiplicity of uses and users of knowledge, diffusion can take a number of forms. The best known and most direct is the early and timely publication of findings, predominantly but (once more) not exclusively by publicly funded researchers. It is not uncommon for companies in certain sectors to engage in the diffusion of knowledge (Cockburn and Henderson, 1998; Rosenberg, 1990). A great deal of interactions between the research and non-research sectors takes the form of collaborative arrangements: from consultancy contracts, collaborative research, joint ventures and informal channels. Informal interactions are commonplace but difficult to get a grip on: studies of engineering practice have shown that engineers often retain links with those who have taught them, and that they use these links in seeking solutions to engineering problems that they encounter (Gibbons and Johnston, 1974 was a pioneering study on this)[9]. The diffusion of knowledge therefore does not have the single goal of spreading results and ensuring appropriability but also distributing problem solving ability more evenly, taking it where it is needed outside the research sector. Research institutions not only spread knowledge, they spread search heuristics, or fruitful ways of approaching problem-solving.

1.3.4 Knowledge maintenance

The stock of knowledge is an invaluable asset that requires maintenance. Being knowledge in its various forms the basic input and output in the research sector, it is also here where preservation and storage are most important and efficiently carried out. These maintenance activities take place in libraries and data archives but also to same extent through the oral transmission of knowledge in seminars and conferences. Maintaining knowledge can be a resource-intensive activity, and the costs of maintenance are not trivial. This can be a major burden for research budgets.

In fulfilling all of these generic roles, the research sector performs a variety of complex activities, requiring highly skilled labour, state-of-the-art facilities for knowledge creation but also for knowledge storage and a steady stream of

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[9] Gibbons M & Johnston R (1974). The Roles of Science in Technological Innovation. Research Policy 3 220-42

resources that will ensure continuity. Although the private initiative engages with the research sector actively, the level of investment required for a high performing science and research system is bound to exceed the private valuation, due to the presence of social spillovers and externalities. The higher social value of research justifies public spending but it does not obviate the need to monitor the proceeds of public investment in science and research. The Research Councils collectively are a major publicly funded partner in the UK science and research system.

2. A framework for the assessment of Seven Research Councils

All Research Councils and the funding they receive have the common goal of maintaining the UK international standing in research generation and exploitation[10]. It is therefore reasonable to seek a common framework for evaluating progress against this macro-level objective. Ultimately research generation and exploitation brings about improved wellbeing and economic growth[11]. These goals can be achieved through many channels. A suitable assessment framework has to allow as well for the particular circumstances of each Council to be taken into account.

Although it is common and convenient to refer to Science and Research as a well defined set of activities, it is also undeniable that this is a simplification. The mix of scientific investments – in people or equipment, for example - for each Council varies according to the discipline or the function that define their remit. Arguably, the human factor is common in all types of research and it could be assessed comparing hours worked and outcomes achieved in the different activities performed by every person. The same principle does not easily extend to capital investments: most scientific activities require some or another kind of equipment but the tools and its uses differ across disciplines. The assessment of capital investments is further complicated by the fact that certain types of capital are shared across many researchers and apportioning costs can be difficult.

It was with these challenges in mind that the current reporting framework was put in place, grouping metrics under broad headings that can easily be linked to macro-level objectives (op. cit. footnote 2). Moreover, the framework

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[10] Departmental Strategic Objective 1: Foster a world class science and knowledge base and promote the commercial exploitation of knowledge, global excellence in research and better use of science in Government. “BIS: A Guide to our Organisation” January 2010. Department for Business Innovation and Skills (BIS).

[11] Science and Research underpin three of the five drivers of productivity growth: innovation, skills and enterprise. “The 2008 Productivity and Competitiveness Indicators” (2009) Department of Business Enterprise and Regulatory Reform (BERR)

includes under each heading enough indicators to capture the variety of activities covered by Research Councils collectively and individually. The overarching link across the whole framework is ‘Economic Impact’ in the sense of identifying the benefits that accrue to society from the activities funded by Research Councils[12].

Because investment in Research is an uncertain activity that extends continuously over long periods of time, Economic Impact is identified by a set of indicators that reflect the outcomes of research activity at different stages of development of a discovery. It is worth noting however that these indicators represent only one part of the observable impact. There are noticeable impacts that cannot be recorded systematically and there are unobservable impacts that can only be approximated, like problem-solving ability within the firm or the knowledge spillovers across firms that occur, for example, in Business Parks[13]. The reporting framework acknowledges these difficulties in the section on Overall Impacts.

The common Economic Impact Reporting Framework evaluates the resource allocation role of Research Councils. To this end Councils account for the resources they have and the alternative sources of funding they draw upon as well for the uses to which their means are assigned. To complete the assessment, Research Councils also account for many outcomes and outputs obtained from their investments, and this is as we shall see complex and occasionally difficult.

Science and Research is a continuous activity, in which the present builds on the past, and achievements are compounded over time and across space, not only in the UK but globally. The basic driver and outcome of Science and Research is knowledge in its various forms, some of which are observable and measurable, others simply build into the future, for example knowing what does not work. It is therefore only rarely possible to link directly current expenditure and effort with current achievements. In addition knowledge is only limitedly appropriable whilst benefiting many parties at the same time. This makes it difficult to put a monetary value on the various forms of knowledge generated within the science and research system.

Taking account of these difficulties, the Economic Impact Reporting Framework (EIRF) collects quantitative and qualitative data, spanning various

[12] “Measuring Economic Impacts of Investment in the Research Base and Innovation: a New Framework for Measurement” (2007) Office for Science and Innovation. Department of Trade and Industry (DTI).
[13] The case of Silicon Valley has been extensively quoted as an example.

phases or modes of development of Science and Research into wellbeing[14]. Any list of all the possible benefits of investment in Science and Research is necessarily non-exhaustive and ought to be flexible. The EIRF reports an array of indicators grouped under four categories: (1) case studies on overall impacts; (2) innovation outcomes and outputs; (3) knowledge generation and (4) investment in the research base and innovation. In addition, there are three classes of influence factors that were not susceptible of belonging to any single one of the suggested categories of impacts. These influence factors are: (a) framework conditions and the regulatory environment surrounding science activities; (b) knowledge exchange efficiency on the quantity and quality of information flows across partners; and (c) the demand for innovation including public attitudes towards innovation.

Although this report builds on the EIRF returns submitted by the Research Councils it does not fully adopt the same structure as above. In what follows Economic impacts of investment in Science and Research are grouped under four headings:

Overall Impacts: this section illustrates the contribution of Research Councils to wellbeing using case studies of specific investments that can be followed from inception through to end users. These studies demonstrate cases of knowledge generated in the distant or near past that have already reached the market or are close to reaching it, thereby allowing for actual or expected values of returns to be estimated for the relevant initial investment.

A key element of this transformation of Science and Research into wellbeing is ***Innovation Outcomes and Outputs:*** this section provides information on new knowledge that is mature enough to be generating income. Spinoffs and Patents are typical examples but other more sophisticated forms of collaboration of Councils with the private sector are becoming more relevant as drivers of impact.

Knowledge generation: this section accounts for the two main sources of knowledge accumulation in the Science system: the knowledge that is codified and published and the knowledge and capability transferred to society with post-graduates. Codified knowledge is partially approximated by the quantity and quality of publications, some of which may develop into an innovative outcome. Post-graduates achieve a level of specialisation that is of value directly in the labour market and indirectly when this knowledge feeds back into the Science and Research system.

Investments in the research base: this section contrasts the resources at the disposal of each Council and the chosen uses of these

[14] "Economic Impacts of Investment in Research and Innovation" (2007) Science and Innovation Investment Framework. Department of Universities Innovation and Skills (DIUS). http://www.dius.gov.uk/~/media/publications/F/file40398

resources in the current spending year. These allocations illustrate the variety of activities run by Research Councils at all stages in the process of Science and Research generation, from funding to exploitation, and it gives an idea of future outcomes to be expected from the present investment.

***Public Engagement**:* in this section considers the roles that Research Councils play in developing and maintaining public support for science.

2.1 Overall Economic Impacts

Economic impacts can be estimated in multiple ways. A standard method in investment appraisal is to discount gains or benefits over time back to the original investment, calculating either the Net Present Value of the benefits at the time of the investment, or the Internal Rate of Return. This is often a very problematic exercise with research results, usually because it is difficult to attribute benefits and to estimate all relevant costs, but it can be undertaken. A recent example commissioned by the MRC looked at the impacts of research into cardiovascular disease and mental health. It analysed gains from both public sector and charitable sector research over the period 1975-1992, and estimated IRRs of 39% and 37% respectively.[15]

Impacts often depend on the use of facilities or research by engineers and companies. This can have widespread spillover effects, though these can be difficult to quantify. For example the STFC's Microelectronics Support Centre (MSC) supports the design tool software used very widely by microelectronics design engineers:

> "Almost all of Europe's microelectronics engineering graduates have been trained on MSC-supported design software. The MSC's EUROPRACTICE Software Service, largely funded by end user subscriptions with a contribution from the EC, encourages knowledge exchange between universities and from university to industry. The MSC partners with 20 of the world's leading microelectronics and Microsystems companies to make advanced design tool." (STFC EIRF 2009)

This example concerns the ways in which Research Councils' activities support the knowledge bases of UK industries. This is a key economic effect, since all industries work on the basis of technical and organisational knowledge, and the competitiveness of any company depends on its knowledge resources. We can map this in a more general way, by looking at the ways in which particular fields fit into the collective knowledge bases of UK industries. This has been done for the EPSRC, with the conclusion that

[15] Wellcome Trust and Academy of Medical Sciences, Medical Research: What's it Worth? Estimating the economic benefits of medical research in the UK', Nov. 2008.

sectors depending heavily on engineering and physical sciences account for around 30% of UK GDP, around 40% of all investment, 75% of all industrial R&D, and nearly 90% of manufacturing exports. NERC's support for the British Geological Survey feed in to the construction industry, the planning system and the insurance industry. General impacts on industries as a whole can be found across the system: BBSRC-funded research, for example, has had significant impacts on wheat production, animal health, food safety and food shelf-life.
An increasingly important economic impact derives from spin-out companies deriving ultimately from research projects. Over the past ten years, university biosciences departments funded by BBSRC have generated over 200 spin-out companies, currently employing over 1000 people.

The creation of new companies is in part related to the creation of new markets. A dynamic area of market creation at the present time is in environmental products and services, and this is likely to accelerate as international accords create new regulatory frameworks and pricing processes. NERC has played important roles in such areas as earth observation, and carbon capture and storage.

Economic impacts also derive from non-technological and non-engineering frameworks. The ESRC supports research with important managerial and policy implications, in such fields as environmental economic evaluation, which in turn feeds into decision-making on such issues as Landfill Tax legislation. The AHRC supports activities that create and support major cultural assets that are at the core of very large service industries.

2.2 Specific Innovation Outcomes

This section reviews evidence on implemented product and process innovations – that is, specific new products or methods introduced into markets or production. Earlier sections of this paper have emphasized that inputs to innovation are very broad, and that the Councils' role should not be confined simply to the commercialisation of new technologies. Nevertheless, this does happen and is often of great economic importance.

An immediate caveat should be made about this type of innovation. This is that we should not expect to find large numbers of successful new products, particularly where products are new to a market or new to the world. Innovation outcomes are highly skewed – there tend to be relatively small numbers of highly successful products, and these products tend to have very wide impacts. So we need to be alert to individual examples of high-impact innovations. At the same time the impacts tend to accumulate over long periods of time. This means firstly that real identification of benefits requires a long-term backward look, because benefits unfold over time, and that future benefits are likely to be difficult to quantify and to require conjectures about likely impacts.

For example, looking backward points us towards the role of the EPSRC in funding pioneering work on Liquid Crystal Displays in the 1970s, and – roughly at the same time – magnetic resonance imaging. Each of these areas has developed via initial innovations into major global technologies with very substantial markets. The general scope of benefits from these technologies is hard to estimate precisely because they are in such wide application, but global markets for each run into many billions (the current MRI market this year is estimated at £4 bn). Looking forward, the European Space Agency's Galileo global positioning system is being launched with technology developed by an EPSRC spinout company (Surrey Satellite Technology Ltd.). Benefits are hard to estimate but are likely to be widespread and substantial (through such impact as improved transport efficiency and safety). Other future-oriented initiatives include wave power systems that will be contributing to the national grid by 2013. NERC research has underpinned major innovations in carbon capture and storage, a rapidly growing market worldwide.

MRC pushes innovations to market via MRC Technology, an affiliated technology transfer operation. This is not simply a patenting and licensing activity – MRCT runs its own laboratories located at the National Institute for Medical Research in London. Fundamental findings at the molecular level do not translate readily into pharmaceutical applications, and sustained development work is often necessary. These labs are therefore a key element in the pharmaceutical innovation process. MRCT organises and carries out this work, in close collaboration with pharmaceutical and biotechnology companies. Perhaps the most recent large-scale example of its work is the sale of rights to a humanised antibody to Centocor Biopharma Inc., a subsidiary of Johnson and Johnson. The specific innovations emerging from MRCT are significant: 12 drugs based on MRC research currently have marketing approval, including the arthritis treatment Humira and the breakthrough cancer drug Herceptin. Ten major pharmaceutical companies – including GSK, AstraZeneca, Merck, Pfizer and Roche - are currently using MRC IP. MRC also innovates around research processes, and more than twenty companies are currently licensed to sell MRC research reagents.

Because of the unpredictability and uncertainty associated with innovation, it is sometimes the case the key innovations emerge suddenly. An example of this follows from the recent terrorist attack on a US aircraft, which has led among other things to demand for a range of enhanced security measures. Central among these is a new generation of body and luggage scanners. This policy option is open to policymakers simply because of the fact that the technology exists; and this, in turn, results from programme R&D funding by the STFC. The technology has been innovated via the UK arm of Rapiscan.Systems. The STFC's Engineering Technology Centre ha supplied specific techniques (such as high-power multi-focus X-ray sources) plus engineering consultancy and design skills leading into the implementation of specific new scanning technologies. This link has been in operation for many years, and has now been able to respond quickly to new needs.

2.3 Knowledge Generation

All Councils strive to push the frontier of knowledge. In allocating funds they have to balance the need to develop existing knowledge and support past investments with the need to explore new knowledge fields and areas of scientific potential. Two types of observable knowledge are followed closely to assess the intermediate productivity of Councils' investments: codified knowledge and embodied knowledge.

2.3.1 Adding to the stock of Codified Knowledge:

Codified knowledge in the form of publications is among the most immediate outputs of research and the furthest away from any consumption or production use. This distance to users makes it difficult to value codified knowledge. Not only is it infrequent to be able to link publications directly to uses but neither are all publications comparable on a like for like basis. In addition not all outputs that can be counted as codified knowledge are susceptible of being published nor peer reviewed. Books and book reviews, technical reports, maps and multimedia publications are examples of outputs that fall outside the radar of refereed publications.

Within the partial picture that refereed publications provide of the production of codified knowledge, citations are conventionally used to discriminate quality, although it is necessary to recognise that citation patterns fluctuate for reasons other than quality. For example, fashions can boost citation patterns in a given year for reasons to do with the popularity of a topic, rather than higher inherent value of research in this area.

For researchers, however, publications and citations are the major signal for academic value. Within the academic and research community, codified knowledge is rewarded with a better reputation, higher wages and successful grant applications[16]. To the extent that the research community is the main

[16] Merton (1968) "The Matthew Effect in Science" Science

market for codified knowledge, despite reservations, publications and citations (or impact) reflect albeit imperfectly the value of the knowledge generated.

The contribution of the UK to the pool of global codified knowledge is remarkable by international standards: second only to the USA in its share of world citations and highly cited papers. The UK is also top of comparably large countries, ahead of all in the G8 group, in terms of publications and citations per pound spent in R&D and per researcher[17]. In addition, the national performance is not driven by any particular discipline, as discipline rankings track the national ones except in the cases of the share of citations of Mathematics and Engineering where it ranks 3rd, and Physical Sciences where it ranks 5th.

The UK Research Councils collect information on the codified knowledge generated by their investments and monitor the performance of the national ranking for the relevant disciplines. It is nevertheless difficult to compare each Council's output with the national ranking since all the Councils feed into more than one discipline. To compensate for the difficulty in identifying cross-disciplinary outputs in publications, Councils report their achievements using various indicators. While a record is made on all publications[18], refereed articles will be used in this report as they meet the standards of quality granted by peer reviews. Although not strictly focussed on the generation of codified knowledge, peer reviews are used by all Councils to assess the quality of research proposals, in the future it may be interesting to report as well on the results of that process, which assesses the quality of the investment from a wider point of view.

Table 1 shows that the total number of publications has been increasing for all Councils with annualised rates of growth between 2005 and 2008 range between 16% for EPSRC and 0.9% for STFC. These figures have to be read with caution as the counting systems are not common to all Councils, preventing cross-council comparisons. Also, whichever the counting mechanism it is likely to obtain lower bounds based on researcher reports or on the name of the first author in a publications database. Still, it is worth observing that the yearly fluctuations within a Council demonstrate the need of considering several years when assessing productivity.

[17] "International comparative performance of UK Research Base" Evidence Ltd. Report for BIS. September 2009.
[18] All publications generally include refereed papers, books and book chapters, edited conference contributions, technical reports, theses and popular articles.

Table 1: Paper based outputs/total publications

	2005/6	2006/7	2007/8	2008/9	Annualised growth
AHRC		2,249	2,185	2,479	3.3%
BBSRC	Sponsored Institutes only – reported in Tables 2b and 3.				
EPSRC	19,095	22,687	19,652	34,649	16.1%
ESRC	4,695	4,876	5,265	6,543	8.7%
MRC	Intramural and refereed only – reported in Table 2				
NERC	6,618	6,884	6,764	6,895	1.0%
STFC	971	874	950	1005	0.9%

Source: Economic Impact Reporting Framework report 2009. Various Councils.

The percentage of refereed publications in the total, shown in the lower half of Table 2, provides a good account of quality assurance in the generation of codified knowledge for some but not for all Councils. This is because not all outputs are susceptible of refereeing and non-refereed outputs are not equally distributed across Councils. Nevertheless, some patterns are worth noting, particularly the fact that the quality of publication outputs, as indicated by refereeing, is improving.

The proportion of refereed publications in the total reported by NERC improved continuously from 0.57% in 2005 to 0.59% in 2008. The performance of BBSRC's sponsored Institutes in terms of the quality assured by refereed publication is remarkable. A more detailed inspection of BBSRC data reveals a slight decrease in refereed publications in recent years which has been caused in part by institute closures. However as Table 2(b) illustrates, this has led to a prevalence of quality assured publications in the total.

Table 2: Publications quality

	2005/6	2006/7	2007/8	2008/9	Annualised Growth
(a) Refereed publications (ISI, PubMed)					
MRC	1,199	1,286	1,334	1,388	3.7%
NERC	3,784	3,910	3,893	4,090	2.0%
(b) Percentage of total refereed					
BBSRC	59%	58%	66%	70%	
NERC	57%	57%	58%	59%	

Source: Economic Impact Reporting Framework report 2009. Various Councils

Absolute numbers of publications are useful accounts of performance but overall differences may be driven by scale effects due to the size of each

Council. Although growth rates are insensitive to size, it is sometimes more helpful to consider relative measures of productivity. The difficulty in calculating relative productivity is that outputs obtained this year rarely relate fully to inputs this year. Science and research are flow activities that build on past knowledge and publication processes delay the visibility of outputs. The advantages and disadvantages of relative productivity metrics are illustrated in Table 3.

Table 3: Relative productivity

	2005/6	2006/7	2007/8	2008/9
(a) Publications per grant within year				
AHRC	n/a	4.1	4.3	5.7
EPSRC	14.1	16.4	20.1	17
(b) Publications per lead researcher				
BBSRC	3.9	3.9	4.4	4.8
MRC	2.8	2.9	3.0	3.2
NERC	2.8	2.9	3.0	2.9
(c) Publications this year per grant number last year				
NERC	11.0	7.1	8.2	7.0

Source: Economic Impact Reporting Framework report 2009. Various Councils

Data from NERC and EPSRC illustrates how the overall number of publications fluctuates according to the number and maturity of grants. Grants closer to completion are more likely to generate publications output than grants at early stages of development. By reporting publications per grant in combination with maturity rates, EPSRC demonstrates how the interaction between these two explains a break in the upward trend they were experiencing. Table 3(a) shows that EPSRC's publications per grant had increased from 14.1 to 20.1 between 2005 and 2007 but stood at 17.0 in 2008/9, despite the number of publications for all grants reaching a record high in the last year (see the EPSRC row in Table 1). EPSCR also reports that a large number of grants matured in the current year, thereby explaining why publications per grant was large thanks to these maturing research, and appears relatively low now because of the waiting time until new projects become productive.

A similar point is made in the case of NERC regarding the need of building lags into relative productivity data. The number of grants reporting on any year is four times the number of grants awarded in that year. The most recently awarded grants are possibly less productive in the current year. The total on the other hand fluctuates with the maturity of the grant, independently of the new expenditure this year. Combining current publications with last years' addition to the grant pool gives a more accurate indication of the productivity per grant.

The stability of the number of refereed publications per research leader in MRC and NERC over time is indicative of consistently high quality investments by these Councils. BBSRC sponsored Institutes' relative productivity per principal investigator increased from 3.9 to 4.8 reflecting a smaller number of highly productive researchers funded in sponsored institutes.

This overview is necessarily partial because of missing data and because of the limited comparability of metrics and the relative relevance of some metrics for some but not all Councils. Other metrics on quality assurance are possible: NERC for example report that 96% of all grants awarded in the period 2003-07 produced at least 1 ISI refereed publication; while EPSRC reports a minimum of 51% of grants completed with at least one published paper with an international co-author. The overall picture on the generation of codified knowledge is clear indication that Councils are performing remarkably well, not only as a result of increased resources to invest but also advancing significantly in the quality of the knowledge generated.

2.3.2 Adding to the stock of Human Capital

The stock of Human Capital is made up of knowledge and skills embodied in the population. Research Councils add to the stock of human capital by funding people to advance their capabilities. Learning can be both formal and informal but despite the importance of informal learning, this is an undeveloped area when it comes to measurement. As well as sponsoring formal training, almost all Councils engage in collaborative training with partners, although this data is still not reported systematically. The relationship between human capital investment and economic growth has been analysed at length and evidence supports the conventional wisdom that human capital investment correlates positively with economic growth and welfare. This relationship is reinforced when considering higher level human capital as an input to innovation which feeds back into the economy via its contribution to productivity[19].

Together Councils fund a minimum of 8,000 PhDs each year. The trends are roughly constant in the four years to 2008 and averages reflect total numbers accurately. The cross-council distribution of PhD funding is however difficult to assess on the basis of EIRF reports, as some Councils account for fully

[19] The literature on Human Capital and Growth is vast and growing, see Temple (2001) "Growth Effects of Education and Social Capital in OECD Countries" OECD Working Paper 04/01 for a review.

funded PhDs, whist others report part-funded and even facility using only students (indirectly funded). Although it is difficult to draw comparisons under these conditions, as a whole it is a significant contribution of highly specialised and technical skills to the science ecosystem and society.

The private and social returns to these investments take time to build. As illustrated in Table 4 for a majority of cases it takes 4 years to submission or completion and these rates are stable where not improving over time. Provided that passing rates follow submission closely[20], Councils have been providing the economy with a steady supply of highly qualified PhDs in the last 4 years. It is worth noting that there is around a five year cumulative lag from the start of the investment for the private returns to PhDs to accrue to the individual through better employment opportunities and salaries and that it would take longer for society to benefit through increased productivity, knowledge spillovers and innovation.

Table 4: Percentage submitted/completed in 4 yrs by start year

	2001/2	2002/3	2003/4	2004/5
AHRC	*76*	*80*	*79*	*85*
BBSRC	73	79	80	80
ESRC	82	80	79	83
MRC	83	81	92	n/a
NERC	69	85	88	76
STFC	n/a	77	81	75

Source: Economic Impact Reporting Framework report 2009. Various Councils. Number of years to submission not available for AHRC.

Knowledge spillovers occur within the organisation where the PhD is employed through informal learning, but also from Academia to other sectors in the economy, whether the Business, Public or Third Sector. Knowledge spillovers within the firm are difficult to estimate but a good account of cross-sectoral spillovers is given by Councils reporting the proportion of PhDs who find jobs outside the Higher Education Sector. Data on this indicator is patchy due to lags in finishing patterns and the voluntary nature of responses to this survey. The Councils are working together towards improving the quality of this indicator and hope to report on it consistently in future EIRF reports.

PhDs (and Masters) may represent the largest contributor to the stock of human capital but Councils diversify investment in this area by funding also qualified researchers, providing continued support to mature past

[20] Councils do not provide information on failing rates but these are not expected to be large or systematically changing the cross-sectional distribution of PhDs across Councils.

investments. All Councils actively support life-long investment in high level skills but not all report on this activity under the same headings.

Research Fellowships illustrate investments in ongoing learning. Table 5 below illustrate increased efforts by the few Councils that reported on this indicator both in terms of funds dedicated to this investment as well as in the number of Fellows. Compared to PhDs, it is more difficult to establish the shape of returns that these investments accrue; however, it is often the case that Fellowships are awarded to researchers of proven reputation. In this respect it is expected that codified knowledge will obtain in the short run, whilst in the medium run innovation outcomes, public engagement and knowledge transfer will most likely follow.

Table 5: Continuing Human Capital Investments

	2005/6	2006/7	2007/8	2008/9
(a) Research Fellowships (study leave for AHRC) spend(£M)				
AHRC	5.0	7.0	7.0	5.0
EPSRC	11.9	16.2	22.2	24.9
MRC	27.6	29.1	30.3	34.5
(b) Research Fellows funded				
EPSRC	271	292	313	310
NERC	98	97	100	86
MRC		592	600	694
STFC	23	24	22	19

Source: Economic Impact Reporting Framework report 2009. Various Councils

Although with a lag of around 4 years until completion, Research Councils' investments have a proven record of contributing to the stock of available human capital, with sustained accumulation of high level skills both in the form of newly trained people as well as continued development of past investments through Fellowships and other forms of support to existing researchers.

2.4. Investments in the Research Base and Innovation

The Science system is such that there is little relation between current expenditure and current outcomes and outputs. Regardless of the nature of the activity funded, science investment takes time to build and therefore not only does the current allocation of expenditure have little to do with the present achievements but also it shapes future benefits in ways that are unclear at the present. Nonetheless, changes in the allocations of resources made by Councils provide an indication of future avenues of impacts to explore.

The largest component of annual income for all Councils is the allocation from BIS, although this is by no means the only source of income they have. Departmental allocations have not suffered dramatic changes in the last four years, whilst they have grown faster than inflation for all Councils, thereby granting real growth of income for all Councils between 2005/6 and 2008/9.

All Councils complement allocated funds with income drawn from external sources although not all reported separately on this category. The composition of "Other income" is not harmonised across Councils and therefore the data in Table 6 has to be read with caution and only over time for each Council without attempting to compare across them. Even if only the time series is considered, however, for within Council comparisons, the evolution of external income is remarkably sharp, more than doubling during the course of the 4 years to 2008/9.

Table 6: Other Income (£M)

	2005/6	2006/7	2007/8	2008/9
AHRC	n/a	8.3	13.5	14.7
ESRC	4.9	5.1	6.7	11.0
MRC	67.5	74.3	101.8	146.5
NERC	48.3	47.1	48.3	52.7
STFC	n/a	n/a	66.9	80.2

Source: Economic Impact Reporting Framework report 2009. Various Councils

Most of the Research Councils' income is dedicated to providing research grants in Higher Education Institutions[21]. All Councils report expenditure in research priorities using different evidence bases and therefore limiting comparability. Among disciplinary priorities, all Councils endeavour to encourage multi-disciplinarity in research. Investment in Cross-Council Programmes illustrates the commitment to collaboration and joint efforts. There are six cross-council programmes in broad research priority areas: Energy; Living with Environmental Change; Global Uncertainties; Ageing, lifelong health and wellbeing; Digital Economy and NanoScience. These cross-disciplinary Programmes have long planned life-spans and with them Councils aim to demonstrate how a joint effort can obtain a better result than the sum of individuals.

Councils perform a diversity of investments beyond allocating research money in grants. Because of the diversity of activities funded by each Council it is difficult to provide an overall picture of each. For example, below a summary of overall amounts spend in collaborative investments by Councils. These figures however do not illustrate sufficiently the varied nature of what is recorded under the heading of "collaborative", including a wide range of interactions with the Business and Public Sectors other than the direct income received.

Table 7: Collaborative Investments (£M)

	2005/6	2006/7	2007/8	2008/9
AHRC	3.8	4.7	7.2	9.0
BBSRC	9.9	17.4	17.7	21.6

[21] EPSRC is the only Council reporting this percentage, accounting for around 2/3rds of total income, but inspection of the Annual reports published by Councils indicate that between a half and 2/3rds of total income is delivered in grants.

EPSRC	56.0	151.0	178.0	99.0
STFC		11.9	15.1	1.0

Source: Economic Impact Reporting Framework report 2009. Various Councils

All Councils report activities under these headings but not all of them use comparable metrics. Councils absent from Table 7 provide instances of collaboration by type, numbers of partners involved and so on. ESRC reports on activities rather than amounts, including academics placed in user organisations (rising from 15 in 2004/5 to 65 in 2007/8) and correspondingly users placed in ESRC investments (from 21 to 52, respectively). Other knowledge exchange activities, reported by several Councils include Knowledge Transfer Partnerships (KTPs), NERC for example distinguishes between KTPs and other looser interactions with partners, while for STFC the use of facilities by non-academic parties and the presence of business incubators are part of their collaborative investments. A common feature from all reports is that the scale of collaboration is on an upward trend, both in the amount and in the number of instances of collaboration, illustrating the commitment of Councils to engage with partners at all stages in the process of Science and Research development.

2.5 Public Engagement

In general, Research Councils have put increasing amounts of funding into public engagement activities. In 2008/09 the Research Councils funded £2.4M of public engagement initiatives through the *RCUK Public Engagement with Research* (PER) team (formerly the RCUK Science in Society unit). In 2008/09, the EPSRC's Public Engagement Programme Spend was £7.1m, a 145% increase on the 2005/06 spend and the STFC contributed £1.5m to the Science in Society unit (now the PER team) programme budget. The PER team have also funded a range of initiatives that support the STEM agenda put forward jointly by the Department for Children, Schools and Families (DCSF) and the Department for Business Innovation and Skills (BIS).

Being able to engage with young people, through interaction with students at schools and universities, can help to spark an interest in the sciences which may lead to increased participation in STEM (Science, Technology, Engineering and Mathematics) subjects at university, essential to support the knowledge economy. The Researchers in Residence scheme is a placement and training scheme for researchers who wish to work with schools, exploiting the synergy of broadening the researcher's skills while the school benefits from having talented academics among their staff.

Public engagement enables Research Councils to learn more about the public's key concerns and issues, and addressing these feeds into strategic science policy. The Councils have also taken steps to embed public engagement within their governance structures. Examples are the EPSRC's Societal Issues panel and the BBSRC Bioscience for Society strategy panel. These practices aim at involving the top levels within the Council thereby embedding public engagement in the corporate agenda from above.

The Research Councils have also invested significantly in supporting public engagement within Higher Education Institutions (HEIs) through the development of the *Beacons for Public Engagement initiative*; some £9.2m has been invested over 4 years, in collaboration with the Funding Councils and the Wellcome Trust. This scheme has established six university-based collaborative centres and a National Coordinating Centre to support, recognise, reward and build capacity for public engagement within HEIs.

Keeping people informed and up to date about RC-funded research is a central aspect of public engagement. One example of how this has been achieved is the 'Darwin Today' exhibition, funded by the RCUK PER team and led by BBSRC, which toured the UK and went to over 30 venues (such as science festivals, cathedrals, schools and museums) and reached over 60,000 people. Each of the Research Councils also organise their own exhibits and give talks at Festivals and their own events, such as ESRC's Festival of Social Science and EPSRC's Impact! Exhibition. These events do much to enhance the public's exposure to science. The RCUK public dialogue on energy research provided valuable insight into the public's priorities for energy research, and has led to the development (in progress) of a guide for researchers on what the public considers important in this area of research. Other examples include the MRC and BBSRC's public dialogue on stem cells and the Nanotechnology Grand Challenge Cross-Council Programme, which used public dialogue to help prioritise research areas for funding.

With broadband connections becoming increasingly common in the UK, innovative and informative websites describing current research and past achievements in science have been accessed by more and more of the population. In September 2008, NERC launched the 'Planet Earth Online' website, which provides news of environmental science from the full breadth of NERC investments, thereby making the science more accessible to the public. The site has received wide interest and was among the 2009 finalists for the Chartered Institute of Public Relations awards for excellence in its category.

3.- Taking Stock

This report illustrates the variety of activities funded by Research Councils and the outcomes obtained. Because the outcomes of research flow from continuous activity, the investments made by Research Councils support scientific activity at all stages of development of an idea. Consequently Research Councils monitor outcomes at different stages, so as to preserve the continuity of research and to ensure that the funds they allocate result in demonstrable impact. Whilst some activities and outcomes are common to all seven Councils, e.g. publications and funding PhDs and Fellows, others, like IP activity or use of research facilities are less general. The monitoring system deployed by Councils includes enough metrics to allow for some flexibility in the reporting of activities while accounting for the use of resources by all Councils.

This report shows where the investments of Research Councils are concentrated and how they continue to generate impact directly, or to maintain the research base to preserve its capacity for impact. Whilst it may be difficult to predict with certainty the likely outcomes of all research activities, ensuring that the capacity to transform ideas into innovations is present and effective is the second best solution for public investments in science and research. The Research Councils are a fundamental piece in the UK innovation system maintaining that capacity.

First Published May 2010
URN 10/917