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Big Science and Innovation

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Table of Contents

Table of Figures

Big Science and Innovation

1. Summary

1.1 This report

This report presents the findings of a study to explore the relationship between large research facilities and innovation. It is a reference document, providing advice about approaches to the evaluation of innovation outcomes alongside a bibliography of past evaluations.

We prepared the document through a literature review and desk study with a small programme of qualitative research involving interviews with key stakeholders.

Large facilities are an important sub-category of research facilities that combine large investments in state of the art equipment and associated infrastructure often with quite large and highly-skilled operational support teams and related services. They are widely held to be critical 'tools for science, central to our ability to push the boundaries of what we know.

Large facilities have tended to be identified with single site facilities such as particle accelerators or telescopes, however, research infrastructures are very much more diverse than this: types of research infrastructure extend far beyond large centralised facilities to include physically distributed resources, such as ultra-high speed communications networks, through to virtual facilities and collections of artefacts of national or international significance.

We used a four-category typology (single site, distributed, mobile, virtual) to help our literature review, albeit with limited success as the majority of publications we identified are concerned with the socio-economic impacts of single-site facilities.

1.2 Overview of capital funding and research infrastructure

In order to set this analysis in context, we looked at the development of the UK's science budget overall and the share of capital funding within it.

The Allocation of Science and Research Funding 2011/12 to 2014/15 (ASRF) shows that capital investment constitutes a small but significant share of the total science budget. The budget for capital funding was around £515M in 2011/12, or around 12% of the total science budget. We estimate that one third is invested in capital projects related to large facilities, but support for larger strategic investments is increasing in absolute and relative terms. The government has made several important announcements in the period since the Spending Review in 2010 (SR10), which are expected to result in very much higher annual expenditure in 2013/14 and 2014/15.

The main budget lines comprise the individual capital budgets of the seven grant-awarding research councils and the four home-country funding councils (46%; 27% respectively), with the UK Space Agency and Large Facilities Capital Fund (LFCF) making up the balance (26%).

The research councils' capital budgets have been used to fund facilities at the councils' own research institutes and university-based facilities. The various higher education institute (HEI) capital funds are designed to ensure universities have the volume and quality of research-related building, equipment and infrastructure to carry out excellent research. The Large Facilities Capital Fund is, as the name suggests, a fund to support capital investment in the country's largest research facilities, existing or under development (e.g. the Diamond Light Source, the ISIS neutron source and the Square Kilometre Array).

We were interested to form a view of the UK's stock of large research facilities, to understand its scale and scope and any evident trends in terms of disciplines or types of facilities.

There is no definitive UK-wide list of facilities, however we were able to take advantage of the MERIL project, an EU-funded initiative to map research infrastructure across the EU.

We compiled a list of large research facilities, predominantly taken from the MERIL database but with additional contributions from The Science and Technology Facilities Council (STFC) and other research councils. The list is presented in the appendices, with the facility name followed by information about the scientific domains addressed. This remains a partial inventory of the UK's stock of bigger facilities, however it was judged to be sufficient in extent to permit some simple analyses.

In the first instance, the analysis makes clear the UK is host to multiple facilities of national or international significance in every discipline, across the natural and physical sciences to the arts. It also confirms the UK has multiple facilities of national or international significance in each of the four categories. The distribution also shows the continuing dominance of single site facilities within the overall mix, with close to half of all entries falling in this category.

1.3 "Big Science" and innovation

The study's second objective was to review the literature on and evidence of the impacts of 'big science' facilities on innovation patterns and outcomes.

We carried out an extensive literature review starting with the references in our pre-existing inventory of around 50 papers and after investing substantial effort, we managed to double the number of references. However, in terms of the better papers, the bibliography is closer to 70 items, split 30:40 between more conceptual work and empirical studies.

The relationship between "big science" and innovation is discussed in the research policy literature, but not to anything like the same extent as the social benefits of public research more generally. The majority of papers in this small body of work comprise empirical studies detailing the achievements of particular facilities, with very few publications that have dealt systematically with the conceptual issues.

From an innovation perspective two things stand out from the conceptual literature, and which mark out large-scale research infrastructure as being materially different in its contributions to innovation:

- The challenges that must be overcome in order to create next generation research facilities often push the boundaries of what is possible technologically for current instrumentation and equipment. Suppliers may be commissioned by facility owners expressly to come forward with innovative solutions, and many are then able to take those new products or services to other markets, at other facilities or even other sectors
- The emergence of national and internationally connected research facilities and large data holdings is supporting new research, but also – through open access policies – facilitating new analytical functions that support innovations in both the public and private sectors

There is an indication that research facilities are generating industrial knowledge spillovers both at the point of their design and construction (e.g. user-led innovation) and through their operation and use (e.g. service innovation and more conventional forms of research-based knowledge transfer).

Turning to the empirical literature, there is a particular focus on three types of broad socio-economic impact:

- The direct and indirect economic benefits of spending large amounts of public money in a single location, both during the construction phase and operation
- The industrial knowledge spillovers that are realised by the contractors that design, build and equip facilities or the spinoff businesses that go on to sell specialist technical services back to the facility (and other facilities)
- The local economic effects and high-technology clusters that grow up around some of the larger facilities

Each of these three broad classes of socio-economic impact tends to be evaluated using a different approach and methodology.

1.4 Evaluating financial & economic outcomes

The great majority of economic impact assessments follow a broadly similar approach, wherein evaluators take expenditure and employment data and feed those historical data into an input-output (IO) analysis to estimate the direct and indirect benefits of public expenditure. The IO analysis uses official IO tables, national or regional.

The evaluations arrive at economic multipliers that typically range between 2 and 3, which is to say that every £1M in public expenditure is generating an additional £2M or £3M in wider economic activity through onward purchases within supply chains and the personal consumption of employees using their wages.

There are differences in the scope and thoroughness of the studies, which we believe reflects differences in the study specification rather than poor and inconsistent implementation. There are several outliers that have used novel methodologies – like contingent valuation – to monetise user value or better secondary data relating to for example the consumption of patented plant varieties and related commodity prices.

The studies are similar in design to the kinds of economic impact assessments used in other policy areas. Their principal weakness is that none of these exercises has sought to make adjustments for additionality or displacement or opportunity costs, to ensure the final estimate is a fair assessment of total net economic impact.

1.5 Evaluating innovation outcomes

We identified 20 publications that had documented the innovations made possible by large research infrastructure. Qualitative research is the foundation stone of all of the studies: a case study methodology is used in most instances to draw out the particular connection between the research facility and an individual innovation. Typically, the case studies are identified through supplier surveys or existing spinoff databases, and then elaborated through a combination of semi-structured interviews and desk research, involving beneficiaries on the one hand and the client contracts department on the other.

While the methodological approaches may be similar, in broad terms, the studies do vary in scope. Only a minority examine a large number of cases in an attempt to arrive at a sample that is representative of the overall population and thus provide the basis for an estimate of gross effects (CERN, NASA).

There are very few examples of reports that have produced any aggregate statistics, but there are some: a survey of high-tech contracts for the Large Hadron Collider concluded that around 40% of suppliers were able to take those experiences and launch new products or services in the market place. NASA's Spinoff 2012 annual report estimates that the 500 or so spinoffs reported across the period 2000-2012 have produced US$ 5 billion in additional revenue and US$ 6.2 billion in cost savings.

The methodological challenges here are twofold. Firstly, in a majority of the reports, just a few case studies are presented and these are lightly treated with a narrative description of the connection to the facility in question. Secondly, where a larger number of cases have been compiled using common analytical framework or template, there is little supporting evidence provided and rarely any corroboration. The potential for overstating the benefits is clear, case by case and in the round.

1.6 Evaluating agglomeration effects

We identified just nine publications that had attempted to say something about the locational and clustering effects made possible by large research infrastructure, including both ex ante impact assessments and ex post evaluations. There are economic impact assessments and case studies. However, the papers are concerned almost exclusively with very large capital investments in very large research facilities located at one or two sites.

Most of the reports combine quantitative analysis of the (local) economic effects with qualitative investigation of the knowledge spillovers.

The approach taken to the quantitative analysis of local economic effects is similar to the economic analyses carried out for major capital investments more generally, which is to say the authors take the public expenditure figures and run these through an input-output model. This enables the analysts to arrive at a global estimate – across the applicable time-period – for local direct, indirect and induced economic impacts. In some cases, authors may choose to simply apply standard IO multipliers, for convenience, rather than attempt to trace / model individual purchases through a national or regional set of input-output tables.

Qualitative research is more generally used to capture growth in co-located businesses, spinoffs or inward investments. The reports identified all use case studies. They vary in depth, but most are quite light touch: a description of the business and a few words about the link between the business and the facility.

None of the reports looked closely at the effects on the wider innovation ecosystem or contributions to major new technologies or sectors. This aspect of RI-benefit is not given much weight in the evaluations identified, which suggests one of the obvious and potentially unique socio-economic contributions remains under-researched and poorly understood.

1.7 Directions for further development and future research

Overall, this area of research and innovation policy clearly remains a work in progress, and we have yet to see any decisive response to the regular calls to improve the methods of assessment of benefits from large research infrastructures.

The most pressing challenges do not appear to be methodological per se, in the sense that the tools and techniques used to evaluate research infrastructure would be rather familiar to analysts carrying out impact assessments in any area of innovation studies. In practice, the most pressing challenges are cultural. These large facilities have rarely been subject to evaluation historically, and that is perhaps where things need to begin to change: beginning to do more evaluation and more assessment of socio-economic effects. Our survey of research facilities suggests there is an appetite to do more. Equally, where evaluations are commissioned, the specification needs to be more ambitious, reaching beyond the simple analysis of expenditures and regional multipliers. The impacts on innovation, on new markets and on local clusters are all worthy of closer investigation.

In terms of next steps, there are several courses of action we would recommend BIS consider, while acknowledging that each of these actions implies additional effort and cost and as such may not be immediately affordable in the current financial climate.

- Creating a joint BIS-STFC working group to oversee the development of evaluation practice relating to research infrastructure
- Improving large research facilities' data infrastructure
  - Agreeing on a list of key UK facilities, and approaching their respective 'owners' with a view to encouraging these organisations to improve their data infrastructure
  - Improving the amount of meta data available about suppliers and users
  - It would also help if these organisations could create information systems for identifying and capturing examples of knowledge spillovers and wider impacts
- Commissioning a series of socio-economic impact assessments to begin to expand the stock of reference material and more generally develop evaluation practice
  - A series of (ex post) evaluations looking at a cross-section of established (10+ years in operation) large-scale research facilities
  - A series of studies to detail the role / contributions of major facilities to the local innovation ecosystem and regional clusters
  - A series of studies to trace and detail the role / contributions of major facilities to the emergence of important businesses and emerging sectors

  - A series of studies that set out to detail the contributions of big science and capital investment programmes to major innovations

2. Introduction

2.1 This report

This report presents the findings of a study to explore the relationship between large research infrastructure and innovation. It is intended to be a reference document for science and innovation analysts on the one hand and facilities owners on the other, providing advice about approaches to the evaluation of innovation outcomes alongside an annotated bibliography of relevant past evaluations.

2.2 The study objectives

This project sought to document the state of the art as regards the relationships between large-scale science facilities and innovation performance. It had three aims, which were to:

- Prepare an overview of the extent of capital investment in science facilities in the UK, detailing trends in the nature or scale of those investments
- Review the literature on and evidence of direct and indirect impacts of 'big science' facilities on innovation patterns and outcomes
- Explore and analyse possible future research directions for conceptualising and mapping the roles of science investment in innovation and growth

2.3 Overall approach

We prepared this reference document through a substantive literature review and desk study with a small programme of qualitative research involving semi-structured interviews with key stakeholders. More specifically, we carried out the following tasks:

- A desk study to compile time-series data on UK capital investment in science, supplemented by interviews with key funders and institutions in order to profile and explain the nature and extent of UK capital funding
- A desk study making use of several recent research infrastructure projects to compile an inventory of major research facilities in the UK, which remains a partial list but might usefully be taken over by BIS or the STFC for further extension
- A literature review to identify and synthesise the key messages revealed in the academic and grey literature on 'big science' facilities on innovation patterns and outcomes. Our meta analysis critically reviewed existing approaches and measurement methodologies, mapping the current state of the art and identifying key gaps and shortcomings
- Preparation of a series of case studies presenting individual evaluation reports, which explain the methodologies used and the innovation-related findings

2.4 Structure of the report

The report is presented in six main chapters

- An overview of capital funding for science, in the UK
- A review of the literature on big science and innovation
- A review of the empirical literature on economic impacts
- A review of the empirical literature on innovation outcomes
- A review of the empirical literature on agglomeration effects
- An overview of the potential directions for future research

We present the various underpinning materials and analyses in a series of appendices.

3. Capital funding and research infrastructure in the UK

3.1 "Big Science Facilities"

The study focused on approaches to measuring the innovation outcomes of *large* research facilities, rather than research equipment more generally.

There are numerous definitions of (large-scale) research infrastructure, which typically revolve around the idea of technologically complex and costly equipment and infrastructure essential to carrying out research at the cutting edge and advancing our understanding of the world.[1] These ideas are discussed at length in the UK research councils' strategic framework for capital investment.[2]

Large-scale research facilities are an important category of research facilities, or 'tools for science,' which combine large investments in state of the art equipment and associated infrastructure with possibly quite large and highly-skilled operational support teams and related services. The adjective large is important here inasmuch as these 'large' facilities are generally understood to be of such a scale that even large scientific nations can afford only one or two – or possibly only in collaboration with other scientific nations – and their scale or power is deemed necessary to support progress with the next wave of cutting-edge research and make possible advances in our collective understanding of the world.

Large facilities have tended to be identified with single site facilities such as particle accelerators or telescopes, however, there is a growing recognition that research infrastructures are very much more diverse than this. If one looks at the growing number of national RI roadmaps,[3] it is clear that research infrastructure extends far beyond large centralised facilities to include physically distributed resources for research, such as ultra-high speed communications networks, and large collections of data or physical objects.

While it was beyond the scope of this study to develop a robust typology of research facilities, we did have a sense that a single-site facility might support innovation in ways that look somewhat different as compared with a virtual research facility. Table 1 offers a simple, fourfold classification of types of research infrastructure.

We used this segmentation in our literature review, albeit with limited success as the majority of publications we identified are concerned with the socio-economic impacts of single-site facilities. We take this to mean the literature has yet to catch up with the expansion in the range of types of facilities that are now caught under the umbrella of research infrastructure.

[1] For example, the Research Infrastructures web pages of the European Commission state that the term 'research infrastructures' refers to **facilities, resources and related services** used by the scientific community to conduct top-level research in their respective fields, ranging from social sciences to astronomy, genomics to nanotechnologies.

[2] See, Investing for Growth: Capital Infrastructure for the 21st Century, RCUK Strategic Framework for Capital Investment (2012).

[3] Examples of the European and several national roadmaps can be found through the ESFRI web site (ec.europa.eu/research/infrastructures). The UK's roadmap was published in November 2012, entitled 'Investing for growth: Capital Infrastructure for the 21st Century'. This is widely referred to as the RCUK's Strategic Framework for Capital Investment, which replaces the 'Large facilities Road Map' (2010).

Table 1 – Taxonomy of large research facilities

Type of facility	Description
Single-site facilities	This refers to a single scientific piece of equipment or complex of linked machines located at a single physical location, so for example CERN's[4] Large Hadron Collider (LHC) is an example of a single site facility, but is also part of a more extensive complex of accelerators, that includes the Super Proton Synchrotron (SPS) and the ISOLDE isotope separator.
Distributed facilities	A distributed facility refers to a group of instruments or facilities located in different places, which operate as a single-machine and while the individual components may not constitute large-scale research infrastructure, the network as a whole does. Radio telescopes are a good example of this, where linking individual telescopes permits astronomers to obtain far higher resolutions (i.e. able to identify greater detail in the objective being observed) than any one facility could achieve. The Square Kilometre Array (SKA) radio telescope takes this idea of distributed power to a new level, whereby some 3,000 individual telescopes will be linked together – across continents – to provide an instrument that will be 50 times more powerful than any available today. Communications networks may be considered distributed facilities too, in some cases. GÉANT for example is a pan-European communications network that links national research and education networks (e.g. JANET in the UK), enabling improved collaboration among researchers in different countries. GÉANT4 will allow users to transfer data at speeds of up to 100 Gbps (500 Gbps for the network core) across the 50,000km network. From the outset, GÉANT has been heavily involved in future network research, in areas such as carrier class network technologies, photonic switching, federated network architectures and virtualisation.
Mobile facilities	A mobile research facility (for example, survey ships or aircraft or satellites) will comprise one or many pieces of equipment that can move or be transported to the location where the instrumentation is required. That is, the object of study is very large (e.g. the Earth), or remote (the Antarctic) or mobile in its own right (e.g. populations). The European Space Agency's (ESA) Advanced Along Track Scanning Radiometer (AATSR), which is being flown on the Envisat satellite (with nine other instruments), continuously orbits the globe providing accurate data on Sea Surface Temperature (SST) to feed into environmental scientists' work on climate change. NERC's research ships, the RRS James Cook and the RRS Discovery, are also examples of 'mobile' research facilities, with the former having been launched in February 2007 at a cost of £40M, and both of which involve multidisciplinary teams of scientists carrying out oceanographic surveys.
Virtual facilities	A virtual facility provides scientists with remote access to research instruments or large data sets over the Internet or some other communications network (e.g. JANET, the higher education sector's high-speed broadband communications network). The UK Economic and Social Data Service (ESDS) is a case in point, wherein the service provides users with a single portal to access numerous qualitative and quantitative data sets (e.g. large-scale government surveys and longitudinal studies) hosted by four separate centres of excellence at two universities in the south east and north west. The ESDS facility is exploiting the collection of skills and data sets at the disposal of these individual institutions and pooling these resources such that it appears to users to be a single organisation with a single, physical location. Physical facilities are also becoming virtual facilities in some respects. For example, the Natural History Museum has very many large collections on display or stored at one or several locations, many of which are being digitised as a means by which to facilitate remote access and multiple parallel use by scholars or the interested public. The Tate gallery or British Museum work in similar ways, with both physical and virtual sites providing access to their globally unique collections.

Source: Technopolis

3.2 Overview of capital funding

In order to set this analysis in context, we looked at the development of the UK's science budget overall and the share of capital funding within it.

BIS published the current science and research budget in December 2010 in a report entitled The Allocation of Science and Research Funding 2011/12 to 2014/15 (ASRF). It shows that

[4] CERN is the European Organisation for Nuclear Research, http://public.web.cern.ch/public/Welcome.html

capital investment constitutes a small but significant share of the total science budget. The budget for UK capital funding for science was around £515M in 2011/12, which was around 12% of the total science budget.

Readers should note that various fiscal events that have occurred in the period following SR10 mean that the capital allocation within the Science Budget understates likely eventual expenditure by a substantial degree. It is difficult to locate these fiscal events and their anticipated future expenditure in the published budget, however we have sought to do this with the help of BIS economists and our resulting summary of the SR10 capital budget and anticipated additional financial commitments is shown in the appendices (see Figure 13). The new announcements are significant: for example, if the £517m budgetary allocation for 2014/15 is augmented with the anticipated additional expenditure from various capital-related fiscal events, the final figure will exceed £1 billion: double the current budget.

For the purpose of this report, we have held to the more detailed analysis set out in the ASRF report. Figure 1 is taken directly from the BIS ASRF report (2010), and shows planned capital expenditure for the period for the individual research councils and funding councils.

Figure 1 – Allocation of capital funding within the science budget (£Ks, cash)

Council	Baseline 2010-11	2011-12	2012-13	2013-14	2014-15	Total	Final Year to Base
Research Councils	393,438	239,821	199,393	181,430	180,967	801,611	46%
AHRC	3,150	0	0	0	0	0	0%
BBSRC	66,480	38,000	29,700	29,700	29,700	127,100	45%
EPSRC	49,261	31,000	35,000	25,000	25,000	116,000	51%
ESRC	20,600	18,700	13,700	12,700	12,700	57,800	62%
MRC	134,517	33,000	29,000	31,000	31,000	124,000	23%
NERC	34,183	32,200	17,800	17,800	17,800	85,600	52%
STFC: Core Programme		19,630	21,981	14,237	14,169	70,017	
STFC: Cross-Council Facilities	85,247	21,070	21,919	22,463	22,931	88,383	76%
STFC-International Subscriptions		46,221	30,293	28,530	27,667	132,711	
Large Facilities Capital Fund	103,380	115,279	61,307	47,769	128,132	352,487	124%
UK Space Agency	19,000	19,000	19,000	19,000	19,000	76,000	100%
HEI Capital HEFCE	166,952	75,170	90,970	90,160	101,500	357,800	60%
HEI Research Capital England	158,420	53,199	64,377	63,810	71,831	253,217	45%
HEI Research Capital Scotland	23,622	8,620	10,431	10,339	11,639	41,029	49%
HEI Research Capital Wales	6,031	2,113	2,557	2,535	2,854	10,059	47%
HEI Research Capital N. Ireland	1,778	798	965	957	1,077	3,797	60%
TOTAL	**872,621**	**514,000**	**449,000**	**416,000**	**517,000**	**1,896,000**	**59%**

Source: Allocation of Science and Research Funding 2011/12 to 2014/15, BIS (2010)

The main budget lines largely comprise the individual capital budgets of the seven grant-awarding research councils and the four home-country funding councils.[5] Each organisation

[5] The STFC is the exception with three budget lines, reflecting its broader role in managing the UK's subscriptions for a series of international scientific organisations (e.g. CERN) and cross-council facilities. The majority of these facilities serve a range of different scientific communities.

has a separate chapter within the BIS ASRF report, which provides a more detailed breakdown of funding commitments.

It is helpful to say something about the different capital budgets, as they do differ somewhat in scale and objectives, and those particularities may have a bearing on their respective 'innovation impact pathways' and the appropriate evaluation strategy.

The research councils' capital budgets are used to fund the expansion and refurbishment of the research facilities at the councils' own research institutes and university-based facilities. These funds help to secure the quality of the research being carried out by these (unique) national centres of excellence. The Councils use a variety of methodologies to determine their individual budgets, however it often revolves around a classic business case, where an institution will prepare a scientific and economic appraisal for consideration by the Research Council in question.

The various HEI capital funds are designed to ensure universities have the volume and quality of research-related building, equipment and infrastructure to carry out excellent research. The HEI funds are allocated in proportion to each institution's research income from research councils (project / grant income) and funding councils (Quality-Related Research Income). The university capital investments are typically measured in the hundreds of thousands of pounds, rather than millions.

The UK Space Agency capital budget might be thought of in a similar vein to the budgets of the individual research councils, and reflects a policy decision to move from a coordinating body (the BNSC) to create a new national space agency in Swindon and a series of related research centres at Harwell in Oxfordshire. For example, the International Space Innovation Centre (ISIC) was built using public and private money, with around £25M earmarked from the UK government. In 2012, ISIC was merged with the ESA UK office within the newly created Space Applications Catapult, which is being co-financed by the Technology Strategy Board. These investments are helping to consolidate the UK's national 'space cluster' around Harwell, building on the longstanding achievements of the Rutherford Appleton Laboratory's (RAL) Space Department.[6] The Space Innovation and Growth Strategy, which was published in 2010, was an important trigger for these investments.[7] The strategy argued that the UK has 6% of the global market in space applications and has the capacity with the right investment and government support to make that 10%. Based on 20-year market development projections, that would account for an additional 100,000 jobs for the UK economy by 2030.

The Large Facilities Capital Fund (LFCF) is, as the name suggests, a fund to support capital investment in the country's largest research facilities, existing or under development (e.g. Diamond Light Source, ISIS, Square Kilometre Array). This is primarily about keeping UK research at the leading edge, but a proportion of LFCF projects are also intended to improve access / value for commercial users. The individual projects have values in the tens of millions and the decision to invest is tied to specific business cases.

[6] STFC's RAL Space department, with support from NERC, plays an underpinning role in satellite navigation technology through the monitoring of space weather and the evaluation of signals from Galileo, the European global navigation system. According to the STFC Impact Report 2012, the GPS-sensitive proportion of UK GDP is around 7% with GPS delivering substantial business efficiencies including a £1.6 billion annual saving by the aviation industry due to reduced delays and lower emissions. The report goes on to say that the satellite navigation industry is expected to generate a value-added contribution of £1.45 billion to the UK economy between 2011 and 2020. These estimates were extracted from an economic impact assessment entitled, 'the economic impact of physics research in the UK: Satellite Navigation Case Study', which was prepared by Oxford Economics (2012).

[7] The increased expenditure is expected to bring short-terms gains for the UK, with the management of the £200M p.a. ESA ARTES advanced telecommunications programme transferring to Harwell in Oxford from ESTEC in the Netherlands. A substantial part of the UK's increased annual commitment to ESA will be invested in the ARTES advanced telecommunications programme (the UK will become the single largest national investor in ARTES). The current ARTES management team numbers around 100 people, and commentators anticipate perhaps half of those individuals moving from windswept Noordwijk to leafy Oxfordshire with the balance being recruited separately from across the ESA member states. The move is unlikely to create any wholly new jobs, but those European scientists and engineers will now sit in the UK and add to the Harwell skill set and innovation ecosystem.

There has been only limited evaluation of these various capital investment budgets, with the evaluations of the university capital funds (SRIF2, SRIF3) being the main exceptions. The two SRIF evaluations looked at academic benefits and wider social impacts, including innovation. In terms of methodologies, they have made use of case studies – to illustrate specific outcomes – and descriptive statistics to reveal the extent to which capital investment is delivering improvements in research quality and industry engagement (for example).

The research councils have adopted a more metrics-based approach (e.g. annual impact reports), and have not tended to evaluate their capital programmes in the round. This perhaps reflects the highly variable nature of the individual investments (projects), however some of those capital projects are beginning to be examined more explicitly, in part prompted by interest from BIS (in return for co-financing).[8]

The UK civil space programme has been evaluated on three separate occasions (2001, 2004, 2008), with attempts to estimate the net economic benefit of total public investment in the period under review. The studies also used case studies to look at specific innovations and spinoffs, and mini-sector studies to trace the longitudinal effects of the national space programme on a segment of the UK industry's performance and competitiveness internationally. None of the three evaluations considered the BNSC's capital investment programme.

The capital budget does not distinguish between expenditure earmarked for the creation or enhancement of large research facilities as compared with smaller investments in buildings or equipment. However if we use the combined budgets for the LFCF, UKSA and STFC international subscriptions as a proxy for big science capital investment, these three budget lines together account for around £180M (35%) of the £515M capital budget.

In summary, the UK has been investing 10-20% of its annual science budget in capital programmes of one kind or another, while capital investment in larger facilities amounts has fluctuated around 30% of the total capital investment.

The final column (right hand side) of Figure 1 makes clear that the capital budget is pretty dynamic, with the LFCF showing a marked increase in cash terms across the period (124%), while other budget lines have seen reductions.

The capital budget overall was reduced by around 40% compared with the previous year's high of £872M, and will reduce further in the two years to 2013/14, to around £400M, recovering to around £517M in 2014/15. The resource component of the science budget is flat in the same period.

The biggest reductions relate to the research councils' capital budgets, which have been halved across the period. University capital investment was also reduced for 2011/12, with some measure of recovery by 2014/15. The third component of the capital budget, the Large Facilities Capital (LFC) fund was held flat for 2012/13 and will increase in 2014/15. This is a reversal of the trend seen in the previous decade, where the overall capital budget increased fourfold, in absolute terms, from around £170M in 1999/00, at the same time, increasing from around 12% of the science budget to around 17%. It is now projected to settle at a level closer to 10%.

While the overall reduction may reflect pressures on public budgets more generally, it is also important to note that capital investment is naturally more variable than recurrent funding. So, for example, a significant proportion of the historical increases in capital investment were designed to correct for long-run under-investment in research facilities at universities, through JIF and then SRIF. That corrective action has been successful and the current fund, CIF, requires a smaller budget as a result. The research councils' capital funds experienced

[8] For example, in 2012, the BBSRC commissioned an evaluation of a £44M extension to its Babraham Research Campus, which was expressly concerned with the quantification of any improvements in the facility's visibility and reputation, its tenants' sales and employment and innovation behaviour. The study report had not been published at the time of writing.

similar increases in the period since 1999/00, to support the upgrading and extension of the various facilities at the research institutes.

The current capital budget has been re-focused on larger facilities, through the LCFC and the UK Space Agency, a move that is perhaps motivated by a concern on the part of government to push both cutting-edge science and science-enabled economic growth. This rebalancing of capital investment does not preclude one-off investments in RI facilities of course, as shown by the DH investment in the MRC.

Readers should note that various fiscal events that have occurred in the period following SR10 (see Figure 13), mean that the capital allocation within the current Science Budget understates likely eventual expenditure by a substantial degree. For example, if the £517m budgetary allocation for 2014/15 is augmented with the anticipated additional expenditure from various capital-related fiscal events, the final figure will exceed £1 billion: double the budget. That combined amount is higher than the 2010/11 budget, both in cash terms and inflation-adjusted terms.

3.3 An inventory of research infrastructure

We were interested to form a view of the UK's stock of large research facilities, to understand its scale and scope and any evident trends in terms of disciplines or types of facilities.

There is no definitive UK-wide list of facilities, however we were able to take advantage of the MERIL project, an EU-funded initiative to map research infrastructure across the EU, which reported at the end of 2012.[9] The basic criterion for inclusion in the database was a research facility judged by proposers and the MERIL team to be of national or European scientific significance, which is a reasonable proxy for large research facilities (our focus here).

The MERIL database is available online and, while it remains a work in progress, it provided an excellent starting point for our ambition to quickly compile a reasonably complete list of current facilities. Definitional questions remain of course and our final list can only be seen as a partial inventory; it is not definitive. However, with 221 entries it is a useful platform from which to form a preliminary view of the current stock. The inventory has been recorded in a digital format suitable for expansion and updating, should that be deemed to be useful.

The MERIL database tagged all of the research infrastructures against eight scientific domains, however the very great majority of entries had just one reference (primary scientific domain) even where those facilities might be expected to serve a number of disciplines. Figure 2 presents the distribution of facilities by primary scientific domain, sorted by number of facilities. While this is only a count of facilities – with no insight about the size or quality of those individual facilities – the analysis does at least make clear the UK is host to multiple facilities of national or international significance in every discipline, across the natural and physical sciences to the arts.

Figure 2 – Distribution of research infrastructure by primary scientific domain

Primary Scientific domain	**No. in the inventory**	**Share**
Earth and Environmental Sciences	54	24%
Physics, Astronomy, Astrophysics and Mathematics	47	21%
Biological & Medical Sciences	44	20%
Chemistry and Material Sciences	24	11%
Humanities & Arts	16	7%

[9] The FP7 project, MERIL (Mapping of the European Research Infrastructure Landscape), which is being run by the European Science Foundation with active support from the UK and in particular Dr Peter Fletcher (STFC) and Professor James Hough (University of Glasgow). The project has compiled a pretty comprehensive inventory of research infrastructure, gathering substantial descriptive data on some 2,400 facilities, covering all disciplines, of which some 180 are located in the UK. The information was meant to be publicly available in September 2012 through an interactive online portal.

Primary Scientific domain	No. in the inventory	Share
Social Sciences	15	7%
Engineering & Energy	13	6%
Information Science	8	4%
Total	221	100%

Source: Elaboration by Technopolis of output prepared by MERIL project team, 2012

We went on to tag each of the entries using our own typology, and Figure 3 shows the resulting distribution and the continuing dominance of single site facilities within the overall mix.

Figure 3 – Distribution of UK facilities by type of research infrastructure

Type of facility	Share
Single-site facilities	48%
Virtual facilities	19%
Mobile facilities	16%
Physical collections and databanks	10%
Distributed facilities	7%

We had hoped the database would include information about the year of foundation and the scale of the associated activities, whether in terms of capital expenditure or numbers of users. However, while these data are available for some facilities, they were not recorded for the majority, and we were therefore unable to investigate evolutionary trends. We fully expect to see a changing disciplinary mix over time, extending from the physical sciences into the natural sciences, social sciences and humanities. We would also expect to see a changing mix of types of facilities, with more distributed facilities and e-science grids. This kind of analysis would require substantial time and resources to complete, albeit it would be a fascinating topic for a PhD thesis perhaps. More feasible perhaps, a subsequent study might consider the possibility of using the applications / awards from the Large Facilities Capital Fund as a reference point for an evolutionary analysis.

The 221 RIs are listed in the appendices, presented in a tabular form with the facility name followed by information about the scientific domains addressed and the type of facility.

4. "Big Science" and innovation

4.1 The relationship between "big science" and innovation

The relationship between "big science" and innovation is discussed in the research policy literature, but not to anything like the same extent as the social benefits of public research more generally. The majority of papers in this small body of work comprise empirical studies detailing the achievements of particular facilities, with very few publications that have dealt systematically with the conceptual issues.

The following is a list of people and references that provide a conceptual overview. All of the papers referred to are available to download, free of charge:

- The work of Professor Erkko Autio and his colleagues at the Helsinki University of Technology, are among some of the most instructive papers.[10] While the papers focus on CERN and the industrial knowledge spillovers derived by suppliers through technology procurement, they do include good introductions and conceptual frameworks
- Olof Hallonsten from the Research Policy Institute in Lund (Sweden) has co-authored a number of accessible conceptual papers[11] and case studies, including a recent special section on 'The Politics of Megascience" in the journal Science and Public Policy (Vol 39, Number 4, August 2012)
- A paper presented Giancarlo Lauto and Finn Valentin at the DRUID 2012 Conference, includes a useful overview of the academic literature and presents a systematic analysis of the research collaborations between staff at the Oakridge National Laboratory in the US and other researchers located in the US and Internationally.[12] It shows the centrality of international networks and the growing important of commercial users / partners
- Within the grey literature, Technopolis has carried out several literature reviews that sought to explain the role of large research facilities from both a scientific and societal perspective. The most recent synthesis was prepared for the Dutch government in 2011[13]

There is a growing body of what one might call 'practitioner' papers discussing the social benefits of large facilities, often presented at conferences organised by groups of research facilities. The European Association of National Research Facilities (ERF) Workshop 2012 is a case in point. Its workshop, "The Socio-Economic Relevance of Research Infrastructures," was held at the German national synchrotron at DESY in Hamburg. The programme and papers are all available to download online (erf.desy.de/workshop/). The ESF Member Organisation Forum on Research Infrastructures is another good route into the RI community's deliberations about the added value of research infrastructure including evaluation needs.[14]

Figure 4 attempts to capture in a single diagram the spectrum of benefit types discussed in the literature; it is an adaptation of a scheme developed for a review of the role of large-scale research facilities, which Technopolis carried out for the Dutch government (Technopolis, 2011).

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[10] As an example, see, Erkko Autio, Ari-Pekka Hameri and Olli Vuola, A framework of industrial knowledge spillovers in big-science centers, Research Policy, vol 33 (January 2004), pp 107-126

[11] Impacts of Large-Scale Research Facilities – A Socio-Economic Analysis, Research Policy Institute, Lund University, Olof Hallonsten, Mats Benner, and Gustav Holmberg, August 2004

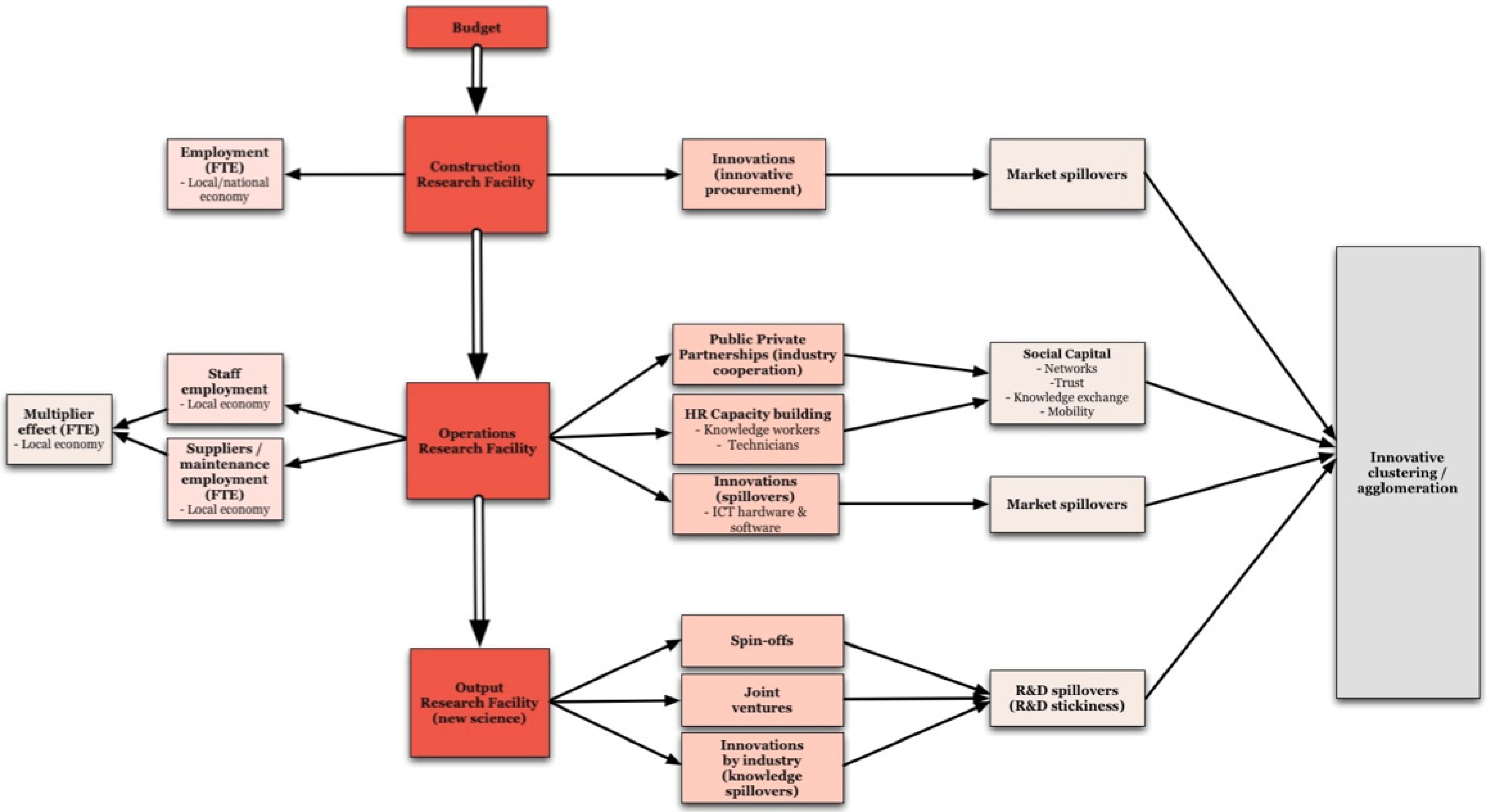
[12] How Large Scale Research Facilities Connect to Global Research, Giancarlo Lauto and Finn Valentin, DRUID 2012 Conference, Copenhagen.

[13] The role and added value of large-scale research facilities (2011), Frank Zuijdam, Patries Boekholt, Jasper Deuten, Ingeborg Meijer and Niki Vermeulen, Technopolis Group.

[14] http://www.esf.org/activities/mo-fora/research-infrastructures.html

It is an input-output model of sorts, making connections between financial inputs and the phases in the facility lifecycle and each of the main categories of socio-economic output. It attempts to capture the benefits that derive from the construction and operation of facilities on the one hand (e.g. technology transfer among equipment suppliers) and, on the other, the benefits of the cutting edge science that is made possible by the facility (e.g. knowledge spillovers that result from research breakthroughs). The model also includes a series of wider effects, from indirect economic benefits (e.g. income multipliers) through to social capital through (e.g. increased international engagement) and industrial agglomeration. It is rather synthetic, and so Figure 5 and Figure 6 present the core ideas in a simple tabular form.

Figure 4 – A schematic showing the social and economic impacts flowing from large research infrastructures



Source: Technopolis, 2013

Figure 5 – A tabulation of direct and indirect social impacts by stage in a facility's lifecycle

Indirect economic benefits	**Direct economic benefits**	**Activity**	**Innovation-related outputs**	**Direct economic effects**	**Indirect economic effects**
Multipliers	Purchase of technical services Employment (designers / engineers)	Design of facility	Service innovations (lead markets / pre-commercial procurement)	Additional sales Additional employment	Market spillovers Multipliers
Multipliers	Capital expenditure Employment (contractors / equipment suppliers)	Build	Product and service innovations (lead markets / pre-commercial procurement)	Additional sales Additional employment	Market spillovers Multipliers
Multipliers	Employment (Facility Staff) Purchases (consumables, utilities, etc)	Operate	Commercialisation of public IP (e.g. Spinoffs) Proprietary research and innovation (non-academic users) New analytical skills (non-academic users) Local agglomeration, including industry retention and inward investment (FDI) Knowledge spillovers from frontier research (Scientific breakthroughs)	Additional sales Additional employment	Market spillovers Multipliers

Source: Technopolis, 2013

Figure 6 – Research design for measuring the direct and indirect social impacts at the design stage

Indirect economic benefits	**Direct economic benefits**	**Activity**	**Innovation-related outputs**	**Direct economic effects**	**Indirect economic effects**
Multipliers	Purchase of technical services Employment (designers / engineers)	Design of facility	Service innovations (lead markets / pre-commercial procurement)	Additional sales Additional employment	Market spillovers Multipliers
Estimate indirect (and induced) economic benefits attributable to the expansion in economic activity resulting from the purchase of design and engineering services. Use national IO tables for this, using 'business services' as the proxy starting point for picking a relevant multiplier	Use management accounts to determine the value of purchases (and in-kind provision by 'own staff) of engineering, design and project management services	Description of key engineering and design activities, what was done by whom and when	Primary research to survey all 'design' contractors to explore the impact of the commissioned work on their service portfolio (may need to be done at different points in time, e.g. contract + 1 year, +3yrs, +5yrs) Seek to identify all service innovations (made possible in part by the design contract)	Primary research to determine the additional annual income (and any associated employment) that is attributable to each of the facility-design enabled innovations Probably need to research each case, as too particular to be able to sample and gross up	Primary research to explore the extent to which each new service innovation is producing additional benefits for users that are not fully captured in the market price Application of general economic multipliers linked back to national IO tables

4.2 Facility lifecycles and implications for innovation

Our impact model assumes large research facilities will deliver different types or combinations of innovation outcomes at each phase in their lifecycle: design and build; operate and use; and decommission. The operation of facilities is also assumed to deliver innovation opportunities, which are distinct from the classic spinoffs and spillovers that follow from the research carried out using the facility or its services.

The following paragraphs present our reading of the conceptual and empirical literature, from these four functional perspectives. We summarise the key points in Figure 7 and Figure 8.

4.2.1 Planning, designing and construction

Planning processes tend to be lengthy as the proposal is usually subject to extensive consultation, involving multiple stakeholders, while regulatory terms, risk assessments, technical specifications and numerous other investigations related to environmental and safety standards are clarified. It is also during the planning process that funding alliances are formed. The outline design and planning process can easily take 5 years, while the time spent designing and building large research facilities to the point of operation, can easily take around 10 years.[15]

The planning and design of large facilities requires deep scientific and technical knowledge, both academic and industrial. The nature of the intellectual effort required to plan and design large facilities, distinguishes this aspect of science investment from other research expenditure.

Carr referred to these facilities as 'modern cathedrals' (Carr, 2002) and as such they constitute an interesting lead market for both technology and equipment.

Often the new equipment or instruments do not exist in the market place and so cannot be purchased 'off the shelf,' therefore scientists often have to cooperate with industry to demonstrate the feasibility and functionality of much of the equipment envisaged by scientists. This phase therefore involves intensive development of new technologies, pushing the technological frontier.

Once feasibility is demonstrated, industry suppliers are then contracted to design and manufacture and assemble the required facilities and scientific instruments. This is commissioned work where the facility tends to take final responsibility (risk) for success, leaving room for industry to gain cutting-edge knowledge and expertise without the associated commercial risks of development. This offers great opportunities to private sector businesses to further develop their R&D.

The physical construction of the buildings and platforms usually engages a range of companies, from geotechnical engineers to steel fabricators. Although much of the procurement process will be open to international bids, it is reasonable to expect that the construction work will mainly benefit regional companies (Hallonsten et al, 2004). However, this is not always the case, for instance, the London-based architects, BFLS (Bogle, Flanagan, Lawrence and Silver), won the contract to design the building for the world's most powerful laser, the £250M Extreme Light Infrastructure (ELI) in the Czech Republic (UKTI, 2012).

The development of the numerous scientific instruments and accompanying technologies, from magnets to mirrors, is the aspect that is expected to deliver the biggest technological push, if not the biggest marketing platform. Eric von Hippel is widely credited as being the person who alerted the world to the critical importance of users in driving innovation in

[15] By way of example, the 39-metre European Extremely Large Telescope (E-ELT), being developed by the European Southern Observatory, will provide scientists with 15 times more light than any telescope operating today. The E-ELT's 2-year baseline design study was followed by a 3-year detailed design study (Phase B), with a budget of €57M, which has mobilised industrial and academic teams across Europe to answer the primary design questions as to how to build this innovative telescope within reasonable bounds of cost and risk, at the same time as meeting the demanding requirements generated by the science teams.

scientific instrumentation, and his paper from 1993 expands on more than 100 cases where scientists and manufacturers collaborated together to produce new or improved instruments for specific projects and which subsequently provided the platform for wider sales or even new product lines.[16] David Connell at the Centre for Business Research in Cambridge was commissioned to write a paper on the power of science as a lead market for technology development and innovation, and develops a number of fascinating stories ranging from Oxford Instruments to Cisco and its origins in Stanford Labs in the US.[17] These are not all big science stories by any means, and indeed there are debates about the relative importance of single facilities within the history of the development of major new research instruments and technologies.[18]

As an indication of the considerable business potential, a 2009 study estimated that the construction of all European research infrastructures inaugurated in the preceding 30 years, had cost around 30 billion Euros (ERID-Watch, 2009).[19] As another example, the budget for constructing the Large Hadron Collider (LHC) at CERN reached almost 5 billion Swiss francs, while the ESO has budgeted €1 billion for the construction of Europe's Extremely Large Telescope (E-ELT).[20] The construction cost for the UK's national synchrotron, the Diamond Light Source (DLS), amounted to some £383m for Phases 1 and 2 combined, and £100m more is being invested for Phase 3 through to 2017.

4.2.2 Operation, maintenance and upgrading

Once the facilities are constructed they usually require a large complement of staff to operate them, many of which are highly skilled scientists and engineers helping to set up experiments or otherwise provide technical support for visiting scientists and other research users.

In many cases, facilities will also provide important opportunities for the private sector ranging from the conventional (e.g. catering services) to the unusual (e.g. calibration services). Private companies have taken advantage of public-sector outsourcing and diversified their general facilities management capabilities offering more specialist management support to scientific establishments. The SERCO Group is perhaps the best known in the UK. It operates the National Physical Laboratory for BIS and also manages the Atomic Weapons Establishment (with Lockheed Martin and Jacobs) and the National Nuclear Laboratory (with Manchester University). This marketisation of aspects of public services has reportedly supported various organisational innovations and helped UK businesses develop new markets and income streams in the UK and internationally.[21]

The running costs can be very large, with private purchases running into the many millions of Euros annually. For instance, in 2011, CERN's budget was 1.16 billion Swiss francs, which was mostly spent on the running costs of the facility such as salaries and energy consumption, however the annual report makes clear that the lab is also procuring a wide range of products

[16] Eric Von Hippel, "The dominant role of users in the scientific instrument innovation process," Research Policy 22.2 (1993): 103-104.

[17] Connell, D. (2010) Scientists are Customers too: How the SBRI can Help Research Councils drive Economic Growth, NESTA, Provocation, May 2010.

18 There was a very public argument about the contribution of the US's Super-conducting Super Collider (SSC) to the development of Magnetic Resonance Imaging, as compared with 'small science,' Can big science claim credit for MRI? Science, 253(5025), pp. 1204.

[19] This figure excludes those facilities under construction at the time and not yet operational (e.g. ITER, ESS, [very much smaller] the big blade test facility at NAREC), and those for which estimation of construction cost had not been possible (e.g. the numerous collections of national museums or ESA's long list of facilities and satellite infrastructure).

[20] As at the end of March 2013, the UK planned to invest £88M in the E-ELT. At that time, the UK industry had already won £9M in E-ELT contracts with the value of that commissioned work expected to increase by x10 up to the end of the construction phase. More info can be found here: https://www.gov.uk/government/news/uk-invests-88-million-in-world-s-largest-ever-optical-telescope

[21] Frank Hull, Bo Edvardsson and Chris Storey, "Customer and supplier involvement in new service development." Involving Customers in New Service Development (2006): 281-312.

and services and as such constitutes an attractive export market for several economic sectors (UKTI, 2012).

Large research facilities are routinely expanded or otherwise upgraded with new generation equipment and instruments and occasional major refurbishments, which may entail extensive planning and design work as well as the associated procurement of novel facilities and equipment. Updating and incorporating emerging scientific advances in the facilities may involve expansion or major refurbishment, which implies re-engaging in the cycle of planning, design and installation all over again. For instance, the ISIS neutron source (one of the UK's world-leading centres for research in the physical and life sciences, based at the Rutherford Appleton Laboratory in Oxfordshire) was originally expected to have an operational life of some 20 years (1985 to 2005), but its continued success led to a process of refurbishment and further investment, which has extended its operational life for a further 20 years.

4.2.3 Use and exploitation

Big science facilities traditionally focused on public science, and the private sector was not part of the investment appraisal.

The innovation and impact agendas are gaining currency, however, even in this relatively protected space and new facilities like the European Spallation Source (ESS) give explicit consideration to industrial use. This process is leading to the gradual emergence of what have been termed as "next-generation international facilities" (UKTI, 2012), designed from the outset as a research resource for both academia and industry. The importance of engaging users, even in the research process itself, is regarded as a viable route to reduce the risks involved in the large capital investments involved in big science, as well as a further justification for their vast costs.

Estimations of the extent to which industry makes use of big science facilities and instrument vary wildly. An extensive study of European research infrastructures (ERID-Watch, 2009) found that industrial use varies a lot across facilities. This study argues that the typical industrial usage is less than 10%, although a small number of infrastructures have substantially larger usage rates: the four largest reported industrial usage figures fell between 30% and 90%. The figures may be lower too! The 'Future access to Neutron Sources' report (CCLRC, 2005) shows commercial (charged) usage of ISIS was less than 1% of all available user days.

Chapter 11 of the STFC evaluation of the Synchrotron Radiation Source (SRS) at Daresbury (STFC, 2010) presents a useful account of 'industrial' use across a 20-year period. It is important to note that this industrial use occurs both directly, through commercial access to the facility, and indirectly, where industrial scientists contribute to academic-led projects. In the former, users pay a commercial rate for beam time and retain the data and any associated intellectual property; there is no requirement to publish results. In the latter arrangement, industrial collaborators may take away new knowledge and insight for private application, however the key findings are published.

The SRS report shows there were 10-20 commercial customers each year and 20-50 commercial projects, producing a combined income of around £2M in the 10-year period 1997 to 2007. User industries ranged from automotive companies to big pharma, but also included a (non-industrial) segment of museums and research institutes: indeed, this last group was the largest single category of users.

The SRS evaluation shows that indirect industrial access, through collaboration with academics, is an important mode of access. The evaluation made use of the bibliographic details in SRS-related publications to identify industry co-authors, and using this bibliometric technique estimated that the number of industry collaborators is as large or larger than the number of commercial users. These academic industry collaborations were reported to have led to some of the most notable social and economic impacts. For example, the University of

Oxford's determination of the 3-D structure of the foot-and-mouth disease virus (FMDV),[22] in conjunction with the Wellcome company (before their merger with Glaxo), underpinned the future development of improved vaccines that offer better protection for livestock and farmers against this devastating disease.[23] The SRS evaluation found that industrial usage – direct and indirect combined – had increased over time. The evaluation underlined the lab's national industrial significance by comparing a list of all non-academic users with the entries in the 2008 R&D Scoreboard and found that almost half of the UK-based firms listed had used the SRS at some point in time over the preceding 20 years.

The use of big science facilities by industry has led to a new range of services being offered by facilities, which provides some additional income (e.g. The SRS accounts show £2 million in income from industrial services in the 10-year period 1997 to 2007).[24] Elsewhere, ISIS reports that industrial clients pay approximately £18,000 to use the facility, per 24-hour period (SQW, 2009). Providing services to industry also allows the identification of potential collaborators in joint R&D projects, as well as future clients for the IP generated at the facility.

This also applies to virtual facilities. The European Bioinformatics Institute (EBI) for example has an 'Industry Programme', which kick-starts research of importance to industry, provides expert training, develops bioinformatics standards, helps its partners with technical development and provides regular networking opportunities. The individual members pay a fee of £32,000, meet around four times a year and workshops are run for their staff (if spaces exist other individuals, academics etc, can join the workshops). Industry partners include large multinational companies in the biotech, pharmaceutical, agricultural, nutrition, personal care and medical devices industries. Additionally, in response to requests from the SME community, in 2002 EBI launched the 'SME Support Forum', which provides networking opportunities, expert tuition, opportunities for technical development through collaboration, consultancy and a priority helpdesk. Members can dip in to the programme on an ad hoc basis paying only for services used, with members ranging from drug discovery to biotech start-ups to bioinformatics service providers (SQW, 2009).

4.2.4 Decommissioning

Ultimately, refurbishment and extension will come to an end and a research facility may need to be decommissioned. We found very little information about this final stage in the facility-lifecycle, which suggests it is not widely studied or reported. However, the STFC has published information about its SRS Decommissioning Project (2011), which provides insight about the kind of equipment recycling and reuse that may be involved:[25]

- Large sections of the newest beamlines were dismantled and shipped to other sources such as the Diamond Light Source (DLS), ANKA and SESAME, for return to active service
- Many other components were also recycled and put to good use elsewhere at Daresbury, while other items of equipment are being stored for possible future use. This required a careful approach to valuation and asset management to maximise the return on the earlier investment of public funds
- Equally important was the requirement to preserve important documents and properly record the impact made by the facility over its lifetime. A significant effort went into sorting through a huge volume of papers and logbooks and finding a suitable permanent

[22] Acharya R, Fry E, Stuart D, Fox G, Rowlands D, Brown F. The three-dimensional structure of foot-and-mouth disease virus at 2.9 A resolution. Nature. 1989 Feb 23;337(6209):709-16.

[23] FMDV is a major killer of livestock; the 2001 outbreak had estimated direct costs totalling £8.4 billion.

[24] SRS market research suggested that industrial users often need support in carrying out experiments and analysis, which led to the decision to create a materials characterisation service (the "Daresbury Analytical Research and Technical Service" [DARTS]) offering an extended service to industry. Over time, the service built up a database of 62 commercial (industrial) clients and 15 academic institutes that paid for access to beam-time. The SRS team launched several other innovative consultancy services unavailable elsewhere, including a facility-brokering service that could be used to prove the validity of a key patent (STFC, 2010).

[25] http://www.stfc.ac.uk/astec/34625.aspx

home in which to store them. Key SRS archive documents have been donated to the Museum of Science and Industry (MOSI) in Manchester to support the exhibits in its Revolution Manchester gallery. The archival material was accompanied by pieces of scientific equipment, including sections of beamlines 16.5 and 2.3. The parts from beamline 2.3, a high-resolution powder diffraction station, are on display in the gallery[26]

[26] http://insidethem60.journallocal.co.uk/2011/05/04/mosi-documents-shine-light-on-daresbury-research/

Figure 7 - Tabulation of innovation outcomes in each phase of a big science facility

	Description of activities	Innovation triggers	Innovation outcomes
Design & build (new or upgrade)	• The design and commissioning work will entail the purchase of high value technical services. • The building and installation work will entail the purchase of various high-value systems and instruments, some of which may involve technological innovation or other advances as compared with the state of the art	• Lead markets / user-led innovation, supporting the creation of new products or services that may be sold to third parties	• Novel, next-generation equipment, instruments and systems, which can be sold to third parties and may be the basis for new economic sectors • Novel design methodologies and services,
Operate and maintain	• Typically facilities will be run by dedicated organisations with highly specialised skills. • This can be public or private, or both • Operations will also involve ongoing purchases of specialist technical services and materials • The scale of operations can also produce local clustering effects, with specialist suppliers be spun off and other firms co-locating to take advantage of ongoing purchases and the wider ecosystem	• Running facilities can drive innovation in the supply side (e.g. privatisation of laboratories in whole or in part, creation of new facility-based consultancy services) • Facilities may require local high-tech support, which can combine with reputational effects to generate further investment and FDI (local agglomeration effects).	• Novel facilities management services that service companies go on to sell to third parties, generating new sales and employment • Novel analytical or technical consulting services, which can be sold to third parties • Creation of new companies to take over the supply of certain high-value services (purchased by the lab in question), which may be saleable more widely • New or expanded clusters of specialist manufacturers and suppliers
Use of facilities	• Access to facilities permits research that may not be possible otherwise, advancing understanding, creating new tools or methodologies and possibly new datasets	• New research-based knowledge and data underpins creation of specific IP and direct technological innovation • New research-based knowledge and data placed in public domain facilitates knowledge spillovers and indirect innovation • Industrial users have direct access to state-of-the-art facilities, which supports / strengthens their proprietary innovation activities	• Specific IP sold to businesses in a better position to take it to market, supporting the commercialisation of public sector IP • Creation of new companies to exploit specific IP arising from the research • Proprietary innovations made possible by application of new knowledge produced through use of the facility • Product and process innovations made possible by application of new knowledge embodied in public research outputs

Figure 8 - Tabulation of innovation outcomes by broad class of facility

	Design & build (new or upgrade)	Operate and maintain	Use
Single site facilities	The need for cutting edge equipment and engineering should provide strong platform for product and service innovation in (very specialised) technology fields	Innovation in service provision through outsourcing and rationalisation of back office operations Agglomeration effects, attracting co-location and possibly inward investment by overseas technology centres	Academic users dominate, so innovation is driven through knowledge spillovers in the main and commercialisation of occasional academic-led IP outputs Some access granted to private sector via collaborative work defined by the private sector, which may have more direct impact on innovation (But private sector more likely to access previous generation facilities, on a charged basis)
Distributed facilities	Typically, novel systems architecture, advanced communications and high-performance analytics, but possibly exploiting more established (observing / measurement) technologies	Innovation in service provision is possible, in particular around terms of access and service models (e.g. international networks of biobanks)	Academic users tend to dominate, so innovation pathways are academic-IP and knowledge spillovers
Mobile facilities	Facilities are likely to be proven technology platforms in themselves, however survey and other measurement instrumentation is often new to the world and may be a source of user-led innovation	Innovation in service provision is possible, in particular around financing and access models Agglomeration effects are less clear, although ships and aircraft do require substantial infrastructure at their home base (so, they are more likely to reinforce agglomeration rather than create it)	Academic and institutional use dominates, however will often combine data streams with other data or research activity, so innovation impacts most likely through knowledge spillovers
Virtual facilities	May be strong impetus for software engineering innovations (database management), networking, data mining algorithms as well as advanced communications	Innovation in service provision is very likely but is probably rather limited in its wider relevance (as a business model). Public facilities likely to follow rather than lead innovation in information services Agglomeration effects less likely (Likely to have a very much smaller footprint than a single-site facility that hosts visiting researchers)	Non-exclusive use of large datasets means facilities can service very much larger user populations in both the public and private sectors, and possibly trigger innovation in far more places However, it may be that this more extensive reach is mirrored by a less intensive use of the facility or information, and that as a result aggregate impact on national innovation is similar to the single site facilities Improved access to and aggregation of multiple data sets through major data centres can produce some costs savings for the public research system and productivity gains for users

4.3 Distinct contributions to innovation

As noted already, the conceptual literature is rather limited in extent and what there is devotes little attention to explaining the unique contribution of large facilities as compared with public research more generally.

From an innovation perspective, large research facilities stand apart from public sector research more generally in that they entail the purchase, and possibly the development, of technologically-advanced equipment and systems. While this kind of user-led innovation may happen at all levels, the scale and intensity of big science projects does appear to provide the platform for more ambitious development efforts and more radical and disruptive technologies. The commissioning of new technologies triggers wider innovation activities, with contractors able to sell the resulting new products and services in other markets.

There are other impact pathways too, as noted above, albeit none quite so distinct as the capital investment / user-led innovation aspect:

- They are unique (or scarce) research tools, which permit new research questions to be posed and increase the likelihood of breakthroughs in understanding, and such insight may have profound social benefits
- They provide access to unique equipment, data or services for an increasingly diverse user base, including growing numbers of businesses working with academic groups or carrying out their own proprietary research and innovation
- They can provide a focal point for local clusters of scientists and engineers on the one hand and high-value, high-technology service companies on the other. These agglomeration effects can help to kick-start new clusters or more often reinforce innovation ecosystems

After reading the conceptual material and discussing many types of impacts among different types of facilities at different stages in their lifecycles, we turned to the empirical literature and were quickly brought down to Earth. The RI evaluation literature, the ex post studies anyway, is really only concerned with two or three types of social benefits:

- The economic impact of expending large amounts of public money on these facilities
- The knowledge spillovers and spinoffs realised by the specialist contractors that supply and develop the cutting-edge technologies necessary to build and operate the facility
- The local economic effects of the substantial amounts of capital (and recurrent) expenditure made in a single location and the agglomeration effects brought about by large numbers of visiting researchers and local specialist suppliers including those industrial spinoffs

The next three chapters present our reading of the treatment of these three sets of phenomena, as set out in the empirical literature and in particular the methodological approaches described evaluation reports that we have separately case studied.

5. Evaluating financial & economic outcomes

5.1 Introduction

In this chapter of the report, we discuss the approaches to measuring the economic impacts arising from large research facilities, as found in the empirical literature.

The focus for the most part is on the benefits that follow from the major public investment in these facilities – capital and recurrent – and the wider effects on the economy; it is not an innovation outcome in a strict sense but it is the cornerstone of much of the evaluation literature on research infrastructure.

We look at approaches to the measurement of innovation outcomes and clustering in the following two chapters.

5.2 Our selection of studies and evaluations

We identified 18 published reports that had measured the economic benefits made possible by specific research infrastructures, and which we considered to be of sufficient quality to be instructive to BIS and colleagues.

Figure 9 lists the authors and titles for each of those 18 reports, presented alongside our description of its overall approach and picking out any particularly noteworthy features, in what amounts to an annotated bibliography.[27] The description is quite synthetic, however there is a more analytical treatment of the methodologies of all of our key references shown in the appendices.

The list of publications includes studies for UK facilities as well as international ones. Most of the studies report on the economic impacts of single-site facilities, with a few examples of studies that have looked at the benefits of slightly different configurations: research collections (e.g. British Library), virtual research facilities (e.g. ESDS) and distributed facilities (e.g. the Human Genome Project).

The selected reports focus on and measure different types of economic impacts, using different methodologies. We classified the observed economic impacts as: (1) effects on economic activity – including direct, indirect and induced economic impacts, and (2) economic effects on users. Three of the study reports stand out as being particularly good examples of 'good practice' in the measurement of these types of economic impacts:

- A national laboratory. The economic impact study for the Berkeley Lab (by CBRE Consulting, 2010) – uses a robust methodology for the overall estimation of indirect and induced economic impacts on the nine counties that make up the San Francisco Bay Area. The study makes a valuable contribution regarding the geographical distribution of impacts. Amongst the direct economic impacts, the study includes 30 spin-out companies linked to the Lab. To estimate these levels of impact the study uses a robust methodology based on an input-output technique (IMPLAN). The model was designed to be relatively automated so that Berkeley Lab can update the estimation of economic impacts on an annual basis by entering its latest fiscal year data
- An international 'big science' programme. The study of the economic impact of the Human Genome Project (by Battelle Technology Partnership Practice, 2011) – is a comprehensive study, covering the 23 years of the project (from 1988 to 2010). The report is an example of good practice in the measurement of benefits on economic activity (including direct, indirect and induced impacts). The estimation of direct economic impacts covers not only impacts arising from actual expenditures on the HGP project on

[27] Around half of the 17 reports addressed innovation outcomes and or regional clustering as well as economic impacts, and this sub-set of reports are also presented in the equivalent bibliographies in the following two chapters. We have sought to capture the aspects relevant to the particular type of impact under discussion, rather than simply repeat the entry in each of the three annotated bibliographies.

the national economy (as is the case in most of the reports presented here), but also includes the impact of follow-on federal research investments in major genomic science programmes, as well as the activities of the genomics-enabled industry sectors. Beyond the direct economic impacts, the study also quantifies the indirect and induced economic impacts (or ripple effects) of these activities by calculating the subsequent spending of suppliers, and what their employees spend in the overall economy, using an input-output methodology to calculate the return on investment of the HGP to the US economy

- A research data centre. The economic impact evaluation of the Economic and Social Data Service (carried out by Charles Beagrie Ltd and The Centre for Strategic Economic Studies (CSES) University of Victoria, 2012) is an example of good practice in the estimation of economic value for users of the data and services provided by 'big research facilities.' To do this, the study combines a range of methodologies to identify and assess the multiple benefits that ESDS brings to its users. The study starts with a minimum baseline of impact (measuring investment and use value) and moves to more complex methodologies including contingent valuation and case studies

The review of the reports allows drawing key features, differences and appropriateness of methodologies for different types of facilities.

5.3 Economic outcomes

The empirical literature looks at the following types of economic impacts:

1. Effects on economic activity. This type of studies can be sub-divided into those:
   - Measuring direct economic impact: Direct economic impacts refer to the economic activity undertaken by the organisations responsible of establishing and operating the large research facilities. Direct economic impact can be measured either in a given year, or over the years (e.g. NPV)
   - Measuring the indirect and induced impacts – the ripple effects. This is mainly through the use of input-output analysis
     - Indirect economic impacts consist of the activity supported as a result of the purchases of good and materials made by the research facilities to their suppliers. They are also known as "supplier impacts" and they involve a wide range of suppliers from the manufacturers of specialised instruments and capital goods, to janitorial companies that clean the facilities.
     - Induced economic impacts are the results of spending of the salaries of the direct and indirect employees of the facilities. This spending creates additional economic benefits in nearly all sectors of the economy.
   - Cost-benefit analysis
2. Effect on users – especially in those facilities that are user-oriented rather than research-oriented (such as collections or data centres). This is mainly done through the application of contingent valuation techniques

5.4 Methodological approaches

Existing reports of the actual or potential economic impacts of large research facilities use a variety of distinctly different methodologies. Moreover, methodologies are often applied with different levels of expertise and depth.

The available empirical literature comprises ex-post and ex-antes studies. Ex-post economic impact studies aim to provide a quantification of the contribution of a specific facility to the local, regional and/or national economy, while ex-ante studies usually have a strategic rationale or planning role.

Ex-ante studies tend to have a broader scope, because their purpose is to identify all areas of potential future benefit in order to inform investment appraisal decisions and competing investment opportunities. Ex-ante evaluations are mainly used to appraise investment proposals, and are often rather more ambitious in their scope than the equivalent ex-post studies. These studies use rather creative methodologies in order to estimate likely future economic outcomes, typically with some form of expert judgement sitting at the centre of the exercise, fed with secondary data from analogous past projects or sector studies to help gauge the shape and size of the application areas they will be addressing. In a number of cases, these impact assessments have been able to take advantage of existing economic models in order to estimate the potential wider impacts of increasing research expenditure or innovation-enabled cost reductions. GMES is one area where these approaches have been well documented[28] and where specific models have been developed (e.g. the FP6 Geobene project and the Felix model). More recently, the Low Carbon Innovation Coordination Group (LCICG)[29] commissioned the Carbon Trust to prepare a series of Technology and Innovation Needs Assessments (TINAs) in areas ranging from offshore wind to nuclear, which make use of the Energy Technologies Institute (ETI) ESME model to explore potential future impacts of technological change in low carbon energy systems.[30]

We have included references to ex ante impact assessments for completeness, but have not recommended BIS seek to emulate the analytical and modelling techniques within the context of future RI evaluations.

Ex-post studies test the actual performance of a research facility. For the purpose of this study, i.e. exploring methodological approaches to measure actual economic impact, we will focus specifically on ex-post studies. As mentioned above, we found studies that estimated (1) effects on economic activity – through the estimation of direct, indirect and induced impacts; and (2) economic effects on users.

(1) The effects on the economic activity can be done: (a) through the estimation of direct economic impacts or (b) through the additional estimation of indirect and induced impacts.

(a) Direct impacts are usually refer to the mere account of the facilities' expenditures on salaries, purchases of goods and services, and output as obtained from the facilities financial records – four out of the 17 studies do not go beyond this level of estimation of direct economic impact.

(b) The estimation of indirect and induced benefits is generally done through the use of input-output analysis – eight out of the 13 studies apply input-output techniques to calculate the broader ripple effect of the facilities in the economy.

The economic effect on users has been estimated through contingent valuation techniques. Contingent valuation is utilised in those facilities that are particularly user-oriented, as is the case of ESDS and the British Library. In our selection of studies only these two use this methodology.

5.4.1 Studies measuring the effects on economic activity

Direct economic impact analyses

We found that four out of 13 studies chose to confine their analyses to the direct economic impacts of establishing the facilities.

- The SQW study for the Cabinet Office (1993) examines the direct economic impacts of six large research facilities (JET, CERN, ESRF, ILL, RAL and Daresbury Laboratory), providing evidence of the comparative economic benefits from hosting a large research facility, in terms of contracts and employment. Taking into account host country contracts, salaries to host nationals and expenditure by foreign nationals in the host economy the study estimates annual expenditure flows into the host economies at between 40 and 70 per cent of the facilities' annual budgets
- A study on ESTEC's impact on the Netherlands (Triarii, 2005), presents the analysis of the expenditures and government contributions to determine the economic value of ESTEC to the Dutch economy. The study provides an account of ESTEC expenditures and employment and in addition it provides a macro-economic estimation of the 'juste retour'

[28] Socio-economic benefits analysis of GMES: main report (2006), prepared by PriceWaterhoueCoopers with ESYS and DNV, for the European Space Agency.

[29] http://www.lowcarboninnovation.co.uk/

[30] http://www.eti.co.uk/technology_strategy/energy_systems_modelling_environment/

principle, by comparing Dutch contributions to ESA, to ESA's expenditures in Netherlands. It is worth noting that this study also includes the expenditure of visitors, which other studies do not. The report concludes that in the period 2000-2004 the total value of ESTEC spending exceeded the Dutch contribution to ESA by €261M and that the value of ESA contracts secured by Dutch industry exceeded the contribution by €24M

- A review of five UK facilities (SQW, 2008) examines direct economic impacts arising from employment and expenditure. In considering these economic effects, the study places particular emphasis on analysing the local effects – such as the geography of staff and suppliers. It concludes that direct local economic impacts of facilities are significant, and arise mainly from the employment of relatively highly paid staff which reside locally, and the awarding of contracts to UK-based suppliers.
- The study on biobanks (Fraunhofer, 2009) includes information about the costs of building and operating the biobank

Direct economic impacts are also estimated in input-output (IO) analyses, as such estimations of direct impact constitute the bases on which indirect and induced impacts are calculated making use or generating multipliers. These studies are explained below.

Input-output analyses

An input-output model is a quantitative economic technique that represents the interdependencies between different sectors of a national economy or regional economies. It 1) identifies all the different industries included in the supply chain of a given economic activity and then 2) estimates the value of the purchases that flow between all those industries in a given period of time. By building an IO matrix/model it is possible to derive economic multipliers, a factor that measures the effect of an additional £1 invested in a given industry or economic activity (direct effect) on the total economy (indirect and induced effects). Different economic impacts would be linked to their corresponding multipliers – e.g. employment multipliers, income multipliers, GVA multipliers, etc.

This is a costly exercise, and most of the economic impact assessments examined here rely on IO multipliers estimated by national authorities or by other previous studies.

This is the most common methodology used to assess indirect and induced impacts – five of the selected studies (out of 13) use IO methodology. However, IO techniques are implemented with different levels of depth. Some studies would take the estimations of direct impact (e.g. employment, expenditures, output, etc) and calculate indirect and induced impacts by applying multipliers obtained from existing sectoral, regional or national IO statistic tables. A second set of studies, run the basic data on direct impacts through existing IO models developed and maintained by regional or national organisations (e.g. IMPLAN model). These models are usually facilitated by software and data tools that allow generating multipliers to quantify indirect and induced impacts on the basis of the facility's financial data. Finally, a third type of study calculates indirect and induced impacts independently, without the use of IO software or existing multipliers. The choice of each of these avenues very much depends on the resources available to perform the evaluation.

The first option is the most accessible, since IO multiplier tables are widely available. In addition, some studies indicate their preference to limit their assessment to the direct economic effects expressing reservations about the accuracy of the estimation of indirect and induced effects. In the selected set of studies, three out of seven studies performing IO analyses, make use of existing IO tables:

- The SRS study conducted by STFC (2010) utilised input-output methodology to measure the economic contribution of SRS directly to the local/regional economy and the wider UK over its construction and 28 year operational lifetime. The study provides metrics for the investment costs, employment and impact on the local economy (percentage of local expenditure). It also includes a post-hoc economic impact assessment, which uses SRS spend – capital and recurrent – over its lifetime as the input to an ONS-derived analysis of indirect and induced effects. However, the study assumes that gross effects equal net effects and does not make any adjustments for displacement.
- A study for TRIUMF (by MMK Consulting, 2009), Canada's national laboratory for particle and nuclear physics located in British Columbia, used the IO methodology to

estimate the direct, indirect, and induced economic impacts generated by TRIUMF on the economy of British Columbia. Estimations of direct impacts included output, GDP (value added), employment, and government fiscal impacts (taxes collected). The analysis used published Provincial Economic Multipliers (BC Provincial Input-Output Model (BCIOM)), rather than running actual TRIUMF data through the BCIOM itself due to the short timeframe to perform the study – although it weighs the average multipliers according to with TRIUMF's activity segments. The results demonstrate the significant impact that the laboratory brings to the province, although noting that when it comes to more specialised technology and skills, the benefits may be more broadly distributed. The main purpose of the study is to analyse the economic returns from a potential expansion of the facility requiring an investment of $60.7 million, estimating the annual economic impacts attributable to future TRIUMF operations under alternate scenarios (with and without expansion).

- The ex-ante impact assessment for the ITER fusion research facility in Southern France (ITER, 2002) examines direct, indirect and induced impact of the facility, differentiating between the construction and operational stages, as well as geographically (regionally, nationally and global). The study presents a detailed account of spending by ITER including purchases of goods and services as well as employment by economic sector. On the basis of the sectors and revenue spending, the economic impacts for production and employment are calculated using the national inter-sector IO matrix for the calculation of national impacts, and the same matrix is adapted for the calculation of regional impacts. The study finds that ITER directly activates 7 of the 37 sectors the economy during the construction phase and 18 during the exploitation phase. The study finds out that the regional indirect and induced effects – in terms of increase in the production and employment – are considerably larger than the national effects during the exploitation phase as compared to the construction phase

The second option – running the facility's data through existing IO software – was chosen by two of the IO analyses. This option requires additional resources, skills and time (for instance IMPLAN package – explained below— costs of around $70,000 – depending on the detail of the geographical coverage)

An IO analysis for Berkeley Lab (2010) quantified the direct indirect and induced economic impact of the Laboratory, focusing on the impacts on job generation, wages, and spending. The study pays particular attention to the geographical economic impact of the Lab differentiating between the local, provincial, regional and national impacts. The methodology is clear and well explained, consisting of an estimation of Berkeley Lab's direct effects of payroll, purchasing, and capital expenditures of the Lab, plus the re-spending effects in the greater economy. To calculate the indirect and induced impact and run this data through the IMPLAN model (IMpact Analysis for PLANning) – a widely accepted IO model developed by the U.S. Department of Agriculture. IMPLAN provides a software system and geographic-specific data regarding economic sector interactions for calculating economic impacts. Indirect and induced effects were aggregated in a single figure. The results indicate that the majority of economic impacts are realised locally as the Lab acts as a catalyst for employment and income. Using the same model, the study also includes an analysis of the direct, indirect and induced economic impacts of 30 start-ups spawned by the Lab's technology in the 20-year period since 1990

- The HGP study (Batelle, 2011) applied IO techniques to total US public expenditure ($3.8 bn), genomics research expenditure (e.g. by the US DOE) and the expansion in the national genomics industry, using the IMPLAN model. The study provides a quantitative estimate of the project's economic impact on the U.S. "genomics and genomics enabled industry", for which the evaluators constructed a "from the ground-up" database of individual companies engaged within the sector. Additionally, it is worth noting that the IMPLAN model has built-in economic "inflators" and "deflators" to allow for the development of cumulative multi-year impact estimation for the 23 years included in the analysis. Finally the study uses these estimations to calculate the return of investment of the HGP to the US economy

The third type of IO analysis makes independent calculations of indirect and induced impacts, coming up with its own multipliers. For this type of study to be well performed, it requires deep and broad consideration of all the potential effects (market, financial, technological, etc) of the facilities expenditures, and for that reason they are rarely performed. These types of studies, when found, tend to make either partial or inflated estimations often arriving to unrealistic results. A study for the John Innes centre (2009) uses this route to estimate the direct, indirect and induced economic impacts. The analysis uses the profile of supplier expenditures to estimate the indirect impacts. Induced economic impact is estimated by modelling the household income from direct and indirect employment using an average consumer profile across the UK

5.4.2 Studies measuring the economic effects on users

Contingent valuation is a method that involves the use of surveys to elicit the willingness of users (actual and potential) to pay for certain programmes. Contingent valuation involves the assignment of money values to non-market goods and services based on preferences. This methodology is particularly useful for those facilities that are user-focused, such as data centres or collections. A study conducted for the British Library in 2007 makes use of this methodology to demonstrate the benefits derived from the *use* of the library. Surveys were conducted amongst (a) physical users of the library, (b) remote users and (c) general public (potential users). The study concluded that the Library generated value worth £363m per year: 4.4 times its annual baseline government funding of £83 million. In addition, the direct value to users amounted to £59m and the indirect value to the wider society to £304m.

An evaluation of the Economic and Social Data Service (ESDS), for the ESRC, also used contingent valuation to estimate the value of ESDS research data to its users. Beyond the willingness to pay, the study also explored wider economic benefits and impacts by looking at the efficiency gains enjoyed by users and assigning an economic value to them (e.g. activity cost savings), and by estimating the impacts of increased data use on returns to investment in the data collection/creation and the related data infrastructure services necessary for hosting and sharing the data. The study found that ESDS had a net economic value of around £18 million per annum for its users, and at least £100 million per annum for the wider community. The return on investment was estimated at 5.4 to 1 (hence, every £1 spent on ESDS realises £5.40 value).

5.5 Data requirements

From this body of literature we can see that estimating the direct economic benefits of large research infrastructure typically requires the following types of data

- Data on the facility's annual expenditure. Broken down by broad function, and by capital and recurrent spend. The better studies make use of time series data
- Data on the source / location of various external purchases
- Data on facility employment, wages, pensions, residency, etc

Estimating the indirect and induced effects usually entails the use of IO matrices and multipliers, or access to IO packages that provide the necessary software and data that allows the analyst to generate its owns multipliers.

5.6 Strengths and weaknesses

The current state of methodology to assess economic impacts is relatively advanced, and certain methodological approaches have been proved and tested – especially in relation to ex-post analyses such as input-output analysis or the contingent valuation techniques – although their implementation varies in terms of depth and coverage.

The HM Treasury Green Paper (2003) set up the requirements in relation to public sector project appraisal, putting emphasis on the economic rationale – proposals need to be underpinned by sound economic analysis, preferably appraised through a cost benefit analysis. However, we found no RI studies making use of this methodology. Methodological guidelines to cost-benefit analysis of investment projects are provided by the European Commission (2009). CBA methods are requested to avoid the risk of too costly or unsuitable projects, and therefore are mostly used for ex-ante analyses. Conducting a full cost/benefit analysis is a lengthy and costly process and requires the consideration of multiple external factors. Realistically most cost-benefit analysis will not have the exact cost and benefit figures; however, there are significant risks if certain variables are overlooked. For this reason CBA tend to be complemented with additional research to support the analysis, implying additional efforts for the organisation. We found no NPV analyses for large research facilities.

Some critical aspects are not adequately measured in current studies, and would require further data collection efforts:

- The issue of **displacement** examines the degree to which the economic benefits of a facility may occur at the expense of other economic activities. This issue is partially addressed in a study of six large research facilities by the Cabinet Office (1993), indicating the importance of considering the net effects of the host country benefits' in winning contracts, which can only be counted as a net benefits to the host country if the orders do not substitute for other sales, either by the supplier or other firms in the host economy. Although the study does not quantify for economic displacement effects, it addresses the issue though a survey to supplier companies and highlights that some economic benefits can only be counted as net benefits if they do not displace other economic activity. The results of the survey nevertheless indicate that the impact of suppliers on markets and employment do not appear to displace any other domestic activity due to the specific nature of the contract.
- A study of the TRIUMF (2010) laboratory also makes interesting observations related to opportunity costs, recognising that certain expenditures, if not made, would be used in another way that would also give rise to economic impacts. In this regard the analysts consider appropriate not to include construction costs within the economic impact analysis arguing that these funds would have been found alternate uses by the Provincial government. While the impacts of alternate investment may differ, the report considers that it would not be reasonable to count all of the economic impact of construction expenditure as being incremental and attributable to TRIUMF. The opposite assessment is given to the operation costs, which are included in the economic impact analysis as incremental to the province – the argument given is that due to the unique nature of the facility, federal funds would have been likely to be deployed for other purpose, possibly outside the province.
- Further data needs to be collected in relation to discount rates and risk profiles of different alternative investments.
- **Short-term, medium and long-term**: we have not found attempts to collect data that allows distinguishing between short, and medium to longer terms and more specifically between construction and operation phases. Although it is noted in some reports (Cabinet Office, 1993) as a recommendation. It is noted that the displacement effects are likely to be determined by the stage in the lifecycle of the facility.
- **Time series** are not used. Attempts to estimate the economic impacts over long periods of time are very limited possibly due to limitations in data collection problems associated with the long time periods. Historical trends are rare with one exception – we found two studies for Berkley lab making a time comparison of the economic assessment at two points in time (2005 and 2009). The historical comparison allows identifying the areas in which the Lab had showed improved economic impacts – such as expenditures. Also the SRS and the HGP studies cover long periods of time (28 and 23 years respectively).
- Ideally, economic impact assessments should estimate the **counterfactual** – i.e. what would occur in the absence of the facility. The analysis of the counterfactual is a critical tool for assessing the effectiveness of specific interventions. However, counterfactuals are rarely addressed in the studies reviewed due to lack of data. We found two exceptions that address this issue partially. One is the evaluation of the economic impacts of ESDS (2012) which partially explores the counterfactual through a users' survey, asking them if they could have obtained the data they used in another way had ESDS not existed. Another exception is a review of economic impacts of large-scale science facilities in the UK (SQW, 2008) addressing the challenge of estimating the counterfactual of the benefits (and costs) incurred by having a UK location as opposed accessing a similar facility located elsewhere; however, this estimation is not done rigorously and relies mostly on the estimation of the local benefits.

- Different **beneficiary groups** would require different evaluating techniques. However, studies do not clearly define the beneficiary groups and so not justify the use of assessments techniques as the most appropriate for their beneficiary coverage – data needs for different beneficiary groups.
- **Quantitative data of costs and benefits** using metrics and impact measures.

5.7 Results and stylised facts

We found few attempts to aggregate economic impacts. The following bullet points present a list of the relevant statistics:

- ESS study (2009) = The minimum cumulative effect on the Skåne region's GDP, up to 2040 (25 years of construction and operation), is estimated at SEK 35 billion (c. €3.5 billion) assuming that the ESS only affects the surrounding community marginally. The maximum effect is estimated at SEK 302 billion (c. €30 billion)
- SRS study (2010) = the total cost of wages paid directly to staff was £220M over the lifetime of the SRS, and the total financial economic impact of the SRS was approximately £992M with the majority of this impacting the local economy
- ESTEC study (2005) = every Euro produces a return of €3.4 for the Dutch economy
- Berkeley Lab study (2010) = in 2009 every 1.0 direct, full-time-equivalent employee of Berkeley Lab contributed to another 3.3 jobs in the United States. The economic local impact of Berkeley Lab's spending in the Bay Area accounts for 72% of its total spending both in 2005 and 2009
- TRIUMF study (2009) = More than 90% of TRIUMF's total Canadian economic impacts occur within British Columbia, where the research facility and the majority of staff are located. TRIUMF's core operations generate an estimated $95.4 million in total annual output, $58.4 million in total annual GDP, and creating a total of 832 FTE jobs, and $5.7 million of annual Provincial revenues
- British Library study (2007) = the BL generated value worth £363m per year: 4.4 times its annual baseline government funding of £83 million. In addition, the direct value to users amounted to £59m and the indirect value to the wider society to £304 million
- ESDS study (2012) = ESDS had a net economic value of net economic value of around £18 million per annum for its users, and at least £100 million per annum or more for the wider user community. The return on investment was estimated at 5.4 to 1 (hence, every £1 spent on ESDS realises £5.40 value)
- Human Genome Project study (2011) = Between 1988 and 2010 the human genome sequencing projects and associated research and industry activity, directly and indirectly generated: (1) $796 billion in U.S. economic output, (2) $244 billion in personal income for Americans, and (3) 3.8 million job-years of employment. A federal investment of $3.8 billion ($5.6 billion in 2010 $) was judged to have made possible more than $796 billion in economic output

5.8 Implications for future BIS evaluations of research infrastructure

The current state of the art tackles the quantification of direct economic effects well enough, and is very much in line with the approach BIS recommends. The quantification of indirect and induced economic impacts also works reasonably well, subject to the limitations of the IO data and the intrinsic assumptions associated with an IO analysis.

The main gap in terms of the scope of the economic impact relates to the second order effects, the knowledge spillovers, which tend to be looked at only occasionally and often in isolation as descriptive case studies. The various CERN and NASA studies do this best, inasmuch as they have sought to arrive at a global estimate of the economic benefits of their 'known' industrial spinoffs. None of the studies we identified attempt to estimate the economic value of knowledge spillovers more generally, for other producers or consumers. The work on data centres is instructive with its use of contingent valuation techniques, however that relates to the immediate use of facility's data or services and not the service innovations made possible by those data.

The principal methodological weakness, common to all impact types, is the perennial challenge faced by any research evaluation, which are the questions of attribution and additionality. Counterfactual analysis is nowhere in sight.

We did not find a single example of an evaluation that had sought to identify, quantify and aggregate all types of economic benefits. We believe this reflects the scale of the methodological challenge that an integrative approach would imply. Implementing a modified-CBA would need the evaluators to deal with all of the classic R&D measurement challenges: attribution, additionality, temporality as well as a series of other factors from displacement to opportunity costs. Counterfactual analyses and other gross-to-net adjustments are not in evidence.

The SRS evaluation is the only example that covered all broad classes of social and economic impact, however the study did not attempt to add it all up.

However, it ought to be possible for BIS or STFC to take things a little further, even with the present state of the art.

A modified cost-benefit approach seems feasible albeit possibly costly and time consuming to carry out in the first few instances. The kind of IO economic analyses describe above will work well enough. The second-order effects need further thought, but probably require a much more involved research design with user surveys, impact case studies and sector studies (with critical peer review) to provide some control and basis for adjustment as regards the nature of the contributions and any deadweight or displacement.

The data needed for a comprehensive economic impact study does not necessarily fully reside in the structure of large research facilities. Often facilities need to work with the business sector and the user community in order to define, collect, and refine the required data.

The quality of the data must be carefully assessed as a basis for selecting the appropriate measures. Since data collection is typically labour intensive and expensive, also careful consideration must be given to the set of stakeholders that may be targeted for surveys. It is important that large research facilities work closely with the key stakeholders (suppliers, users, etc) in setting up the data requirements and minimise the cost of data collection.

Figure 9 – List of RI studies and evaluations that sought to measure the economic impact of the facility

Year	Author(s)	Title	Comment on the approach
2002	Alpe-Conchy, D	EISS Cadarache, European ITER Site Studies, IDEP Study	The ITER ex ante impact assessment (2002) used a reasonably detailed breakdown of the facility's actual and planned construction purchases over a 13-year period to feed into an analysis of indirect and induced economic benefits. The author fed this composition analysis into France's national accounts, using IO analysis and multipliers, and then applied a (unexplained) modification to adjust for the particular regional characteristics
2011	Battelle Technology Partnership Practice	Economic Impact of the Human Genome Project	The study of the economic impact of the Human Genome Project (by Battelle Technology Partnership Practice, 2011) – is a comprehensive study with a long timescale, covering the 23 years of the project (from 1988 to 2010). The report is an example of good practice in the measurement of benefits on economic activity (including direct, indirect and induced impacts).
1993	Cabinet Office	Economic Impacts of Hosting International Research Facilities	SQW prepared this UK government study, which is based on empirical analysis of the cost-effectiveness of hosting large facilities as compared with simply supporting them as a member. It looks at JET, CERN, the ESRF and the ILL It notes that on the basis of these four institutions, that 40-70% of expenditure accrues locally but contends that this may not constitute a net impact given full employment, displacement etc. There is presumed to be a positive transfer of tax payments from other member states. For supplying companies, there is some technology transfer and skills development as well as the direct sales income
2010	CBRE Consulting	BERKELEY LAB ECONOMIC IMPACT STUDY, Lawrence Berkley National Laboratory, March 2010	This report presents an estimate / analysis of the direct, indirect and induced economic effects attributable to this national laboratory located in California. It explains its methodology clearly, however it uses as US-specific set of input-output tables to derive multipliers It includes an analysis of the direct / indirect benefits of the 30 IP-startups (2,393 FTEs in 2009) created in the 20-year period since 1990. Tech transfer success stories, 13,000 jobs nationally and 700M
2012	Charles Beagrie Ltd and The Centre for Strategic Economic Studies (CSES) University of Victoria	Economic Impact Evaluation of the Economic and Social Data Service	This report estimates the economic impacts of the UK's Economic and Social Data Service (ESDS), a national research data centre that is financed by the ESRC and operated by several universities (a distributed facility). It uses a range of approaches to explore the economic value and benefits of ESDS data and services: from measures of direct impact of investment and use, to more complex approaches including contingent valuation using stated preference techniques, welfare approaches to estimating consumer surplus, and a macro-economic modelling approach to explore the returns to investments in data creation and hosting.
2009	DTZ	Economic impact of the John Innes Centre	The economic impact methodology is in line with other reports: it counts the centre's annual income and expenditure in order to estimate indirect and induced effects using IO multipliers and finds that a £30M a year spend produced £90M a year in economic value to the UK economy The report offers a fascinating account of how to value an institution's research breakthroughs, so for example, it states that the JIC was responsible for creating the original dwarf wheat stock judged to have been responsible for half of the increase in global wheat yields in the 20-year period, 1986-2006. This produces an estimated impact of £75M pa in the UK and £3.4 billion around the world!

Year	Author(s)	Title	Comment on the approach
			A JIC spinoff company is reported to be working on a solution for Clostridium Difficile, with a £3M grant from Wellcome Trust and high expectations of a breakthrough. The value of preventing the 6400 deaths annually from C Difficile is estimated at £200M, using NICE estimates for life-years saved. The report also estimates the economic value to the UK of the collaborative research (made possible by JIC), the industrial cost for which amounts to around £2.5M a year and DTZ estimate is worth £5.2M at market prices. DTZ also add in the full and combined annual turnover of the four JIC spinoffs (£2.8M) to arrive at a total volume of UK industrial activity based on JIC R&D of £8M. DTZ also include a figure for JIC licence income, which was £171K in 2009, perhaps another view of the price the market is willing to pay for the JIC IP of the past 30-40 years
2009	Ecorys	Economic effects of the Supernode in the Netherlands	Report is in Dutch. It is an ex ante economic impact assessment of the Dutch government's e-science programme (€45M, 2008-2011), carried out by Ecorys. It estimates the direct and indirect economic effects of the planned public investment, and also adjusts from gross to net using existing coefficients
2009	Fraunhofer Institute (ISI)	Case Study on the Economic Impact of Biobanks Illustrated by EuroCryo Saar	This paper presents a case study of a biobank created in Germany in 2002, setting out its scientific case and its wider links to other biobanks and biomedical research institutes. It includes information about the costs of building and operating the biobank, the contract research income that has been made possible in part by the existence of the biobank and also outlines in a paragraph or two the activities of three spin-off companies co-located with the biobank
2004	Hallonsten, Benner & Holmberg	Impacts of Large-scale Research Facilities: a socio-economic analysis (2004)	This report is an ex ante impact assessment Wide-ranging discussion of the potential benefits of major research infrastructure as part of a discussion about how the European Spallation Source (ESS) is likely to impact the Oresund region
2009	Lindström, C. et al,	The ESS in Lund - its effects on regional development (2009)	This report is an ex ante impact assessment, analysing likely future benefits to the city, region and country of a possible decision to locate the European Spallation Source (ESS) at Lund in Sweden The analysis is concerned mostly with the economic growth that will follow the investment and direct employment It does anticipate an impact on GERD and TFP, however it estimates these macro effects by applying the factors devised by Dominic Guellec and others to the anticipated increase in R&D expenditure locally
2009	MK Consulting	Economic and Social Impacts of TRIUMF	This report presents an analysis of the provincial and national economic benefits of the TRIUMF laboratory in British Columbia over the subsequent five years, with and without a new 60M Canadian investment. It has parallels with the Berkeley Lab study, and considers direct, indirect and induced effects and uses the province's existing IO tables for the multiplies (but weights these according to TRIUMF activity segments) It talks about innovation briefly, however its treatment is largely a series of short case examples of businesses and the related employment of this 'nuclear research cluster
2007	Pung Caroline, Ann Clarke &	Measuring the economic impact of the British library	This report presents an analysis of the economic impacts of the British Library, which is rather more than a research facility however it is recognised by as an Independent Research Organisation by AHRC and has participated in projects funded through the EU RTD Framework Programme's Research Infrastructures

Year	Author(s)	Title	Comment on the approach
	Laurie Patten		programme. The BL houses numerous unique and world-renowned collections, which support a wide range of scholarship as well as more general public interest. The report does not focus on research users specifically, however it uses a contingent valuation methodology to explore / quantify the willingness to pay by users and potential users. This is a similar approach to that used by Charles Beagrie in their assessment of the economic impacts of the UK's Economic and Social Data Service, which is a research data centre first and foremost
2008	SQW	Review of economic impacts relating to the location of large-scale science facilities in the UK	This report reviews the economic benefits to the UK deriving from five major, UK-based research facilities (SRS, DLS, ISIS, etc). The approach used revolves around the economic analysis of facility expenditure and employment, estimating total local output and employment effects
2010	STFC	New Light on Science: the social and economic impact of the Daresbury Synchrotron Radiation Source (1981-2008)	Direct local and national economic impacts illustrated through metrics on investment costs and employment It also includes a post-hoc economic impact assessment, which uses SRS spend – capital and recurrent – over its lifetime as the input to an ONS-derived analysis of indirect and induced effects. It assumes gross effects equal net effects and does not make any adjustments for displacement
2005	Triarii	ESTEC's value to The Netherlands: final report	Analysis of expenditures and contributions to determine the economic value of ESTEC to the Dutch economy in general. It pays particular attention to the national economic benefits for supplying companies in the Dutch space industry
2003	Working Group on Neutron Facilities: European Strategy Forum on Research Infrastructures	Medium to long-term future scenarios for neutron-based science in Europe	This report is an ex ante impact assessment. Scenario building analysis by the Working Group on Neutron Facilities, analysing three scenarios for the future development of the neutron science landscape in Europe (from more to less ambitious) – involving the expansion of existing facilities (ILL and ISI) and the construction of new ones (ESS).

6. Innovation outcomes

6.1 Introduction

In this chapter of the report, we discuss the approaches to measuring the innovations arising from large research facilities.

6.2 Our selection of studies and evaluations

Figure 10 lists the English-language publications we identified as having documented the innovations made possible by large research infrastructure.

This table includes several entries that are also shown in the preceding table (Figure 9), where those studies address both economic impacts and innovation outcomes. The description of the report's methodology focuses on those aspects relating to innovation outcomes. Several references are repeated again in the following table, Figure 11, where they have covered both innovation outcomes and high-tech clustering.

The empirical literature begins in the early 1970s, with early studies by NASA and by CERN to summarise the impact of the creation of facilities and programmes on industrial technology and to estimate the economic benefits therein. This work picked up on major innovation studies underway elsewhere of course, such as Project Sapho at the Science Policy Research Unit at the University of Sussex.

In the European literature, CERN dominates. In the US, NASA SPINOFF reports dominate. The European Space Agency (ESA) has commissioned a number of studies down the years, and has created a dedicated TTO and spinoff database. The European Commission has recently launched a study to look at the impact of the research infrastructure component of the EU RTD FP

The STFC has taken a lead in this area, with a growing body of publications and studies on research and innovation impacts. The DESY conference (2012) and our own survey of facilities (2012) suggests that several major facilities are also looking at ways to improve their ability to capture and quantify innovation effects.

6.3 Innovation outcomes

This rather limited body of empirical literature is dominated by studies looking at one or more of three broad innovation pathways

- Innovations that result from suppliers' provision of technological advances / solutions required by big facilities, which as with other lead markets can underpin subsequent success in other markets
- Innovations that result from the direct use of a facility by industry, through collaborations with academic research groups or proprietary research
- Innovations that result from the commercialisation of the facility's research breakthroughs, through licensed access to IP (royalties) or spinoffs (not facilities don't own a lot of the IP created with the help of their instruments and services)

We found no studies that attempt to identify and value the innovations that may result from the manifold insights and learning arising from the public-sector research carried out at or with the aid of the facility. Knowledge spillovers in the classic sense are especially hard to identify and attribute to a specific body of research, and the methodological challenge is arguably all the harder with research infrastructure, where facilities may be used only briefly within the context of a larger study that is being carried on elsewhere.

6.4 Methodological approaches

Qualitative research is the foundation stone of all of the studies reported here: a case study methodology is used in most instances to draw out the particular connection between the research facility and an individual innovation. Typically, the case studies are elaborated through a combination of semi-structured interviews and desk research, involving beneficiaries on the one hand and the client contracts department on the other.

While the methodological approaches may be similar, in broad terms, the studies do vary in scope. Only a minority examine a large number of cases in an attempt to arrive at a sample that is representative of the overall population and thus provide the basis for an estimate of gross effects. The two CERN studies (1975, 1984) are examples of this approach. NASA's SPINOFF 2012 report included an estimate of aggregate impacts for the first time. BETA's[31] work (1992) on measuring the knowledge spillovers within firms arising from ESA technology programmes is well regarded and well described in the papers by Bach and Cohendet; it does revolve around quite laborious qualitative research in order to trace, attribute and quantify the wider effects on behaviour, products and services and competitiveness.

The BETA group is currently carrying out an EC supported project called EvaRIO, which aims at developing a framework and a set of specific tools well suited for the evaluation of the economic impact of RIs.[32] The approach tries and explores the particular role of RIs in the currently changing context towards an open innovation and research environment. The project consists primarily in adapting the "Beta approach of evaluation" to the case of RIs, an approach used so far for ex post evaluations of some economic impacts of a large variety of publicly funded RD programmes. The adaptation focuses on learning effects experienced by various actors involved in the building, operation and use of RIs, and is run in connection with in-depth investigations of the evolution of RIs and the research networks around them. The presentation will introduce the current status of development of the approach and of its first implementation for testing purposes on the case of some BMS RIs.

Arriving at an estimate of gross effects through this kind of qualitative research is time consuming and costly, particularly if it is going to be done from first principles. NASA for example has been tracking spinoffs since the early 1970s and so it has an established data infrastructure that captures a good proportion of the specific data requirements automatically and provides a platform for targeting its primary research. However, its monitoring reports have only recently begun to dimension the scale of the attributable impacts, putting aside its longstanding concerns about data limitations and such like.

This kind of case study approach is vulnerable to challenges about representativeness, however. A majority of the studies address a small number of cases, typically fewer than 10, where the total population of cases may run into the hundreds. The ambition is to showcase what sorts of socio-economic impacts can occur, and how, in the expectation that the reader will be impressed with the obviously noteworthy examples.

Individual case studies can vary in depth and thoroughness, too. Having identified a candidate innovation, it may be a matter of a few person days to carry out interviews and do some desk research, in order to develop an overview of the innovation and its related commercial effects. Making a definitive connection between an innovation and the underpinning research / research facility can be a lot harder, and take rather more time. None of the reports considered here went as far as to seek corroborating evidence as to the critical and distinctive role of the research infrastructure.[33]

The majority of innovation studies from CERN, ESA and NASA focus principally on the effects of their commissioned work on their industrial suppliers.

The review of the social and economic impacts of the 30 years of work on the Daresbury Synchrotron Radiation Source (New Light on Science, STFC 2010), is more expansive in its coverage than the very great majority of the empirical studies. It includes descriptive case studies covering knowledge spillovers from SRS-enabled science as well as suppliers' subsequent innovations. It also includes case material on several spinoff companies. It

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[31] BETA (Bureau d'Économie Théorique et Appliquée) is an economic research group at the University of Strasbourg.

[32] EvaRIO – Toward a method of evaluation of RIs in open innovation and research systems – Sandrine Wolff, BETA University of Strasburg. This was a presentation of a 2-year EU-funded project - Evario - that began in November 2011, and intends to convert the Beta economic impact assessment methodology into something applicable for RI

[33] The REF Impact Pilot found that universities were taking 5-8 staff days to produce a rather ordinary case study and that the more robust work could easily take two or three times as much effort (Technopolis 2010).

attempts to be comprehensive, if not exhaustive, but acknowledges this is unlikely given the need to track backwards to identify examples of impacts and the rather limited view of innovation outcomes held by the SRS and STFC monitoring systems. The individual cases include some quantification of effects, however there are lots of cases and they are only lightly treated ultimately with no possibility of feeding them into any kind of integrative CBA. This is a good, wide-ranging report however, and it is presented as one of our featured studies in the appendices.

There is some variation in this case study approach – well an extension – with several institutions also publishing key performance indicators in annual reports, with point-in-time statistics, trend data and performance ratios covering for example:

- Non-academic users and usage
- Innovation inputs (invention disclosures, patent applications, etc)
- Knowledge transfer outcomes (licences, licence income, spinoffs, etc)

These data can be used both as a means to target qualitative research and as a factor for weighting sample results and grossing up.

The Berkeley Lab Economic Impact Study (CBRE Consulting 2010) includes an analysis of the economic impact of the 30 or so IP-based startups launched in the 20-year period since 1990 and still trading. However, the lab maintains annual statistics on for example income and employment for all of the startups where it had a material interest, and the economists were able to work with readily available data on economic sectors, revenue and employment to compute the indirect benefits to the local, state and national economies.

The STFC annual impact report[34] is improving year on year, with more statistics and more impact cases, albeit these individual accounts are not always linked to specific facilities and there is no analytical framework or model with which to estimate the gross effects.

6.5 Data requirements

The reports presented here have tended to use one or more of the following three approaches: supplier surveys, impact case studies and knowledge transfer statistics. These require a number of different types of data, primary and secondary, objective and subjective.

The supplier survey is arguably the most straightforward. It requires good information about supplier contracts and contractors over time, in order to be able to run sample surveys to profile innovation outcomes, estimate commercial effects and identify innovations worthy of case study. The various CERN studies suggest it may be helpful to work with facility staff to target the surveys, using purposive sampling rather than purely random. The surveys will need to generate primary data from large numbers of suppliers, so it may be helpful to response rates if the facility were to include some kind of obligation to support evaluations within its standard terms and conditions of contract, alongside a commitment to guarantee to treat such feedback in strict confidence. None of the studies used control groups, and it is not clear how one could, practically at least. It would be of some small value, if the facilities or evaluators were able to obtain time-series (secondary) data detailing the key economic and innovation statistics for a selection of relevant economic sectors. This would provide some potential for a wider contextual analysis.

One needs to try to factor in the idea of deadweight, as most of these supplier organisations would have been busy doing development work somewhere else so the net impact is unlikely to be 100%. There is also the need to adjust for any displacement or opportunity cost, again to avoid over valuing the contribution.

Turning to the case studies, given the rather variable and unpredictable nature of innovation, its not obvious one could specify the exact requirements ahead of time. However, any attempt

[34] The STFC annual Impact Report is a reporting requirement defined by BIS, which all of the Research Councils are bound to provide. It is not supposed to be broken down at the individual facility level. STFC has also been developing case studies and an impact evaluation framework to better capture and describe the impacts of all of its activities, not just the large facilities.

to detail and value those outcomes is going to require compilation and analysis of a mixture of secondary and primary data.

Any case study will require wide-ranging information (objective and subjective) to dimension the contribution of the research facility and to explain the significance of that activity as the trigger for innovation. The case study will also need to characterise and dimension any subsequent investments by the innovator or others, before going on to estimate the scale of cost savings, increased revenue, etc that are judged to be attributable to the innovation. There should also be some consideration given as to the time frame over which the innovation might be expected to continue to deliver those commercial benefits. Ideally, any projection of future income should be corroborated through discussions with other stakeholders that may have a view on the life expectancy of innovations and various other risk factors

Ideally, research facilities would maintain a comprehensive and up-to-date database of technology transfer statistics, from patent applications to licence income to an inventory of startups. Unfortunately, while this may hold for the largest research infrastructures (e.g. CERN or ESA), and if the study of research data centres holds more generally (Technopolis Research Data Centres, 2009), the great majority of facilities will have no data on innovation outcomes.

This situation is unlikely to change quickly given the costs of developing such monitoring systems and given that much of the research is being carried out elsewhere and its social and economic benefits claimed by employers (e.g. HEIs and REF impact case studies).

The interim solution could be

- An up-to-date database covering the entire population of non-academic users and suppliers over the life of the facility
- An up-to-data database of supplier contracts and projects / awards, which can be tied back to the population of users and suppliers

6.6 Strengths and weaknesses

The supplier surveys have a neatness about them, inasmuch as one has a captive audience and it is clearly possible to produce quite robust feedback about the types of innovation outcomes that have been realised and generalise that for the overall population. One can therefore estimate gross effects. However, none of the survey-based studies sought to get to grips with any kind of counterfactual; what those technology companies might have been doing had they not been supplying or working with a given facility. There is also a tendency for authors and investigators to rely on self-assessment by the beneficiaries, as regards both the attribution and scale of the benefits. There is also a tendency to give equal weight to anticipated future income, where cashflow predictions are notoriously inaccurate and over-optimistic.

It's not clear that the methodological approach differs very much from work to identify and estimate the economic impact of innovations deriving from public research more generally. In that respect, BIS' existing guidelines could usefully be followed and thereby improve the robustness of such surveys where they are carried out in future (in the UK).

The use of impact case studies is a good choice given the manifold ways in which specific innovations develop and unfold over time; they provide a level of flexibility that is indispensible. The technique also encourages a more systemic and dynamic perspective, which again is rather important in this context where innovations will almost always arise as a result of a cocktail of inputs. Distinguishing the nature and extent of the contribution of the facility to a given innovation demands a degree of openness and a priori experience on the part of the investigator.

The case studies tend to be quite limited in their scope and ambition: the supposed impact of big science on radical new technologies or applications from lithium ion batteries to DNA profiling to MRI is only just beginning to be addressed in the literature. The STFC published two good impact case studies, in November 2012, looking at the role of its research facilities in the development of Magnetic Resonance Imaging (MRI)[35] and the Global Positioning System (GPS) used in satellite navigation.[36]

The downside to case studies as an evaluation methodology is the challenge of relating these examples of positive outcomes to the population overall, and the process of grossing up from a small number of cases. Producing larger numbers of case studies is a partial solution, however that does increase M&E costs substantially.

The innovation metrics approach has its benefits in that it can be implemented relatively simply, using a standard framework or menu across facilities, to permit a degree of benchmarking and learning. On the downside, it is not easy to gather and maintain outcome statistics that link back to the facility in question (cannot use secondary data as they are too macro) and it is very much easier to collect input and output metrics, which are weak proxies for innovation outcomes.

All three approaches will tend to make a better job of identifying and quantifying the visible and obvious innovation outcomes, and will miss the (non-obvious) knowledge spillovers and wider impacts on other producers and consumers.

Overall, the innovation outcomes of research infrastructure is an under-researched topic, which relies to a large degree on itemising and describing individual cases.

6.7 Results and stylised facts

We found few attempts to aggregate innovation impacts, and where they did this focused primarily on the effects of the public procurement of cutting edge technologies. The following bullet points present a list of the relevant statistics:

- CERN study (1975) = CHF 900M in supplier contracts in 20-year period from 1955, which delivered an estimated CHF 5 billion in additional income or savings among suppliers
- CERN study (1984) = CHF 3.1 billion in additional income / cost savings for all supplier contracts in the period 1973-1987, set against purchases of around CHF 748 million (in 1982 prices). This amounts to around 60% of the overall cost of running the organisation in the same period. Some 75% of this additional, innovation-related economic activity occurred in markets outside high energy physics
- CERN study (2004) = 38% of high-tech / high value contracts issued in the period 1997 – 2002 (part of the LHC project) facilitated new products or processes
- NASA spinoff database = 1,800 spinoffs, going back to 1976. NASA estimates (SPINOFF 2012) that the 500 or so spinoffs reported across the period 2000-2012 have produced US$ 5 billion in additional revenue and US$ 6.2 billion in cost savings
- John Innes Centre evaluation (DTZ, 2009) = annual KT income of around £170K, benefits to UK BERD of around £8M and benefits to the UK economy (through e.g. improved wheat yields from new strains) amounting to £75M annually

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[35] The economic impact of physics research in the UK: Magnetic Resonance Imaging (MRI) Scanners, a case study (Oxford Economics, November 2012, for the STFC). The case study describes how the Rutherford Appleton Laboratory's work in the 1960s on superconducting magnets – as a means by which to generate more powerful magnetic fields for particle accelerators at CERN – was further developed by Oxford Instruments and resulted in various commercial applications including MRI clinical instruments. The economic impacts are addressed too, but principally by reference to the global sales of MRI-related equipment (c. £4 billion in 2010) and the direct and indirect economic impacts of the MRI industry in the UK (c. £110M). Other social benefits are described and sometimes monetised, but not aggregated.

[36] The economic impact of physics research in the UK: satellite navigation case study (Oxford Economics, November 2012, for the STFC). This case study picks out a series of notable contributions, from the role of the physicists at the National Physical Laboratory, who built the first reliable atomic clock in 1955 (accurate measurement of time is critical to satellite-based positioning), through to RAL Space, which has been at the forefront of research to provide 'ionospheric correction' to improve the accuracy of satellite navigation systems by providing ionosphere monitoring using an 'ionosphere sounder' located at RAL that works by transmitting and then receiving and analyzing short pulses that are reflected at various layers of the ionosphere.

6.8 Implications for future BIS evaluations of research infrastructure

The case study-based approaches can work well, however current studies / practice tend to be rather too positive and some of BIS' established principles could be applied to reduce the likelihood of studies overstating the scale of the 'additional' effects.

Done well, and addressing a large proportion of known cases, a case-study approach would provide a platform for both estimating net effects and bringing to life the way in which science can drive innovation. A powerful narrative that can catch the attention of the public and the Treasury alike

As one-off studies, case-study approaches they will tend to be time consuming and costly, £250K rather than £50K, might be typical. They can be done rather more efficiently where there is good underpinning monitoring data, however that is unlikely to hold in the majority of settings. Even where there are good monitoring data, there will still be a requirement for an independent check of the critical nature of the contribution and the added value of the specific contract or research.

6.9 Development needs

Consider support to STFC and other facility owners and funders with the development of more extensive and generally better monitoring data, focusing on:

- The maintenance of up-to-date databases of current and past contractors, with named contacts and key descriptors for the volume and type of goods and services supplier (and standard terms and conditions requiring suppliers to support future evaluations where they can; and telling people that their records may be shared with other parties for the purposes of audit or evaluation
- The routine execution of user surveys – annual or biennial – to better understand user experiences, motivations, usage and wider effects
- The creation of a database of impact case studies, which might be built bottom up through discussions with staff and research users and might follow the basic principles and structure of the REF Impact Case studies
- The compilation and publication of an annual report for the larger facilities, which follows the basic structure of the RC impact assessment framework

Figure 10 – List of RI-related studies and evaluations that have investigated innovation outcomes

Year	Author(s)	Title	Comment on the approach
2004	Autio, E., A.-P. Hameri, & O. Vuola	A framework of industrial knowledge spillovers in big-science centers	This is an academic paper exploring innovations arising from CERN's development of the LHC. It looks at three specific examples – case studies – of businesses that were newly created or hived off from larger corporations to take a new product to market The analysis is concerned principally with understanding how big facilities may cause this to happen. It does not name the organisations. There is some facts and figures about the innovation and the size and age of the venture. There is no attempt to infer any likely overall propensity to create spinoffs or to monetise them
2003	Autio, E., M. Bianchi-Streit & A. -P Hameri	Technology Transfer and Technological Learning through CERN's Procurement Activity	This is an academic study to analyse the technological learning and innovation benefits deriving from CERN's procurement activity A questionnaire survey of 154 suppliers of high-value, high-technology goods (500M Swiss francs) No attempt to classify innovations or monetise commercial benefits and no attempt to gross up to the lab overall, however the study did find that 38% of suppliers launched new products as a result of their CERN contract. This study has been cited in various CERN presentations by their KT team
1992	Bach et al	Measuring and managing Spinoffs: the case of the Spinoffs generated by ESA programmes	The BETA group, at the Louis Pasteur University of Strasbourg, estimated the impact on ESA contractors of spinoffs and indirect effects. In the BETA methodology, the term 'spin-off' refers to internal spillovers (within contractors' own organisations) derived from the ESA funded activities and not to the spinoffs (or spillovers) to other economic actors. The methodology is designed to capture the impact of ESA grants not only on productivity and sales but also on business organisation and methods ('behavioural additionality'), on human capital – skills and the establishment of a 'critical mass' of researchers – and benefits from new collaborations and networks. Their objective is to 'make as exhaustive an inventory as possible of indirect effects resulting from ESA programmes among the ESA contractors.' A similar approach to analysing the benefits of NASA-funded life sciences R&D was used by Henry Hertzfeld, at George Washington University.
1986	Bianchi-Streit, M. et al	Quantification of CERN's Economic Spin-off	This 7-page note digests the findings of the economic utility studies carried out by Schmied in 1975 and Bianchi-Streit in 1984, adding some additional data into the mix to stretch the time-series out to 1987
1984	Bianchi-Streit, M. et al	Economic Utility Resulting from CERN Contracts (Second Study), CERN yellow report 84-14, Geneva: CERN.	A follow-on to the first economic utility study, from 1975, which again estimated the secondary benefits to high-technology CERN suppliers for the intervening period and comes to the same conclusions: strongly positive impacts of a scale approximating to total CERN investment and 60% plus benefiting areas other than HEP
2000	Byckling, E., A.-P. Hameri, T. Pettersson & H. Wenninger,	Spin-offs from CERN and the case of TuoviWDM	This is an academic paper presenting an in-depth longitudinal analysis of a single spin-off from one of CERN's projects supporting the LHC. Its focus is on explaining how the CERN project facilitated the development of the web tool. There is no substantive analysis of the business, its sales or its competition
2010	CBRE Consulting	BERKELEY LAB ECONOMIC IMPACT STUDY, Lawrence Berkley National Laboratory, March 2010	This report includes an analysis of the direct / indirect benefits of the 30 IP-startups (2,393 FTEs in 2009) created in the 20-year period since 1990. Tech transfer success stories, 13,000 jobs nationally and 700M
2005	CERN	CERN technology transfer to industry	This report provides a compendium of CERN-related spinoffs along with accessible descriptions of the sorts of socio-

Year	Author(s)	Title	Comment on the approach
		and society	economic benefit that derive from the design and operation of CERN Entirely descriptive, no attempt to look at the scale of benefits or the unique added value of CERN
2009	DTZ	Economic impact of the John Innes Centre	A JIC spinoff company is reported to be working on a solution for Clostridium Difficile, with a 3M grant from the Wellcome Trust and high expectations of a breakthrough. The value of preventing the 6400 deaths annually from C Difficile is estimated at £200M, using NICE estimates for lifeyears saved. This kind of shadow pricing is interesting. DTZ also add in the full and combined annual turnover of the four JIC spinoffs (2.8M) to arrive at a total volume of UK industrial activity based on JIC R&D of 8M. DTZ also include a figure for JIC annual licence income, which was 171K
2009	Fraunhofer	Case Study on the Economic Impact of Biobanks Illustrated by EuroCryo Saar	This 17pp paper presents a case study of a biobank created in Germany in 2002, setting out its scientific case and its wider links to other biobanks and biomedical research institutes. It includes information about the costs of building and operating the biobank, the contract research income that has been made possible in part by the existence of the biobank and also outlines in a paragraph or two the activities of three spin-off companies co-located with the biobank
2009	MK Consulting	ECONOMIC AND SOCIAL IMPACTS OF TRIUMF	This report talks about innovation briefly, however its treatment is largely a series of short case examples of businesses and the related employment of this 'nuclear research cluster
2012	NASA	SPINOFF 2012, National Aeronautics and Space Administration (NASA)	The NASA spinoff program office publishes an annual report (each year since 1976) showcasing many tens of spinoffs (a commercially available product service or process that that takes NASA-related technology and brings it to a broader audience). There is an online database of almost 2,000 spinoff case studies. The treatment of socio-economic benefit has been developing, and the 2012 report's executive summary includes for the first time a series of aggregate estimates of the NASA contribution to global revenue, cost savings, jobs and lives that have resulted through the work of the many spinoffs. The report does not explain how those estimates were calculated, but it may be worth looking deeper into this
1975	Schmied, H.,	A Study of Economic Utility Resulting from CERN Contracts, CERN yellow report 75-5, Geneva: CERN.	A straightforward account of an approach to estimating the additional economic value derived by CERN contractors The paper presents a range of estimates of utility (sales and savings) ratios based on around 400M in purchases from 127 companies and 1.7 billion in net income or savings, which range from 2 (cryogenics) to 31 (precision engineering) Uses the estimates for the 400M to gross up to the 0.9 billion spent with European industry in the period 1955 – 1973, valuing the additional subsequent commercial benefits to CERN contractors at around 5 billion Splits out sales to high-energy physics (HEP) and sales to other sectors (20:80) The paper deals with the counterfactual by asking firms if and when they might have brought the related innovation to market without the CERN contract. It doesn't consider displacement effects or multipliers
2010	STFC	New Light on Science: the social and economic impact of the Daresbury Synchrotron Radiation Source (1981-2008)	This report has a broad scope, covering all aspects of social and economic impact from Nobel prizes to industry usage stats to the creation of IP-based spinoffs part-owned by Daresbury In terms of innovation effects, it makes use of descriptive case studies primarily. These cover knowledge spillovers from SRS science, new tools and techniques and products from suppliers and spinoff companies. It attempts to be comprehensive, but acknowledges this is unlikely. The cases include some quantification, however there are lots of cases and they are only lightly

Year	Author(s)	Title	Comment on the approach
			treated ultimately with no possibility of feeding them into any kind of integrative CBA It also includes a post-hoc economic impact assessment, which uses SRS spend – capital and recurrent – over its lifetime as the input to an ONS-derived analysis of indirect and induced effects. It assumes gross effects equal net effects and does not make any adjustments for displacement
2010	STFC	E-ELT Impact - The Impact of the European Extremely Large Telescope	This report discusses the likely future benefits for the UK that may follow the construction and operation of the EELT, noting the UK involvement in design and engineering studies and the potential for up to 200M in contract income Innovation is touched on through for example references to several HEI spinoffs in the astronomy field, like ZEEKO

Figure 11 – List of RI-related studies and evaluations that have investigated regional and locational outcomes

Year	Author(s)	Title	Comment on the approach
2002	Alpe-Conchy, D	EISS Cadarache – IDEP Study (European ITER Site Studies)	The ITER ex ante impact assessment (2002) estimated the regional, national and international distribution of the various economic effects studied
1993	Cabinet Office	Economic Impacts of Hosting International Research Facilities	SQW prepared this UK government study, which is based on empirical analysis of the cost-effectiveness of hosting large facilities as compared with simply supporting them as a member. It looks at JET, CERN, the ESRF and the ILL It notes that on the basis of these four institutions, that 40-70% of expenditure accrues locally but contends that this may not constitute a net impact given full employment, displacement etc. There is presumed to be a positive transfer of tax payments from other member states. For supplying companies, there is some technology transfer and skills development as well as the direct sales income
2010	CBRE Consulting	BERKELEY LAB ECONOMIC IMPACT STUDY, Lawrence Berkley National Laboratory, March 2010	This report includes an analysis of the direct / indirect benefits of the 30 IP-startups (2,393 FTEs in 2009) created in the 20-year period since 1990. Tech transfer success stories, 13,000 jobs nationally and US$700M
2004	Hallonsten, Benner & Holmberg	Impacts of Large-scale Research Facilities: a socio-economic analysis (2004)	Wide-ranging discussion of the potential benefits of investing in major research infrastructure as a preface to a discussion about how the European Spallation Source (ESS) could impact the Oresund region were it to be sited in Lund Nothing about innovation specifically, and no attempt to dimension the costs or benefits of the ESS to the region
2009	Lindström, C. et al, PriceWaterhouse Coopers	The ESS in Lund - its effects on regional development (2009)	PWC estimate the accumulated economic benefit (regional output for Skane) over the next 30 years may fall in the range €3 billion – €30 billion, with €20 billion the preferred scenario The study does anticipate an impact on regional and national GERD and TFP, however it arrives at an estimate simply by applying the factors devised by Dominic Guellec to projected additional research expenditure in general
2009	MK Consulting	ECONOMIC AND SOCIAL IMPACTS OF TRIUMF	This report presents an analysis of estimated future provincial and national economic benefits of the TRIUMF laboratory in British Columbia over the subsequent five years, with and without a new C$60M Canadian investment. It has parallels with the Berkeley Lab study, and considers direct, indirect and induced effects and uses the province's existing IO tables for the multipliers (but weights these according to TRIUMF activity segments) Section 4.1 presents a series of case examples of 6 co-located businesses and the related employment (c. 600 FTE inc 475 at

Year	Author(s)	Title	Comment on the approach
			triumph itself) of this growing ‘nuclear research cluster’
2008	SQW	Review of economic impacts relating to the location of large-scale science facilities in the UK	This report explores the economic benefits the UK derives from several UK-based research facilities (SRS, DLS, ISIS, etc). It is mostly concerned with estimating local employment effects and multipliers, and does not address innovation particularly The report touches briefly on the benefits to suppliers of building the facilities, but suggests the UK does poorly here supplying concrete rather than technology for the most part.
2010	STFC	New Light on Science: the social and economic impact of the Daresbury Synchrotron Radiation Source (1981-2008)	This report has a broad scope. In terms of local economic effects, it includes a separate chapter and looks briefly at the retention of SRS spend locally, local employment and inward investment. It uses SRS spend – capital and recurrent – over its lifetime as the input to an ONS-derived analysis of indirect and induced effects. It assumes gross effects equal net effects and does not make any adjustments for displacement
2005	Valentin, F, M.T. Larsen and N. Heineke	“Neutrons and innovations: What benefits will Denmark obtain for its science, technology and competitiveness by co-hosting an advanced large-scale research facility near Lund?”	A report outlining the sorts of academic and other benefits that could be expected to follow from a decision by Denmark to join with Sweden in hosting the ESS (which happened in 2010). ESS should start construction in 2013 and open for operations in 2019

7. Clustering and agglomeration effects

7.1 Introduction

In this chapter, we discuss the approaches to measuring the locational effects arising from large research facilities.

7.2 Our selection of studies and evaluations

Figure 11 shows the nine publications we identified as having attempted to say something about the locational and clustering effects made possible by large research infrastructure. There are other studies cited in the grey literature, which we could not obtain: for example, an ex ante impact assessment of the Square Kilometre Array (SKA) prepared by the UK consultancy, Quotec, for the National Research Foundation of South Africa as an input to its national discussions about the benefits of seeking to host the new facility. This report is not in the public domain.

There is no clear pattern as regards the types of studies considered in this small group of publications, there are both ex ante impact assessments and ex post evaluations. There are economic impact assessments and case studies. However the papers are concerned almost exclusively with very large capital investments in very large research facilities located at one or two sites.

7.3 Innovation outcomes

This rather limited body of empirical literature is reasonably coherent as regards the types of agglomeration effects (technology clusters) that can result from major capital investments:

- The largest scientific facilities attract global talent into an area, with possibly several hundred permanent scientific staff and hundreds or even thousands of visiting researchers passing through the facility on a continual basis. These arguments were used to persuade the Danish government to back Sweden's campaign to host the European Spallation Source (ESS) in Lund and within the Oresund region
- The creation or deepening of the ties between facilities and regional universities and research institutions, which can provide a focal point for research and expanded opportunities for exchanges and cooperation
- The ability to incubate and or host new startup businesses, which may have been founded as a result of the research being carried out at a facility or more often to commercialise and expand the market reach of specialist service functions
- The largest facilities can sit at the heart of an advanced technology cluster. These local clusters may comprise firms selling to the facility (suppliers of goods and services) or firms using the facilities as part of their own R&D activities or technical consulting as part of a larger grouping of businesses and institutions. The UK's national Printable Electronics Centre is a case in point. The former regional development agency, One NorthEast, brought together regional, national and European funding to create a prototyping facility to demonstrate pre-commercial manufacturing of plastic electronics products (e.g. flexible displays) located at NETPARK, a new technology park outside Sedgefield in Country Durham, 10 miles to the south of the University of Durham.

  The NETPARK web site states (February 2013) that the park is home to one of the fastest growing technology clusters in the UK, with the Printable Electronics Centre at its heart

  In 2009, the centre secured £12M in funding from the BIS Strategic Investment Fund (SIF), the proposal for which suggested that a £20M additional investment (with £12M from BIS for kit) would save or create 80 jobs in the region by 2011 and 250 jobs by 2012, in part through the creation of 8-20 new businesses and increase VC investment. The investment appraisal went on to state that the impact nationally could be substantial with national GVA increasing by as much as £200M by 2013 (these estimates may have been produced and approved before the full extent of the global economic crisis was understood, however the BIS economists judged the capital investment to offer a positive NPV)

In some cases however these local technology clusters pre-date the creation of the facility, and may be part of the argument for locating a facility in the region in the first instance. For example, the UK's International Space Innovation Centre (ISIC) was set up at the Harwell Science and Innovation Campus to take advantage of an existing cluster and to provide a national focal point for a somewhat fragmented UK space endeavour (public and private)

7.4 Methodological approaches

Most of the reports here make use of a dual research strategy, combining quantitative analysis of the (local) economic effects with qualitative investigation of the knowledge spillovers.

The approach taken to the quantitative analysis of local economic effects is similar to the economic analyses carried out for major capital investments more generally, which is to say the authors take the public expenditure figures and run these through an input-output model. This enables the analysts to arrive at a global estimate – across the applicable time-period – for local direct, indirect and induced economic impacts. In some cases, authors may choose to simply apply standard IO multipliers, for convenience, rather than attempt to trace / model individual purchases through a national or regional set of input-output tables.

Others suggest the number (multiplier) will be different in some small degree but not by an order of magnitude and therefore not warrant the time and cost of a bespoke study.

Qualitative research is more generally used to capture growth in co-located businesses, spinoffs or inward investments. The reports identified all use case studies, of a sort. They vary in depth, but most are quite light touch: a description of the business – with some facts and figures about its employment and turnover – and a few words about the link between the business and the facility.

The Berkeley Lab Economic Impact Study CBRE Consulting 2010) includes an analysis of the economic impact of the 30 or so IP-based startups launched in the 20-year period since 1990 and still trading. However, the lab maintains annual statistics on for example income and employment for all of the startups where it had a material interest, and the economists were able to work with readily available data on economic sectors, revenue and employment to compute the indirect benefits to the local, state and national economies.

7.5 Data requirements

The local economic impact assessments require similar kinds of data to other economic impact assessments, but principally it requires detailed breakdowns of expenditure over time, by type of spend and location. Those institution specific data can then be used in an IO analysis, using national IO tables to estimate the indirect and induced effects.

The case study work is not particularly exhaustive, and would only require a list of local suppliers and spinoffs in order to assemble some basic statistics on income and employment and perhaps an interview to obtain an up to the minute view of the links between the facility and the business in question. The TRIUMF and Berkeley Lab studies also took those spinoffs statistics and fed them into the same regional IO analyses.

The passing references to science parks and incubators amount to simple descriptions of scale, scope and location, which could be obtained from a facility's own web site.

7.6 Strengths and weaknesses

Overall, the studies make a pretty good job of estimating the local economic impacts of the facilities, based on expenditure and employment.

The functional analysis of the expenditure is also illuminating, suggesting that while the local economy will benefit most from major capital investment programmes, the procurement of higher-value, higher-technology equipment and systems is very much less skewed geographically. A significant proportion of the most important purchases – from a user-led innovation standpoint – will be bought nationally or internationally and may have very little local stickiness.

The analysis of technology clustering is poorly dealt with, and largely comprises listing the principal technology suppliers – including spinoffs – and offering a few sentences about what they are and how they link back to the lab. The work in these reports falls far short of the quality and robustness of other work in the regional studies domain, which is almost certainly a function of the study specification rather than poor execution.[37]

There is no substantive analysis of the benefits derived by the various co-located science parks or incubators, and no consideration of inward investment at all. The TRIUMF study makes a passing reference to FDI.

Overall, this is an under-researched topic, and on the basis of the literature identified here, the least developed of the three areas.

7.7 Results and stylised facts

Several stylised facts are revealed in this small body of 'geographical' literature:

- There is a local effect evident in all studies, during both the construction and operational phases, with 20-30% of all of estimated gross economic benefits being realised within the local economy
- The locational effects of the high-value, high-technology components of the capital investment is studied to a much lesser degree, however it seems less prominent. The SQW work in the UK argues that the high-value work will be sourced globally
- The studies suggest the local effect during the operational phase is dominated by people being resident in or visiting the region (employment or visitors)

The ITER ex ante impact assessment (2002) used a reasonably detailed breakdown of the facilities actual and planned construction purchases over a 13-year period to feed into an analysis of indirect and induced economic benefits. The author fed this composition analysis into France's national accounts, and then applied some (unexplained) modification to adjust for the particular regional characteristics. This analysis estimated a regional multiplier of 3.7 (for each Euro spent), and an average annual increase in regional economic output of around €280M and €320M for the rest of France. The multiplier for the rest of France was estimated at 6.3. The employment generated was estimated at around 1400 FTEs in the region and a further 1600 for the rest of France.

The Berkley Laboratory Economic Impact Study (2010) entailed a more exhaustive analysis, making use of a national US input output model with federal and state-level resolutions and city-level analysis of spending and employment (among the three Bay Area Campuses). This analysis estimates the output multiplier for the Bay Area of 0.4, which is to say that $500M of direct spending (FY 2009) was estimated to have produced around ¢190M of indirect and induced spending. The lab's gross economic impact on the US economy overall was estimated to be ¢1.6 billion.

The authors of the economic and social impacts of TRIUMF (2009) in British Columbia (BC) in Canada used expenditure and payroll data to estimate the direct economic benefits of a planned C$60M investment in upgrading the facility. Given the highly specialised nature of the work at TRIUMF and the high proportion of staff that are recruited from outside the province and Canada, the analysts took the view that it was appropriate to count the induced economic impacts (employee spending) in the overall estimate. Due to the short timeframe,

[37] SQW and several of the other authors included in the list have a reputation for excellent work in cluster analysis, with for example the 1985 book, the 'Cambridge Phenomenon' being very widely referenced, www.sqw.co.uk/special-feature/cambridge-phenomenon

the authors used economic multipliers published by BC Statistics as derived from the BC Provincial Input Output Model (BCIOM). BC multipliers distinguish different economic impacts for different types of economic activities and the consultants therefore used a series of weighted average multipliers to estimate TRIUMF economic impacts (e.g. 15% weighting for chemicals manufacture including isotope production; 45% weighting for non-profit educational institutions). Taken together, these calculations produced an overall output multiplier of around 2.0. More than 90% of the facility's total economic impacts occur within British Columbia where the facility and the majority of staff are based.

7.8 Implications for future BIS evaluations of research infrastructure

The implication of our literature review is that this important aspect of RI benefits are not given much weight in evaluations, and one of the obvious and potentially unique socio-economic contributions remains under-researched and poorly understood.

The obvious response would be to insist that the impact on the local economy and technology clusters should form part of any evaluation specification, and require bidders to come forward with innovative methodological approaches to research the question.

7.9 Development needs

Given the assumed importance of R&D investment in general and big-ticket items in particular, as a driver of inward investment (e.g. FDI) and regeneration, it would be worthwhile BIS considering the feasibility / affordability of launching a series of further exploratory studies to look at the role of big science in local agglomeration effects.

There are potentially good examples to be looked at in long-established high-tech city-regions, like Cambridge or Oxford, as well as regions that are looking to research and innovation as a platform for regional development. Daresbury and the North West could be another candidate, as would the North East, with its creation of a group of centres of excellence (CELS, CPI, NAREC, PETEC, Newcastle Science City, etc).

There is a pretty extensive literature on clusters, within the domain of regional studies and economic geography. This body of work helps to explain how and why such clusters emerge and points to the sorts of data and methodological tools required to study both the necessary preconditions and the triggers for local agglomeration.[38]

[38] Thomas Brenner and Andre Muhlig present a useful overview of this literature in their journal article, Factors and Mechanisms Causing the Emergency of Local Industrial Clusters: a Summary of 159 cases, Regional Studies, pp 480-507, Volume 47 Number 4, April 2013.

8. Directions for further development and future research

Overall, this area of research and innovation policy clearly remains a work in progress, and we have yet to see any decisive response to the regular calls to improve the methods of assessment of benefits from large research infrastructures.[39]

The literature we have identified suggests there is little in the way of a consensus with respect to scope and depth of coverage for the evaluation of the socio-economic benefits of large-scale research infrastructure, nor indeed is there agreement about the most appropriate analytical framework (including choice of metrics and impact measures), and design of data collection strategies. The studies make use of conventional data collection tools and analytical techniques. A majority will use some combination of the following in order to compile relevant data and opinions to feed into their micro-economic analyses: desk studies to collate and analyse financial and activity data, semi-structured interviews with facilities owners, users and other stakeholder, supplier and user questionnaire surveys and the acquisition of relevant official statistics and structural data. In terms of analytical techniques, there is widespread use of IO analysis as a means by which to estimate economic impacts and there is equally widespread use of case studies to create specific narratives or stories that connect the facility to the innovation outcome in question. User and supplier surveys support descriptive statistics, helping to profile and locate innovation outcomes, while more specialist STI analyses are used only occasionally, for example, co-publication analysis (bibliometrics). Even when widely accepted methodologies are chosen, they tend to be used in variable combinations and are executed with different degrees of rigour, and as a result the results are seldom directly comparable.

We found no evaluations of large research infrastructure that had made use of NPV and CBA techniques, the Treasury's preferred methodology for socio-economic impact assessment with longer-term investments. Moreover, we found no examples of studies that had attempted to identify all classes of socio-economic benefit in a manner sufficient to support monetisation and aggregation through some form of integrated methodology.

The most pressing challenges do not appear to be methodological per se, in the sense that the tools and techniques used to evaluate research infrastructure would be rather familiar to analysts carrying out socio-economic impact assessments in any area of innovation studies.

This is not to say there are no methodological challenges: the classic evaluation headaches are all in evidence; how can one confidently trace and quantify a wide-range of tangible and intangible effects that unfold over many years and are invariably tied to numerous investments, both public and private. Indeed, the measurement challenge may be tougher for research infrastructure, inasmuch as facilities are tools and typically just one input of many to the programmes of research being carried out in academia and industry. The knowledge spillovers that arise as a result of the intellectual advances made possible by 'big science' may be largely invisible to facility owners; certainly the empirical literature devotes very much more attention to the more immediate economic effects and technology transfer associated with building or running the labs. The STFC's expanding portfolio of impact case studies is the exception, at least within the English-language literature we have been able to assemble.

In practice, the most pressing challenges are sociological or cultural. These large facilities have rarely been subject to evaluation historically, beyond peer review, and that is perhaps where things need to begin to change: simply beginning to do more evaluation and more assessment of socio-economic effects. Our mini-survey of research facilities suggests there is an appetite to do more (or know more) on socio-economic benefits.

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[39] In 2006 the House of Commons Committee of Public Accounts report on "Big Science: Public investment in large research facilities", made a clear recommendation to improve the existing methodology to measure the economic impact of hosting large research facilities.

Where evaluations are commissioned, the specification needs to be a little more ambitious, reaching beyond the economic analysis of public expenditure to probe the impacts on innovation. The literature is clear-cut on this point: big facilities do trigger innovation, can create or expand new markets and on do reinforce local clusters and attract inward investment; these are all worthy of closer and more systematic investigation. Because it is an under-developed area of evaluation practice however, those future studies will benefit if they are given the time and space to find their way through the methodological cul-de-sacs that will no doubt reveal themselves and critically the gaps and limitations in the available data. Data shortages may be the biggest medium-term challenge.

In the short term, the biggest challenge will be tight public finances. While an economic impact assessment can be carried out reasonably quickly and efficiently, using readily available expenditure data and standard IO tables and multipliers, detailing the major innovation outcomes will be more costly. How much more costly will depend to some extent on the research facility and the quality of its existing monitoring data: can they direct the evaluators to the main impacts or will the analysts have to search them out? Having identified a good cross-section of innovation outcomes, estimating the size of the benefits and the nature of the facility's contribution will invariably require primary research, which is altogether more costly than a desk study.

In terms of next steps, there are several courses of action we would recommend BIS and the research councils consider (subject to available funds):

- Creating a joint BIS-STFC working group to oversee the development of evaluation practice relating to RI, based on a pragmatic approach similar to that followed by the ESRC Evaluation Committee (a heuristic approach, learning by doing). This exists already informally, however a little more structure may be helpful
- Improving large research facilities' data infrastructure
  - Agreeing on a list of say 100 key UK research facilities, covering types of infrastructure and a cross-section of disciplines, and approaching their respective 'owners' with a view to encouraging these organisations to improve their data infrastructure. Many facilities will have some of required data collection and reporting systems in place already, as they are no doubt feeding into the RCs impact assessment process, however broadening that to all and ensuring it is consistent would be helpful
  - Equally important, improving the amount of meta data and related intelligence available in an institution's financial records and contractor databases will be helpful to both the basic economic analyses but also any attempts to trace, attribute and quantify wider effects
  - It would also help if these organisations could create information systems for identifying and capturing examples of knowledge spillovers and wider impacts
- Commissioning a series of socio-economic impact assessments to expand the stock of reference material and more generally develop evaluation practice and associated stylised facts. This in turn would benefit from the inclusion of a lessons-learned component within each study specification, which would be reported in the methodological chapter:
  - A series of (ex post) evaluations looking at a cross-section of established (10+ years in operation) large-scale research facilities, to add to and build on the SRS evaluation
  - A series of studies to detail the role / contributions of major facilities to the local innovation ecosystem and regional clusters
  - A series of studies to trace and detail the role / contributions of major facilities to the emergence of important businesses and emerging sectors
  - A series of studies that set out to detail the contributions of big science and capital investment programmes to major innovations (breakthroughs in analytical procedures or devices, therapeutics, information services, etc)

Appendix A Glossary

AATSR	Advanced Along Track Scanning Radiometer
AHRC	Arts & Humanities Research Council
ARTES	Advanced Research in Telecommunications Systems
ASRF	Allocation of Science and Research Funding
BADC	British Atmospheric Data Centre
BAS	British Antarctic Survey
BBMRI	Biobanking and Biomolecular Resources Research Infrastructure
BBSRC	Biotechnology and Biological Sciences Research Council
BCIOM	British Columbia Provincial Input Output Model
BETA	Bureau d'Economie Théorique et Appliquée (Research Centre in Theoretical and Applied Economics)
BODC	British Oceanographic Data Centre
CCLRC	Council for the Central Laboratory of the Research Councils
CBA	Cost-Benefit Analysis
CELS	Centre of Excellence for Life Sciences
CERN	Conseil Européen pour la Recherche Nucléaire (The European Organisation for Nuclear Research)
CIF	Capital Investment Fund
CIGMR	Centre for Integrated Genomic Medical Research
CPI	The Centre for Process Innovation
CSES	The Centre for Strategic Economic Studies
DARTS	Daresbury Analytical Research and Technical Service
DELNI	Department for Employment and Learning in Northern Ireland
DLS	Diamond Light Source
DOE	US Department Of Energy
EATRIS	European Advanced Translational Research Infrastructure in Medicine
EBI	The European Bioinformatics Institute
ECRIN	Infrastructures for Clinical Trials and Bio-therapy
E-ELT	Europe’s Extremely Large Telescope
EIDC	Environmental Information Data Centre
EIRF	Economic Impact Reporting Framework
EIRIISS	European Industrial and RI Interaction and Support Study
ELI	Extreme Light Infrastructure
EMBL	European Molecular Biology Laboratory
EMSO	European Multidisciplinary Seafloor Observatory
EPSRC	Engineering and Physical Sciences Research Council
ERF	The European Association of National Research Facilities
ESA	The European Space Agency
ESF	The European Science Foundation
ESDS	The UK Economic and Social Data Service
ESFRI	The European Strategy Forum on Research Infrastructures

ESRC	Economic and Social Research Council
ESRF	The European Synchrotron Radiation Facility
ESS	European Spallation Source
ESTEC	The European Space Research and Technology Centre
ETI	Energy Technologies Institute
EvaRIO	Evaluation of Research Infrastructures in Open innovation and research systems
DIUS	former Department for Innovation, Universities and Skills
FDI	Foreign Direct Investment
FenRIAM	Foresight enriched Research Infrastructure Impact Assessment Methodology
FMDV	Foot & Mouth Disease Virus
GEOSS	Global Earth Observation System of Systems
GERD	Gross Domestic Expenditures on Research and Development
GMES	Global Monitoring for Environment and Security
GNSS	Global Navigation Satellite System
GVA	Gross Value Added
HEFCE	Higher Education Funding Council for England
HEFCW	Higher Education Funding Council for Wales
HEI	Higher Education Institute
HEP	High-Energy Physics
HERG	Health Economics Research Group
HGP	Human Genome Project
ICOS	Integrated Carbon Observation System
ILL	Institut Laue-Langevin
IMPLAN	IMpact Analysis for PLANning
ING	Isaac Newton Group of Telescopes
INSTRUCT	Integrated Structural Biology Infrastructure
IO	Input-Output analysis
ISIC	International Space Innovation Centre
ISIS	Centre for research in the physical and life sciences at the Rutherford Appleton Laboratory
ITER	International Thermonuclear Experimental Reactor
JET	Joint European Torus
JIC	The John Innes Centre
JIF	Joint Infrastructure Fund
JISC	Joint Information Systems Committee
JUICE	Europe Jupiter System Mission
KRDS	Keeping Research Data Safe
LCICG	Low Carbon Innovation Coordination Group
LFCF	Large Facilities Capital Fund
LHC	Large Hadron Collider
LRF	Large Research Facilities
MCS	Millennium Cohort Study
MERIL	Mapping of the European Research Infrastructure Landscape
MGF	Mosquito Genetic Facility

MRC	Medical Research Council
MRI	Magnetic Resonance Imaging
NAREC	National Renewable Energy Centre
NCESS	National Centre for Electron Spectroscopy and Surface Analysis
NEODC	Earth Observation Data Centre
NERC	Natural Environment Research Council
NETS	National Establishment Time-Series
NGDC	National Geoscience Data Centre
NIH	National Institutes of Health
NowGen	NorthWest Genetic Knowledge Park
NPV	Net Present Value
ONS	UK Office for National Statistics
PDC	Polar Data Centre
PETEC	The Printable Electronics Technology Centre
PhRMA	Pharmaceutical Research and Manufacturers of America
PPARC	Particle Physics and Astronomy Research Council
RAL	Rutherford Appleton Laboratory
REF	Research Excellence Framework
RI	Research Infrastructure
ROI	Return On Investment
SARA	the Netherlands' supercomputing centre
SHEFC	Scottish Higher Education Funding Council
SIOS	Svalbard Integrated Arctic Observing System
SKA	Square Kilometre Array
SRIF	Science Research Investment Fund
SRS	Synchrotron Radiation Source
SSC	Super-conducting Super Collider
SST	Sea Surface Temperature
STFC	Science and Technology Facilities Council
STI	Science, Technology and Innovation
TFP	Total-Factor Productivity
TGAC	The Genome Analysis Centre
TINA	Technology and Innovation Needs Assessment
TRIUMF	Canada's National Laboratory for Particle and Nuclear Physics
TTO	Technology Transfer Office
UDBN	UK DNA Banking Network
UKCMRI	UK Centre for Medical Research and Innovation
UKIRT	United Kingdom Infrared Telescope
WTCCC	Wellcome Trust Case Control Consortium
WTA	Willingness to accept
WTP	Willingness to pay

Appendix B Overview of capital funding for science

B.1 Introduction

This appendix sets out a more complete presentation of our review of capital investment in science in the UK, expanding upon the material presented in Chapter 3.

B.2 Data sources

In terms of a research process, the primary work revolved around the acquisition and compilation of relevant expenditure data. BIS itself is responsible for the overall UK science budget, and the single best source of data on UK capital funding for science is the Allocation of Science and Research Funding (ASRF) 2011/12 to 2014/15, which is published by BIS. It includes splits for capital and recurrent expenditure for the overall national science budget and also for the individual RCs / FCs.

The individual RCs and FCs publish more detailed financial accounts – and strategies – relating to their capital investment, which link back to the headline figures presented in the BIS overarching report. As a case in point, HEFCE's £550 million research capital budget (covering the 4-year period from 2011/12) is itemised, institution by institution, in a report entitled Capital Investment Fund 2 (CIF2): Capital allocations for learning and teaching 2012-13; and Capital allocations for research 2011-12 to 2014-15.

Each ASRF report provides the budget for the year it was published and a forward-looking account for the three years following. In addition to presenting financial data, the reports also include a qualitative account of key trends or changes within the period they cover.

In order to compile information on capital funding throughout the period in question we used four successive editions of the ASRF reports. There was a gap in the data for the years 2002-03 and 2003-04 because the respective document for this period could not be found. We used alternative sources[40] to fill in this missing information.[41]

The analysis is set in the context of the UK's overall science budget, to show its significance within the wider research funding landscape and to reveal any changes in relative importance of this element over time. We have used a period of 10 years, going back to 2000 where possible, to reduce the risk that the lumpiness of capital investment when looked at in a shorter timescale can easily mislead any attempts at a trend analysis. The period will also capture several important developments in respect to research facilities, including the inauguration of the Science Research Investment Fund (SRIF), the build and launch phase of the Diamond Light Source (DLS) at the Rutherford Appleton Laboratory (RAL) and the creation of the Science and Technologies Facilities Council (STFC) from the merger in 2007 of the Council for the Central Laboratory of the Research Councils (CCLRC) with the Particle Physics and Astronomy Research Council (PPARC).

B.3 The UK Science and Research Budget

BIS published the current science and research budget in December 2010 in a report entitled The Allocation of Science and Research Funding 2011/12 to 2014/15 (ASRF). The tables on pages 17 and 19 of the ASRF report show the distribution and evolution of national funding over the 5-year period from 2010/11 for the resource budget and capital budget respectively.

The resource component of the science and research budget was around £4.5 billion a year in 2011/12, while the capital budget is around £0.5 billion.

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[40] Information from the Seventh report of the Select Committee on Science and Technology available at http://www.publications.parliament.uk/pa/cm200102/cmselect/cmsctech/860/86004.htm and Science & innovation investment framework 2004-2014, Section on capital funding of science on pages 48-49

[41] The Science & innovation investment framework 2004-2014 was used to update the figures on capital budget in 2005-6 to 2007-2008 because one particular component was not included in the breakdown.

The first of these two tables shows that the resource component of the science budget will be held at the same level across the period to 2011/15, with just a small number of substantive changes in the individual budget lines. The majority of research councils and funding councils show a 3% reduction in cash terms (MRC is the exception, at 105% of baseline), savings that are being used to fund increased investment in cross-council facilities (134% of baseline), international subscriptions (178% of baseline) and the UK Space Agency (110% of baseline). These growth points are all closely linked with research infrastructure.

Figure 12, which is also presented in the main report (Figure 1), shows planned expenditure for 2012/13 (£450M) running at around 50% of the £870 million budget for 2010/11. The Research Councils' and Funding Councils' capital budgets have been reduced, while the capital budgets of the STFC and the UK Space Agency have been held steady. The Large Facilities Capital Fund (LFCF) is the only budget line to show an increase over the period (124% of baseline). Overall, the changes reflect a move towards prioritising larger more strategic infrastructure. This process of strategic prioritisation is also evident in the Delivery Plans and Budgets of the individual research councils.

Figure 12 – Allocation of capital funding within the 2011/12 science and research budget

Council	**Baseline 2010-11**	**2011-12**	**2012-13**	**2013-14**	**2014-15**	**Total**	**Final Year to Baseline**
Research Councils	393,438	239,821	199,393	181,430	180,967	801,611	46.00%
AHRC	3,150	0	0	0	0	0	0.00%
BBSRC	66,480	38,000	29,700	29,700	29,700	127,100	44.68%
EPSRC	49,261	31,000	35,000	25,000	25,000	116,000	50.75%
ESRC	20,600	18,700	13,700	12,700	12,700	57,800	61.65%
MRC	134,517	33,000	29,000	31,000	31,000	124,000	23.05%
NERC	34,183	32,200	17,800	17,800	17,800	85,600	52.07%
STFC – Core Programme		19,630	21,981	14,237	14,169	70,017	
STFC–Cross-Council Facilities	85,247	21,070	21,919	22,463	22,931	88,383	75.98%
STFC-Int. Subscriptions		46,221	30,293	28,530	27,667	132,711	
Large Facilities Capital Fund	103,380	115,279	61,307	47,769	128,132	352,487	123.94%
UK Space Agency	19,000	19,000	19,000	19,000	19,000	76,000	100.00%
HEI Capital HEFCE	166,952	75,170	90,970	90,160	101,500	357,800	60.80%
HEI Research Capital England	158,420	53,199	64,377	63,810	71,831	253,217	45.34%
HEI Research Capital Scotland	23,622	8,620	10,431	10,339	11,639	41,029	49.27%
HEI Research Capital Wales	6,031	2,113	2,557	2,535	2,854	10,059	47.32%
HEI Research Capital NI	1,778	798	965	957	1,077	3,797	60.57%
TOTAL	**872,621**	**514,000**	**449,000**	**416,000**	**517,000**	**1,896,000**	**59.25%**

Source: Allocation of Science and Research Funding 2011/12 to 2014/15, BIS (2010)

It is important to note that in the period since the 2010 Spending Review, the government has made a series of additional commitments to increase funding for research facilities, both for universities and selected strategic projects. These fiscal events are not easy to locate in the formal budget, however we have sought to do so with the support of BIS economists and a summary of the SR10 allocations and the various additional capital commitments is shown in Figure 13. Taken together, these individual announcements have increased the total financial commitment to capital by around £1.4 billion across the 4-year period, from £1.9 billion to £3.3 billion, an increase of more than 70% on the original allocation. Notable additions include the creation of the £300M UK Research Partnership Investment Fund (UK RPIF), the £145M investment in High Performance Computing (HPC) and associated e-infrastructure, £120M in Space and £50M in the Graphene global research and technology hub.

Figure 13 – Summary of SR10 capital allocation (SR10 Science Budget) and additional commitments (fiscal events) to research capital (£000s)

Area (£M)	Within SR Fiscal Event	2011-12	2012-13	2013-14	2014-15	SR Total
HEI Research	SR10 Allocation	140	169	168	189	666
	Budget 2011	26				26
HEI Research Total		166	169	168	189	692
RC	SR10 Allocation	355	261	229	309	1,154
	Budget 2011	205				205
	Autumn Statement 2011		40	69	45	154
	Graphene		9	29	12	50
	Autumn Statement 2012		4	229	251	484
RC Total		560	313	556	617	2,047
RPIF	UKRPIF 2011		20	50	30	100
	UKRPIF 2012			70	130	200
RPIF Total			20	120	160	300
SPACE Total		34	40	109	94	277
Grand Total		759	523	833	900	3,015

Source: BIS, 2013

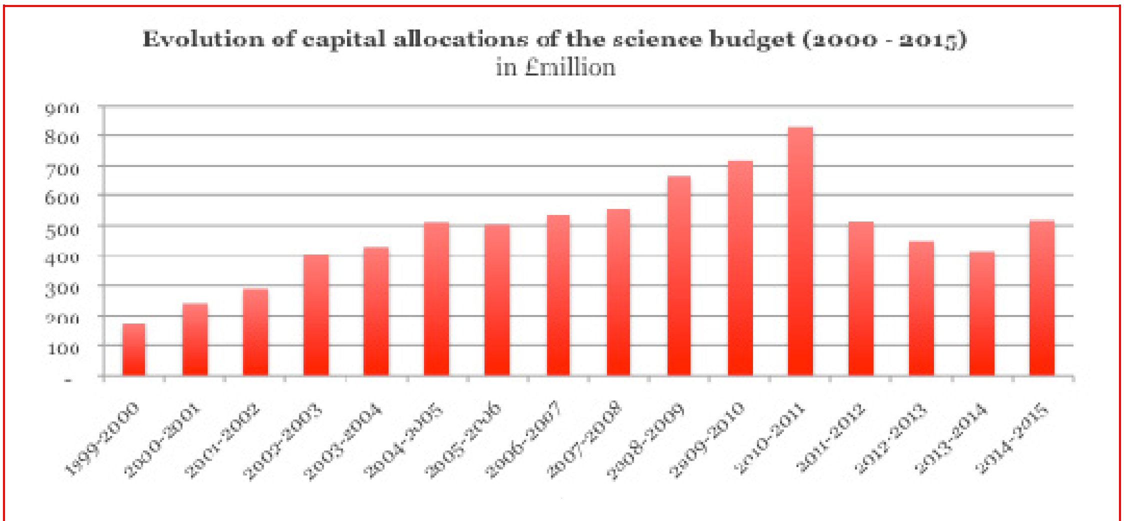
B.4 General description of the trends in capital budget

The capital budget grew from £173.6m in 1999-2000 to nearly £827m in 2010-2011. The most significant increases were in relative terms recorded in the first three years and in 2008-2009, each year growing by at least 20%. In absolute terms the highest year-on-year increases took place in 2002-2003, 2008-2009 and 2010-2011, each year by more than £100m.

SR10 reduced the research capital budget substantially: to £514m in 2011-2012 and is to be further reduced over the two consecutive years before increasing to £517m in 2014-2015. Reductions were implemented across the board, with the exception of the UK Space Agency and Large Facilities Capital Fund (LFCF). The LCFC is the only budget line to show an increase over the period (124% of baseline) within what is a very challenging budget overall. By the end of these planned reductions, in 2014/2015 the capital budget will be on par with 2006/2007 levels. Overall, the planned changes show a move – under pressure of very tight finances – towards prioritising larger more strategic infrastructure. This process of strategic prioritisation is also evident in the Delivery Plans and Budgets of the individual research councils. Another reason for a recent decrease in capital budget relates to the completion of the construction of CERN accelerator and major ESO projects, which will result in a greater proportion of the subscriptions being used on operating costs (and not on capital). Figure 14 illustrates the evolution in the UK's capital budget over time.

Readers should note that various fiscal events that have occurred in the period following SR10 (see Figure 13), mean that the capital allocation within the current Science Budget understates likely eventual expenditure by a substantial degree. For example, if the £517m budgetary allocation for 2014/15 is augmented with the anticipated additional expenditure from various capital-related fiscal events, the final figure will exceed £1 billion: double the budget. That combined amount is higher than the 2010/11 budget, both in cash terms and inflation-adjusted terms.

Figure 14 - Evolution of capital allocations of the science budget (2000 – 2015)



Source: Compilation by Technopolis based on data taken from the 'Allocation of Science and Research Funding, 2011/12 to 2014/15' BIS (2010)

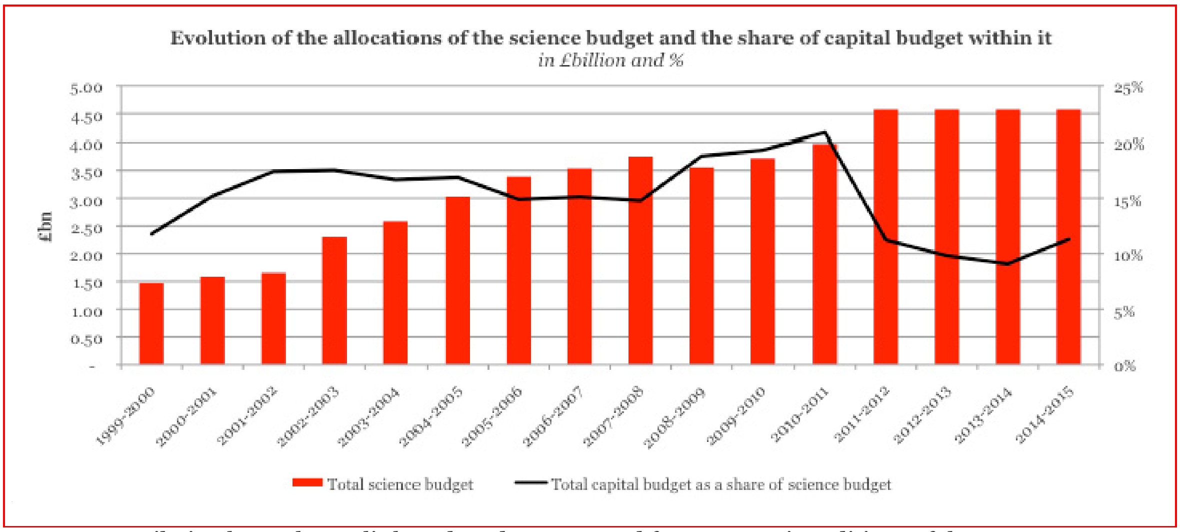
B.5 Analysis of capital expenditure in relation to the science budget

In order to set this analysis in context, we looked at the development of UK's science budget overall and the share of UK's capital funding within it.

Figure 15 shows a 15-year trend in the UK's annual science budget and overlays that bar chart with a line graph showing the evolution in the share of the capital budget within the overall science budget. The science budget experienced a substantial growth throughout the period until 2011-2012, in cash terms. The share of the capital budget within the science budget increased in the years before 2003, when growth was higher than that of non-capital science budget. During the years 2003-2008 the science budget continued to increase but the capital component grew at a similar rate, resulting in relatively stable share between 15-17%. After 2008, there was a period leading towards the peak in capital budget and its share within the science budget in 2010-2011. In 2011-2012 the share of the capital components dropped from nearly 21% to 11%. In the following three years (ending 2015), the capital component will fluctuate around 10% of the science budget.

As already mentioned, the various fiscal events that have occurred in the period following SR10 (see Figure 13) will also have a significant positive impact on this analysis and mean the outturn for capital expenditure as a share of the overall science budget is likely to recover strongly and approach the 20% figure achieved in 2010/2011.

Figure 15 - Evolution of science budget and the share of capital budget within it



Source: Compilation by Technopolis based on data extracted from successive editions of the government's science budgets, 'Allocation of Science and Research Funding'

B.6 Description of the capital budget for science

The capital budget for science has over the whole period consisted of various components. The most logical way that one might go about categorising them is based on what type of organisations they were allocated to.

B.6.1 Capital funding dedicated to HEIs

The first category is capital dedicated to Higher Education Institutions (HEIs). Almost all of the funds within this category throughout the period comprised dedicated Funds for this purpose. The first two of these dedicated funds – the Joint Infrastructure Fund (JIF) and Science Research Investment Fund (SRIF) – were temporary funds established to address the recognised problems caused by historic under-investment in renewal and refurbishment of the physical infrastructure of universities. On the other hand the current Capital Investment fund (CIF) is a permanent fund for maintaining the research infrastructure.

The Joint Infrastructure Fund (JIF) was launched in 1999 and ran for two years with five rounds of funding involving competitive bidding between universities. The JIF, equally funded by the Government and the Wellcome Trust, covered the full spectrum of science, engineering, economic and social sciences. It provided for buildings, major equipment and other elements of HEI's infrastructure. The Wellcome Trust component of the Fund (£300 million) was by virtue of the Trust's charitable objects, used for infrastructure relevant to biomedical and related research facilities. In total, the JIF awarded £750 million to science research infrastructure projects at 40 UK universities.

Following on from the success of JIF a new fund – the Science Research Investment Fund (SRIF) – was announced in 2002. SRIF was allocated on a formula basis rather than through competitive basis, allowing greater transparency and giving institutions a much greater say in how the money is spent and to meet their own priorities. The funds were jointly funded by the Science Budget and HE funding and are currently delivered by HEFCE in England, SHEFC in Scotland, HEFCW in Wales and DELNI in Northern Ireland. There were three rounds of SRIF over the period 2000-2008, with combined budget of over £2 billion.

In 2008 a new permanent funding stream – Capital Investment Fund (CIF) – was created, replacing the fixed-term Science Research Investment Fund. CIF encompasses teaching and research capital and is designed to help Universities to maintain their buildings, equipment and information technology at a level necessary to ensure research excellence.[42] CIF allocates its research capital funding in proportion to other institutional research income, split roughly between: research income an institution receives from the Research Councils; and the QR research income received from the funding councils.

CIF is distributed through the funding councils of the four home countries and those four streams are shown in the ASRF budget as: HEI Capital HEFCE, HEI Research Capital England, HEI Research Capital Scotland, HEI Research Capital Wales, and HEI Research Capital Northern Ireland.

B.6.2 Capital funding dedicated to Research Councils

The second category is Capital dedicated to Research Councils (RCs), which comprises the capital budgets of the individual Research Councils and a separate budget for the Large Facilities Capital Fund (LFCF). The capital budget dedicated to individual research councils (institutes, centres, and surveys) supports facilities used to carry out research and other activities, which have characteristics (such as scale or duration) that make them impractical for universities to carry out.

The Large Facilities Capital Fund (LFCF) was introduced in 2002/2003 as a dedicated fund for large scientific facilities complementing existing funding mechanisms provided to the Research Councils. The fund was designed to allow Research Councils to seek additional capital for large-scale investments in infrastructure to ensure UK scientists have access to the facilities they need. The fund has covered both large national facilities and participation in international facilities located both in the UK and abroad. A Large Facilities Road Map is maintained and updated every two years, and periodic prioritisation exercises are carried out to earmark money from the fund. Past projects partly funded by the Large Facilities Capital Fund (LFCF) include the Diamond Light Source, a second target station for the ISIS neutron source, and new marine vessels.

During the period 2004-2010 LFCF provided about £750 million. The LFCF continues to form a part of the capital funding within the science budget and was projected to allocate £352 million during the four years ending 2015.

B.6.3 Other funding

It was not possible in some cases, especially for the period before 2004, to establish whether the budget was dedicated to HEIs or to RCs and therefore there is also a third budget line (i.e. 'other' capital). Within this category we included the UK Space Agency, although its capital budget is specified in the ASRF (2010).

B.7 Trends in capital budget by category

Figure 16 provides a visual representation of how levels of funding within each of the categories changed over time.

[42] Over the three years 2008-2010 there was further capital funding provided from within the Higher Education capital budget (£266m/ £266m/ £292m over the three years respectively). This funding is not included in our analysis as it is not part of the science budget.

B.7.1 Trends in Capital funding dedicated to HEIs

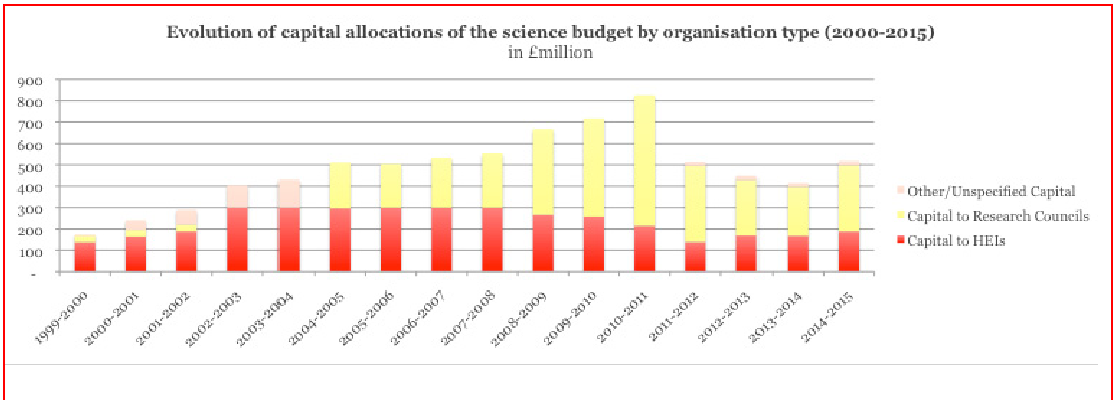
The capital budget dedicated to HEIs increased during the period before 2002-2003[43] and then remained high until 2007-2008. Much of this period of growth and sustained funding to HEIs was allocated through temporary funds described in previous section (JIF and SRIF). Since then the capital budget dedicated to HEIs experienced decline in years 2009-2012 but is predicted to increase by about 21% in 2012-2013. This lower level of funding relates to the changed rationale in funding of capital infrastructure in HEIs. Whereas during 2000-2008 was the UK trying to cure underinvestment in this type of infrastructure, the CIF is designed to maintain and prevent backlog reoccurring, hence the reduced level of funding.

B.7.2 Trends in Capital funding dedicated to RCs

The capital budget dedicated to RCs initially formed only a small share of the capital budget for science. Since 2004-2005 this share increased significantly and by 2008-2009 it was bigger than the part of the capital budget dedicated to HEIs. This significant growth continued until 2010-2011 and cannot be attributed to one single fund as the increases took place across the board (individual research councils as well as in the LFCF). The most notable increases over the period were:

- Construction of the Diamond Light Source (DLS) on the site of the Rutherford Appleton Laboratory. During the period 2004-2007 more than £170 million was dedicated to this single project (£80 million in year 2004/2005)
- Nearly doubling of LFCF budget in 2007-2008 (from £50 million to £100 million) and in 2010-2011 from (£138 million to £265 million)
- Merger of PPARC and CCLRC in 2007 and formation of the STFC; PPARC and CCLRC had a combined budget of £53M in 2007/08, whereas STFC had a budget of nearly £100 million the following year

Figure 16 - Evolution of capital funding of science by organisation type



Source: Technopolis compilation based on data taken from ASRF 2011/12 to 2014/15, BIS 2010

43 The analysis does not include capital expenditure by the Wellcome Trust, which co-funded the Joint Infrastructure Fund. Should this be included, the increase from 2001-2002 to 2002-2003 would be less pronounced

Appendix C Inventory of large research facilities

C.1 A partial UK inventory

The following list is derived from the inventory of facilities compiled by the FP7 project, MERIL (Mapping of the European Research Infrastructure Landscape), which is being run by the European Science Foundation with active support from the UK and in particular Dr Peter Fletcher (STFC) and Professor James Hough (University of Glasgow).

The project has compiled a pretty comprehensive inventory of research infrastructure, gathering substantial descriptive data on some 2,400 facilities across Europe, covering all disciplines, of which the UK makes use of 360 and hosts 180 of those. We have added some additional facilities through correspondence with the individual UK research councils and the table below includes 221 facilities.

The MERIL database can be searched online through an interactive online portal. (portal.meril.eu/converis-esf/publicweb/startpage)

	Name	Primary Domain	Form
1	Institute of Aquaculture	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
2	Mosquito Genetic Facility (MGF)	Biological & Medical Sciences	Genomic, Transcriptomic, Proteomics and Metabolomics Facilities
3	Centre for Environment, Fisheries & Aquaculture Science	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
4	Coastal observatory Liverpool bay	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
5	Planetary simulators - OU	Physics, Astronomy, Astrophysics and Mathematics	Space Environment Test Facilities
6	Planetary simulators - UWA-MAPS	Physics, Astronomy, Astrophysics and Mathematics	Space Environment Test Facilities
7	UCAM-CCP	Biological & Medical Sciences	Genomic, Transcriptomic, Proteomics and Metabolomics Facilities
8	BLADE	Engineering & Energy	Civil Engineering Research Infrastructures
9	Centre for Atmospheric Science	Earth and Environmental Sciences	Atmospheric Measurement Facilities
10	Culham Centre for Fusion Energy (including Mega Amp Spherical Tokamak)	Physics, Astronomy, Astrophysics and Mathematics	Nuclear Research Facilities
11	Central Laser Facility	Chemistry and Material Sciences	Intense Light Sources
12	Diamond Light Source (Phases I, II and III)	Chemistry and Material Sciences	Intense Light Sources

	Name	Primary Domain	Form
13	Medium Energy Ion Scattering Facility	Chemistry and Material Sciences	Intense Light Sources
14	National Centre for Electron Spectroscopy and Surface Analysis (NCESS)	Chemistry and Material Sciences	Analytical Facilities
15	Solid State NMR	Chemistry and Material Sciences	Analytical Facilities
16	EPCC	Information Science & Technology	Centralised Computing Facilities
17	National III V Centre (Sheffield)	Physics, Astronomy, Astrophysics and Mathematics	Micro- and Nanotechnology facilities
18	The Ecotron (Imperial)	Earth and Environmental Sciences	Environmental Management Infrastructures
19	Forestry Research Spatial Modelling GIS	Biological & Medical Sciences	Agronomy, Forestry, Plant Breeding Centres
20	Health and safety laboratory	Engineering & Energy	Environmental Health Research Facilities
21	Total Environment Simulator	Engineering & Energy	Marine & Maritime Engineering Facilities
22	Institute for Animal Health (NOW PIRBRIGHT INSTITUTE)	Biological & Medical Sciences	Environmental Health Research Facilities
23	UK Longitudinal Studies Centre	Social Sciences	Registers and Survey-led Studies/Databases
24	ISIS Neutron and Muon Source (including ISIS Target Station 2 - Phases II and III)	Chemistry and Material Sciences	Intense Neutron Sources
25	James Clerk Maxwell Telescope	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
26	Mary Lyon Centre	Biological & Medical Sciences	Genomic, Transcriptomic, Proteomics and Metabolomics Facilities
27	Moredun	Biological & Medical Sciences	Environmental Health Research Facilities
28	National Centre for Research Methods	Social Sciences	Data Mining and Analysis (Methodological) Centres, including statistical analysis
29	British Geological Survey	Earth and Environmental Sciences	Solid Earth Observatories, including Seismological Monitoring Stations
30	National Institute for Medical Research	Biological & Medical Sciences	Translational Research Centres
31	Henry Wellcome Building for NMR	Biological & Medical Sciences	Structural Biology Facilities
32	Mass Spectrometry Service (Swansea)	Chemistry and Material Sciences	Analytical Facilities
33	Centre of Plant Integrative Biology	Biological & Medical Sciences	Agronomy, Forestry, Plant Breeding Centres
34	National physical laboratory -Fuel Cells	Engineering & Energy	Energy Engineering Facilities (non nuclear)

	Name	Primary Domain	Form
35	Sample Analysis - Open University	Physics, Astronomy, Astrophysics and Mathematics	Space Environment Test Facilities
36	UOXF Protein Production	Biological & Medical Sciences	Genomic, Transcriptomic, Proteomics and Metabolomics Facilities
37	MicroKLab	Physics, Astronomy, Astrophysics and Mathematics	Extreme Conditions Facilities
38	Scottish marine institute (Scottish Association for Marine Science)	Biological & Medical Sciences	In situ Marine/Freshwater Observatories
39	Wellcome Trust Sanger Institute	Biological & Medical Sciences	Genomic, Transcriptomic, Proteomics and Metabolomics Facilities
40	SuperSTEM (Daresbury)	Chemistry and Material Sciences	Analytical Facilities
41	Ion Beam Facility (Surrey)	Physics, Astronomy, Astrophysics and Mathematics	Intense Light Sources
42	Aston Labs	Engineering & Energy	Energy Engineering Facilities (non nuclear)
43	UOXF.AL	Biological & Medical Sciences	Structural Biology Facilities
44	Laboratory for Molecular Biology	Biological & Medical Sciences	Analytical Facilities
45	Schofield Centre	Engineering & Energy	Civil Engineering Research Infrastructures
46	UEDIN-LS	Chemistry and Material Sciences	Materials Synthesis or Testing Facilities
47	Manufacturing Engineering Centre	Physics, Astronomy, Astrophysics and Mathematics	Micro- and Nanotechnology facilities
48	Leeds Nanoequipment Facility	Physics, Astronomy, Astrophysics and Mathematics	Micro- and Nanotechnology facilities
49	European Marine Energy Centre	Engineering & Energy	Energy Engineering Facilities (non nuclear)
50	New and Renewable Energy Centre Limited	Engineering & Energy	Energy Engineering Facilities (non nuclear)
51	Queen's University Marine Laboratory	Engineering & Energy	Energy Engineering Facilities (non nuclear)
52	UEDIN - The Edinburgh Curved Wave Tank	Engineering & Energy	Energy Engineering Facilities (non nuclear)
53	South West Mooring Test Facility	Engineering & Energy	Energy Engineering Facilities (non nuclear)
54	PRIMaRE HF Radar Environmental Monitoring Facility	Engineering & Energy	Energy Engineering Facilities (non nuclear)
55	National Oceanography Centre	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories

	Name	Primary Domain	Form
56	National Centre for Atmospheric Science	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
57	National Centre for Earth observation	Earth and Environmental Sciences	Atmospheric Measurement Facilities
58	Plymouth Marine Laboratory	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
59	Sea Mammal Research Unit	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
60	The North Wyke Farm Platform	Biological & Medical Sciences	Agronomy, Forestry, Plant Breeding Centres
61	The Genome Analysis Centre (TGAC)	Biological & Medical Sciences	Genomic, Transcriptomic, Proteomics and Metabolomics Facilities
62	The ARK-Genomics Centre for Comparative Functional Genomics	Biological & Medical Sciences	Genomic, Transcriptomic, Proteomics and Metabolomics Facilities
63	High Performance Computing facility, ARCHER	Information Science & Technology	Centralised Computing Facilities
64	Research Complex at Harwell	Physics, Astronomy, Astrophysics and Mathematics	Micro- and Nanotechnology facilities
65	UK Centre for Medical Research and Innovation (UKCMRI) - renamed Francis Crick Institute	Biological & Medical Sciences	Translational Research Centres
66	Energy Recovery Linac Prototype	Physics, Astronomy, Astrophysics and Mathematics	High Energy Physics Facilities
67	HECToR: UK National Supercomputing Service	Information Science & Technology	Centralised Computing Facilities
68	European 3rd Generation Gravitational Wave Observatory (Einstein Telescope)	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
69	British Antarctic Survey (BAS)	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
70	Centre for Ecology and Hydrology	Earth and Environmental Sciences	Polar and Cryospheric Research Infrastructures
71	Argon Isotope Facility	Chemistry and Material Sciences	Analytical Facilities
72	Chilbolton Facility for Atmospheric Radio Research	Chemistry and Material Sciences	Atmospheric Measurement Facilities
73	Facility for Nanoparticle Analysis and Characterisation	Chemistry and Material Sciences	Analytical Facilities
74	Field Spectroscopy Facility	Chemistry and Material Sciences	Analytical Facilities
75	Geophysical Equipment Facility	Earth and Environmental Sciences	In situ Earth Observatories
76	Ion Microbe Facility	Chemistry and Material Sciences	Intense Light Sources

	Name	Primary Domain	Form
77	Isotope Community Support Facility	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
78	Mesosphere, Stratosphere and Troposphere Radar Facility	Earth and Environmental Sciences	Atmospheric Measurement Facilities
79	Molecular Spectroscopy Facility (moving to NERC pay-as-you-go recognised status)	Chemistry and Material Sciences	Analytical Facilities
80	National Marine Equipment Pool	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
81	NERC Isotope Geosciences Laboratory	Chemistry and Material Sciences	Analytical Facilities
82	Space Geodesy Facility	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
83	Airborne Research & Survey Facility	Earth and Environmental Sciences	Research Aircraft
84	Polar Research Ship (replacement for RRS Ernest Shackleton)	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
85	Facility for Airborne Atmospheric Measurements	Earth and Environmental Sciences	Research Aircraft
86	RRS James Clark Ross (research)	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
87	RRS Ernest Shackleton (primarily logistics)	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
88	RRS Discovery	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
89	RV Prince Madog	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
90	Oceanographic Research Ship (replacement for RRS Discovery)	Earth and Environmental Sciences	Polar and Cryospheric Research Infrastructures
91	STFC Campus Centres (Hartree Centre, Harwell Imaging Partnership, International Science and Innovation Centre and CALTA)	Physics, Astronomy, Astrophysics and Mathematics	Micro- and Nanotechnology facilities
92	UK Brain banking network	Biological & Medical Sciences	Biobanks including Seed banks
93	UK DNA Banking Network	Biological & Medical Sciences	Biobanks including Seed banks
94	Chemistry Database Service (Daresbury)	Chemistry and Material Sciences	Chemical Libraries and Screening Facilities
95	Census of Population Programme (UK Data service)	Social Sciences	Data Mining and Analysis (Methodological) Centres, including statistical analysis
96	ACTRIS Data centre	Earth and Environmental Sciences	Atmospheric Measurement Facilities

	Name	Primary Domain	Form
97	ECRIN	Biological & Medical Sciences	Communication Networks
98	UK Data Service (formerly Economic and Social Data Service)	Social Sciences	Data Mining and Analysis (Methodological) Centres, including statistical analysis
99	EMMA-MRC	Biological & Medical Sciences	Animal facilities
100	British Household Panel Survey	Social Sciences	Registers and Survey-led Studies/Databases
101	UK Household Longitudinal Study (now called Understanding Society)	Social Sciences	Registers and Survey-led Studies/Databases
102	Digital Social Research (old name National Centre for e-Social Science)	Social Sciences	Data Mining and Analysis (Methodological) Centres, including statistical analysis
103	Virtual Microdata Laboratory	Social Sciences	Data Mining and Analysis (Methodological) Centres, including statistical analysis
104	Species 2000	Earth and Environmental Sciences	Registers and Survey-led Studies/Databases
105	Archaeology Data Service	Humanities & Arts	Databases
106	The Rothamsted Long-Term Experiments, Sample Archive and e-RA database	Biological & Medical Sciences	Agronomy, Forestry, Plant Breeding Centres
107	British Election Study	Social Sciences	Registers and Survey-led Studies/Databases
108	English Longitudinal Study of Ageing	Social Sciences	Registers and Survey-led Studies/Databases
109	Administrative Data Liaison Service	Social Sciences	Data Archives, Data Repositories and Collections
110	Secure Data Service	Social Sciences	Data Archives, Data Repositories and Collections
111	Birth Cohort Study and Cohort Resources Facility	Social Sciences	Registers and Survey-led Studies/Databases
112	Environmental Omics Bioinformatics Facility	Biological & Medical Sciences	Bio-informatics Facilities
113	British Atmospheric Data Centre (BADC)	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
114	National Geoscience Data Centre (NGDC)	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
115	British Oceanographic Data Centre (BODC)	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
116	Polar Data Centre (PDC)	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres

	Name	Primary Domain	Form
117	Environmental Information Data Centre (EIDC)	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
118	Earth Observation Data Centre (NEODC)	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
119	British Isles continuous GNSS Facility	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
120	British Ocean Sediment Core Research Facility	Earth and Environmental Sciences	Solid Earth Observatories, including Seismological Monitoring Stations
121	Cosmogenic Isotope Analysis Facility	Chemistry and Material Sciences	Analytical Facilities
122	NERC Biomolecular Analysis Facility (formerly Molecular Genetics Facility)	Biological & Medical Sciences	Genomic, Transcriptomic, Proteomics and Metabolomics Facilities
123	NERC Earth Observation Data Acquisition and Analysis Service	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
124	CABI Bioservices	Biological & Medical Sciences	Biobanks including Seed banks
125	National collection of pathogenic viruses	Biological & Medical Sciences	Biobanks including Seed banks
126	Royal Botanic Gardens Kew	Earth and Environmental Sciences	Natural History Collections
127	Natural History Museum, London	Earth and Environmental Sciences	Natural History Collections
128	Royal Botanic Gardens Edinburgh	Earth and Environmental Sciences	Natural History Collections
129	UK Biobank	Biological & Medical Sciences	Biobanks including Seed banks
130	British Library	Humanities & Arts	Research Libraries
131	British Museum	Humanities & Arts	Collections
132	Imperial War Museum	Humanities & Arts	Collections
133	The National Archives	Humanities & Arts	Research Archives
134	The National Gallery	Humanities & Arts	Collections
135	The National Maritime Museum	Humanities & Arts	Collections
136	National Museum Wales	Humanities & Arts	Collections
137	National Portrait Gallery	Humanities & Arts	Collections
138	Royal Commission on the Ancient and Historical Monuments of Scotland	Humanities & Arts	Research Archives
139	Tate	Humanities & Arts	Collections
140	Victoria and Albert Museum	Humanities & Arts	Collections
141	National Museums Liverpool	Humanities & Arts	Collections
142	National Museum of Science and Industry	Humanities & Arts	Collections
143	National Museums Scotland	Humanities & Arts	Collections

	Name	Primary Domain	Form
144	John Innes Germplasm Resources Unit	Biological & Medical Sciences	Biobanks including Seed banks
145	European Arabidopsis Stock Centre	Biological & Medical Sciences	Biobanks including Seed banks
146	UK Stem Cell Bank	Biological & Medical Sciences	Biobanks including Seed banks
147	Cape Verde Observatory	Earth and Environmental Sciences	Atmospheric Measurement Facilities
148	Rothera Research Station R	Earth and Environmental Sciences	Polar and Cryospheric Research Infrastructures
149	Halley Research Station	Earth and Environmental Sciences	Polar and Cryospheric Research Infrastructures
150	Bird Island Research Station	Earth and Environmental Sciences	Polar and Cryospheric Research Infrastructures
151	King Edward Point Research Station	Earth and Environmental Sciences	Polar and Cryospheric Research Infrastructures
152	Ny-Ålesund Arctic Research Station	Earth and Environmental Sciences	Polar and Cryospheric Research Infrastructures
153	LT (Liverpool Telescope)	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
154	ING (Isaac Newton Group of Telescopes)	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
155	UKIRT	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
156	DuneXpress observatory	Physics, Astronomy, Astrophysics and Mathematics	Astro-particle and neutrino detectors and observatories
157	Mars exploration mission	Physics, Astronomy, Astrophysics and Mathematics	Space Environment Test Facilities
158	Cluster	Physics, Astronomy, Astrophysics and Mathematics	Space Environment Test Facilities
159	James Webb Space Telescope	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
160	Europe Jupiter System Mission (JUICE)	Physics, Astronomy, Astrophysics and Mathematics	Space Environment Test Facilities
161	Laser Interferometer Space Antenna	Physics, Astronomy, Astrophysics and Mathematics	Gravitational wave detectors and Observatories
162	Marco Polo	Physics, Astronomy, Astrophysics and Mathematics	Space Environment Test Facilities
163	PLAnetary Transits and Oscillations of Stars	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
164	Planck Telescope	Physics, Astronomy, Astrophysics and Mathematics	Telescopes

	Name	Primary Domain	Form
165	Hubble Space Telescope	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
166	Solar Orbiter: Exploring the Sun-heliosphere connection	Physics, Astronomy, Astrophysics and Mathematics	Space Environment Test Facilities
167	Far-Infrared Interferometer	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
168	Space Infrared telescope for Cosmology and Astrophysics	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
169	Solar Dynamics Observatory	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
170	Lunar Radio Explorer/ Lunar Low Frequency Array/Lunar Dark Ages Mapper	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
171	The Dark UNiverse Explorer (now combined with SPACE in EUCLID)	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
172	CryoSat-2	Earth and Environmental Sciences	Earth Observation satellites
173	X-ray observatory, now part of IXO	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
174	Herschel Telescope	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
175	Data Processing and Analysis Consortium (GAIA mission)	Information Science & Technology	Complex Data Facilities
176	Envisat	Earth and Environmental Sciences	Earth Observation satellites
177	Probing Heliospheric Origins with an Inner Boundary Observing Spacecraft	Physics, Astronomy, Astrophysics and Mathematics	Space Environment Test Facilities
178	X-ray Multi-Mirror Mission	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
179	Titan and Enceladus Mission	Earth and Environmental Sciences	Earth Observation satellites
180	Multi-spacecraft mission to detect Earth-like planets	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
181	European *I*ncoherent *Scat*ter	Earth and Environmental Sciences	Atmospheric Measurement Facilities
182	European Synchrotron Radiation Facility	Chemistry and Material Sciences	Intense Light Sources
183	Very Large Telescope	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
184	X-ray Free Electron Laser	Chemistry and Material Sciences	Intense Light Sources

	Name	Primary Domain	Form
185	Extreme Light Infrastructure	Chemistry and Material Sciences	Intense Light Sources
186	European High Power laser Energy Research facility	Chemistry and Material Sciences	Intense Light Sources
187	Square Kilometre Array	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
188	European Spallation Neutron Source (ESS)	Chemistry and Material Sciences	Intense Neutron Sources
189	Institut Laue-Langevin (ILL)	Chemistry and Material Sciences	Intense Neutron Sources
190	Large Hadron Collider	Physics, Astronomy, Astrophysics and Mathematics	High Energy Physics Facilities
191	European Extremely Large Telescope	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
192	La Silla Observatory (incl. New Technology Telescope and Max-Planck-ESO telescope)	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
193	APEX (the Atacama Pathfinder Experiment)	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
194	Atacama Large Millimeter/submillimeter Array	Physics, Astronomy, Astrophysics and Mathematics	Telescopes
195	Euro-Argo	Biological & Medical Sciences	Agronomy, Forestry, Plant Breeding Centres
196	MaRINE Renewables Infrastructure Network for Emerging Energy Technologies	Engineering & Energy	Marine & Maritime Engineering Facilities
197	Council of European Social Science Data Archives	Social Sciences	Data Archives, Data Repositories and Collections
198	Gigabit European Academic Network	Information Science & Technology	Communication Networks
199	EMECO	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
200	Biobanking and Biomolecular Resources Research Infrastructure (BBMRI)	Biological & Medical Sciences	Biobanks including Seed banks
201	Infrastructures for Clinical Trials and Bio- therapy (ECRIN)	Biological & Medical Sciences	Telemedicine laboratories and E-Health technologies
202	European Multidisciplinary Seafloor Observatory (EMSO)	Earth and Environmental Sciences	Earth, Ocean, Marine, Freshwater, and Atmosphere Data Centres
203	Integrated Carbon Observation System (ICOS)	Earth and Environmental Sciences	Atmospheric Measurement Facilities
204	Svalbard Integrated Arctic Observing System (SIOS)	Earth and Environmental Sciences	Earth Observation satellites
205	European Centre for Systems Biology	Biological & Medical Sciences	Structural Biology Facilities

	Name	Primary Domain	Form
206	European Advanced Translational Research Infrastructure in Medicine (EATRIS)	Biological & Medical Sciences	Translational Research Centres
207	ComBase resource for predictive food microbiology	Biological & Medical Sciences	Biobanks including Seed banks
208	Food Information Data banks	Biological & Medical Sciences	Bio-informatics Facilities
209	PHI-base: The Pathogen Host interactions Database	Biological & Medical Sciences	Bio-informatics Facilities
210	Common Language Resources and Technology Infrastructure	Humanities & Arts	Research Facilities
211	e-Science and Technology Infrastructure for Biodiversity Data and Observatories	Earth and Environmental Sciences	In situ Marine/Freshwater Observatories
212	Enabling Grids for E-sciencE III	Information Science & Technology	Distributed Computing Facilities
213	Integrated Structural Biology Infrastructure (INSTRUCT)	Biological & Medical Sciences	Bio-informatics Facilities
214	Zeplin 111 (United Kingdom)	Physics, Astronomy, Astrophysics and Mathematics	Astro-particle and neutrino detectors and observatories
215	European Life Sciences Infrastructure for Biological Information	Biological & Medical Sciences	Bio-informatics Facilities
216	European Social Survey	Social Sciences	Registers and Survey-led Studies/Databases
217	Near-Earth Space Data Infrastructure for e-Science	Information Science & Technology	Complex Data Facilities
218	European Bioinformatics Institute	Biological & Medical Sciences	Bio-informatics Facilities
219	Infrastructure for Systems Biology-Europe	Biological & Medical Sciences	Systems Biology/Computational Biology Facilities
220	IBC; The European infrastructure for phenotyping and archiving of model mammalian genomes	Biological & Medical Sciences	Animal facilities
221	Heliophysics Integrated Observatory	Information Science & Technology	Communication Networks

Appendix D Literature review and bibliography

D.1 Literature review

The study's second objective was to review the literature on and evidence of the impacts of 'big science' facilities on innovation patterns and outcomes.

We carried out an extensive literature review using the Scopus database of peer-reviewed abstracts to identify conceptual or empirical literature detailing the innovation outcomes of large research facilities. We used the references listed in our existing inventory of around 50 papers and reports as a starting point for the searches, as well as a variety of key word searches and linked searches within publishers' databases. Additionally, we searched the web sites of various public and intermediary bodies with a particular interest in research infrastructure, including for example the research infrastructures web pages of the European Commission, the ESF Member Organisation Forum on Research Infrastructures and the OECD. Colleagues at the STFC also supplied various reference materials, albeit mostly individual case studies. Lastly, we wrote to representatives of more than 100 large facilities (using the MERIL database) to ask whether impact assessments had been carried out and, if so, how we might obtain a copy of the evaluation report.[44]

The search yielded some 20 or so additional references of particular relevance to the study, which were not in our starting bibliography. These additional items were mostly identified in the grey literature, rather than the peer-reviewed journals.

We catalogued and segmented the reports identified in order to help prioritise the search for work that is of greatest relevance, which are publications that deal directly with the innovation-related impacts of large research facilities. This central category numbers around 70 reports and papers, and includes both conceptual pieces (20) and empirical studies of specific facilities (50). In searching out these central references, we identified various reports that are of more general interest, relating to research infrastructure on the one hand or impact assessment methodologies on the other. We have been rather parsimonious with this more general literature, only recording a small fraction of the total body of material. Table 2 presents our simple segmentation of the materials presented in our final bibliography, shown in the appendices.

Overall, the literature review confirmed our starting hypothesis, which is that this is an under-researched topic and that there is scant literature available that makes a good job of capturing and explaining the specific innovation outcomes of this substantial strand of public investment in science.

[44] This mini-survey revealed very few new reports, and confirmed that there has been very little evaluation of facilities. However there was widespread interest in doing more evaluation work and an interest more generally in the results of this methodological review.

Table 2 – Classification of the literature encompassed by our review

Broad category	Sub-category	Description	Examples
A. Literature *directly* related to Big Science facilities	A.1 Empirical studies	Evaluations and impact assessments of specific large research facilities	STFC (2010) The social and economic impact of the Daresbury Synchrotron Radiation Source (1981-2008) Autio et al (2003) "Analysis of organisational & technological learning and innovation benefits that occur in the relationships between CERN and its individual supplier companies"
	A.2 Conceptual papers	Methodological and conceptual discussions on innovation impacts of LRFs	Toward a method of evaluation of RIs in open innovation and research systems: the EVARIO project, Sandrine Wolff, presentation to ERF conference on socio-economic impacts of RI, DESY, Hamburg (2012) FenRIAM (Foresight enriched Research Infrastructure Impact Assessment Methodology) framework (2011)
B. Literature related to other aspects of STI impact assessment	B.1 Empirical studies	Evaluations and impact assessments of other STI investments that may not fit the description of "LRF" but can provide valuable insights	Medical Research: What's it worth? Estimating the economic benefits from medical research in the UK, Health Economics Research Group (HERG), the Office of Health Economics and RAND Europe (2008) The impact of universities on the UK economy: fourth report, Universities UK (2009)
	B.2 Conceptual papers	Conceptual discussions or guidelines on socio-economic impact assessment of STI stuff	Economic impacts of the UK Research Council system: an overview. Science and innovation analysis (SIA) team (Ref. 10/917) Identifying and Quantifying the Benefits of GEOSS (Global Earth Observation System of Systems), by Ian McCallum et al., (2010) in Articles, Earth Observation, Economy, GEOSS/ICEO News
C. Policy and other contextual literature	C.1 Research Infrastructure	Policy studies with direct relevance to LRFs	Kate Barker, Deborah Cox and Thordis Sveinsdottir (2012), European Industrial and RI Interaction and Support Study (EIRIISS), final report, Manchester University Paul Beckers, et al, MERIL, Research Infrastructures of European relevance: A comprehensive inventory [final report of the FP7 project, Mapping of the European Research Infrastructure Landscape (MERIL)]
	C.2 Impact assessment methodologies	Key guidelines for measuring socio-economic impact, not restricted to STI	The Green Book (HM Treasury) Guide to COST-BENEFIT ANALYSIS of investment projects: Structural Funds, Cohesion Fund and Instrument for Pre-Accession (EC)

D.2 Bibliography

Year	Author(s)	Title
2010	ACIL Tasman Pty Ltd	The economic value of earth observation from space: A review of the value to Australia of Earth observation from space
2012	Agrell, Wilhelm	Framing prospects and risk in the public promotion of ESS Scandinavia
2003	Autio, E., Bianchi-Streit, M., & Hameri, A. –P.	Technology Transfer and Technological Learning through CERN's Procurement Activity
1996	Autio. E., Hameri, A-P., & Nordberg, M.	A Framework of Motivations for Industry-Big Science Collaboration: A Case Study
2004	Autio. E., Hameri, A-P., & Vuola, O.	A Framework of Industrial Knowledge Spillovers in Big-Science Centres
1993	Bach, L et al. (BETA)	Economic evaluation of the effects of the Brite-Euram programmes on the European Industry
1992	Bach, L et al. (BETA)	Measuring and managing Spinoffs: The case of the Spinoffs generated by ESA programmes
2011	Barker, K., Cox, D., & Sveinsdottir, T.	European Industrial and RI Interaction and Support Study (EIRIISS), final report
2011	Battelle Technology Partnership practice	Economic Impact of the Human Genome Project
2012	Beckers, P., et al.	MERIL, Research Infrastructures of European Relevance: A Comprehensive Inventory [final report of the FP7 project, Mapping of the European Research Infrastructure Landscape (MERIL)]
2003	Bessette, R. W.	Measuring the Economic Impact of University-Based Research, Journal of Technology Transfer 28: 355-361.
2005	Bianchi-Streit, M., et al	Learning, making innovation a reality, Giornale di Fisica, Vol. XLVII, N. 1.
2005	Bianchi-Streit, M., et al	CERN Technology Transfers to Industry and Society
1986	Bianchi-Streit, M., et al	Quantification of CERN's Economic Spin-offs
1984	Bianchi-Streit, M., et al	Economic Utility Resulting from CERN Contracts (Second Study), CERN yellow report 84-14, Geneva: CERN.
2001	Biermann, F.	Big science, small impacts - In the South? The influence of global environmental assessments on expert communities in India. Global Environmental Change, 11(4), pp. 297-309.
2010	BIS	Economic impacts of the UK Research Council system: an overview. Science and innovation analysis (SIA) team (Ref. 10/917)
2011	Boisot, M.	Generating knowledge in a connected world: The case of the ATLAS experiment at CERN. Management Learning, 42(4), pp. 447-457.
2011	Booz & Company	Cost-Benefit Analysis for Global Monitoring for Environment & Security (GMES)
1992	Bozeman, B. & Coker, K.	Assessing the Effectiveness of Technology Transfer from US Government R&D Laboratories: the Impact of Market Orientation
2004	Bressan, B.	A study of the research and development benefits to society resulting from an international research centre: CERN (academic dissertation)
2012	Brottier, Franck., & Gliksohn, Florian.	The ELI's (Extreme Light Infrastructure) experience in the ex-ante evaluation of socio-economic impact
2000	Byckling, E., Hameri, A-P., Pettersson, T., & Wenninger, H.	Spin-offs from CERN and the case of TuoviWDM
1993	Cabinet Office	Economic Impacts of Hosting International Research Facilities, SQW Consulting for the Cabinet Office
2010	CBRE Consulting	Berkeley Lab Economic Impact Study
2005	CCLRC	Future access to neutron sources: A strategy for the UK
2009	CEA et al	European Research Infrastructures, Development Watch (ERID-Watch). Commissariat à l'Energie Atomique (CEA) lead partner of the consortium
1991	Chaffee, C.D.	Can big science claim credit for MRI? Science, 253(5025), pp. 1204.

Year	Author(s)	Title
2012	Charles Beagrie Ltd	Economic Impact Evaluation of the Economic and Social Data Service (ESDS)
2005	CHASS	Measures of quality and impact of publicly funded research in the humanities, arts and social sciences. Prepared for the Australian Department of Education, Science and Training by Council for Humanities, Arts & Social Sciences (CHASS)
2011	Consulting InPlace	Impact evaluation of the Millennium Cohort Study
2012	Cosgrove, S. & Robertson, K.	STFC's approach to evaluating the impact of research infrastructures
2010	COST	Benefits of Research Infrastructures beyond science: the example of the Square Kilometre Array
2011	Curaj, Adrian & Katja Pook (eds)	Foresight enriched Research Infrastructure Impact Assessment Methodology (FenRIAM)
2005	Davies, S., Nutley, S., & Walter, I.	Assessing the impact of social science research: conceptual, methodological and practical issues. London: ESRC Symposium on Assessing Non-Academic Impact of Research, May. http://www.esrc.ac.uk/ESRCInfoCentre/Images/non-academic_impact_symposium_report_tcm6-16593.pdf
2010	Dormans, S., & Kok, J.	An Alternative Approach to Large Historical Databases: exploring best Practices with Collaboratories
2009	DTZ	Economic impact of the John Innes Centre
2011	EC	Research Infrastructures for Industrial Innovation, Research Infrastructures Unit, DG RTD
2008	EC	Guide to cost benefit analysis of investment projects: Structural Funds, Cohesion Fund and Instrument for Pre-Accession
2004	EC	Study of the impact of the IST programme, and its predecessor programmes ESPRIT IV, ACTS, TAP
2009	Ecorys	Economic effects of the Supernode in the Netherlands
2010	ESFRI	European Strategy Forum on Research Infrastructures Roadmap, Luxembourg: Office for Official Publications of the European Communities
2003	ESFRI	Medium to long-term future scenarios for neutron-based science in Europe
2010	European Court of Auditors	The Effectiveness of the design studies and construction of new infrastructures support scheme under the 6th Framework Programme (2010)
2009	Fraunhofer ISI	Case Study on the Economic Impact of Biobanks Illustrated by EuroCryo Saar
2012	Galbraith Muir Consultancy	STFC case studies with e2v and OI
1992	Galison, P., & Hevly, B.	Big science: the growth of large-scale research
1996	Glasner, P.	From community to 'collaboratory'? The Human Genome Mapping Project and the changing culture of science
2009	Graham, M. & Milligan, N.	Review of Daresbury Science and Innovation Campus, Manchester Independent Economic Review, PWC
2004	Hallonsten, Benner & Holmberg	Impacts of Large-scale Research Facilities: a socio-economic analysis
2011	Hallonsten, O.	Growing big science in a small country: MAX-lab and the Swedish research policy system. Historical Studies in the Natural Sciences, 41(2), pp. 179-215.
2011	Hallonsten, O.	Growing Big Science in small country: MAX-lab and the Swedish Research Policy System
2000	Hameri, A-P.	Technology Transfer from Accelerator Laboratories
1997	Hameri, A-P.	Innovating from big science research
2008	Health Economics Research Group (HERG), et al	Medical Research: What's it worth? Estimating the economic benefits from medical research in the UK
2003	HM Treasury	The Green Book Appraisal and Evaluation in Central Government. London: The Stationary Office Books.
2011	Horlings, E. et al.	The societal footprint of big science

Year	Author(s)	Title
2008	Horlings, E., & Versleijen, A.	Large-scale research facilities in the Dutch science landscape (in Dutch)
2007	House of Commons, Committee of Public Accounts	Big Science: Public investment in large scientific facilities
2012	Institute of Physics	The Importance of Physics to the Economy
2009	Institute of Physics	Particle physics – it matters: A forward look at UK research into the building blocks of the Universe and its impact on society
1985	Irvine, J., & Martin, B.R.	Evaluating big science: CERN's past performance and future prospects. Scientometrics, 7(3-6), pp. 281-308.
2002	ITER	ITER Economic Impact Study - EISS2 Caradache
2012	Jack, R., et al.	European Industrial and RI Interaction and Support Study (EIRIISS)
2012	Jacob, M. & Hallonste, O.	The persistence of big science and megascience in research and innovation policy, Introduction to the special section: the politics of megascience
2007	James, T.	Big science. Engineering and Technology, 2(6), pp. 38-42.
2009	Kelly, U., McLellan, D. & McNicoll, Professor, I.	The impact of universities on the UK economy: fourth report (Universities UK)
2012	Lauto, G. & Valentin, F.	How Large Scale Research Facilities Connect to Global Research
2009	Lindström, C. et al.	The ESS in Lund - its effects on regional development
2009	London Economics	Economic Analysis to support a Study on the Options for UK Involvement in Space Exploration
2006	Martin, B. & Tang, P.	The Benefits from Publicly Funded Research
1981	Martin, B., & Irvine, J.	Spin-Off from basic science: The case of radioastronomy, Phbs Techno1, Vol I.
2010	McCallum, et al.	Identifying and Quantifying The Benefits Of GEOSS
2009	MK Consulting	Economic and Social Impacts of TRIUMF
2007	National Audit Office	Big Science: Public investment in large scientific facilities
2012	NERC	Impacts Arising from Large Capital Investment: NERC
2011	NERC Cruise Programme Review Group	Cruise Programme Review Group Terms of Reference including RRS James Cook Benefits Realisation Plan
2003	Nordberg, N. et al.	Using customer relationships to acquire technological innovation: A value-chain analysis of supplier contracts with scientific research institutions
1994	Nordberg, N.	Contract Benefits and Competence-based Supplier Strategies - CERN as a Case Example, Helsinki University of Technology, Geneva. Pages: 173.
2012	NordForsk	Evaluation of NORDSYNC and Nordic membership of the ESRF
2008	OECD Global Science Forum	Report on Roadmapping of Large Research Infrastructures
2012	Oxford Economics	The economic impact of physics research in the UK: Magnetic Resonance Imaging (MRI) Scanners Case Study
2012	Oxford Economics	The economic impact of physics research in the UK: Satellite Navigation Case Study
2008	Oxford Economics	Study of the Impact of the Intermediate Research and Technology Sector on the UK Economy
2008	Oxford Economics	The case for space: The Impact of Space Derived Services and Data
2007	PA consulting	Study on the economic impact of the Research Councils (Part I and Part II)
2012	PACEC	Evaluation of Research Capital Funding (SRIF 2006-08) to Higher Education Institutions (Third Round)
2004	Papon, P.	European scientific cooperation and research infrastructures: past tendencies and future prospects
2001	Pfhaler, W.	IO-Analysis: A Users' Guide and Call for Standardization
2010	Pilling, Professor M. J	BAe 146 Review

Year	Author(s)	Title
2008	Public Partner Consulting Group	Stanford University Economic Impact Study
2004	Pung, et al.	Measuring the economic impact of the British Library
2009	Rambøll, Matrix, Eureval.	Community Support for Research Infrastructures in the Sixth Framework Programme: Evaluation of pertinence and impact (Synthesis report), Evaluation study for the European Commission
2007	RCUK	Measuring economic impacts of investment in the research base and innovation – a new framework for measurement
2006	Research Council Economic Impact Group	Increasing the economic impact of Research Councils (DTI, 06/1678)
2010	Royal Astronomical Society with support from STFC	A new view of the universe, big science for the big society
2001	Salter, Ammon, J., & Martin Ben R	The economic benefits of publicly funded basic research: a critical review, Research Policy, Volume 30, Issue 3, Pages 509-532.
1975	Schmied, H.	A Study of Economic Utility Resulting from CERN Contracts, CERN yellow report 75-5, Geneva: CERN.
2010	SKA Programme Development Office	Non-astronomy benefits of the Square Kilometre Array (SKA) radio telescope
2009	SQW Consulting	The economic impact and potential of higher education institutions in the North West: A report to the Northwest Development Agency
2008	SQW Consulting	Review of economic impacts relating to the location of large-scale science facilities in the UK
2012	STFC	Measuring impact at I-TAC (Innovations Technology Access Centre, Daresbury)
2012	STFC	STFC Impact Report 2012
2011	STFC	STFC Impact Report 2011
2010	STFC	E-ELT Impact - The Impact of the European Extremely Large Telescope
2010	STFC	Lasers in our lives – 50 years of impact
2010	STFC	New Light on Science: the social and economic impact of the Daresbury Synchrotron Radiation Source (1981-2008)
2010	STFC	STFC ISIS facility impact case studies
2004	Stroetmann, Veli & Karl A. Stroetmann	Impact Study: Micro-electronics & Microsystems, Healthcare and Mobile Technologies
2011	Technopolis	Data centres: their use, value and impact, for the research information network (RIN) and JISC
2011	Technopolis	The role and added value of large-scale research facilities
2010	Technopolis	BBMRI: an evaluation strategy for socio-economic impact assessment, a report for the pan-EU Biobanking and Biomolecular Resources Research Infrastructure (BBMRI) project, 2010
2009	Technopolis	Science Research Investment Fund (SRIF): a review of Round 2 and wider benefits
2006	Technopolis & Interface	Evaluating the Pertinence and Impacts of EU support to Research Infrastructures
2005	Triarii	ESTEC's value to the Netherlands
2012	UK trade and Investment	Business opportunities from large research facilities: UK industrial and research capability serving the world
2011	United for Medical Research	An Economic Engine: NIH Research, Employment, and the Future of the Medical Innovation Sector
2005	Valentin, F., Larsen, M.T., & Heineke, N.	Neutrons and innovations: What benefits will Denmark obtain for its science, technology and competitiveness by co-hosting an advanced large-scale research facility near Lund?" Copenhagen Business School.
2009	Vermeulen, N.,	On building large-scale research projects in biology

Year	Author(s)	Title
2006	Vuola, O. & Hameri, A-P.	Mutually benefiting joint innovation process between industry and big-science
1961	Weinberg, A.M.	Impact of large-scale science on the United States. Science, 134(3473), pp. 161-164.
2012	Wilhelm, Prof. Dr., Pfahler, Unversity of Hamburg	Regional and Sectoral Demand Effects of Research Infrastructure Facilities (RIFs) - The case of the X FEL at Desy, Hamburg
2010	Williams, Mark, Chair, RCUK Performance Evaluation Group.	Research Councils UK Approaches to Impact Assessment
1988	Williams, T.l., Lemkau JR., H.L., & Burrows, S.	The economics of academic health sciences libraries: Cost recovery in the era of big science. Bulletin of the Medical Library Association, 76(4), pp. 317-322.
2001	Williamson, et al.	The Socioeconomic Benefits of Earth Science and Applications Research: Reducing the Risks and Costs of Natural Disasters in the United States
2012	Wolff, Sandrine.	Toward a method of evaluation of RIs in open innovation and research systems
2006	Wylie, R., Markowski, S., & Hall, P.	Big science, small country and the challenges of defence system development: An Australian case study. Defence and Peace Economics, 17(3), pp. 257-272

Appendix E Case studies

E.1 Case studies of selected evaluation reports

We have prepared case studies for 11 of the evaluation reports identified, in order to provide readers with more insight as regards the kind of methodological approach used in specific studies and the rationale for that choice.

The cases are presented using standard headings, beginning with a description of the facility before going on to explain the methodological approach that was used and concluding with a brief summary on the innovation outcomes and wider economic impacts. The case studies are intended to be a resource and as such they are abridged versions of the published reports and are not judgemental, albeit in each case we have picked out the elements in the approach that we believe are particularly noteworthy and relevant to BIS. None of the reports is particularly reflexive, simply executing the client specification and not offering a view on any methodological lessons that may have been learned. None of the reports provide any indication as to the scale of effort involved, whether that is 100 person days or 1,000, and the great majority is also silent on elapsed time.

Figure 17 lists the reports we have chosen to describe in detail, which comprises a cross-section of studies for each of the three broad classes of socio-economic impacts of interest.

Figure 17 – Evaluation reports presented as case studies in the appendices

Author(s)	**Title**
Autio, E., M. Bianchi-Streit & A. -P Hameri	Technology Transfer and Technological Learning through CERN's Procurement Activity
Battelle Technology Partnership Practice	Economic Impact of the Human Genome Project
CBRE Consulting	Berkeley Lab Economic Impact Study, Lawrence Berkley National Laboratory (2010)
Charles Beagrie Ltd	Economic Impact Evaluation of the Economic and Social Data Service (2012)
Ecorys	Economic effects of the Supernode in the Netherlands (2009)
Hallonsten, Benner & Holmberg	Impacts of Large-scale Research Facilities: a socio-economic analysis (2004)
Lindström, C. et al,	The ESS in Lund - its effects on regional development (2009)
MK Consulting	Economic and Social Impacts of TRIUMF
Science & Technology Facilities Council	New Light on Science: the social and economic impact of the Daresbury Synchrotron Radiation Source (1981-2008)
SQW	Review of economic impacts relating to the location of large-scale science facilities in the UK
Triarii	ESTEC's value to The Netherlands

E.2 Economic Impact of the Economic and Social Data Service by Charles Beagrie Ltd and the Centre for Strategic Economic Studies (CSES) Victoria University (2012)

E.2.1 Introduction

This study is an evaluation of the Economic and Social Data Service (ESDS), a distributed data service facility co-funded by ESRC and JISC with an annual operating budget of £3.3 million. The study was produced by Charles Beagrie Ltd and the Centre for Strategic Economic Studies (CSES) Victoria University. The evaluation took place during 2011 and was published in March 2012.

The report is the result of ESRC's effort to assess the economic benefits of its investment in ESDS. The evaluation team was selected through a process of open competition and the study was conducted over a period of approximately 9 months (between July 2011 and March 2012). The data collection took about 6 months.

The study is publicly available at the ESRC website[45] and is part of the Research Council's ongoing efforts to develop approaches to the economic valuation of social science research as part of its impact assessment framework.

E.2.2 Overall methodology

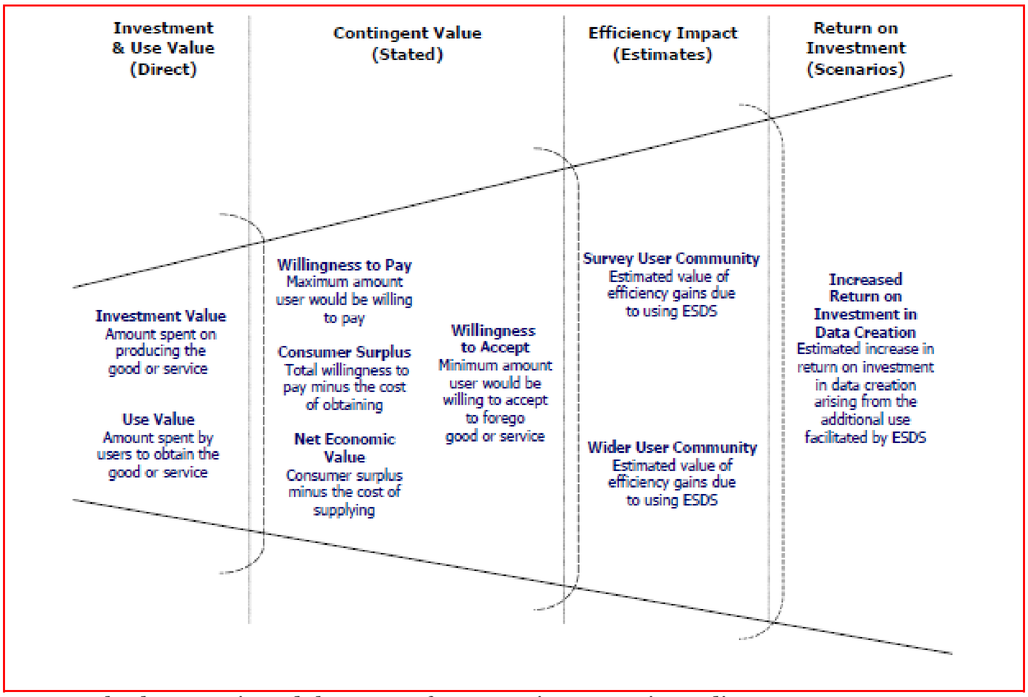
The study used a mixed methodology, combining (a) a range of quantitative techniques to estimate economic value, (b) case studies to build on the economic approaches and set them in a broader economic and policy context and (c) analysis of the wider benefits based on Keeping Research Data Safe (KRDS) Benefits Framework[46].

In the former (a) the study adopted a 'cumulative' approach in the estimation of economic value, starting with the most immediate and direct measures of value that are likely to represent lower bound estimates of the value of ESDS data and services to its active registered user community, and move outwards to more uncertain estimates of the wider benefits. To measure the economic value for its users, the study relied on contingent valuation using stated preference techniques, welfare approaches to estimating consumer surplus, and a macro-economic approach that seeks to explore the impacts of increased use on returns to investment in data creation and collection.

[45] http://www.esrc.ac.uk/_images/ESDS_Economic_Impact_Evaluation_tcm8-22229.pdf

[46] Woollard, M. (2011). KRDS Benefits Framework, Value- Chain and Benefit Analysis Tools: UK Data Archive Case Study. Paper presented at the JISC Digital Preservation Benefits Tools Project Workshop, London, 12 July 2011

Figure 1 The economic value and impacts of ESDS research data infrastructure.

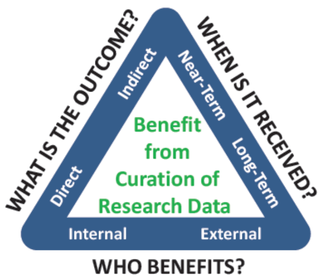


Source: Charles Beagrie and the Centre for Strategic Economic Studies, 2012

In addition to the quantification of economic impact, the authors constructed three case studies (climate control, knife crime, and obesity) to illustrate the impact that research based on ESDS has had in terms of debate and media coverage of these major social issues.

Wider economic benefits are presented using the KRDS (Keeping Research Data Safe) Benefits Framework, developed by Beagrie, Ltd and funded by funded by the Joint Information Systems Committee (JISC). This framework provides a standard tool for identifying, assessing, and communicating the benefits from investing resources in the curation and long-term preservation of research data. The Framework organises benefits along three broad dimensions: the outcome achieved; when the outcome is achieved; and who benefits from the outcome. Each of these dimensions can be subdivided into two categories: direct and indirect benefits, near-term and long-term benefits and internal and external benefits respectively.

Figure 2: KRDS Benefits Framework



Source: Charles Beagrie and The Centre for Strategic Economic Studies, 2012

A User Guide for this framework has been developed – which includes KRDS Costs Framework, KRDS benefit analysis and guidelines for case studies – funded through the JISC Managing Research Data Programme[47]. The same framework is currently being used to evaluate the Archaeology Data Service and the British Atmospheric Data Centre.

47 http://www.jisc.ac.uk/publications/reports/2010/keepingresearchdatasafe2.aspx#downloads

E.2.3 Scope of the evaluation questions

The objective of the evaluation is two-fold (1) to assess the economic benefits and impact of ESDS to its users and (2) to develop impact evaluation methods that can provide ESRC with robust and consistent estimates for its investments in data service infrastructure.

Scope of research questions

The study targets the economic impact associated with all the range of activities carried out by the ESDS –not focussed on specific activities. It additionally covers all main stakeholders including: (1) users (academic and non-academic), and (2) ESDS depositors of data. The results of two surveys conducted amongst registered users and depositors were extrapolated and weighed to obtain aggregated results representing the value to the total population.

Most of the economic analysis is focused on unravelling the different levels of economic benefits that ESDS data and services bring to its users, as well as the counterfactual – what would happen in the absence of the facility. The study also explores policy impacts alongside the economic analysis. It does not attempt to quantify policy impacts but it does include case studies to illustrate the broader context and provide understanding of the breadth of both quantifiable and qualitative benefits including areas such as policy.

The wide scope of the evaluation was described by the evaluation team as 'ambitious' by the evaluation team, who recommended longer timescales (or narrower scope) for future studies.

Scope of the empirical research

First hand data was mainly obtained through 25 interviews and 2 surveys (to users and depositors). The study targeted all registered users, with the exception of registered school students and under-graduates along with a small number of registered consenting users from non-Anglophone, non-Eurozone countries. The analysis indicated that exclusion of school and under-graduate students from the survey had little impact on the economic analysis. Besides the above-mentioned exceptions, survey respondents were self-selected: (i) because, in the case of users, they opted to allow ESDS to contact them upon their registration with ESDS, and (ii) because they responded to the survey.

In relation to interviews, the identification of interviewees was done by ESDS staff, based on their knowledge of users, depositors and other stakeholders; and complemented by a scrutiny of ESDS literature. The list of potential interviewees was then prioritised in consultation with ESRC.

E.2.4 Data collection methods

- Desk-based research
- 25 interviews to with key stakeholders – including ESDS staff, users and depositors of data at academic and non academic organisations, and policy makers and practitioners.
- Two online surveys to depositors and ESDS registered users – 6,773 people were invited to contribute to the report, of which 1,178 (17 per cent) responded.

E.2.5 Data sources

The evaluation examined drawn from a range of sources, including statistics on ESDS users and the data they use; evaluations of research data infrastructures in other disciplines; and documentation on the costs of accessing similar services in the UK and abroad. The main data sources include:

- Existing evaluation literature and reports
- Existing management and internal data collected by ESRC and ESDS (eg. User registrations, downloads and sessions, data collections, operations and activity costs), internal reports, and the ESDS Mid-Term Review
- UK Office for National Statistics (ONS), OECD and Eurostat
- ESDS staff, ESDS users (including academic users and policy makers) and depositors.

E.2.6 Analytical techniques

The economic analysis included a range of approaches, starting with the most immediate and direct measures of value that are likely to represent lower bound estimates of the value of ESDS data and services and moving outwards to estimates of the wider economic benefits. They included:

- Investment and use value – with the amount of time and money spent producing/ obtaining ESDS data and services indicating the minimum value of ESDS;
- Contingent value – with the amount that users would be willing to pay to access ESDS data and services and/or willing to accept to forego access indicating the value of ESDS to them;
- Consumer surplus – with the total willingness to pay minus the cost of obtaining indicating the benefit they derive from ESDS;
- Net economic value – with the users' benefits derived minus the cost of providing ESDS data and services indicating the net economic value;
- Efficiency gains – with estimates of the value of research and teaching efficiency gains realised by ESDS users indicating the impacts of ESDS on the user community; and
- Increases in returns on investment in data creation and infrastructure – with estimates of the potential increases in returns to investment arising from the additional use facilitated by ESDS indicating the impacts of ESDS on the funder, data creator/depositor and user communities.

The evaluation team found it difficult to identify case studies (b) that could conclusively show direct impact on policy and practice. This was said to be a challenging task because of the widely acknowledged difficulties associated with attribution and time-lags.

E.2.7 Strengths and weaknesses

The study constitutes a well-rounded analysis of the value of ESDS to its users applying multiple methodologies (qualitative and quantitative), combining direct estimations of costs and benefits with contingent valuation techniques, and case studies.

The study produces a set of indicators that are comparable with other evaluations and studies – these indicators include: investment value, use value, willingness to pay, consumer surplus, net economic value and return on investment.

One of the noted strengths of contingent valuation technique is that it allows capturing non-markets benefits. Additionally, it does not infer values from actual choices but rather ask directly to users, how much they would be willing to pay. However, applying the contingent valuation method is generally complicated, lengthy, and expensive. In order to collect useful data and provide meaningful results, surveys must be designed, pre-tested, and implemented in a considerably large population.

The case studies provide a good complement to the quantitative economic analyses, providing a broader view of policy impacts. However, the report shows difficulty in connecting the direct impact on policy and practice due to the difficulties associated with attribution and time-lags.

E.2.8 Results

Economic impacts

The most immediate and direct measures of value, likely to represent the lower bound estimates, of the value of ESDS data and services to its active registered user community was calculated at around £23 million per annum (excluding the value to school and under-graduate users). This is reflected in the contingent valuations, where users' willingness to pay amounts to around £25 million per annum. Hence, the consumer surplus is around £21 million per annum (after deducting user access costs) and the net economic value (net of operational costs) around £18 million per annum - more than five-times the ESDS operational budget.

As is typically the case in contingent valuation techniques, what users would be willing to accept in return for foregoing access to ESDS data and services is much higher, at £111 million per annum.

The wider economic impacts and benefits of ESDS research data infrastructure, were estimated by efficiency impacts for ESDS's active registered user community (excluding school and under-graduate students) at £68 million to £112 million per annum, which might translate to at least £100 million per annum or more for the wider user community. Exploring scenarios in the study suggests that ESDS research data infrastructure services facilitate an increase in the return on annual investment in the data and ESDS research data infrastructure services of £58 million to £233 million over 30 years (Net Present Value).

Given non-sunk data infrastructure costs of around £23 million per annum, this suggests a 2.5-fold to 10-fold return on investment (RoI).

The evaluation team compared these results to economic impact assessments of comparable research infrastructures reported over the last decade and concluded that the ESDS data and services provide comparable though slightly higher value for money than academic, special and public library services.

Policy and practice impact

Three impact case studies were undertaken to put the economic evaluation into context. The case studies represent a spread of use of the main ESDS data collections and focus on the major policy issues of climate control, knife crime, and obesity.

Wider benefits

Wider benefits of ESDS were presented in the report distinguishing between: Direct and Indirect Benefits (costs avoided); Near Term and Long-Term Benefits; Private and Public Benefits. Some examples of such benefits are presented in Figure 18.

Figure 18 - Examples of wider benefits from evaluation of EDSD

Direct Benefits	**Indirect Benefits (Costs Avoided)**
Time and resource savings for researchers and teachers	No re-creation of data -Trusted Digital Repository status eliminates re-ingest costs
Verification of research through increased data citation thanks to relevant citation information and tools	Lower future archiving costs increase likelihood of data being available, earlier in the lifecycle
Access to data provides new research opportunities by increasing use of data within collections thanks to proper Collections Development Policy	Re-purposing data for new audiences
Near Term Benefits	**Long-Term Benefits**
Value to current researcher and students	Data preserved for the long-term
Single point of access	Secures value of high quality data for future researchers and students
Increasing speed of access to data	Value added over time as collection grows and develops critical mass
Private Benefits	**Public Benefits**
Benefits to sponsor of research	Source of high-quality and often unique data
Benefits to sponsor of data service provider	Motivating new research
Benefits to researcher	Enables research that otherwise could not be undertaken

Source: Charles Beagrie and The Centre for Strategic Economic Studies, 2012

E.3 Economic Impact of the Human Genome Project by Battelle Technology Partnership Practice (2011)

E.3.1 Introduction

The Economic Impact of the Human Genome Project was prepared by Battelle Technology Partnership Practice and published in May 2011. It presents an economic impact assessment of the Human Genome Project (HGP) in the US. The HGP was a US-led global endeavour to decode the human genome, however this report focuses on the US government's expenditure and related economic benefits realised in the US.

The work was commissioned by the Life Technologies Foundation, part of the Life Technologies Corporation, a US$3.7 billion a year biotechnology company.

The report is available to download from Battelle and from the National Human Genome Research Institute (an institute of the US National Institutes of Health).[48]

E.3.2 Overall methodology

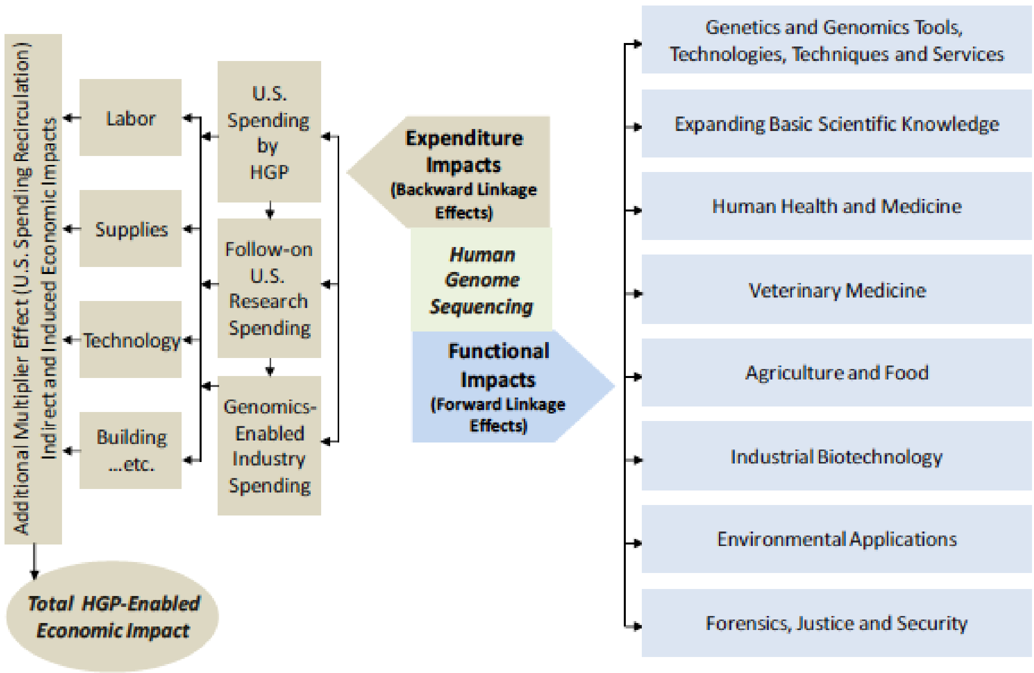
This is a return on investment (ROI) analysis, which compares the US government's investment of $3.8 billion (£2.5bn) in the HGP project across the 10-year period 1993-2003 with the combined effects of that expenditure on the US economy and on the US genomics industry. Overall, the report estimates a return on investment of 141:1 for the federal investment in the programme.

Battelle's analysts applied input/output techniques to HGP expenditure figures; wider genomics research expenditure (e.g. by the US DOE) and the expansion in the national genomics industry. Three different kinds of economic impact were included: direct, indirect and induced. Direct impact means the specific expenditures, such as each year's NIH and DOE funding on genomics, or specific spending by a given economic sector such as pharmaceuticals on genomics-related research. Indirect impacts are those on suppliers to those industries, such as companies that provide services, reagents, equipment and so on. Finally, induced impacts are the follow-on effect of the suppliers and employees spending money in the general economy.

The study was implemented through a methodology of backwards linkage effects (expenditure impacts) and forwards linkage effects (functional impacts) associated with the Human Genome Project (HGP). The study took a holistic view of human genome sequencing impacts addressing the HGP's expenditure and functional impacts. These are shown in greater detail in Figure 19.

48 http://www.genome.gov/27544383

Figure 19 - The Structure of Forward and Backward Linkage Impacts Associated with the Human Genome Sequencing



More specifically the approach followed by the study team included:

- A quantitative measurement of the direct and indirect economic impacts in the United States derived from actual expenditures of the HGP project and follow-on federal expenditures in major genomic science programs. This was quantified using input/output analysis.
- A quantitative estimate of the economic impact of the U.S. "genomics and genomics-enabled industry", with acknowledgement that those within the industry credit the HGP and related programmes as being integral components in the development of the industry.

In addition to examining direct, indirect and induced impacts, the authors constructed case studies of functional impacts in six fields of application (Human Health, Veterinary Medicine, Agriculture and Food, Industrial Biotech, Environment, and Forensics, Justice and Security).

E.3.3 Scope of the evaluation questions

The main aim of the report was to fill a gap in the literature regarding the Human Genome Project by assessing its economic and functional impacts.

The scope of the assessment was the US government programme and US beneficiaries. The Human Genome Project (HGP) refers to the federally funded programme that ran from 1990 to 2003 (though it also included initial funding in 1988 and 1989).

Part of the economic analysis focused just on this essential and galvanizing component of the total effort to unravel the human genome. But the total effort to decode the human genome involved many public and private players over many more years, and the work of entities such as Celera Genomics played an important part. The author's analysis of the functional impacts of the HGP necessarily included all these contributions.

E.3.4 Data collection methods

Data collection methods for this study included:

- Interviews with key leaders in the field for this project
- Experts inputs

- Requests for secondary data from Walls & Associates, NIH and DOE

E.3.5 Data sources

- National Establishment Time-Series (NETS) database developed by Walls & Associates (built upon annual records from Dun & Bradstreet)
- Pharmaceutical Research and Manufacturers of America (PhRMA)
- NIH and DOE databases (Historical R&D data)
- National Establishment Time-Series (Historical employment data)

E.3.6 Analytical techniques

The indirect and induced effects were estimated using a US-specific I/O model, the IMPLAN system, a software platform that is widely used for calculating economic impacts. Battelle looked at six economic sectors that were mapped to the closest economic sectors in IMPLAN.

These were as follows (IMPLAN sector in parentheses):

- Genomics-Related Bioinformatics (Custom computer programming services)
- Genomic & Related Testing (Medical and diagnostic labs)
- Genomic-Related Biologics & Diagnostic Substances (Biologics & diagnostics)
- Genomic Instruments & Equipment (Analytical laboratory instrument mfg)
- Genomics R&D/Genomics Biotech (Scientific R&D services)
- Drugs & Pharmaceuticals (Drugs & pharmaceuticals)

The model looked at trade flows between these sectors across the U.S. economy for a 23-year period (1988-2010) and estimated impacts on "employment, personal income (including both wages and benefits), economic output, state and local tax revenue (including income and property taxes), and federal tax revenue (including contributions to Social Security)."

E.3.7 Strengths and weaknesses

The main strength of this study is its ability to link research expenditure to a reasonable and coherent group of economic sectors separately identified within the US economy, and fully captured by the IMPLAN software. In that sense, the estimation of indirect and induced economic effects ought to be more accurate than simply using multipliers derived from more generic IO tables.

The report also made a good job of elaborating on the sorts of innovations made possible by genomics research as well as future possibilities, however this more qualitative work (case studies) was not monetised and integrated with the economic analysis.

Its principal weakness is the assumption that the expansion in the US genomics industry is attributable in full to the HGP, and while it may have been profoundly important full attribution seems grossly unreasonable. The relevance of the industry analysis for other studies is also a little uncertain, inasmuch as this was a moment in history, a mega project, fundamental breakthrough, industry-take-off, that may not be replicated elsewhere.

E.3.8 Results

The study found that the economic and functional impacts generated by the sequencing of the human genome are already large and widespread. Between 1988 and 2010 the human genome sequencing projects, associated research and industry activity – directly and indirectly – generated an economic (output) impact of $796 billion (£525bn), personal income exceeding $244 billion (£161bn), and 3.8 million (2.5m) job-years of employment.

The federal government invested $3.8 billion (£2.5m) in the HGP through its completion in 2003 ($5.6 billion (£3.7bn) in 2010). This investment was foundational in generating the economic output of $796 billion (£525bn) above, and thus shows a return on investment (ROI) to the U.S. economy of 141 to 1 – every $1 of federal HGP investment has contributed to the generation of $141 in the economy.

In 2010 alone, the genomics-enabled industry generated over $3.7 billion (£2.4bn) in federal taxes and $2.3 billion (£1.5bn) in U.S. state and local taxes. Thus in one year, revenues returned to government nearly equalled the entire 13-year investment in the HGP.

The study report contains case studies of functional impacts visible in the development of genomics tools, technologies and techniques. Final sections of the report considered future impacts along various genomic pathways.

E.3.9 Further results

The sequencing of the human genome has had a profound and paradigm-shifting impact on basic biological science and our understanding of biomolecular life processes. In addition, the large-scale sequencing programs, led by the HGP, spurred the rapid development of advanced sequencing equipment and technology that spawned an entire genomics-based technology sector. Today's sequencing platforms can analyse whole genomes at a speed never before thought possible. Genome sequence information has great utility across a broad range of scientific and technical disciplines. In human biomedical science a new class of advanced diagnostic tests has been developed because of advances in human genomics, and the field of pharmacogenomics is forming the underpinning of personalized medicine and emerging biomedical applications such as gene therapy and regenerative medicine. In addition, the human reference genome and the technologies of modern genomics have significantly affected science and applied technology deployment in multiple fields outside of human medicine. Disciplines including veterinary medicine, agriculture and food production, forestry, environmental science, industrial biotechnology, biofuels development and biosecurity and forensics are all beneficiaries and users of the knowledge and technological advancements made possible by the HGP and associated programmes.

E.4 Review of Economic Impacts Relating to the Location of Large-Scale Science Facilities in the UK by SQW consulting (2008)

E.4.1 Introduction

The report reviews the economic impacts arising from employment, expenditure and knowledge transfer from five UK large research facilities – Synchrotron Radiation Source (SRS), the Diamond Light Source, ISIS, the Joint European Torus (JET), and the European Bioinformatics Institute (EBI) – derived from the location of facilities in the UK as opposed to access to similar facilities abroad.

The review was commissioned by the former Department for Innovation, Universities and Skills (DIUS) in order to strengthen the evidence base on impacts arising from large science investments. The report was prepared by SQW Consulting, an external evaluator, in 2008 and is freely available at BIS website.[49]

E.4.2 Overall methodology

The approach adopted by the study team revolves around the economic analysis of facility employment and expenditures, estimating total local output and employment effects. Results of direct economic impacts were compared across the five facilities, giving particular attention to the geographical location of employment (by level of salary and occupation). The study does not go beyond the calculation of direct economic effects. It did not attempt to calculate the indirect and induced impacts. However, the study illustrated the benefits of having the facility in the UK instead of abroad, by emphasising the local impacts and the analysis of suppliers and users (businesses and academics), and by assessing the local impacts of agglomeration.

The study combined desk review of background information with multiple interviews, visits and regular consultations to the facilities, as well as interviews to suppliers and users – using structured aide memoires with academic and business users and suppliers to the facilities. Whilst the data collection methodology combined different approaches, the information obtained was analysed and presented in a rather descriptive form, without a robust analytical methodological approach.

E.4.3 Scope of the evaluation questions

Scope of research questions

This is the final report of a review of the impacts of five large-scale science facilities (LSSFs) in the UK. It is concerned with both economic and scientific impacts. The review was commissioned by DIUS in order to strengthen the evidence based on impacts arising from large science investments. The key research question is whether changes to the local economy and the UK research base are a result of locating the LSSF in the UK rather than elsewhere.

This review assessed two main categories of impact: economic and social effects resulting from the physical location of facility itself, focussing on local economic effects; and the impacts associated with the flow-on enhancements to the UK research base, and any subsequent changes to the economic impacts of the research base.

Scope of the empirical research

Five facilities were covered in the study, which enabled the representation of a range of experimental devices as well as a variety of management and funding structures, and facilities at different stages of their lifecycles. The facilities subject of this study is:

- SRS primarily a UK facility funded by the UK scientific funding councils, the first second generation synchrotron in the world
- ISIS was originally built as a UK funded project by the UK scientific funding councils, the most advanced spallation neutron source in the world at that time
- JET started as a pan European fusion project

[49] http://www.bis.gov.uk/assets/BISCore/corporate/MigratedD/ec_group/0000000050-08-S_on.pdf

- DLS an organisation funded by the STFC and a UK-based research charity, the Wellcome Trust, and established as an independent UK company owned by these two organisations
- The European Bioinformatics Institute (EBI) located at Hinxton in Cambridge, an outstation of the European Molecular Biology Laboratory (EMBL) in Heidelberg

Beyond the staff at the above facilities, the study also covered the experience of suppliers and users (academic and industrial).

E.4.4 Data collection methods

The data obtained differs in coverage between each of the facilities and each is discussed separately. Primary data was collected from staff at the facilities. Additional primary quantitative and qualitative data were obtained from suppliers and users (both academic and business) of the facilities through interviews and consultations. Basic secondary data on employment and expenditure were also made available by the facilities. This allowed for the discussion and evaluation of 'Economic impacts through expenditure on goods and services and employment.' Although the analysts tried to obtain the most recent data at the time of the consultations, the time coverage differs between each of the facilities.

27 UK-based suppliers to the facilities were interviewed. The interviews aimed to explore whether the suppliers gained benefits from the contract over and above the additional business (commercial, marketing and technological benefits). The suppliers were identified by the facilities and thus were intentionally non-randomly selected. The resulting evidence was used to compile a table depicting a matrix of the cross supply of products to the other facilities in study for this report, and the wider global market.

As well as interviews with suppliers several users from the academic community for Diamond, ISIS, EBI and SRS were interviewed. Different amounts of interviews were conducted in relation to each of the facilities:

- ISIS: interviewed nineteen academic users and attended one experiment (LOQ beam-line) at ISIS. Interviewees were chosen to reflect a range of locations across the UK in order to explore the benefits associated with proximity through a sample of researchers drawn from universities in different cities
- Diamond: Consultations were held with five researchers, with one based within a Research Council laboratory, and the others affiliated with universities across England. The research of three of those consulted centred around protein crystallography studies with a particular interest in protein structures and their molecular interactions. Two other researchers focused on nanotechnology applications, one within the field of chemistry and one being more physics oriented
- SRS: Data taken from the beam line application schedules which record the number of different requests for beam line access
- EBI: four academic consultees who were all located at the University of Cambridge were interviewed and their specific research areas centered on bioinformatics and computational studies of genetics and genomics

E.4.5 Data sources

- Basic data on employment and expenditure were made available by the facilities, with the exception of JET for which information was obtained from previous studies.
- Data from suppliers and users (both academic and business)

E.4.6 Analytical techniques

The authors used data collected from primary sources (interviews) and secondary data often provided by the facilities themselves. JET provided data which allowed the author valuable insights into the impact of the facility in particular areas such as employment and purchasing.

E.4.7 Strengths and weaknesses

The study provides a valuable contribution in the identification of key economic impact areas; however, it does not assess the absolute benefits (and costs), which generated by the facilities. Ultimately, these depend on the quality and usefulness of the scientific outputs they facilitate.

Their value to the UK will depend on national research strategies and the UK's ability to exploit them will depend on existing and developing scientific capabilities within the UK and these issues were outside the scope of the study.

The study provides good examples of large research facilities transferring knowledge and technologies to their suppliers. However, the studies interviews did not suggest this was occurring on a substantial scale, given the volume of contracts involved. In addition, there appeared to be limited scope for the suppliers to translate these advances into new products or markets. The major exception is, again, synchrotron supplies where there are many facilities globally (and several under construction) giving rise to continuing demands for leading edge products and services.

Furthermore, researchers reported sufficient evidence to indicate that large research facilities are making valuable contributions. However, this statement needs to be interpreted in the context of specific examples in order to hold any ground.

E.4.8 Results

All facilities yielded similar results in their employment patterns in that they have all created additional jobs (the number obviously depending on the scale of expenditure) and that almost all those who have been recruited are resident in the local economy, in fact most being in the same post code as the facility's location. This applies especially to the scientific posts, but in general local residents took a significant proportion of all jobs, around half in the case of ISIS.

UK-based companies appear to have been successful in securing 'low technology' supply contracts, which are mainly for construction equipments and services but can amount to very substantial amounts. However, they were far less successful in securing 'high technology' contracts. Very few suppliers to any of the facilities for which there was data were located in the immediate local economy. Nevertheless, there are some benefits, which derive from a UK location. These were consistently identified by all users who were interviewed for the study and this is perhaps one of the reasons why UK researchers are globally competitive and able to access foreign facilities.

The evidence indicates that the five facilities are contributing to the technology-based clusters around their locations and the report identified the following kinds of relationships, which they strongly suspected would be associated with any kind of large research facility.

- Knowledge transfer to suppliers, some of which are located within the same cluster.
- Skills development – the technicians and engineers working at the LSSFs develop skills, which are valued highly by businesses. However, the consultations with suppliers did not identify any recruitment of LSSF staff by businesses; indeed there were some references to staff movements in the opposite direction as a result of relatively attractive employment terms within the public sector
- Interactions with universities, both locally and further afield – the Cockroft Centre at Daresbury provides a physical presence for (three) university partners and there are ambitions for a similar development at Harwell. EBI is actively collaborating with Cambridge University staff and also its neighbour the Wellcome Trust Sanger Centre. The facilities also host postgraduate training and the large number of visiting scientists enhances the opportunities for contact with UK researchers
- The importance of the facilities in this respect. Large research facilities recruit significant numbers of scientists and technicians from outside the UK
- There is evidence that LSSFs are contributing to the development of high technology clusters in their local areas and we expect this to continue in the future. However, the clusters, in general, predate the establishment of the facilities and the facilities are small in relation to the total volume of scientific investment. As such, the study doubts whether these facilities could, on their own, seed the development of clusters

In terms of direct economic impacts, it is clear that a larger more costly facility is likely to have bigger impacts e.g. through construction, procurement, staff numbers, etc. However, such economic benefits would accrue from almost any similar investment e.g. a large hotel, casino or hospital. What was of particular interest to the study was the extent to which large facilities encourage the development of wider scientific/ knowledge benefits that could not be achieved by a large hotel or similar investment.

E.5 Economic Impact of the Lawrence Berkeley National Laboratory ('Berkeley Lab') by CBRE Consulting (2010)

E.5.1 Introduction

This is an economic impact study for Lawrence Berkeley National Laboratory ('Berkeley Lab') conducted by a CBRE Consulting. The study was done for the FY 2009 and published in 2010. The report can be accessed at the Lab's website[50].

The Berkeley Lab commissioned this evaluation in 2009 to demonstrate its impacts on the local community, the surrounding region, and beyond. For the purpose of the study CBRE Consulting focused on job generation, wages, and local and regional spending. This study for FY 2009 is an update to a similar study conducted by CBRE Consulting for the Lab's FY 2005, which was issued in July 2007.

E.5.2 Overall methodology

The economic analysis consists of an estimation of Berkeley Lab's direct effects of payroll, purchasing, and capital expenditures of the Lab, plus the re-spending effects in the greater economy. To calculate the broader indirect and induced effects, the study applied an economic multiplier analysis using a widely accepted input/output model developed by the U.S. Department of Agriculture known as IMPLAN (IMpact Analysis for PLANning). Indirect and induced effects were aggregate in one figure.

Using the same model, the study also included an analysis of the direct, indirect and induced economic impacts of 30 startups that had spun-off in the 20-year period since 1990.

E.5.3 Scope of the evaluation questions

Scope of research questions

The main purpose of the study was to demonstrate the economic impacts of the Lab's activities in various geographical areas – from the most immediate locally, to wider coverage up to the national level). The economic analysis was performed for six geographic regions, as follows: City of Berkeley, City of Walnut Creek, City of Emeryville, Bay Area (nine-county), the State of California, and the United States. The individual city locations correspond with existing Lab operations, including the main Lab facilities in Berkeley as well as the additional facilities located away from the main Berkeley campus.

The scope of the study therefore covers all expenditures of the Lab, and the beneficiaries in the US economy. The study does not differentiate between industries or sectors in the presentation of results.

Scope of the empirical research

The Data provided by Berkeley Lab were entered into a series of linked spreadsheets prepared by CBRE Consulting. All data collected and analysed pertained to the most recent fiscal year for which data were uniformly available from Berkeley Lab (Fiscal Year 2009). The intention was to provide a template of key economic variables in such a way that the economic impact of the Lab could be measured and updated regularly with minimum cost and effort.

The time frame of the study also allowed comparison of results with similar studies of previous years, as well as making projections of future economic impacts of potential investments. The evaluation report dedicates one section to compare the results for FY2009 with a similar study conducted for FY2005, and also one section to the estimation of anticipated effects of a potential increase of $221.0 million in the Lab's budget. Regarding the latter direct impact projections were multiplied by the weighted average multipliers found in the analysis of the FY 2009 impacts.

E.5.4 Data collection methods

- Desk research

[50] http://www.lbl.gov/community/pdf/CBRE-LBNL-Economic-Impact-Study-FINAL.pdf

- Data provided to evaluators by Berkeley Lab – payroll, purchasing of goods and services, capital expenditures, and start-up companies
- Interviews to confirm the data obtained from Berkeley Lab

E.5.5 Data sources

- Berkeley Lab
- Government officials
- City and County documents
- Multipliers – 2008 IMPLAN tables of multipliers by geographical region

E.5.6 Analytical techniques

In conducting the analysis of the Lab's direct spending on salaries, purchases of goods and services and capital expenditures, the evaluation team worked with the Lab to limit the estimates to those expenditures that could be identified as having occurred in a specific location (i.e. the cities of Berkeley, Emeryville, and Walnut Creek, the nine-county Bay Area, the State of California, and the United States). The same geographical segmentation was done in the analysis related to the 30 start-ups, matching business locations to the same geographical areas.

Based on these estimates, the study then calculated indirect and induced impacts using the IMPLAN model, which organises the economy into 440 separate industries and has comprehensive data on every area of the United States.

To calculate the indirect and induced impacts of spending, CBRE Consulting organised all Lab purchasing and payroll into the IMPLAN industry classifications and used the IMPLAN tables of multipliers. The IMPLAN model is based on incorporating regional purchase coefficients, which measure trade flows (the proportion of local demand purchased from local producers).

Calculations of the economic impact of the 30 start-ups were mainly based on employment data, whilst spending and payroll characteristics were estimated following "averages" for its industry.

E.5.7 Strengths and weaknesses

The study provides a careful account of direct, indirect and induced economic impact in various geographical areas, allowing differentiating between local, regional and national economic impact of the facility. IMPLAN allows the development of local-level input-output models that can estimate the economic impact of a facility by using industry-specific multipliers. The IMPLAN model is also commonly used the economic impact not only of large facilities but also economic sector, therefore provides comparable results to other studies. The design of data collection in an automated and standardised fashion facilitates historical analyses and future projections.

One of the weaknesses is that the study does not present the results of the economic impact by industrial sector. The study also does not attempt to calculate the return on investment (ROI).

E.5.8 Results

According to the study, the majority of economic impacts are realised locally as the Lab acts as a catalyst for employment and income. It is estimated that Berkeley Lab's spending in the Bay Area accounted for 72% of its total spending. However, the national economic impacts are also significant, as every 1.0 direct, full-time-equivalent employee of Berkeley Lab contributed to another 3.3 jobs in the United States. Across the country, the Lab's direct payroll of $320.7M generated another $400.5M (£254.2M) of indirect and induced personal income, accounting for total personal income impacts of $721.1M (£475.8M).

The study also highlighted the importance of the economic impact accrued through technology transfer to start-up companies, which exceeded the impacts of the Lab itself, due to the aggregate level of employment that start-up companies represent. The spending impacts of the start-up companies, their vendors and associated employees, totals $2.8 billion (£1.85 bn) throughout the United States.

E.6 Technology Transfer and Technological Learning through CERN's Procurement Activity by Erkko Autio et al. (2003)

E.6.1 Introduction

This report presents a study undertaken by academics from Helsinki Institute of Physics and internal employees of CERN. The empirical work was carried out during autumn and winter 2002/2003 and the report is publicly available on the High Energy Physics website[51].

E.6.2 Overall methodology

The report presents an empirical study that sought to quantify the innovation and economic benefits CERN's suppliers derive from its LHC-related procurement activities. The study examined the generation of technological learning and innovation benefits in the context of big science centres. In its initial stage the study team carried out a series of case studies, following the grounded theory approach. This theoretical framework outlined the conditions under which are these benefits most likely to be realised. The framework also defined the factors that determine the magnitudes of realised benefits and provided a focus and hypothesis to test by collecting empirical data.

Through interviews with CERN physicists and engineers, the evaluators were able to select the most relevant survey recipients. Survey results allowed the evaluation team to test the hypothesis based on the theoretical framework. The questionnaire survey asked questions relating to four outcome categories and their attribution to the project in collaboration with CERN: Technological Learning, Market Learning, Organizational, and Performance.

Data collected through the surveys allowed the authors of the evaluation to test their model. For example they analysed bivariate correlations between relationship governance and relationship outcome variables so as to get an understanding of how these relationships work in practice (according to their model, the learning outcomes from CERN's relationships with suppliers are dependent on particular relationship characteristics).

E.6.3 Scope of the evaluation questions

Scope of research questions

The main objective of this study was to examine CERN as an environment for industrial innovation and learning. The team's ambition was to go beyond the quantitative input-output studies, which have quantified the direct financial impact of Big Science centres' procurement budgets. The objective was to look at Big Science centres, CERN in particular, as environments for technological learning and innovation.

Specific objectives of the study were:

- Identifying the various technological, market, organizational, and other learning and innovation benefits that CERN's supplier companies may derive from their interaction with CERN
- Developing measures for the quantification of such learning and innovation benefits
- Empirically estimating the magnitude of such learning and innovation benefits in the context of CERN's recent large-scale installation projects
- Exploring how the learning and innovation benefits are distributed among various kinds of supplier companies and among various kinds of supplier projects
- Identifying and estimating various organizational factors that determine the magnitude of such learning and innovation benefits within individual projects and within individual companies
- Presenting recommendations for CERN on how to enhance the technological learning and innovation impact generated by its procurement activity

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[51] http://www.hep.ucl.ac.uk/~markl/pp2020/CERN_ProcurementBenefits.pdf

The primary focus of the study was on technological, market, and other forms of learning and innovation benefits that accrue to CERN's industrial suppliers. Because such learning benefits are difficult to track and can be measured only in qualitative terms, and because 'input–output' studies have already extensively documented the financial impact of CERN's procurement activity, the direct financial quantification of learning and innovation benefits was deemed outside the scope of this study.

Scope of the empirical research

The period selected, although it focused mainly on LHC procurements and relative prototyping development, included all companies that had had business with CERN during this period. The period 1997–2001 was chosen to minimize recall bias that would distort data pertaining to earlier interactions with CERN. A separate list containing orders above CHF200K (£140k) included also companies from Japan and USA that had participated as suppliers to the LHC project. This initial list comprised 6,806 companies with total orders amounting to CHF 2,132M (£1.4 billion).

Several selection criteria were applied to this list to isolate technology-intensive procurements and projects (excluding small projects, civil engineering suppliers and suppliers that had supplied off-the-shelf standard products suppliers of simple services.

The next step consisted of contacting the technical contact person at CERN responsible for each project in order to eliminate the remaining projects with no significant technological development component associated. The elimination rounds resulted in a final list of high technology suppliers to CERN that comprised a total of 612 companies distributed in all CERN member states, seven from the USA and 10 from Japan.

E.6.4 Data collection methods

The data collection methods employed in this study were desk research (to compile supplier database and profile purchases), semi-structured interviews to validate the list of companies and to draw up case studies based on a grounded theory approach and two questionnaire surveys.

Furthermore, the aim of these case studies was to develop a theoretical framework describing influences on organisational learning in Big Science–supplier relationships (Autio et al., 2003). This framework was then used to plan a wide-scale survey among CERN's supplier companies.

The supplier questionnaire survey was carried out during autumn and winter 2002/2003.

A parallel survey was carried out amongst CERN's personnel responsible for coordinating purchases in order to explore learning effects and collaboration outcomes at CERN's end of the relationship with the supplier. The focus of the survey was on CERN-related learning, organizational, and other benefits that accrue to CERN's supplier companies by virtue of their relationships with CERN. The survey questionnaire was designed according to the best survey practice: multi-item scales were used to measure both predictor and outcome variables, and the scales were derived from previously validated scales whenever possible. When CERN-specific scales were developed, this was done by paying close attention to pertinent theoretical frameworks. All scales were pre-tested in test interviews, and the feedback from these was used to iron out any inconsistencies and potential misunderstandings.

The supplier questionnaire[52] was prepared in English, French, German, Italian, Spanish, and Portuguese by native speakers of the language so as to minimize the potential for misinterpretations. It was issued in hard copy, by mail, and online, through a web version of the questionnaires. All necessary steps were taken to ensure the confidentiality and protection of the information gathered. The unit of analysis in the questionnaires was an individual supplier project.

The CERN internal questionnaire resembled closely the questionnaire used in the supplier survey. This questionnaire was prepared in English and in French only. Alongside analysing learning impacts at the CERN end of the dyad, the main aim of the CERN internal survey was

[52] The 10-page English version of the questionnaire is included in the publicly available version of the report.

to provide data for cross-checking the data gathered amongst CERN supplier companies. During the validation phase of this questionnaire it became clear, however, that interaction with the companies had produced quite significant learning and competence development benefits for the CERN personnel involved in procurement projects. Therefore, it was decided that a separate analysis of this point was also necessary.

E.6.5 Data sources

The Supplies, Procurement and Logistics Division at CERN provided a preliminary list of suppliers and purchase orders by year and value. The list also included information on orders (e.g. description of the procurement contract and amount) companies (name, contact person on the company when known, address, telephone, fax), and the name of the CERN purchasing officer and of the CERN technical coordinator. The CERN technical coordinators were involved in sample selection (see section 0). CERN suppliers provided estimates and judgements through surveys.

E.6.6 Analytical techniques

The authors employed, as the primary statistical analysis methods to analyse the survey data, descriptive statistical analysis, logistic regression, and multiple (OLS) regression analysis. These tests were followed by examination of bivariate correlations between relationship outcome variables and their predictors (and examining how the various outcomes are related to one another).

E.6.7 Strengths and weaknesses

This was one of the first studies to empirically document the innovation and learning benefits associated with Big Science procurement activity. Its main strength is that it found universal determinants of learning and innovation outcomes in CERN's supplier relationships.

The evaluators set out to contribute to the understanding of Big Science centres as environments of technological learning by carrying out a survey that focused on innovation and learning benefits that accrue to CERN's technology-intensive supplier companies by virtue of their supplier relationship with CERN. Using this approach, they attempted to take a closer look at Big Science than what had been achieved by previous 'input–output' studies that had attempted to quantify the secondary economic impact of Big Science centres. While valuable, 'input–output' studies do not provide much insight into how Big Science centres operate as learning environments. Enhancing technological learning and innovation benefits becomes possible only when one understands what causes them. The findings of this study have potential to prove valuable in this respect, not only for further research, but also for the management of Big Science centres and their supplier companies alike.

E.6.8 Results

The study has implications for researchers, practitioners, and policy-makers. For researchers, findings suggest that the interface between the industrial and public research spheres is multifaceted, and that different research institutions may possess distinctive potentials for the creation of knowledge spillovers in the economy. The authors have highlighted a number of pertinent mechanisms for the creation of such spillovers, and have developed approaches for their empirical estimation. The study demonstrates that it is possible to examine such distinctive potentials empirically, and that the phenomenon is of great significance.

Specifically the empirical results show that CERN's impact on supplier companies is measurable and can be quantified. The main conclusion is that very significant technological learning, market learning, organizational development, new product development, and performance benefits are associated with CERN's technology-intensive procurement activity. These benefits, while speculated about in earlier studies, have never before been explicitly reported, and this is the first study to empirically document the innovation and learning benefits associated with Big Science procurement activity.

In numeric terms, the innovation and learning benefits associated with CERN's technological procurements are indeed impressive:

- As many as 38% of all respondents reported having developed new products as a direct result of the supplier project.

- During the period from 1997 to 2001, we estimate that a total of some 528 new industrial products and services have been developed because of CERN's technology-intensive procurements
- Some 60% of the firms had acquired new customers (other than CERN) because of the CERN supplier project. In total, we estimate CERN's technology-intensive procurements to have solicited the acquisition of some 4400 new customers among CERN's technology-intensive supplier firms
- 13% of CERN's supplier firms started new R&D teams as a direct outcome of the CERN project
- 14% started a new business unit
- 17% opened a new market
- 42% increased their international exposure
- 44% indicated technological learning
- 36% indicated market learning
- 52% would have had poorer sales performance without CERN
- 21% would have had lower employment growth without CERN
- 41% would have had poorer technological performance
- 26% would have had poorer performance in valuation growth

Three important observations regarding relationship outcomes were highlighted in the conclusions. First, the marketing benefit (use of CERN as a reference in the firm's marketing activity) appears to be the universally present outcome in CERN's supplier relationships. Virtually all of CERN's suppliers appeared to derive genuine reference value from their interaction with CERN. Second, the other types of relationship benefits appeared unevenly distributed – with only a percentage of CERN's technology-intensive suppliers able to derive significantly higher learning and innovation benefit from their CERN collaborations. Third, the various relationship outcomes appeared quite strongly inter-correlated. This was attributed to the fact that the various benefits have a tendency of occurring together: if the relationship succeeds in producing any given outcome, other outcomes are also more likely to follow.

The universal determinants of learning and innovation outcomes in CERN's supplier relationships were found to be:

- Interaction frequency between CERN and its supplier firm
- The extent of interaction, measured as the number of the firm's and CERN's people frequently interacting during the project
- Relational social capital
- Structural social capital
- The firm's investment in its CERN relationship

E.7 ESTEC's value to The Netherlands, by Triarii (2005)

E.7.1 Introduction

The European Space Research and Technology Centre (ESTEC) is the European Space Agency's (ESA) main technology development centre, which is located in Noordwijk in the Netherlands.

This evaluation report was produced for ESA and the Dutch Ministry of Economic Affairs in the event of 30th anniversary of ESA, in order to celebrate ESTEC's value to the Netherlands. There were two previous studies looking into ESTEC's value to the Dutch economy but this time it additionally provided a description of the value of ESTEC to the Dutch knowledge society, whereas the previous two reports had not.

The report is publicly available on the website of a Dutch consulting company, Triarii, that undertook the study.[53]

E.7.2 Overall methodology

The overall approach of this study consisted of analysing value of ESTEC's knowledge to Dutch knowledge society and that of the macro-economic value of ESTEC for the Dutch economy in general.

The study, in order to showcase the two types of benefits, used descriptive analysis of quantitative and qualitative data and a separate macro-economic analysis. It was carried out in two phases. In the first phase ESTEC's perspective was investigated. There was analysis of the interaction between ESTEC and the Dutch knowledge society. For this, a desk study was carried out and 35 interviews inside ESTEC were held.

In the second phase the inward looking perspective was investigated. Interviews were held with selected organisations outside ESTEC and macro-economic value was estimated. This phase presents the analysis of the expenditures and contributions to determine the economic value of ESTEC to the Dutch economy in general.

E.7.3 Scope of the evaluation questions

Scope of research questions

The first study question relating to the value of ESTEC's knowledge resulted in a qualitative account of case studies relating to knowledge exchange between ESTEC and Dutch knowledge society. The types of benefits described were broad-ranging from high-level link to Dutch innovation policy through alignment of Dutch high tech industry with ESTEC's knowledge portfolio, upstream and downstream segments and highlighting cases of individual start up companies in each of those, through to pointing out the impact on improved job mobility.

The second study question addressed the cost to the Netherlands (both through contribution via ESA and other additional investments) and the expenditures of ESTEC in the Netherlands. In this section the study team analysed the trends since 1980 in order to arrive at the conclusions.

Scope of the empirical research

The study was carried out in two phases. In the first phase ESTEC's perspective was investigated. For this, a desk study was carried out and 35 interviews inside ESTEC were held.

The second phase investigating the inward looking perspective included interviews with selected organisations outside ESTEC. These were from the government (Ministry of Economic Affairs, Ministry of Education and Research, City of Noordwijk), public knowledge infrastructure (TU Delft, SRON, NLR, TNO Space, University of Utrecht, and NIVR), and commercial industry and services (including incubators, Dutch space industry and suppliers).

E.7.4 Data collection methods

- Desk research

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53 http://www.triarii.nl/docs/Triarii%20-%20Value%20of%20ESTEC%20to%20NL.pdf

- Interviews with ESTEC
- Interviews with organisations outside ESTEC

E.7.5 Data sources

The main data sources used in the study were ESTEC's and the Ministry of Economic Affairs' documents. These were both, those that contain information about the costs and expenditure as well as studies identifying impact case studies.

E.7.6 Analytical techniques

For the most part, analytical techniques employed were descriptive analysis of quantitative and qualitative data from desk research and the series of interviews.

The techniques and calculation of the macro-economic impact of ESTEC is not well described in the report and therefore cannot be commented on.

E.7.7 Strengths and weaknesses

The strength of this approach is in a broad consultation of both internal and external stakeholders of ESTEC, which resulted in a long list of the types of benefits, which can be expected from such establishment.

It is difficult to assess the methodological rigour of the macro-economic assessment due to lack of clarity of what each of the components encompasses and how the authors arrived at the estimates.

E.7.8 Results

The report came to the following conclusions:

- Firstly that the ESTEC's direct value for Dutch knowledge society is very high. ESTEC, ESA's prime technology centre, is the sixth largest knowledge institute in the Netherlands, and employs 2010 permanent staff and contractors, among which some 1,200 are engineers and scientists. ESTEC's volume of research and technology development is estimated at 212 M€ (£183m)(6% of its total spending). Furthermore, a significant share of the Dutch space cluster benefits from this knowledge development. The Dutch upstream space sector (producing hardware for ESA's space missions) consists of approximately 40 parties, employing 1100 people and has an annual turnover of M€ 170 (£147m). A much larger part of Dutch space sector indirectly benefits from ESTEC as user of space hardware (e.g. telecom industry, earth observation). Their turnover in this field is estimated at B€ 2 (£1.72bn). They particularly benefit in an indirect way, from the universities around ESTEC that have acquired ESTEC knowledge
- Secondly, ESTEC's interaction with Dutch space cluster though substantial leaves ample room for improvement. The report found that there were many mechanisms through which ESTEC and the Dutch space cluster benefit from each other's investment in knowledge development. It also stated that some of these mechanisms hold significant opportunities for further development
- Finally, Dutch spending on ESTEC is still very good value for money, because the total spending of ESA in the Netherlands in 2004 amounted to M€ 284 (£245m). Thus, every Euro of the Dutch contribution of M€ 88 (£76m), produces a return spending of €3.4 for the Dutch economy. In this respect the Dutch contribution of 88 M€ (£76m) can be considered as a very good investment. However the relative value in the Netherlands compared to 1989 and 1995 of ESTEC is declining slightly, which is caused mainly by stagnating ESA budgets and by inflation and economic growth

E.8 New Light on Science: The Social & Economic Impact of the Daresbury Synchrotron Radiation Source, (1981 - 2008) by STFC (2010)

E.8.1 Introduction

The study into the social and economic impact of the Daresbury Synchrotron Radiation Source was undertaken by the STFC, a funder of large-scale scientific facilities in the UK.

The report is available to download from the STFC website[54]

E.8.2 Overall methodology

This study represents a very comprehensive, mainly qualitative account of Synchrotron Radiation Source's impact with economic modelling of impact specified wherever possible. It is the first complete study in the world, which explores the social and economic impact of a large science facility over its whole lifetime. It highlights the many ways in which the SRS has impacted at the regional, national and international level.

For economic impact the study adopted the definition of the green book[55] and the economic impact framework developed by the Department of Innovation Universities & Skills (DIUS) (now the Department of Business Innovation & Skills) in 2007. In addition to the literature review (including Research Councils' Economic Impact Baseline reports) and interviews with various stakeholders including users of SRS, the study calculated local economic impacts (both indirect and induced) through use of economic multipliers.

E.8.3 Scope of the evaluation questions

Scope of research questions

The main aim of the project was to illustrate the vast economic impact that has come from the SRS over its lifetime and continues to make after its closure. It was not attempting to document the extensive scientific or technical output of the SRS. However research that has made an impact to daily lives, for example healthcare or environmental research, has been highlighted.

Secondly the objective was also to highlight any issues with gathering this data that could inform future economic impact reporting on large facilities across the Science and Technology Facilities Council's (STFC) projects and programmes.

Scope of the empirical research

The study attempted to cover nearly the whole lifetime of the SRS (1981 – 2008). The facility was constructed in 1977 closed in 2008.

E.8.4 Data collection methods

Research was both qualitative and quantitative in nature and encompassed a series of interviews with key stakeholders involved with the SRS over its lifetime. These included industrial partners, SRS users and SRS staff. The majority of the research was done via desk research and questionnaires for users were also utilised.

The desk research focused among other things on Economic Impact Baseline reports detailing impacts under the following four themes:

- Generation of knowledge and skills – both tacit and codifiable knowledge.
- Improving UK business competitiveness – Improved business competitiveness for UK companies through improved products and processes, Creating opportunities for UK business, Attracting and retaining investment in the UK, Commercialisation

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[54] www.stfc.ac.uk/resources/pdf/srsimpact.pdf

[55] 6 HM Treasury's "The Green book: Appraisal and Evaluation in Central Government" (2003)

- Impact to international partners – contribution to the scientific and technological development of other countries both in the EU and internationally at both an academic and industrial level
- Welfare impacts – contribution to health, environmental, cultural, social and national security outcomes through research programmes

E.8.5 Data sources

Data sources included SRS annual reports, publications of research carried out on the SRS, the SRS user database and other economic impact studies.

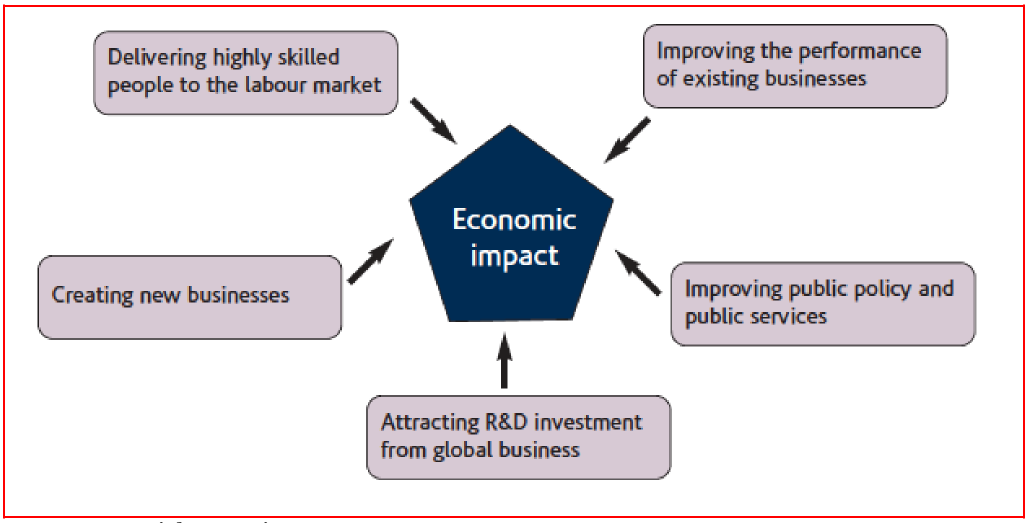
Due to the extensive time period, which this study covered, there were inevitably gaps in the recorded information. For example details of commercial companies engaged in the construction of the SRS do not exist. This is because the construction was in the 1970s when the importance of such data was not then recognised and the advent of the desk PC had not yet taken place.

E.8.6 Analytical techniques

The whole approach resulted in a more qualitative account of SRS's impact but the economic impact was given wherever possible. In the cases where financial economic data has not been available, qualitative case studies have been used to illustrate the impacts. This also means that it has not been possible to put a figure on the total economic impact of the SRS, but some financial impacts have been modelled. All financial figures have been indexed to reflect them at today's costs.

For economic impact the study adopted the definition of the green book[56] and the economic impact framework developed by the Department of Innovation Universities & Skills (DIUS) (now the Department of Business Innovation & Skills) in 2007. The areas of impact that should be reported on by the Research Councils within this framework are illustrated in Figure 21.

Figure 20 - Five key ways of generating economic impact from research, DIUS 'Economic Impact Framework' – May 2007



Source: New Light on Science, STFC, 2010

The local economic impacts (indirect and induced) were calculated by using so-called economic multipliers, which vary depending on industry sector and region in the UK. This method is commonly used by similar studies assessing economic impact of research infrastructures.[57] [58]

[56] 6 HM Treasury's "The Green book: Appraisal and Evaluation in Central Government" (2003)

[57] www.berkeley.edu/econimpact/2005-2006-econimpact-report.pdf

[58] "The economic impact of UK higher education institutions", Universities UK, (2006),

For example, the indirect economic multiplier used to calculate the economic impact of the Intermediate Sector by Oxford Economics is 1.6. "This means that for every £1 million of output generated by the Intermediate Sector, another £0.6 million of output is generated indirectly in its supply chain in the UK." In the UK, economic multipliers are generally based on or taken directly from the "United Kingdom Input-Output Analytical Tables" produced by the Office of National Statistics (ONS) in 2001. The Input-Output framework brings together components of Gross Value Added (GVA), industry inputs and outputs, product supply and demand, and the composition of uses and resources across institutional sectors for the UK economy.

Figure 21 - Indirect economic multipliers

Source	Industry	Type II multiplier output	Type II employment output
Partnerships UK (2006)	UK HEIs	2.52	1.99
ONS (2001)	Research & development	1.44	1.23
Oxford Economics (2006)	Intermediate sector	1.6	
Birmingham University (2007)	Birmingham University	1.4	1.7
SQW (2009)	North West HEIs	1.5	1.5

Source: New Light on Science, STFC, 2010

The evaluation team used the R&D multipliers set by the Office of National Statistics as the Regional Development Agency did not produce specific multiplier for North West England where the facility was based.

E.8.7 Strengths and weaknesses

The study represents an impressive account of types of impacts that can be attributed to the SRS over its lifetime. It also recognised the limitations of an ex-post economic impact assessment, especially in terms of caveats relating to the data available.

The authors stated that this method of research could never capture the full economic impact of the SRS and that whatever was captured in the report is an underestimate due to the limitations with the data.

E.8.8 Results

The economic impact of the research carried out on the SRS has been vast and the impact straddles all of the economic impact areas - Generation of knowledge and skills, Improving UK business competitiveness, Impact to international partners and Welfare impacts. Hence the impact from the science has come in many forms[59]:

- A significant amount of codified knowledge in the form of publications and the solution of many protein crystal structures
- The multidisciplinary and collaborative nature of science on the SRS has facilitated a great number of new scientific and technical developments
- The requirement of cutting edge technology has additionally facilitated leading edge science on the SRS and the technology itself has led to further economic impact by its usage by other large scale facilities and industry
- The development of new scientific techniques on the SRS is a significant impact; the example of PX development on the SRS was a major contributing factor for the need for 3rd generation light sources and was responsible for the private sector investment in the Diamond Light Source, with an initial investment of approximately £50M from the Wellcome Trust

www.universitiesuk.ac.uk/Publications/Documents/economicimpact3.pdf

59 The appendices to the report include examples within each of these impact areas within the STFC economic impact baseline (2007/2008), including commercial case studies

- The impact to society and our everyday lives has been vast - research into drug discovery, the prevention of diseases, cancer diagnosis and even the assistance of archaeology and marine animal colouration have or will have an impact on our lives and affect other organisations such as the NHS. Using the FMDV example, if research at the SRS saves just 1% of the cost of a potential future outbreak, it could save the UK over £80million
- It is also clear that a significant amount of this research has directly benefited industry and underpinned commercial advances in areas such as magnetic recording media, drug design and catalyst development. Research on the SRS has also benefited developing countries in the fight against malaria and the search for clean drinking water. However, it is extremely difficult to put a value on some of these groundbreaking research activities. Even if one only takes the examples that have figures attributed to them, this runs into the hundreds of millions of pounds. It is also worth noting that the examples presented above are a very small fraction of the research, which took place on the SRS

The most significant recognition comes from pharmaceutical and bioscience companies for huge commercial potential that lies behind understanding the multitude of processes that take place within living organisms at a molecular level. Advances in Structural Biology have accelerated greatly as a result of access to the synchrotron facilities that have been developed around the world.

Delivering highly skilled people to the labour market.

A critical mass of highly skilled engineers, technicians and instrumentation developers was built up over the lifetime of the SRS, with staff numbers peaking at 325 in 1998/99. The skills required to design, run and support the research at the SRS was vast, requiring world-class expertise in a range of technologies. This allowed SRS staff to transfer their expertise and knowledge to industry, universities and other research establishments. Over 100 staff from the SRS transferred to academia, industry or other synchrotrons around the world, transferring the knowledge and skills learnt at the SRS. The SRS also developed the skills of its scientific and industrial users; over 11,000 individual users used the SRS during its lifetime from over 25 countries. In addition it also played a big part in the studies of many students, 4,000 of which used the SRS as part of their degrees or doctorates, with 2,000 post-doctoral researchers using the SRS for their research. The supply of skilled graduates and researchers who are trained at large facilities such as the SRS and then transfer to industry or other public sector bodies is a key impact from research.

Direct local impacts

The final level of impacts from the SRS are direct, short term and tangible and occurred through the location of the facility in the North West of England – Stimulating the economy in the North West of England. There was increased economic activity in the North West through the creation of jobs and the construction and operation of the facility between 1975 and 2008. This represented a direct financial impact of £600 million, the majority of which was spent in the locality of the SRS. Due to multiplier effects, this initial investment increased to create an estimated total financial impact of nearly£1 billion to the North West.

The SRS also acted as a purchaser of goods and services in the local area and wider UK. Throughout its lifetime, the SRS has traded with over 300 local businesses. This purchase of goods or services from suppliers leads to a further chain reaction of purchases from their supply chain and also has indirect effects on employment, spend and taxation.

Future impacts

Finally, the SRS has facilitated several activities, which are creating impact for many years into the future – Shaping the future of science and innovation. The Daresbury Science and Innovation Campus was created to exploit the critical mass of expertise, facilities and industrial links that were created around SRS and the wider Daresbury Laboratory. In addition to the scientific facilities already on the site, the Campus has led to the establishment of a world class centre for accelerator science, the Cockcroft Institute and will further benefit from two other centres based on computational science and detectors systems in the near future. In addition, 100 high tech businesses from a wide range of commercial backgrounds are now located in the Campus's Daresbury Innovation Centre. Tenants come from sectors including biomedical, energy, environmental, advanced engineering and instrumentation industries. In 2008/2009, companies in the Innovation Centre delivered £14.9M in sales, secured £20.5M in investment and had an average growth turnover of 67%. Nearly half of all Campus companies have made significant use of the facilities, services and expertise at Daresbury Laboratory. 97 new jobs have been created in these tenant companies since they located onto the Campus with many companies expanding their businesses, recruiting more staff and looking to increase the size of their operations on Campus.

Academic impacts

During its lifetime, the SRS has collaborated with almost every country active in scientific research. The SRS produced beams of light so intense that they revealed the structure of atoms and molecules inside a wide range of different materials. Over the lifetime of the SRS, synchrotron light supported cutting-edge research in biology, chemistry, materials science and physics and opened up many new areas of research in fields such as medicine, earth sciences (including both geological and environmental studies) and archaeology. The SRS has contributed to the publication of over 5,000 papers and solved over 1,200 protein structures, which have been deposited in the worldwide Protein Data Bank database repository. The contribution to the global pool of research knowledge is another example of significant, yet unquantifiable impact of the facility.

The SRS was used by around 1,500 scientists per year to study the basic structure of matter. The award of Nobel Prizes in Chemistry (1997 and 2009) to two SRS users highlight the significant scientific output of the SRS.

E.9 Case study of UK DNA Banking Network, by Technopolis (2010)

E.9.1 Introduction

The case study of UK DNA Banking Network was written within an evaluation strategy for socio-economic impact assessment for the BBMRI. The study was undertaken by an external evaluator, Technopolis, and the work was commissioned by the BBMRI.

The report is available on Technopolis Group website.[60]

E.9.2 Overall methodology

This report represents one of 10 case studies constructed within the ex-ante socio-economic impact assessment of BBMRI. UK DNA Banking network was chosen as one of the likely future partners of BBMRI. The case study provides information on how the biobank has evolved and how it structured its collaborative strategy.

The case study is a descriptive account based on structured interviews with biobank directors, coordinators and user organisations. The primary collection data was complemented by a literature review and the final case studies provide a fine-grained analysis of the way different biobanks have evolved, and have structured their collaborative strategies.

E.9.3 Scope of the evaluation questions

Scope of research questions

The main question that the case study, in combination with the other nine, was trying to answer was to understand the diversity of biobank initiatives and the way in which their evolution is affected by specific contextual conditions. Knowledge of the diverse conditions under which biobanks have operated is important for defining indicators and understanding the extent to which proposed indicators are relevant and applicable to different types of biobanks and contexts.

Scope of the empirical research

Empirical research consisted of a series of interviews with biobank directors, coordinators and user organisations.

E.9.4 Data collections methods

The study team used structured interviews to collect the necessary information.

E.9.5 Data sources

The interviews were complemented by a documentary research. The documents were gathered from the UK DNA biobank network's website as well as from online journal search. An example of an article found through this route was The UK DNA banking network: a "fair access" biobank, (2009) Cell Tissue Bank.

E.9.6 Analytical techniques

The analytical techniques employed in this study were mainly consisting of interpretation of interview transcripts and secondary research. The collection methods as well as analytical techniques were driven by the structure of the case study under five headings: Background, Organisational structure, Funding, Outreach and Future.

E.9.7 Strengths and weaknesses

The main weakness of this study is its scale. As one of 10 case studies its depth was greatly affected and if the evaluator focused just on this one particular infrastructure, the findings could be more extensive and informative.

However as the main objective of the study was to perform find examples of how different biobanks evolved due to specific conditions, the case study fulfilled its task and provided some indications on how effective were the attributes of UDBN in its achievement of academic and societal impacts.

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[60] http://www.technopolis-group.com/resources/downloads/life_sciences/1093_BBMRIfinalreport_100921.pdf

E.9.8 Results

Academic impacts

The study presented the fact that UDBN has distributed over 60,000 DNA aliquots for 34 peer-reviewed studies, of which 16 were for Genome Wide Association (GWA) studies. Any bona fide collector in any jurisdiction may deposit appropriately consented materials in UDBN after signing a Material Transfer Agreement. Also, any bona fide researcher in any jurisdiction may receive materials from UDBN for a peer-reviewed ethically approved investigation after signing a Material Transfer Agreement.

Some of the disease collections were developed and included in the Wellcome Trust Case Control Consortium (WTCCC). The WTCCC has been very successful: their first Nature paper has been cited over 1,200 times in just two years. It was also awarded the journal "Science" Research Lead award for 2007. Subsequently, this consortium has published many papers. Without the UDBN biobank / network initiative these outcomes would not have readily occurred, indicating a great scientific impact and added value of the networking. Each of the individual collectors has a number of high impact publications as a result of the collections.

Societal or economic impacts

So far, the UDBN collections extended into the WTCCC have collectively identified a number of genetic factors relating to environmental findings. In hypertension 8 genes have been characterised; in diabetes type 1 already 13 genes and in coronary heart disease 14 genes, indicating that robust information was derived from the biobanking related studies. In diabetes type 1 they identified genes that predict which drug is most efficient. Still, the main impact of biobanks is still the scientific impact.

Benefits to private parties

- A small number of UDBN customers are SMEs who have accessed DNA samples in collaboration with collectors, after approval by specific disease committees
- A biobanking course has been designed and delivered to 50 students at the Astra Zeneca headquarters. AstraZeneca has contributed by hosting a day at their Manchester facility where issues connected with tissue banking were presented and discussed

Benefits to society

- The experience of UDBN has served as a major component of intensive courses in practical biobanking organised by CIGMR jointly with the NorthWest Genetic Knowledge Park (NowGen) and with AstraZeneca. Four courses have been held so far. They have attracted participants from across the EU and from North and Central America. Attendance has risen up to 60 people. The role of NowGen is to promote understanding of post-genomic science and the practical biobanking courses have therefore been significant deliverables for that organisation
- UDBN's Principal Investigators have contributed to biobanking courses and education in the UK (Wellcome Trust / P3G Summer School; UK Confederation of Cancer Biobanking conference), the EU (UK Embassy / Polish Research Ministry workshop) and elsewhere (Saudi Arabia; Japan)
- The media is used to convince people having a disease of the possibility and importance of giving a sample. The reason to use the media in this way is because in the UK the data protection act prohibits the direct approach of patients with a disease. One collector organised a bus tour through all regions and got 35,000 applications in 6 months, showing the scope for proactive approaches to sample collection. After the project was finished the general results were fed back to the patients. No specific (i.e. individual) actions were taken on the basis of the results

E.10 Economic and Social Impacts of TRIUMF, by MMK Consulting Inc. (2009)

E.10.1 Introduction

This report presents an evaluation of the economic and social impacts of TRIUMF, Canada's National Laboratory for Particle and Nuclear Physics, which was carried out by MMK Consulting. The report is available on TRIUMF's web site.[61]

The study was completed in 2009 and looked at the socio-economic impacts of the facility as an input to a decision about a proposed facility expansion. No indication was given in the report as to the scale of this exercise, apart from the fact that the authors stated that the timeframe for this assessment was short.

E.10.2 Overall methodology

The methodology was designed to estimate the direct, indirect, and induced economic impacts generated by TRIUMF on the economy of the province of British Columbia (BC) in Canada. This is less than the total economic impact of TRIUMF's operations, due to the fact that approximately 20% of TRIUMF's expenditures were purchased from suppliers outside of British Columbia, and therefore did not generate economic impacts within British Columbia.

Furthermore, the study estimated the impacts of TRIUMF with and without the facility expansion. The report compared these two scenarios of expansion and no expansion in order to estimate whether TRIUMF is forecasted to have a strong net positive economic impact on British Columbia – generating increases in economic activity. In order to come to this assess this impact, the authors undertook the initial assessment, and used economic multipliers published by British Columbia Stats as derived from the British Columbia Provincial Input-Output Model (BCIOM). The British Columbia Provincial Economic Multipliers distinguish between different economic impacts for different types of industries and economic activities. Given the diverse nature of TRIUMF's activities, weighted average multipliers for TRIUMF based on the actual activities of TRIUMF were constructed.

In summary, the economic impact methodology used for this analysis:

- Does not include the economic impacts from spending the $60.7 million (£40m) sought from the Province of BC for construction of new facilities at TRIUMF
- Assumes no social safety net, as workers are primarily from out-of-province
- Considers direct, indirect, and induced economic impacts

E.10.3 Scope of the evaluation

Scope of research questions

TRIUMF was seeking $60.7 million (£40m) in Provincial government funding to support three proposed facility expansions.

- In order to continue and advance its research in these three fields, TRIUMF proposed three capital projects for development over the next three to five years:
- Nuclear medicine centre, to provide dedicated lab space and a shielded cyclotron vault to further develop new potential opportunities in the fast-growing field of nuclear medicine. The cost for this 8,100 square foot facility was estimated at $17.5 million (£11.6m)
- Tier 1 data centre, to house 8,000,000 gigabytes of data storage capacity. The cost for this 18,000 square foot facility was estimated at $12.5 million (£8.3)
- Advanced Rare IsotopE Laboratory (ARIEL), to provide for the construction of a new underground beam tunnel and potential new linear accelerator facility (subject to federal funding) that will allow TRIUMF to better capitalize on existing investments in research capabilities, and broaden its research capabilities in material science and particle physics. The cost for this 24,450 square foot facility (and related underground tunnel infrastructure) is estimated at $30.7 million (£20m)

[61] http://www.triumf.ca/

This report assessed the expected economic impacts of TRIUMF's ongoing operations both with and without the proposed facility expansion; to determine the net incremental economic impacts if the proposed facility expansions proceeded. This report also examined the broader socio-economic impacts that TRIUMF generates within British Columbia.

Scope of the empirical research

The scope of empirical research was limited to interviews with TRIUMF's management.

E.10.4 Data collections methods

Data collection methods used during this study included interviews with TRIUF management, liaison with British Columbia Stats and the department that disposed of the actual data on direct output, payroll, employees and taxes paid for TRIUMF's existing operations.

E.10.5 Data sources

The economic impacts generated by TRIUMF were estimated based upon the following sources of information:

- The actual operation of the TRIUMF facility itself
- The operation of related MDS Nordion facility
- Conferences and visiting researchers hosted by TRIUMF on a frequent basis

Information was extracted and based on these three primary sources.

E.10.6 Analytical techniques

Within this framework of direct, indirect, and induced economic impacts, a number of statistical considerations were used to analyse economic impacts.

Opportunity cost analysis, which assumes that certain expenditures, if not invested in a given project, would be used in some other (non-specific) expenditure, which would also give rise to economic impacts.

Social safety net assumptions impacted the magnitude of calculated economic impacts, particularly with respect to government tax revenues. Given the highly specialized work undertaken at TRIUMF, and that about 40% of TRIUMF's scientific staff are from outside of Canada (with many more coming from other provinces within Canada), MKK consulting applied a model that assumed no social safety net.

The closed model was used to induce economic impacts related to employee spending, and is relevant when jobs created are new to the province, attract new workers, and therefore increase the overall level of personal spending within the province.

E.10.7 Strengths and weaknesses

One of the strengths of this approach is that the British Columbia Provincial Economic Multipliers and BCIOM distinguish between different economic impacts for different types of industries and economic activities. This allowed construction of weighted average multipliers for TRIUMF based on the actual activities of TRIUMF.

The study considered direct, indirect and induced economic impacts but adopted some strong assumptions such as the fact that no social safety net would be needed as workers are primarily from out-of-province. The results presented were subject to these significant limitations:

- Estimates of future levels of TRIUMF funding and activity were provided by TRIUMF management based on their experience and expertise in past dealings with the National Research Council. Therefore MMK Consulting cannot verify the accuracy of these estimates;
- Due to the short timeframe required by TRIUMF for completion of this initial assessment, economic multipliers published by British Columbia Stats as derived from the British Columbia Provincial Input-Output Model (BCIOM) were used instead of running actual TRIUMF data through the BCIOM itself. This latter approach would result in some refinement of the estimates presented in the report, but did not result in dramatically different estimates.

E.10.8 Results

The study report concluded with the following results:

Economic Impacts:

Assuming that the proposed facility expansion proceeds ($60.7 million (£40.1m) from the Provincial government) inclusive of direct, indirect and induced impacts, it has been estimated that TRIUMF will generate $912 million (£603m) in provincial output, $511 million (£338m) in provincial GDP, $50 million (£33m) in provincial tax revenues, and 1,284 FTE jobs over the proceeding five years. These impacts were in addition to construction jobs that will theoretically be created by the facility expansion project. It is estimated that 179 person-years of construction employment will be created between 2009 and 2012, with 71 FTEs having been created by 2010. The study suggested that this one-time investment of $60.7 million (£40.1m) is expected to result in:

- A net increase of $125 million (£82.6m) in federal/NRC funding for TRIUMF from 2010 to 2014, from $203 to $328 million (£134 to £217m)
- A net increase in total provincial GDP $156.5 million (£103m) over five years
- A net increase in total provincial employment of 373 FTE jobs
- And a net increase in Provincial tax revenues of $15.5 (£10.3m) million from 2009 – 2014

However, in the longer term the report concluded that a failure to re-invest in TRIUMF's facilities and infrastructure could lead to the closure of the facility, due to it falling behind the pace of world-leading research. This closure could result in the loss of more than 1,000 existing jobs in British Columbia and more than $78 million (£51.5m) in existing annual Provincial GDP.

Socio-economic Impacts:
In addition to these pure economic impacts, TRIUMF also generated a range of broader socio-economic impacts that could not be so readily quantified. In particular:

- TRIUMF represents the heart of a growing advanced technology cluster in British Columbia focused on nuclear medicine and particle accelerator technology. TRIUMF's existence directly supports private industry in BRITISH COLUMBIA (e.g., MDS Nordion, Advanced Cyclotron Systems, PAVAC Industries, and D-Pace) as well as not-for-profit agencies and organizations (e.g., BRITISH COLUMBIA Cancer Agency and Advanced Applied Physics Solutions, Inc.)
- TRIUMF leads Canada's role in global "big science" collaborations (e.g., CERN Large Hadron Collider, T2K, CSUNS) that are seeking answers to questions of fundamental physics such as the cause of the big bang, the dominance of matter over anti-matter in the universe, and the existence of parallel dimensions of time and space. TRIUMF's leadership role in these collaborations keeps BRITISH COLUMBIA scientists at the forefront of global science, attracts highly qualified personnel to BRITISH COLUMBIA to live and work, and provides opportunities for domestic firms to participate in the supply of equipment and apparatus required by these global projects
- TRIUMF research projects include applied research into technologies that have the potential to be of significant practical benefit to British Columbia, Canada, and Canadian industry. These projects include applications in healthcare (e.g., treatment of diseases including Parkinson's, diabetes, Alzheimer's, and various cancers), the environment (e.g., reductions in CO_2 and other pollutants), natural resources (e.g., improved efficiency in papermaking and improved interpretation of geological data), and industry (e.g., aerospace systems and electronics design)

These benefits accentuated the importance of TRIUMF in maintaining and enhancing the competitiveness of the British Columbia economy in this technology-driven era. Relative to the benefits produced, the investment required to keep TRIUMF on the leading edge of global particle and nuclear physics appeared from the findings of the report to be relatively modest.

E.11 Impacts of Large-Scale Research Facilities – A Socio-Economic Analysis, by Olof Hallonsten et al. (2004)

E.11.1 Introduction

This study attempts to estimate the likely future socio-economic effects of the anticipated decision to construct the new European Spallation Source (ESS) in southern Sweden, based on the experience of other existing large scale research facilities. The ex ante impact assessment was conducted by researchers at the Research Policy Institute, at Lund University and published in 2004. The final report is publicly available at RIFI project website.[62]

E.11.2 Overall methodology

This report has been compiled mainly from an investigation made through interviews and the study of written material on the occurrence of large research facilities in certain contexts of the local, regional, national and international community.

The authors chose to follow a different methodological course of action by presenting and analysing their findings aside different perspectives and presenting them by inquiries of relations. The relations they refer to are the relations between a facility in action and its organization, administration and research groups and different forces or interests in society on a local level as well as regional or national.

E.11.3 Scope of the evaluation questions

Scope of research questions

This study aimed to analyse the preconditions for and effects of the location of a new Large Research Facility on the host country, in this case the European Spallation Source (ESS) and the Oresund region of Sweden and Denmark.

When looking at the impacts on a city, region or nation of hosting an international large research facility, the report stressed the idea that all presumable impacts are inseparable and presented their outcomes connected to each other. The study attempts to direct its research questions to the broad socio-economic effects of hosting a large research facility, including considerations related to economic, innovation and agglomeration effects.

Scope of the empirical research

The empirical research focuses on the analysis of the interactions of relations between a facility in action and its organisation, administration and research groups, and different forces and interests in society, on a local level as well as regional and national. The study looks at the relations emerging from the facility, taking into consideration a different range of dual-way impacts, both positive and negative effects. The empirical research includes the analysis of relations of the facility with industry, regional actors (in terms of employment and other business activity), environmental relations as well as relations with the general public, the local government, the communications infrastructure and the academic community (universities and other research organizations).

E.11.4 Data collection methods

- Visits to five research facilities – FRM II, ESRF, CERN, ILL and EMBL. Interviews were conducted to members of staff and background reports were obtained
- Interviews to relevant authorities of strategic planning in Sweden – relevant data and information related to the ESS
- Desk-research – secondary data was collected mainly through literature review of existing reports

E.11.5 Data sources

- Five research facilities – FRM II, ESRF, CERN, ILL and EMBL

[62] http://www.rifi-project.eu/wp-content/uploads/public_doc_REPORT_impact_of_large_scale_RI.pdf

- Authorities of strategic planning in Sweden
- Existing reports and literature

E.11.6 Analytical techniques

The analysis of relationships is broadly descriptive and relies on the validation of certain observations and statement with the qualitative information obtained from the interviews. Therefore, the analysis is mainly qualitative as it directly uses statements made by interviewees that are pertinent to describe a specific relation.

E.11.7 Strengths and weaknesses

Site visits and in depth interviews provide valuable qualitative data that allow the identification of key areas of impact of large research facilities. The study also does not isolate economic impacts from other socio-economic effects providing a more integrated perspective of the potential range of impacts that a facility may bring. Additionally the study also considers the negative impacts of large research facilities (for instance environmental), which are usually out of the scope in other evaluations. Finally, it makes valuable considerations regarding local economic effects, including agglomeration.

In terms of limitations, the report does not provide results that are comparable with other studies and does not attempt to quantify or measure in a more precise manner the relations identified.

E.11.8 Results

The study concluded that scientific facilities ought to be placed in already functional technological localities, as the authors found that cooperation with universities, involvement of the industry and healthy relations of facilities with their local community were the three main conditions necessary for experiencing positive impacts.

In the perspective of the ESS (European Spallation Source) being located in Lund and the Oresund Region, the study predicted a strengthening of an already prosperous and competitive knowledge based cluster. However, they found that a non-commitment to ESS, in a long-term perspective, would probably result in this existing competitive knowledge-based cluster losing its possibilities to develop into one of the leading areas of innovation and science in the fields related to the ESS. Thus they concluded that investment in the region, with ESS as a new node in the existing cluster, as a natural centre of competence, knowledge and innovation capacity, would make the Oresund Region, as well as Scandinavia as a whole, a highly competitive region in many areas of knowledge, science and technology.

E.12 Study on Economic Impacts of the Establishment of a New Supernode in the Netherlands by Ecorys (2009)

E.12.1 Introduction

This is a report of an ex-ante impact assessment of a new supernode in the Netherlands. The study was undertaken by a European research and consultancy company, Ecorys ,which specialises in economic studies. It was commissioned by the Ministry of Science, Education, and Culture (OCW) and Ministry of Economic Affairs. The aim of the study was to make an inventory of the economic impacts of the proposed establishment of a new supernode in the Netherlands.

The Ministry of OCW is responsible for the coordination of science policy while the Ministry of Economic Affairs is responsible for ICT infrastructure in general. Both of these ministries have decision-making power in relation to investment in a new supercomputer. The study performed by Ecorys was one of the inputs for the decision making process.

This study was undertaken in the context of Dutch efforts to establish a Principal Partnership of PRACE (the Partnership for Advanced Computing in Europe). If the Netherlands becomes a Principal Partner, one of the five supernodes in Europe will be in the Netherlands.

The final report, in Dutch, is available from the central access point for all information about government organisations in the Netherlands.[63]

E.12.2 Overall methodology

The approach of the evaluation team was a combination of descriptive case studies and an economic impact analysis.

The first stage of the study was a desk research of all relevant documents, such as policy papers, studies on the relevance of High Performance Computing in the Netherlands, international impact studies, etc. concerning the establishment of the supernode in the Netherlands. Analysis of these documents was followed by a number of interviews with representatives of ICTRegie (coordination body for ICT research and innovation), SARA (the current supercomputing centre) and the Ministries of OCW and Ministry of Economic Affairs.

These initial desk research and interviews resulted in the selection of three case studies:

- The Supercomputing Centre in Barcelona (Spain);
- The Swiss Scientific Computing Centre in Lugano (Switzerland);
- The Julich Research centre (ForschungsZentrum Julich) (Germany).

In the literature these centres were highlighted as examples of positive economic impacts. The revolved around the following four headings:

- The history of the project
- The scientific effects and impact on innovation
- The economic impact of the supernodes
- The amount of public and private investments

The results of the case studies were discussed in an expert group meeting. Central theme in the meeting was the expected economic impact of a new supernode in the Netherlands. The insights from the case studies were used to explore the potential impacts.

Quantification of the economic impacts of a new supernode was attempted where possible.

E.12.3 Scope of the evaluation

The study focused on the economic impact of the establishment of a new supernode in the Netherlands. The focus was solely on economic impacts – i.e. other societal effects were omitted. Economic impact was operationalised in one single indicator – employment in FTE

63 https://zoek.officielebekendmakingen.nl/blg-48238.pdf

or Labour years. Other common indicators, such as turnover or patents, were not considered by the study team.

In order to arrive at a more meaningful analysis, Ecorys benchmarked three similar research infrastructures: one in Spain, one in Switzerland and one in Germany. These benchmark studies were instrumental to the analysis of the expected impact in the Netherlands.

E.12.4 Data collections methods

The desk research and interviews with representatives of ICTRegie (coordination body for ICT research and innovation), SARA (the current supercomputing centre) and the Ministries of OCW and Ministry of Economic Affairs.

The study predominantly focused on collection of qualitative indicators (desk research, interviews, expert meeting). The quantitative elements were limited to input figures of estimated investment of € 45 million and the formulation of multiplier effect based on the three case studies (1,19 for indirect employment in R&D).

E.12.5 Data sources

For the study Ecorys used the following data sources:

- Relevant documents about the supernode in the Netherlands
- Case studies: documents and interviews
- Interviews
- Expert meeting

E.12.6 Analytical techniques

For the analysis of the economic impact Ecorys has defined the following categories of impacts: Temporary and structural effects, direct and indirect effects and gross and net effects. Their definitions are described below.

Temporary and structural effect

Temporary effects are effects that occur during the preparation and development (construction) of a major facility like a supernode. Longer-term, structural effects occur after commissioning of the supercomputer and are expected to have the greatest impact on the Dutch economy.

Direct and indirect effects

Direct effects involve all activities that are directly linked to the project. Indirect effects are derivative: they are not directly linked to the supernode, e.g. economic effects occurring in other sectors that benefit from the new business and new activities at the supernode.

Gross and net effects

The gross effects do not take into account contextual factors. In this context they exclude the possible displacement of competing companies, the relocation of activities within the Netherlands and do not address the extent of substitution effects (impact that has a negative impact of others outside the intervention). The net effects do take into account these factors and encompass the real additional effect on Dutch economy.

E.12.7 Strengths and weaknesses

The strength of the study is that it presents a rather straightforward conceptual model for the economic impact assessment. It focuses on the employment effects and uses an analytical framework with six dimensions. The impact analysis takes into account contextual factors (distinction between gross and net effects).

The downside of the approach is that Ecorys was not able to quantify most of the impacts. Especially the more indirect effects are described in rather general terms without any quantification. In the report Ecorys acknowledges that they do not have a reliable method to quantify these effects. The study also presents a multiplier for R&D, but the ground for the calculation of this multiplier is not clearly described (i.e. the report does not explain how the multiplier was established).

Overall the report presents a good economic impact assessment based on employment creation, but does not contain a more in-depth analysis of mechanisms and effects that might occur if a new supernode is established.

E.12.8 Results

The figure below shows in short the results of the study. Further explanation is provided below the table.

Figure 22 - Overviews effects new supernode in the Netherlands

Effect	Direct Employment		Indirect employment	
	Gross	Net	Gross	Net
Temporary effects				
- Development housing supernode	120 – 300 labour years	120 – 300 labour years	110 – 180 labour years	110 – 180 labour years
- Development supernode	Mainly outside NL	Mainly outside NL	Outside NL	Outside NL
Structural effects				
- Personnel supernode	100 – 150 FTE	40 – 90 FTE	20 – 35 FTE	10 – 25 FTE
- (In)direct users supernode	2000 – 4000 FTE	0 – 1000 FTE	40 – 160 FTE	0 – 40 FTE
- Supercomputer as a factor for business location	++	+	++	+
Other effects				
- Spinoffs	+	+	+	+
- Market applications	++	++	++	++
- Level of education	++	++	++	++
- Regional effects	+	+	+	+

Source: Ecorys

Temporary effects

Temporary effects relate to job creation as a result of the development and construction of the supernode itself. The magnitude of these effects depends to a large extent on the choice of the location. When a totally new building has to be developed, this creates temporary employment in the construction sector. This involves 120-300 working years, depending on the specifications of the building. The required investment is estimated at €45 million (£39m). This kind of investment will result in 270 direct labour years. Furthermore, there will be a cascade effect on the suppliers of the construction companies. This will result in 110 - 180 person-years of employment. The estimated investment of €45 million will hence result in approximately 250 person-years of employment.

Employment that occurs as a result of the development of the supernode itself (the hardware) will probably not occur in the Netherlands. The reason for this is that in the area of high performance computing there are only a few companies suitable for the job, none of which are Dutch: IBM, Cray, Hewlitt-Packard, and SGI Bull. The assignment for the supernode will be given to one of these (foreign) companies. Therefore the temporary effect as a result of the installation of the supercomputer in terms of employment in the Netherlands were expected to be very limited.

Structural effects

Structural effects relate mainly to the employment of staff of the computer centre. Based on the three case studies, this is estimated to be 100 to 150 FTEs. The current data centre contains about 60 FTEs directly related to the supercomputer. The net employment effect is therefore estimated between 40-90 FTE. The maintenance and the supply of energy, water etc. includes approximately 20-35 FTEs. The net employment effect will be 10 to 25 FTEs. The use of the supercomputer will also create employment.

About 400 to 800 scientists (from outside the computer centre) will be using the supernode in their research. Since these scientists usually work in teams of 5, there are between 2,000 and

4,000 scientists depending (directly) on the supernode. Currently about 600 scientists are using the supercomputer. The net effect would be therefore around 200 scientists. The net effect stemming from the indirect use adds up to 800 FTEs. The scientists are using very specific software for analysing the results of the use of the supernode. This specific software has to be developed, either by people form the supernode or by (external) companies. The employment effect of the software development is 40 to 160 FTE. The net effect would be a maximum 40 FTE.

Structural effects also occur from companies and organisations who establish themselves near the supernode. Proximity to the supernode is a decisive element for the choice of the location for certain companies. Therefore agglomeration effects are expected to occur. In general European investment in supercomputing and ICT companies will be concentrated in countries with the fastest supercomputers and the best ICT infrastructure. The employment resulting from these agglomeration effects is difficult to quantify.

Other effects

Finally, the study identified a number of other effects. This involves in the first place spin-offs. The work on supernode is like to generate knowledge-based companies, including start-ups and SMEs that develop technology into (possibly) market applications. The extent, to which this effect occurs, depends on the way the supernode is used and the intensity of the cooperation between universities, industry and government (Triple Helix). Intensive cooperation aiming at the creation of market applications is thought to increase the number of spin-offs.

The market applications of research breakthroughs create another important economic effect. The strategic research themes, which are generally facilitated by supercomputers make it likely that these kinds of effects occur. It is however very difficult to calculate the magnitude of this effect. One of the other main effects, which the case studies have pointed out, is the strategic importance of a supercomputer for the training of personnel for knowledge institutions and companies. On average, computer centres renew their supernode every five years. Research institutes continue to use the 'old' supercomputers for lower prices. Five years later the supercomputer may be widely used by industry. The staff of the computer centre are highly skilled people and of great value for research based companies and institutes. Often these people are hired by research institutes or industry. All of the above developments in the supernode's life cycle are the result of public investment in ICT.

A final effect arises as a result of expenditures made in the regional economy. This might include for example spending of the staff of the supercomputer or visitors in the local retail or caterings services. The study did not calculate the effects of this sort.

Conclusion

Set against the investment required, the impression might be that the employment effects of the possible establishment of a supernode are rather small. In the economic impact analysis only part of the effects are quantified. However, the unquantifiable effects appear to be important for the (economic) development of a country. The investment in a supernode could lead to competitive advantages of the industry. Furthermore, the supernode is thought to give an impulse to the enhancement of competences of people. The study concluded that if the Netherlands decided not to invest in a supernode, the current cycle of enhancement would be interrupted. This would in turn have a negative impact on Human Capital. Specific competences and highly skilled people would disappear as a result. In general supercomputers contribute to research of strategic importance and state of the art research infrastructure. Finally, the choice of the location for the supernode will be of crucial importance for the magnitude of the described effects. The most logical choice was thought to be Amsterdam. The new supernode could then reinforce the IT cluster around SARA (the current supercomputer centre) and stimulate different kind of economic effects.

Appendix F Analytical overview of methodologies used in key reports

Report	Type of analysis	Analytical framework	Data collection	Data analysis	Quantitative	Qualitative	Main findings
How Large Scale Research Facilities Connect to Global Research, (2012), Lauto, G & Valentin	Ex-post Bibliometric analysis	Global collaborative research networks	Bibliometric records from ISI-Web of Science	Econometric – regression analysis	Research publications	Not performed	LSRFs are powerful hubs in the creation of research networks. Scientists employed at the facility drive a substantial part of the collaborations in this network
Economic Impact Evaluation of the Economic and Social Data Service (2012), Charles Beagrie Ltd and The Centre for Strategic Economic Studies (CSES) University of Victoria	Ex-post Economic analysis	Keeping Research Data Safe (KRDS) Benefits Framework	Desk research Interviews (25) Two online surveys of EDSD registered users and depositors	Contingent valuation method Partial Counterfactual analysis	Investment value Use value Consumer surplus Net economic value Efficiency gains Return on Investment ratio	Three impact case studies in policy areas such as climate control, knife crime and obesity	Investment value: £23 m per annum Use value: £24 m per annum Willingness to pay: £25m Willingness to accept: £111m Consumer surplus: £21m Return on Investment: 5.4 to 1
Economic Impact of the Human Genome Project (2011), Battelle Technology Partnership practice	Ex-post Economic analysis	Backwards linkage effects (expenditure impacts) and Forwards linkage effects (functional impacts) associated with the Human Genome	Interviews Experts inputs Historical R&D data using NIH and DOE databases Historical employment data using the National Establishment Time-Series	Input/Output analysis IMPLAN model has built in economic inflators and deflators to allow for cumulative multi-year estimation Genomic enabled industry database built using IMPLAN	Direct, indirect and Induced impacts on employment (job years), personal income, output, local tax revenue, and federal tax revenue Impact multiplier	Case studies of functional impacts in six fields of application (Human Health, Veterinary Medicine, Agriculture and Food, Industrial Biotech, Environment, and Forensics, Justice and Security).	Economic (output) impact of $796 billion, personal income exceeding $244 billion, and 3.8 million job years of employment Genomics enabled industry generated $3.7 billion in federal taxes and $2.3 million in US state and local taxes Return on investment (ROI) to the U.S. economy of 141 to 1 Functional impacts visible

Report	Type of analysis	Analytical framework	Data collection	Data analysis	Quantitative	Qualitative	Main findings
							in the development of genomics tools, technologies and techniques Wider Social impacts are still emerging
Data centres: their use, value and impact (2011), Technopolis	Ex-post Value analysis Usage analysis	Not specified	Interviews with research funders Online survey of users Interviews with experts	Descriptive analysis of trends and users opinions	Trends on data users ad usage Research efficiency Research quality Research novelty	Case studies on research efficiency, research quality and research novelty Case studies on wider impact on new tools and methodologies, new policies and products and services	Considerable benefits to do with research efficiency and research quality Lesser benefits regarding research novelty
Benefits of Research Infrastructures beyond science: the example of the Square Kilometre Array (2010), COST	Ex-ante Descriptive socio-economic analysis	Not specified	Experts views (workshop)	Descriptive analysis of experts views	Various ad-hoc indicators on markets, technologies and skills	Compilation of experts views of SKA impacts on ICTs, sensor technology and real monitoring, wireless communications, renewable energy and human capital	SKA is likely to generate a wide range of benefits in a number of adjacent industries and technologies
New Light on Science: the social and economic impact of the Daresbury Synchrotron Radiation Source (1981-2008), (2010), STFC	Ex-post Socio-economic analysis	Economic Impact Reporting Framework (EIRF)	Surveys Interviews	Economic analysis: Input/output analysis Wider impacts: Descriptive analysis of quantitative and qualitative data	Financial impact: Direct impact: employment and expenditure Indirect "supply chain" impact: employment, spend and taxation Induced: employment, spend of those employed directly and indirectly by SRS Ad-hoc metrics and indicators on market, technology, users, and	Direct impacts Case studies on research collaborations Case studies on user-led technological innovations and spin-outs Indirect impacts Skills formation and training Description of agglomeration effects	Total financial economic impact of SRS £992M SRS has developed skills via users, training programmes and staff transfers SRS has inspired young people to take up science SRS has improved the performance of the UK industry, created new companies and stimulated the economy of the North West

Report	Type of analysis	Analytical framework	Data collection	Data analysis	Quantitative	Qualitative	Main findings
					skills trends		Clustering benefits via the Daresbury Science and Innovation Campus
E-ELT Impact - The Impact of the European Extremely Large Telescope (2010), STFC	Ex-ante Socio-Economic analysis	Economic Impact Reporting Framework (EIRF)	Use of existing market studies, surveys, and data on contractual agreements by E-ELT	Descriptive analysis of quantitative and qualitative data	Ad-hoc metrics and indicators on markets, technologies and trends in astronomy	Brief case studies on spin-offs Brief case studies on prospective technology developments (user-led innovation)	E-ELT will have direct economic benefits through the development of new technology. And direct benefits to industry by way of contracts of hundreds of millions of Euros
Berkeley Lab Economic Impact Study (2010), CBRE Consulting	Ex-post Economic analysis	Not specified	Not specified	Economic analysis: Input/output analysis	Direct, indirect and induced impacts of (1) local and regional spending and (2) employment and payroll, (3) and spin-off companies (based on database of spin-off companies) Multipliers for spending employment and income Economic impacts by geographical area (local, regional and national)	Not used	In 2009, the Lab contributed $501M directly to the local economy Including indirect and induced spending, the contribution rises to $690M The Lab's gross economic impact on the U.S. economy was estimated to be nearly $1.6 billion. Every 1.0 direct, full-time-equivalent employee of Berkeley Lab contributes to another 3.3 jobs in the US Since 1990, Berkeley Lab technologies have formed the basis for 30 startups, creating 2,393 jobs
BAe 146 Review (2010), BAe146 Review Group	Ex-post Advisory Group Assessment	Not specified	Experts from the assessment team	Critical review of BAe 146 research achievements and contribution to "national good"	Ad-hoc figures for scientific publications and collaborations with the wider research community (knowledge	Description of BAe 146 role in the development of new instruments and technologies	BAe 146 contributes to the UK wellbeing through the functional applications of research outputs and increasing the Met Office

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					spillovers)	Brief case studies on functional impacts of research activity (e.g. climate change, natural hazards, etc)	capability to predict and manage events.
Lasers in our lives – 50 years of impact (2010), STFC	Ex-post Broad impact assessment	Not specified	Not specified (presumably experts inputs)	Highlights of 50 years of laser technology achievements	Not used Two ad-hoc figures of patents and value of laser market	Highlights of functional application of laser technologies in the fields of: () measuring and analysis, (2) defence and national security, (3) Medicine and health (4) energy (5) comms, (6) environment and climate (7) Uses by the manufacturing sector	Laser technologies have a broad range of impacts that affect our everyday lives.
STFC Impact Report 2011 (2012), STFC	Ex-post Socio-economic analysis	Economic Impact Reporting Framework (EIRF)	Not specified (presumably data from STFC centres)	Descriptive analysis of quantitative and qualitative data	Ad-hoc metrics and indicators on markets, technologies, research and skills and use by industry in line with the impact areas of EIRF	Brief case studies on contributions to climate change, specific discoveries and technologies (e.g. MRI), spinoff companies and public engagement programmes	STFC main impact function are: (1) research, (2) innovation and (3) skills Programmes are delivered in collaboration with key stakeholders including other Research Councils, HEIs, industry and public sector organisations Outcomes delivered through multiple routes; from the development of novel medical detectors and vaccines for viruses, to working with industry to deliver more competitive mobile telephone components
Economic effects of the Supernode in the	Ex-ante Economic impact analysis	Analytical framework with six dimensions:	Relevant documents about the supernode in	Descriptive analysis of quantitative and	Employment in FTE or Labour years.	Three case studies on similar facilities in Europe	**Temporary effects:** Direct employment 120-

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Netherlands (2009), Ecorys		Temporary and structural effects, direct and indirect effects and gross and net effects	the Netherlands Case studies: documents and interviews Interviews Expert meeting	qualitative data Quantification of the economic impacts of a new supernode was attempted where possible	Other economic indicators, such as turnover, patents were not considered		300 labour years, indirect employment 110-180 labour years **Structural effects:** Personnel of supernode: Direct Net 40-90 FTE, Direct gross 100-150 FTE, Indirect Net 10-25 FTE, Indirect Gross 20-35 FTE Users of supernode: Direct Net 0-1000 FTE Direct Gross 2-4000 FTE Indirect Net 0-40FTE Indirect Gross 40-160FTE
The ESS in Lund - its effects on regional development (2009), Lindström, C.et al,	Ex-ante Economic and social analyses	Regional vision building based on the region's present position and assets	Questionnaire, interviews and seminars Desk research: general background material, earlier analyses, experiences from other facilities	Quantitative analysis (Scenario building analysis – comparison of base scenario vs scenario with ESS) Qualitative analysis (Analysis of megatrends based on the experiences from other international facilities)	Costs (construction and operations) of the facility Regional growth and employment effects Estimations of impact indicators (prices, employment, income, etc) on various sectors (property market, communications, energy, R&D, public services)	Megatrends (globalisation, competition, urbanisation, migrations, etc) Strengths, opportunities, Weaknesses and Problems. Strategic driving forces Cooperation and interactions of stakeholders Risks and sector analysis	Direct economic regional effects of ESS are likely to be significant (GRP (Gross Regional Product in the region of 0.08 per cent per year on average and an average increase in employment of about 700 jobs per year in Skåne up to 2040) Long-term indirect effect is decisive and the greatest Very significant effects on the property market, infrastructure, R&D and public services) Importance of the engagement and interaction of key players
Economic and Social Impacts of TRIUMF	Ex-post Economic analysis	Not specified	Data provided by the facility management	Economic analysis: Input/output analysis	Economic impacts from existing operations and related activities – direct,	Brief description of technology cluster	Inclusive of direct, indirect and induced impacts, it is estimated

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(2009), MK Consulting	Ex-ante economic analysis of potential expansion of the facility		Multipliers from public statistics	Scenario building (with expansion, without renovation)	indirect and induced impacts on output, GD, employment and provincial output Estimated economic impacts attributable to future operations under alternate scenarios – direct, indirect and induced impacts	Brief description of international "big science" research collaborations Description of functional applications of TRIUMF's technologies (healthcare, environment, natural resources, etc)	that TRIUMF will generate $912 million in provincial output, $511 million in provincial GDP, $50 million in provincial tax revenues, and 1,284 FTE jobs in the short run (5 years). It is estimated that 179 person-years of construction employment will be created between 2009 and 2012, with 71 FTEs being created by 2010.
Case Study on the Economic Impact of Biobanks Illustrated by EuroCryo Saar (2009), Fraunhofer	Ex-post Evaluation of economic impact	Not specified	Not specified	Case study	Budget and investment Number of employees Publications and patents	Connection of the biobank to industry and the related R&D groups Description of spinoffs	The evaluation of a biobank has to be seen in combination with the research done in cooperation with this biobank The economic impact of the biobank is seen in a rising number of employees in the biobank and the connected R&D groups as well as in the three spinoffs raised from the research done.
Economic impact of the John Innes Centre (2009), DTZ	Ex-post Economic impact	Operating impact, final market impacts and wider qualitative benefits	Not specified	Economic analysis: Input/output analysis Market analysis	Direct, indirect and induced impact on output, employment, income and GVA Market value (commodity prices) Value of proxy indicators associated with the outputs of research – new	Not used	Total impact on output £83.4 Total impact on employment = 950 FTE Total impact on income = £30.1 Total impact on GVA £42.4

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					sales, avoidance of wastage, or sustaining activities that would otherwise diminish. Non-economic indicators: Publications, Number of scientific staff		Substantial financial market impacts on Cereal Crops, other crops, antibiotics and other cross cutting impacts.
Review of economic impacts relating to the location of large-scale science facilities in the UK (2008), SQW	Ex-post Economic impact analysis	Not specified	Literature review Consultations at five facilities (data on employment, expenditures, etc) Interviews to staff of facilities, industrial and academic users, and suppliers	Descriptive analysis of quantitative and qualitative data Counterfactual – benefits (and costs) incurred by the UK from a UK location as opposed to UK access to a LSSF located elsewhere	Direct impact on employment, purchases (high-tech contracts) Direct commercial benefits to suppliers Industrial usage of the facilities	Suppliers' perspectives on benefits of having the facility based in the UK Technological benefits Marketing benefits Academic users' perspectives on benefits of having the facility based in the UK Comparison with alternative options Benefits of proximity Strategic benefits Industrial users' perspectives on benefits of having the facility based in the UK	The major economic impacts arise from: Employment of relatively highly paid staff, most of whom reside close to the facility Awarding of contracts to UK-based suppliers Contributing to local technology clusters Transferring knowledge and technologies to their suppliers Attracting significant additional international direct investment
Mutually benefiting joint innovation process between industry and big-science (2006), Vuola, O. & A.-P. Hameri, A.-P	Ex-post Study of innovation impact on various stakeholders	The article develops an innovation process model for new technology based CERN-company cooperation	Combination of an in-depth case study method, participative experimentation and retrospective interviews	Test of the model constructed through longitudinal analysis of nine in-depth case studies	Not used	Financial, organisational, technological and social outcomes of collaboration for key stakeholders involved in big-science research including: Research organisations, Member states and Industry	There is a wide range of innovation outcomes that emerge from big-science collaboration with different stakeholders-especially collaboration with industry should be pursued.
CERN technology transfer to industry and society	Ex-post Technology transfer	Knowledge creation model (scientific process,	CERN TT database	Descriptive analysis of quantitative and	Number of publications Number of fellows,	Domains of transfer: Application of CERN	CERN's proactive TT policy introduced in 2000

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(2005), CERN	impact	knowledge process, technological process)		qualitative data	unpaid associates, apprentices and students	technologies to scientific disciplines (ICTs, medicine, energy and environment) 5 Case studies on Innovation process in industry due to the use of CERN's technologies 56 Examples of technology transfers from CERN's experiments (spinoffs)	to identify, protect, promote, transfer and disseminate its innovative technologies in the European scientific and industrial environment have yield successful innovations and spinoffs in a range of technological fields.
ESTEC's value to the Netherlands (2005), Triarii	Ex-post Knowledge value and economic value analysis	Not specified	Desk study and interviews	Descriptive analysis of quantitative and qualitative data Macro-economic analysis	Direct economic impact in terms of employment and expenditure (regional and national) ESTEC share in GDP of the Netherlands Financial figures outsourcing to Dutch industry	Description of upstream and downstream interactions of ESTEC with the Dutch space cluster Description of interactions of ESTEC with the Dutch knowledge infrastructure Description of the commercial utilisation of the ISS	Proximity ESTEC to Dutch actors adds value for The Netherlands Visibility of ESTEC knowledge assets can be improved Every euro of the Dutch contribution of M€ 88, produces a return value of €3.4 for the Dutch economy.
Learning-making innovation a reality, Giornale di Fisica, (2005), Streit-Bianchi M., et al	Ex-post Study of knowledge transfer and innovation impact on suppliers	Model of interactions facilitating learning and knowledge acquisition in procurement processes	Secondary data from existing studies: 1 Study on technological learning in suppliers Survey to suppliers (154 suppliers) 2 Studies of knowledge spillovers to CERN staff (411 Finds and 106 Italians; 167 Austrians, 106 Portuguese)	Descriptive statistical analysis of survey results	Indicators for type of benefits associated with the procurement activity Indicators of strength of cognitive capital Indicators of development of new skills and competences, and impact on career by CERN scientists	Not used	Learning benefits are important both for companies and for engineers and physicists working on a High-Technological, challenging procurement project
Neutrons and	Ex-ante	Pathways from science to	Not specified (but	Descriptive analysis of	Not used	Description of likely	Direct economic benefits

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innovations: What benefits will Denmark obtain for it science, technology and competitiveness by co-hosting an advanced large-scale research facility near Lund?" Copenhagen Business School (2005), Valentin et al.	Social, economic and systemic analysis	economic growth 1) The relationships between science and technological problem-solving 2) The role of firms and of their interaction with university science. 3) Science-economy relationships considered as systems involving linkages between multiple organisations	presumably desk research, experience with other regions and experts views)	experts views and reflections Scenario building		impacts on ESS on knowledge spillovers, education & training, industrial technology, innovation and systemic effects	are connected with procurement to the facility Additional indirect and systemic effects from the establishment of the ESS include, the creation of a highly specialised transit local talent pool, a training ground for young researchers, and a node for forefront research that would bolster the local scientific community and fuel the further growth of the high-tech industries located in the region.
A framework of industrial knowledge spillovers in big-science centers (2004), Autio et al	Ex-post Review of the indirect and the non-monetary benefits that stem from collaboration between industry and big science centres	The article develops a framework of motivations and actions for collaboration between big science centres and industry	Not specified (presumably surveys/ Interviews)	In-depth case studies to test the proposed framework	Not used	Brief case studies illustrating financial, technological, strategic, and educational motivations of firms to collaborate with CERN	Big science centres possess significant industrial potential because of their ability to document technological trajectories (reduced uncertainty) and to provide suppliers with well-defined specifications (complex product system maintenance ability) Collaboration of big science with industry is likely to improve learning processes, lead to breakthrough innovations, and have significant commercial impacts
Impacts of Large-scale Research Facilities: a	Ex-post	Impact of ESS depend on its relations to different	Desk research and	Descriptive analysis of quantitative and	Not used	Description of economic relations with industry	The cooperation with universities, the

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socio-economic analysis (2004), Hallonsten et al	Socio-Economic Analysis of effects in the host country	stakeholders and forces of interest in the society (local, regional and national)	interviews Experiences from other large research facilities	qualitative data		and local government; case studies/description of technology transfer experiences by other LRFs Description of local relations of the LRF with the environment, local population/public, and local infrastructure	involvement of industry, and the local community are the three main conditions for the ESS to have a positive impact in the host region.
A study of the research and development benefits to society resulting from an international research centre CERN, Academic dissertation (2004), Bressan	Ex-post Analysis of knowledge spillovers to staff	Theoretical contributions on Knowledge creation path: takes into account scientific, technological and social processes of knowledge acquisition and the four modes of knowledge conversion from tacit to explicit	CERN The TT database Online questionnaire to CERN staff (411 Finns and 106 Italians)	Descriptive Statistical analysis of the quantitative data collected Qualitative analysis Comparison of the two sub-samples (Finns and Italians)	Quantitative indicators for type of acquired knowledge, interactions, impact of training, and impact of CERN experience in career development.	Qualitative analysis of knowledge acquisition, learning, skill, know-how, social capital (social interaction, relationship quality, network ties) and competitive advantage (inventions, technological distinctiveness)	Individuals create and expand knowledge through a social process, and that there is an interaction between tacit and explicit knowledge. Importance of interacting within and outside the Organization and of being confronted with different disciplines and technologies The transfer of acquired knowledge through people represents important direct benefit to society
Technology Transfer and Technological Learning through CERN's Procurement Activity (2003), Autio et al	Ex-post Study of spillovers and innovation benefits to suppliers	Organizational learning that occurs in the relationships, or dyads, between CERN and its individual supplier companies	Series of case studies were carried out, following the grounded theory approach to develop the framework of analysis Survey to 154 supplier companies Interviews of CERN physicists and engineers to validate suppliers answers	Descriptive Statistical analysis and correlation analysis of the quantitative data collected Qualitative analysis	Quantitative indicators for Technological Learning Outcomes: (1) Market Learning Outcomes, (2) Organisational Outcomes, (3) Performance Outcomes	Qualitative data to complement and interpret the statistical analysis	38% of suppliers developed new products or services as a direct result of the supplier project; 13% started new R&D units; 14% started new business units; 17% opened a new market; 42% increased their international exposure; and 44% indicated significant technological

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							learning. Importance of technologically challenging projects for CERN itself, as technologically demanding projects were associated with a high level of knowledge acquisition and motivation among CERN staff.
Medium to Long-Term Future Scenarios for Neutron-Based Science in Europe (2003), ESFRI	Ex-ante Comparative socio-economic analysis	Not specified	Expert group (workshop of scientists and instrument specialists)	Scenario building of the neutron source facilities landscape: 3 scenarios from more to less ambitious Comparison of scenarios on the basis of: (1) Output aspects, (2) life time aspects, (3) input aspects	Indicators of source gains and instrument gains Comparisons of indicators of scientific output Cost comparisons (operating costs, and spending)	Description of direct, indirect and global impacts of each scenario	Summary of the three scenarios, the ILL Millennium Programme and the ISIS-2 second target station Transition to any of the proposed scenarios will require a capital injection in the range 600 to 1500 M€. Such an investment would sustain the field for the next 25 to 40 years. Using a payback period of 40 years and 2.5% government borrowing rates, they would result in an additional annual spending of 75 M€ for the full ESS, 50 M€ for the LPTS first in a staged approach towards ESS, 42 M€ for AUSTRON and 31 M€ for ISIS upgrade.
Using customer relationships to acquire technological innovation A value-chain analysis of	Ex-post Study of innovation impacts on suppliers	Value chains	Survey and interview data were collected on 49 suppliers to CERN from 10 different member	Descriptive statistics, correlation and factor analysis	Indicators of value-chain effects on suppliers of the CERN contract	Qualitative data complementing the interpretation of	Longer-term value-chain effects based on supplier learning are most likely to occur when suppliers are

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supplier contracts with scientific research institutions (2003), Nordberg et al			states. Interviews with CERN engineers to validate/triangulate the data provided by suppliers Identification of categories of commercial and technical benefits though interviews		Indicators of Value-chain effects of CERN contracts as a function of supplier goals (Long-term benefits, Short term benefits, Diversification benefits)	statistical analysis	pursuing strategic goals linked to their core competencies
Spin-offs from CERN and the case of TuoviWDM (2000), Byckling et al.	Ex-post Study of technology transfer process in a spinoff company	Not specified	Not specified	Case study	Not used	Detailed description of the processes of technology development, technology transfer, and collaboration with industry	In many cases the best yield from big science collaboration emerges through intangible profits, i.e. through education, new skills and products, unforeseen markets and partners
Technology transfer from accelerator technologies (2000), Hameri, A.P.	Ex-post Study of technology transfer from big-science laboratories to a particular member state and its industry	Not specified	Not specified	Case studies	Not used	Description of spinoffs and the intangible benefits of technology transfer (e.g. opening routes to international markets, pushing motivation of spinoff companies, pushing the development of new technologies)	SMES and large companies may have different motivations to collaborate with big science facilities In addition to direct profit-making companies may, or perhaps should, seek for pure technological advantages in terms of new solutions and catalysed product development processes
Contract Benefits and Competence-based Supplier Strategies - CERN as a Case Example, Helsinki University of Technology, Geneva. Pages: 173 (1994),	Ex-post Study of suppliers benefits in their collaboration with big science (PhD dissertation)	The report aims to develop a model/framework to analyse benefits to suppliers	Literature review Interview with experts Survey to CERN engineers and suppliers	Descriptive statistics, correlation and factor analysis	Indicators for commercial (profits, capacity, customers, contract control, marketing, etc) and technical benefits (advanced product development, process	Qualitative data complements the interpretation of statistical analysis	The highest benefits from collaboration with big science for suppliers are related to marketing and technical aspects

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Nordberg, M.					methods, quality, R&D, skills, motivation, etc)		
Economic Impacts of Hosting International Research Facilities, (1993), Cabinet Office	Ex-post Study of cost-effectiveness in international scientific collaboration	The objective of the study was to evolve a framework which can be used to appraise the costs and benefits that arise from hosting a large international scientific facility	Interviews at 6 large research facilities Interviews with suppliers, consultations with members of the UK scientific community and the Science and Engineering Research Council (SERC) officials	Descriptive analysis of quantitative and qualitative data	Direct economic impact of expenditure and employment Contracts from the facilities: Value, geographical distribution, financial and industrial return Employment and technical skills Use of the facility	Description of agglomeration effects and benefits of proximity Description of the benefits to the local economy (services, tax revenues, etc) Description of impact on the national science base (prestige, networking, time and travel costs) Description of technology transfer: spinoff companies	The host country has substantially higher proportion of awarded supplier contracts and employment at the facilities Proximity provides valuable opportunities to the supplier base, scientific base and local economy.
Quantification of CERN's Economic Spin-offs, (1986), Biachi et al	Ex-post Study of technical and economic benefits to supplier firms	Not specified	Interviews to 166 European firms	Calculation of economic utility for the sample for firms (Economic Utility = Increased Turnover + Cost Savings) Extrapolation of the utility obtained for the random sample to the total family of 519 firms from which the sample was taken was made using the group averages.	Estimates of increased sales and cost savings due to CERN contracts Estimation of economic utility	Examples of CERN-generated utility	"Economic Utility" of CERN totals 3107 million Swiss francs (up to the year 1987) compared to sales to CERN in 1973--82 amounting to 748 million Swiss francs in 1982 prices. It is estimated that, by 1987, CERN's high technology purchases made in 1973--82 will have generated Economic Utility amounting to about 60% of the overall cost of the Organization during the same period.
Evaluating big science: CERN's past performance and future prospects. Scientometrics, 7(3-6),	Ex-post Assessment of the scientific impact of CERN	Not specified	Databases of publications and citations Peer-evaluation data	Method of converging partial indicators (publication counts, citation analysis and peer-	Bibliometric indicators (publications and citations)	Not used	No conclusions on socio-economic impact

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pp. 281-308 (1985) Irvine and Martin	activity		developed at the Science Policy Research Unit (SPRU)	evaluation)	Peer evaluation assessments (self-rankings vs peer rankings)		
Economic Utility Resulting from CERN Contracts (Second Study), CERN yellow report 84-14, Geneva: CERN. (1984)	Ex-post Study of technical and economic benefits to supplier firms	Not specified	Interviews to 166 European supplier firms	Calculation of economic utility for the sample for firms (Economic Utility = Increased Turnover + Cost Savings) Extrapolation of the utility obtained for the random sample to the total family of 519 firms from which the sample was taken was made using the group averages.	Estimates of increased sales and cost savings due to CERN contracts Estimation of economic utility	Examples/ case studies of CERN-generated utility	"Economic Utility" of CERN totals 3107 million Swiss francs (up to the year 1987) compared to sales to CERN in 1973--82 amounting to 748 million Swiss francs in 1982 prices. It is estimated that, by 1987, CERN's high technology purchases made in 1973--82 will have generated Economic Utility amounting to about 60% of the overall cost of the Organization during the same period.
A Study of Economic Utility Resulting from CERN Contracts, CERN yellow report 75-5, 41Geneva: CERN.(1975)	Ex-post Study of technical and economic benefits to supplier firms	Not specified	Interviews to 127 European supplier firms 110 interviews to CERN staff	Calculation of economic utility for the sample for firms (Economic Utility = Increased Turnover + Cost Savings)	Estimates of increased sales and cost savings due to CERN contracts Estimation of economic utility	Examples/ case studies of CERN-generated utility	Economic utility totals 1,665 million Swiss Francs (up to 1978) compared with a sales value to CERN of 394 MSF. Utility/sales ratios range from 0.9 to 7.3 for application fields of cables, magnets, cooling systems and steels; they are as high as 17.3 for computers and 31.6 for mechanics. Some 80% of the total reported utility results from sales to markets outside high-energy nuclear physics.

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							For the 877 MSF spent by CERN in European industry from its overall budget of 3,500 MSF during 1955-1973, the total utility is estimated to be nearly 5,000 MSF.
STFC ISIS facility impact case studies.	Ex-post 16 case studies on scientific impact of ISIS research	Not specified	Not specified (presumably STFC)	Case study	Not used	16 individual case studies of functional applications of ISIS research (medical, environmental, etc)	Not available
ITER Economic Impact Study - EISS2 Cadarache	Ex-post Economic analysis of the construction and exploitation phases	Not specified	Not specified (presumably from ITER)	Input/output analysis National inter-sector matrix for the calculation of national impacts	Direct impacts on production and employment Sectoral expenditures Global economic impacts	Not used	The ITER project activates 7 of the 37 sectors of the economy during the construction phase and 18 during exploitation phase In the construction phase one euro spent in ITER is about 3,7 for the local region and 6,3 for France In the exploitation stage one Euro spent in 3,5 for the local region and 5,7 in France.
Impacts arising from Large Capital Investments: NERC	Ex-post Analysis of scientific and economic impact	Not specified	Not specified	Not specified	Not used	Description of technology development, spinoff companies and functional applications of the facilities	Not available
Impact Evaluation of the Millennium Cohort Study (ESRC) – Centre for Longitudinal Studies (2011), Consulting in	Ex-post Study to assess the impact of MCS on policy-making and makers, institutions, professional practitioners,	'Tracking forwards' approach to identify three types of impact: Instrumental – influencing the	Document review (MCS-related publications, Media review, Policy document and legislation review)	Detailed qualitative analysis of MCS research impact on policy and practice Identification of key	Usage of MCS	Policy case studies (Early years policy, Child poverty policy) Case studies to illustrate the ways in which MCS	Instrumental impact: MCS being mentioned explicitly in policy Conceptual impact: majority of research

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place	and other groups outside academia.	development of policy, practice, or service provision, shaping legislation, altering behaviour Conceptual – enhancing understanding, informing and reframing debates Capacity building – technical/personal skill development	Interviews (CLS and ESDS staff, staff in policy departments and researchers)	research themes where MCS data has been utilised Identification of implications for policy Impact on central government		has been used to inform policy or strategy decisions in Northern Irelands, Scotland and Wales) Evidence of recognition of MCS at senior policy levels Review of factors affecting impact generation	outputs reviewed that have used MCS data are policy relevant Capacity building impact: Use of the data helps to develop the UK skills base for longitudinal analysis
Measuring the economic impact of the British Library (2007), Pung et al	Ex-post Economic analysis	Not specified	Three surveys to physical users of the library, remote users and general public	Contingent valuation method Consumer surplus	Willingness to pay (WTP) Willingness to accept (WTA) Investment in access Price elasticity of demand Cost of alternatives	Not used	The Library generates value worth £363m per year, which is 4.4 times its annual baseline government funding of £83 million The direct value to users amounts to £59m and the indirect value to the wider society amounts to £304m

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