Government
Office for Science

Realising our ambition through science

A review of Government Science Capability

Guidance

November 2019

Preface

Science is crucial for the success of the country and plays a vital role in government, providing the evidence and support we need to achieve impact in our policy-making and operations. It ensures government is resilient against shocks and emergencies, and equips us to capitalise on the emerging opportunities that technology provides.

This is an important review of our science capability. It points to a common purpose to incentivise more effective use of the UK's R&D capital and realise the opportunity we have as we move to increase UK spending on R&D to 2.4% of GDP. It shows how we can utilise the resources we have from Chief Scientific Advisers, through to our public laboratories, the teams who operate and deliver across institutional boundaries, and the world class science and scientists in the private and public sectors.

As we consider the challenges and opportunities we face, it is vital that we use science and technology to help us tackle problems, enhance our economy and improve our operational performance as a government. The report provides a clear set of recommendations on how we can achieve this goal and I recommend it to all Departments.

Sir Mark Sedwill

Cabinet Secretary

Foreword

In a globally competitive knowledge economy, Research and Development (R&D) is critical. This is recognised in the private sector where R&D investment is correlated with growth, innovation and enhanced performance, and where companies that spend little on R&D risk being low margin, low productivity, low growth, non-innovative companies. It is also recognised at a national level with the ambition of the UK to increase its R&D spending to 2.4% of GDP (and then to 3% in the longer term) as an essential part of ensuring economic and societal success; it is a key pillar of the Government's vision for a global Britain founded on openness, innovation, competition, and high quality, intelligent, regulation. The creation of UK Research and Innovation (UKRI) as a new funding body which works in partnership with our world-class universities, research organisations, businesses, charities, and government to enable the research and innovation environment to flourish, is a key part of delivering this. However, government departments also have a role to play, and this review carried out by the Government Office for Science with HM Treasury looks at the state of science within government. The review makes recommendations for enhancing the use of science to promote government effectiveness and better policy-making. There are several key messages:

- Whilst there are pockets of excellence, science activity and expenditure is variable across government and weak and fragmented in some departments. Science budgets have reduced in many departments and spend on R&D in some cases is a fraction of one percent of total spend. Better leadership and delivery of science, and a greater use of science in departments and across government would create a stronger evidence base for decision making, enhance government performance and contribute to government social goals and economic growth.
- Departmental science expenditure should be formally documented as part of the public science spend, and there need to be clear mechanisms to ensure that it is used well and that the outcomes are assessed. Each department should have a clear plan for science and consideration should be given to what target percentage R&D spend each department should aim for in relation to its ambition and needs.
- Departmental Chief Scientific Advisers (CSAs) need to provide leadership for science in government and beyond. They should act as a team/pool across government, with the appropriate resource and provide an authority for science in their departments. Chief Scientific Advisers should sign-off departmental science research plans and the resource requirements and use. The outcomes of science must be assessed.
- To improve impact of our science, it is necessary to work across government and with the wider scientific community in academia and industry, in the UK and internationally. Departmental Areas of Research Interest (ARIs) and longer-term science objectives should be at the centre of this, and there is a need for much closer dialogue and capability building between CSAs and Whitehall's key policy leaders. ARIs have already demonstrated areas where departments have common interests and greater coherence can be achieved in for example, data science, behavioural sciences, environment and security.

- Government's own expertise and laboratories will be critical in shaping missions and facilitating and conducting the kind of research that takes promising new knowledge and turns it into valuable new products and services. In our public laboratories we have an extraordinarily valuable asset, and we need to do more to nurture them and exploit their potential, including the intellectual property generated.
- New models for working with private sector innovative companies will be required to meet the science needs of government. This will be an essential part of the science system, as well as the existing links between government, academia and research institutes.
- Skills and capability building across government are needed. This must include the government science and engineering profession, analysts, and crucially the policy professionals and others who will need to be part of defining problems to be addressed by science and using science to improve performance and outcomes.

There is an opportunity to recharge and redefine science capability in government to improve the evidence base for decisions and create opportunities for innovation and growth. Spending Reviews should be used to drive the changes that are required for us to realise our ambitions as a government by creating an expert, efficient and leading S&T system.

Sir Patrick Vallance

Government Chief Scientific Adviser

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Key findings and recommendations

Science is a cornerstone of our future economy and science will impact increasingly upon every part of government and society, and prosperity in a global Britain. However, leadership for science activity and expenditure is variable across government and weak and fragmented in some departments. Science is a central part of effective government and should not merely be seen as an ancillary function. There need to be clear mechanisms to ensure that it is used well and that the outcomes are assessed, and the activities are central to the government's social and economic agenda, increasing our ability to use science for prosperity and societal benefit. Departmental science spending should be formally documented as part of the public science spend.

Departments need a clearer model of science leadership, supported by an effective system of science commissioning. Such leadership should have a defined role to articulate an integrated statement of the department's research, innovation, and development science needs; in the preparation of spending plans to meet those needs; and in the development of intra- and extra-mural solutions for the conduct of the work.

> **Recommendation 1**
> *Every department should have a clearly defined science system. A central role here is leadership in the articulation of the entire range of a department's science needs in a single document which is endorsed by the department's Executive Committee.*
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> *This should form an integral part of overall business planning within departments: unlike Areas of Research Interest (see below) it should address the whole range of science activity conducted within the department and at arm's length from it. It should also include mechanisms for how non-government funded R&D will be used and incentivised.*
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> *A core part of the departmental Chief Scientific Adviser's role is to be accountable for the existence of such a plan, signing off on issues including prioritisation, ensuring that it addresses the key science issues facing the department throughout its operational work and policy cycle and that these will be tackled in the most appropriate way.*
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> **Recommendation 2** – *All Departments should publish, and refresh annually, Areas of Research Interest documents with a view to encouraging extra-mural activity and collaborations and the commissioning of key R&D. They should be co-developed by Chief Scientific Advisers, Analysts, and Heads of Policy*

Profession in departments, putting scientific thinking at the centre of departmental processes, including policy and operations. The Government Office of Science, with CSAs, should make the documents consistent and ensure they provide potential collaborators with the key information (including the availability of data) that they need to engage effectively with the relevant research questions.

The wide range of **Public Laboratories that are owned by government present a significant resource for government in the leadership of outstanding 'directed' R&D, but several decades of their devolution from central government have created obstacles to a more strategic deployment of this resource**. These Public Sector Research Establishments (PSREs) need to work in a more integrated way and excellence-based funding competitions should be opened up to them. It will be important to determine whether any are no longer representing value or meeting a need.

Recommendation 3 - *The Government should create a policy-focused Forum for Public Laboratories, to raise their profile within government and to create greater knowledge exchange about their role amongst policy-makers. The Government Office for Science should lead on this, working closely with department sponsors. An early task for the forum will be to advise on the development of a framework for evaluating their performance and value.*

Recommendation 4 - *The Government should make greater use of Public Laboratories as leaders in directed R&D programmes, and in supporting innovation through intermediate technology readiness levels. Government should give greater support to them in this role. This should include: a) departments ensuring that they have adequate long-term funding for the pursuit of their core missions for government; b) research funders opening up excellence-based competitions to Public Laboratories, where they might compete with universities and other research institutes, c) the creation of a specific fund geared to the work of Public Laboratories, for which they can compete for funds for innovation activities to be conducted in partnership with business, and d) clear processes for the protection and maintenance of intellectual property generated. The Department for Business, Energy & Industrial Strategy (BEIS) as part of its 2.4% roadmap should address the role of Public Laboratories across government in supporting and enabling research and development in the private sector, and the accountability to deliver this should rest in the department in change of that sector.*

With the advent of UKRI, the **research funding system is presenting unprecedented levels of opportunity** for government to engage with research and development, both nationally and internationally. Government is not yet engaging in the strategic way with funders that is necessary to realise the potential benefits. The development of ARI documents needs to be derived from, and mainstreamed into, policy thinking, and the documents need to become more strategic in focus. Governance arrangements in areas of joint research interest need to ensure that both scientific excellence and clarity of focus on delivering programmes' strategic objectives are assured.

> **Recommendation 5** – *UKRI should lead development of tailored forms of governance for research programmes relating to government strategic priorities taken forward under the Strategic Priorities Fund and related areas.*

There are a several R&D areas which are significant to multiple departments, but where the fragmentation of existing work is unhelpful (e.g. in behavioural science, data science, and mental health). Government needs to develop and exploit funding opportunities for the development of strategic cross-government research programmes in these areas. The creation of UKRI's Strategic Priorities Fund has been a very welcome development, but Government needs to be more systematic in its engagement and work on the basis of clearer priorities.

Leading businesses and R&D actors in the private sector are developing new and sophisticated partnerships with small and medium-sized innovative companies, yet **government has not fully exploited the potential of such business development approaches in its innovation programmes, particularly in ways that achieve future optionality across the breadth and depth of science and technology**. The government should allocate funding and create commercial and business-scouting expertise and collaborative R&D to support this, as well as build upon existing mechanisms, such as the National Security Strategic Investment Fund (NSSIF), the International Research and Innovation Strategy (IRIS) and collaborative Security S&T programmes. Implementation should take advantage of intellectual property developed by government science and be informed by the findings of the Balance Sheet Review and *Getting smart about intellectual property and other intangibles in the public sector*[1].

> **Recommendation 6** - *The Government Office for Science should work with the UK Government Investments and the British Business Bank to explore the use of government venture capital and business development models in innovation, and to provide expert resource to support departments in developing these.*

> **Recommendation 7** – *The Government Office for Science should develop proposals for the implementation of business development functions, including experience from similar approaches taken from defence and security, to identify wider applicability. This will ensure that the landscape of small and large company activities is well understood, and we have good links with those companies and their backers and are able to exercise a range of business partnerships effectively. This work should then be taken forward within the centre of excellence (see recommendation 13 below).*

Science budgets have been vulnerable to disproportionate reductions in those departments whose administration budgets have come under pressure, and the existing controls that aim to secure central oversight of the process have not been observed. This has at times created poor outcomes for government as a whole, as well as missed opportunities where science can improve performance of government delivery. In future Spending Reviews, allocations should contain a clear statement of

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[1] 'Getting smart about intellectual property and other intangibles in the public sector' published at https://www.gov.uk/government/publications/getting-smart-about-intellectual-property-and-intangible-assets

levels of science expenditure over the period of the review, underpinned by a rationale for the outcomes that science aims to provide. This should also apply to Overseas Development Aid (ODA) funds for science. Agreed expenditure levels should be published, and departments should be ready to account for any departure from them over time.

Recommendation 8 - *Submissions by departments to the Treasury ahead of Spending Reviews should incorporate a statement of research and development need and costed plans for meeting those needs (including an assessment of the percentage of overall departmental expenditure they aim to spend, in absolute terms, on science) and how this compares with international benchmarks for R&D spend in their policy areas. Departments should include a clear statement of where particular R&D work streams fit within the spectrum from basic to applied R&D. In support of the government's objective to spend 2.4% of GDP on R&D, departments should also set out plans for stimulating wider economic investment in R&D in industries of relevance to their policy portfolios. Consistent with existing practice, consultation with the Government Chief Scientific Adviser (GCSA) and HM Treasury should take place if there are significant deviations from planned expenditure.*

Recommendation 9 - *The Government Chief Scientific Adviser should work with HM Treasury and the Office for National Statistics (ONS) to ensure that government expenditure on research and development is transparently reflected in public expenditure statistics so that in the future there will be comprehensive data on which to assess spending on science within government.*

Recommendation 10 - *The Government Science and Engineering (GSE) Profession Board should work with the Analysis Function Board to ensure that the civil service as a whole has the scientific skills it needs and the mechanisms to deploy them effectively through the wider civil service functional agenda being led by the Cabinet Office. Plans should be developed to remedy any shortages (working with UKRI and the Department for Education where appropriate), reporting early in 2020.*

Recommendation 11 - *All departments should have a clear sign-off mechanism for science expenditure, involving joint accountability for the Director of Finance and Chief Scientific Adviser, in reporting to the departmental Executive Committee and to Ministers.*

Science governance, administration, and access to key resources have grown weak in those departments where budgets have been most reduced, impairing the government's ability to commission and oversee excellent science, and to broker partnerships with research leaders elsewhere. There is a need for a small centre of excellence from which departments (particularly smaller departments) might draw support, as well as strengthening departmental resource in this area. In particular, the opportunities of cross-government data are huge and need to be grasped.

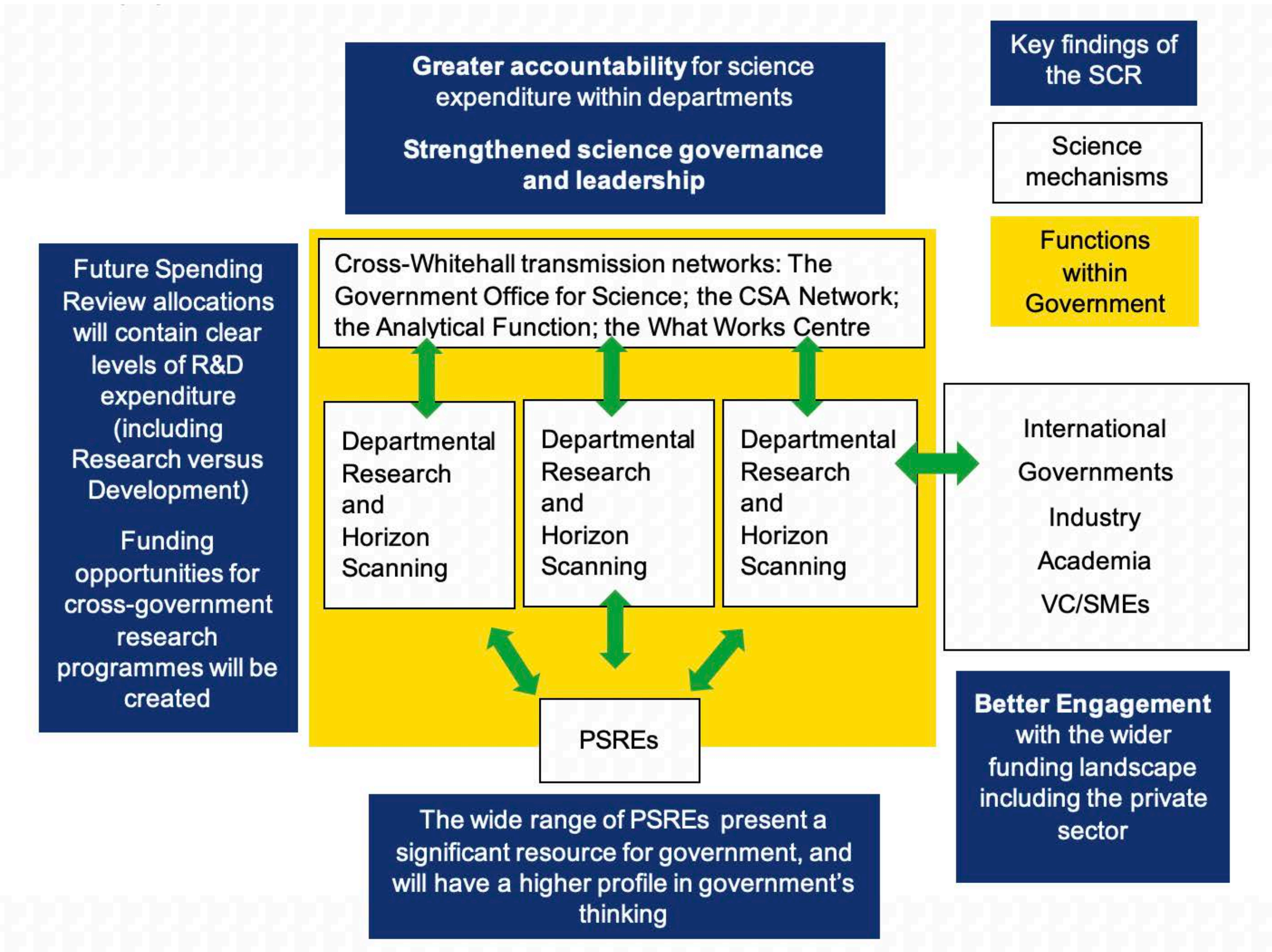
Recommendation 12 – *CSAs should work to ensure (and have support from their departments in doing so) that science specialists have access to the tools,* *research journals and data that are essential to understanding, evaluating and undertaking excellent research.*

Recommendation 13 – *The Government Office for Science should work with UKRI to develop guidance for government departments on best practice for a) improving peer review and research integrity and b) benchmarking of quality and outcomes.*

Recommendation 14 - *A centre of excellence should be created to support those departments with smaller science and evidence budgets in areas of basic capability that underpin the conduct of an effective research programme, such as data quality and integrity, research procurement, research governance, best practice in the use of grant and contract, and the use of financial instruments and business development approaches in the development of R&D programmes.*

Recommendation 15 – *For important cross-government areas of science, shared governance models consistent with the recommendations of the National Audit Office (NAO) report on cross-government research and development should be established to improve co-ordination and to maximise funding opportunities, including opportunities to link up internationally. To support this, the Government Digital Service should work on a platform to allow important R&D projects to be logged within a single database.*

The following diagram brings these themes together with the key findings of this review.



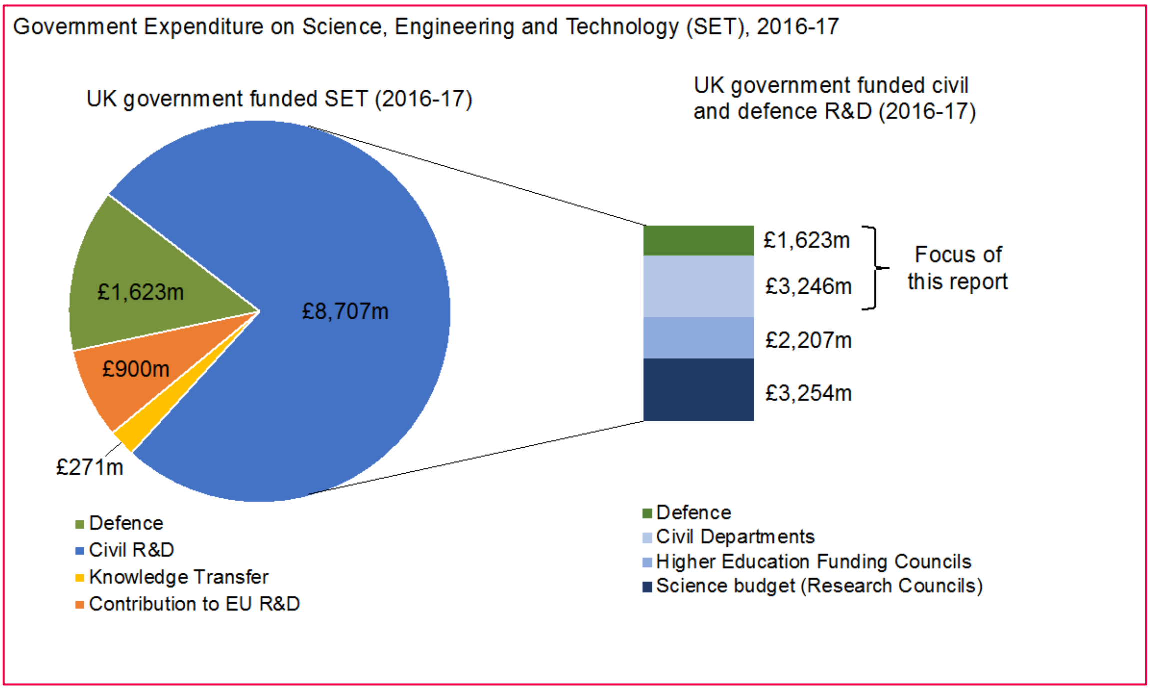
Chapter 1
Introduction

Background to the Review

1. Government conducts and commissions a wide range of science, research, and evidence-gathering activity in support of its functions (including policy development but also in direct support of government operations). Government sponsors research in the national and public interest, first, mainly to support the growth, development and evolution of the wider economy by sponsoring pre-competitive activity and, second, to service its own needs as a user of research outputs.

2. The remit of this report has been on science and engineering specifically. The work of scientists does not take place in a vacuum. Internally, they work alongside the many civil service professions - analysts, policy-makers, project managers, HR specialists and others – that make the whole enterprise possible. Externally, research funders, and researchers in the university and private sectors are major partners. Collaboration is the starting point, and not a luxury, for scientists and engineers in the twenty-first century. This is as true when they are taking forward the work of government as it is in the research sector. The report argues that science, and the excellent R&D which is its essential support, needs to have a higher profile in the way that government thinks, and there are a number of recommendations that address this. These are not, in themselves, enough. The challenge is just as much on government scientists to rise to the relevant challenges and reach out to our colleagues within the civil service and beyond, to work together on resolving the key issues affecting government.

3. Sometimes, government's own role within the research system is neglected, except as a funder of activity by Higher Education Institutes (HEIs). The government science system is large, complex, and diverse. Understanding government science as a system in itself, but also in the context of the UK's wider research, and innovation systems, is critical if the UK is to be properly equipped for the challenges and opportunities of a rapidly changing world.



4. One important focus of this report is activity classified in the national statistics as activity amounting to some £4 billion of national expenditure: research and development conducted and commissioned by the main civil and defence departments in pursuit of their objectives. [2] Comparable activity which is funded by expenditure through UK Research and Innovation (UKRI) through universities, institutes and Catapult Centres (commonly and misleadingly treated as if it this were the totality of the "science budget" within government) is relevant, but does not fall within the review's scope.

5. The last major reviews of government science were published in 1993 and 2007.[3] Work on the 1993 White Paper Realising our Potential was led by William (subsequently Lord) Waldegrave as Chancellor of the Duchy of Lancaster. It led to a reorganisation of science management within government, including the creation of the Office of Science and Technology, the progenitor of the Government Office for Science. One of its recommendations was that those PSREs that formed part of government should be reviewed to assess whether alternative organisational forms, including conversion into executive agencies or privatisation was appropriate. This has perhaps been the dominant theme of government policy since, driven by a cycle of reviews of specific science bodies. Lord Sainsbury's review of 2007 also considered aspects of the government's own

[2] This does not align precisely with all science activities in government, but this figure represents our best proxy for the scale of the activity involved.
[3] *Realising our potential: a strategy for science, engineering and technology.* The then government's response is available at: https://www.gov.uk/government/publications/realising-our-potential-a-strategy-for-science-engineering-and-technology

science base.[4] Its most important legacy was the transformation of the Technology Strategy Board (the predecessor of Innovate UK) into an independent body. One of its recommendations for the government R&D budgets that are the focus of this report was that these should be more closely controlled, and only be reduced following consultation with the GCSA and HM Treasury. The fact that a similar recommendation is required in this report is testimony to the fact that the failure to give the right priority to government science emphasised by the 2007 review has not diminished in the intervening years.

6. Why now? The nature of science, and the context in which government operates, has changed beyond recognition in the decades since these reports were published. The internet and the data revolutions have continued to transform the character of all kinds of work. The art of making government policy has become more complex in a context where these deeply transformative technologies are changing society and the economy. There has been a very significant structural change in the science funding landscape with the creation of UKRI, part of whose mission is to ensure the relevance of science and research for societal challenges. New funding streams have been created for mission- and challenge-led funding, reflecting the government's commitment to a significant increase in national expenditure on R&D by 2027. There is a new consensus that government has a lead role in setting the framework for innovation, marked by the publication of the Industrial Strategy in 2017. Open science and innovation techniques are transforming the research and development landscape more broadly, making science a more deeply collaborative and highly networked enterprise both nationally and internationally. Government budgets and science headcount have come under pressure with fiscal consolidation, but there has been a proliferation of new partnership models in the ways in which government works with the university and private sectors. Currents within civil service reform have brought new levels of professionalism to the ways in which government's specialists work. The UK's imminent departure from the European Union (EU) will put new demands on our domestic science capability.

7. The Ministry of Defence's (MOD) publication, *Global Strategic Trends*, makes the case that we are at an 'inflection point' marked by the unprecedented speed of change, as familiar trends in terms of demography, technology and the environment interact in ever more complex ways, putting a premium on our ability to cope with constant innovation.[5] This affects the whole range of government's business.

8. Science will be critical in this new context, and this is the focus of the review. The definition of science within government is not straightforward. One approach is to

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[4] *The race to the top: a review of government's science and innovation policies*, available at: https://www.gov.uk/government/publications/implementing-the-race-to-the-top

[5] *Global Strategic Trends: the Future Starts Today*, available at: https://www.gov.uk/government/publications/global-strategic-trends

deal with research and development, in the sense of the pursuit and application of knowledge and understanding of the natural and social world following a systematic methodology based on evidence, in the form of testable explanations and predictions, and use of this stock of knowledge to devise new applications.[6] Some relevant activities however relate to the application of science and technologies in specific situations, rather than the development of new knowledge (for instance testing to establish the presence or effects of a specific pathogen, rather than developing new knowledge on the pathogen). Such activities are excluded from the internationally accepted Frascati definition of research and development, which is given in full in Annex A[7]. A more pragmatic definition would be to focus on those activities conducted by the GSE Profession, but the issues do have implications for activities conducted by professions for other analysis functions within government – work on data science, for instance, is relevant across all the analytical disciplines, not just those associated with the natural sciences and engineering.

9. While there are some similarities with the work of the other professions which form part of the Analysis Function (economists, statisticians, operational researchers, data scientists, social researchers and actuaries), government science and engineering has some distinctive attributes that set it apart: the importance of science in setting the strategic context of government, the prominent role of CSAs in departments, who are generally recruited from outside government, the scale of expenditure on work conducted in partnership with universities and the private sector, the multiplicity of arm's length bodies that it deploys in delivering its functions, the large scale of the relevant workforce, the diversity of specialisms within the profession, and increasing need for interdisciplinarity.

10. The definition of scientific research used in Sir Paul Nurse's review of the research councils is a good starting point in clarifying our focus:

"In this review the terms 'research' and 'science' are usually used in the context of the entire academic landscape, reflecting the Latin root, 'scientia', meaning knowledge. All academic disciplines contribute to the vigour of the research endeavour, including the natural sciences, technologies, medicine, the social sciences, the arts and the humanities."

"Scientific research, wherever it is carried out, shares common values and practices. It must be built on a respect for reliable and reproducible data; a sceptical approach which challenges both orthodoxy and the researcher's own

[6] In this sense we mean scientific method to be objective observation through measurement and data (including using mathematical approaches); generating evidence, through experiment and/or observation to testing hypotheses, induction and reasoning to establish general rules or conclusions drawn from facts or examples, repetition and critical analysis; and verification and testing: critical exposure to scrutiny, peer review and assessment. (See Science Council as an example of definition: https://sciencecouncil.org/)
[7] The Frascati definition is found at Annex A and here: https://www.oecd.org/sti/inno/frascati-manual.htm

ideas; an abhorrence of the falsification or cherry picking of data; and a commitment to the pursuit of truth. Science can only succeed when it is grounded in integrity and ethical behaviour. However, despite sharing many values and practices there are specific differences in the ways that research is carried out in different parts of the system."[8]

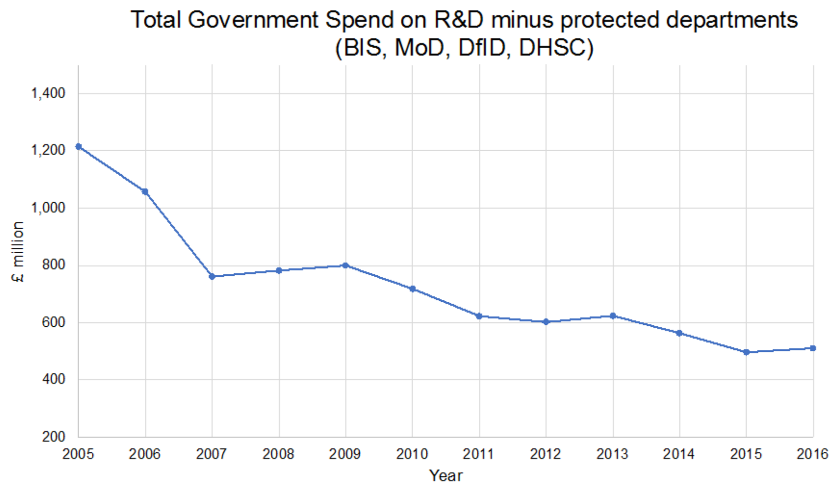
11. "Research and development" – for which government expenditure figures are published annually – is a subset of scientific activity, geared to the development and some forms of application of new knowledge. If we were to extend this definition to embrace the *application* of scientific research findings to the work of government, then this gives a clear idea of the breadth of activity embraced by government science.

12. It is important to note at the outset that science expenditure is an input in any undertaking. It does not represent a good in itself. Its effects – better delivery of the government's objectives (particularly government's long-term and strategic objectives) – are all-important. Clarity about the effects that science is intended to serve, and effective scrutiny to ensure that science is delivering the relevant outcomes, is an important part of an effective science system. There is no suggestion that there is, in the abstract, an ideal proportion of departmental budget which ought to be allocated to science. This will vary considerably: it will be different given the functions of particular departments and the various research "ecosystems" of which they form a part. Rather, the aim of this review is to identify specific areas of weakness and to identify changes to process which will drive better stewardship of the system, securing greater leverage of activity elsewhere in pursuit of the government's objectives, and greater value for money.

13. The starting point for this review was a consideration of the way in which R&D expenditure in UK government has developed over the previous years, and in particular an exploration of the implications of reductions of expenditure in a number of departments. The last dataset was published earlier this year, for the year 2016. There are some comments on the treatment of these figures in Chapter 4 below. The overall trend (for government as a whole) has been of an absolute increase in expenditure over the period. This masks the way in which patterns of expenditure have changed at departmental level, particularly in smaller departments. Some (protected) budgets have remained relatively stable, while others have shown marked decline relative to departmental expenditure as a whole. Graphs describing the overall trends of spending and those within some specific departments are set out in Annex B. The overall spend of non-protected departments is plotted below:

[8] Ensuring a successful UK research endeavour (2015) pp. 1 and 4.

Total R&D expenditure since 2005



14. The review has focused on the work of Whitehall departments.[9] Our method of evidence-gathering is detailed in Chapter 6. It has focused on four key themes:

- What science is needed in government?

  While government funds curiosity-driven research under the direction of researchers themselves, government also funds science in direct pursuit of its own functions and needs. The latter is the primary focus of this report. For the government decision-maker, the starting point is to understand the role of science within the system, and in establishing clarity as to those areas where scientific research and activity is necessary, including whether government is equipped to deal with emerging issues, like the rapid development of new technologies and the risks and opportunities that these bring.

- Given the nature of those needs, what form should the activity take?

  The ways in which government science is delivered have become significantly more diverse since the mid-twentieth century. Several decades of civil service and public sector reform have multiplied the range of methods, and the range of institutional frameworks and partnerships, whereby government science is delivered. Decisions need to be informed by the range of options that are available, and a sense of where these are appropriate. Different methods of delivery call for different management methods. As the number of partnership and networked models grow, there is a need for investment in excellent science administration. Chapter 3 will review the range of models available, and good practice in some emerging areas.

[9] The review has not considered science in the devolved governments.

- How much is needed?

  In his review which led to the creation of UKRI, Sir Paul Nurse made the following observation on the ideal quantum of research expenditure. His point is equally applicable to science expenditure managed by government;

  "In delivering an effective research endeavour it is useful to recognise that there are upper and lower bounds to what is optimal. If the boundary is set too high then there is a danger that resources are wasted and the quality of research supported is too low; if the boundary is set too low then the research endeavour becomes inefficient and even dysfunctional, with funding decisions behaving more like a lottery."[10]

  It is not possible to establish an ideal quantum in the abstract: this is a matter of judgement founded on deep expertise, and the answer will differ markedly in different departmental contexts. This also entails a judgement as to what forms of activity are appropriate to a given department's work – whether (to use terms which are familiar to the layperson but can be deceptive in practice) basic, translational, or more applied. Chapter 4 will highlight some recommendations for departments to improve their ability to determine this amount, and highlight some areas where provision needs to be stronger.

- How is the resource allocated through these routes best managed, and how should the government ensure value for money?

  Securing value for money – ensuring that money is spent well – has three dimensions: economy, efficiency, and effectiveness. Each of these are as relevant to science expenditure as to any other area, and there needs to be a clearer (shared) sense of good practice in the conduct of any government science programme. Chapter 5 will explore existing good practice and what other government departments might learn from this.

15. The review is in part an assessment of the state of UK government science governance and practice in 2018-19. It also outlines the characteristics of an optimally managed government science system in the distinctive UK context.

[10] Ensuring a successful UK research endeavour, 2015, p. 16.

Chapter 2

Understanding the functions of science in government

1. This chapter will address at a high level the ways in which science supports government in its work, and best practice in the governance and processes around understanding and articulating those areas where it is needed, including the role of Chief Scientific Advisers.

Science leadership

2. Some initial observations on the role of science leadership are appropriate. There is a danger of regarding science as a whole as a service, an ancillary aspect of government's work that can be performed at arm's length from its core functions.

3. This reflects a tendency that has been a keynote of policy since the publication of the Waldegrave Report. It recommended that "the ownership of S&T capabilities and the procurement of S&T should be separated". Its aim was to bring greater efficiency and entrepreneurship to the way in which science was conducted, consistent with the objectives of civil service reform in that period, and this has in many respects been successful. However, the assumption that science capability could be entirely outsourced has brought fragmentation and has damaged science leadership within government. In the 21st century, science needs to be part of the conversations that inform government's leadership and strategy. As part of the review, the Government Office for Science reviewed the drivers that are, and will, affect the demand for science within government (see Annex C). The long-term trends that will demand innovation and deep technical knowledge, including global warming and demographic change, are familiar. The technological changes – automation, the big data revolution, new genetic technologies, new computing power – are transforming the context within which government works, but also the analytical tools and policy instruments at its disposal. Science needs to inform mainstream policy thinking.

4. A recent example from Japan illustrates how the application of scientific techniques to high-level decision-making can transform strategies. A project led by the Japanese Council for Science, Technology and Innovation applied Natural Language Processing[11] techniques to documentation produced by government departments relating to their expenditure on science, to help inform decisions in a challenging fiscal environment. It identified where R&D was needed for decisions and incentivised the use of R&D to answer key questions. This allowed for work to be joined up across departments, and savings from areas of duplication were redirected to a ring-fenced budget which was dedicated to more targeted science activity. Applications of this approach to other areas of government expenditure are now being explored.

5. A common observation in interviews with senior finance and policy officials undertaken as part of this review was that technological change (especially in areas where policy needs to deal with the development and maintenance of the forms of infrastructure that are being revolutionised by digital technologies) had already brought issues to a point of complexity where mutual comprehension between the generalists who put advice to ministers, and the specialists upon whom they rely, has become challenging. As one senior official put it: "I am confident that I can understand the technical content of a particular business case, but I am not well equipped to challenge it."

6. The Fulton Report (1968) emphasised the importance of the specialist in a civil service previously dominated by the generalist. It is instructive to reflect on the different ways in which this recommendation has affected two government professions: economics, in particular, has become a very strong force within Whitehall, well represented in all the key discussions taking place throughout departments. Meanwhile science and engineering has widely come to be seen as the domain of specialist delivery agencies operating outside the centre. A key question, however, is how much science is needed to be undertaken in-house in order to be able to commission external and arms' length bodies effectively. Looking for best practice elsewhere, most in industry would generally argue that they need to do enough themselves to be a good commissioner of external R&D.

7. Leadership capability rooted in expertise in science and technology will increasingly be needed at departments' centres. The role of Chief Scientific Advisers is critical here. The following is a description of the role taken from the existing guidance[12].

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[11] A cluster of data science techniques, serving to draw meaningful information from large quantities of written texts.

[12] This guidance is currently being reviewed. In addition to the role described above, critically a number of CSAs also run significant science functions and have oversight of their departmental arm's-length PSREs.

The role of the departmental Chief Scientific Adviser

Chief Scientific Advisers (CSAs) work alongside the other analytical disciplines and with ministers and senior teams, to ensure robust, joined-up evidence is at the core of decisions within departments and across government. CSAs also work together, and with Research Councils and others, under the GCSA's leadership to address and advise on issues which cut across government.

Mirroring the role of the GCSA, the core role of departmental CSAs is to ensure that departmental decisions are informed by the best science and engineering advice. They do this both through offering advice directly to ministers and official colleagues and by oversight of processes for ensuring that departments take account of, and commission where appropriate, relevant scientific and engineering evidence.

The precise role and responsibilities of the CSA necessarily varies from department to department. In all cases, the CSA is a senior official in a position to influence departmental decision-making. The specific roles of CSAs should as a minimum include the following:

- Provision of advice and challenge directly to the secretary of state, other ministers and policy-makers in the department
- Performing an independent challenge function to the department, ensuring that science and engineering evidence and advice for departmental policies and decisions is robust, relevant and high quality and that there are mechanisms in place to ensure that policy-making is underpinned by science and engineering
- Oversight of departmental systems for ensuring that policy-makers consider relevant science and engineering evidence
- Assuring the application of the 'Principles of Science Advice to Government' to all external scientific advice to their department
- Oversight of the effective operation of any departmental Scientific Advisory Committees
- Working with CSAs in other departments to share good practice across government and maximise the collective expertise of the CSA network to identify and resolve cross departmental problems

This and further guidance on the role of the CSA can be found in: https://www.gov.uk/government/publications/chief-scientific-advisers-and-their-officials

8. It might be added that the CSA's role has both an "outside-in" and "inside-out" quality, building bridges and relationships between government and the wider worlds of science and technology. The role of the CSA has been described as that of a "licensed dissident", providing challenge and leadership at the centre of the department. This is a distinct role to that of Director of Analysis whose role it is to oversee the analytical resources used in the development of policy. The CSA should usually be a distinguished external scientist, recruited externally. They

should bring deep science and/or engineering knowledge and be able to work fluently across a range of science. It is an advice role that derives authority from knowledge, the ability to convene respected authoritative groups, and personal standing in the scientific world. It has a clear outside-in function (understanding what is going on in the world of research and bringing the best of it into the department) as well as helping with inside–out communication (building partnerships and networks for more effective innovation). It provides challenge at the most strategic level.

9. To carry out this role successfully, CSAs need to be excellent communicators and collaborators. This includes operating with confidence well outside their own discipline, and building strong working partnerships with Ministers, officials, and external collaborators alike.

10. This Review has a number of recommendations relating to the governance of science within departments. In practice the CSA often plays an executive role in these, but this should not be to the detriment of these critical leadership and challenge functions. Whatever the position, it is important that this core challenge function should be retained, and that their role should include giving assurance that such processes are fit for purpose.

11. To perform this role adequately requires sufficient resource (both in terms of staff and research budget), and provision in many departments falls short of what is required to perform it fully. There is a case, for instance, for all CSAs to have access to a budget for the conduct of department-specific Foresight projects to provide evidence to inform strategic decisions as well as work to deepen the evidence available to Ministers to support specific decisions.

The purposes of science in departments

12. Government invests in science, evidence development, and the underlying capability which helps supports them, for a wide range of reasons:

- At its most transformational, government investment in science helps to take forward society's understanding, particularly where long-term trends are fundamentally changing the context within which government operates. The Hadley Centre for Climate Science and Services was first created by the government in 1990. The development, by the former Department for Energy and Climate Change (DECC), of the 2050 Calculator is another example.[13] This award-winning computer model allows citizens to put themselves in the place of policy-makers and model the implications of their own policy decisions for the reduction of UK emissions, clarifying the trade-offs and interdependencies that affect the decisions involved. This work has had an

[13] The Calculator is now owned by BEIS, following machinery of government changes, and is available here: https://www.gov.uk/guidance/2050-pathways-analysis.

international impact; a version of the calculator has been developed by the Chinese government.

- Policy-makers need to have direct access to the best scientific evidence and advice in order to ensure that robust decisions in the short term are made. Science can reduce risk around policy decisions and provide options which in turn reduce future risks. For instance, departments involved in policy relating to air quality interventions are currently working on the Clean Air Strategy. The Department for Environment, Food & Rural Affairs (Defra) -led initiative aims to reduce atmospheric pollution from all sources, including emissions from agriculture, industry, transport and in the home.

- The development and presentation of evidence which will enable public service delivery partners outside government to make robust decisions. For instance, DfE funds work by the Education Endowment Foundation, one of a network of “What Works Centres” which presents the evidence underpinning a variety of classroom interventions and their impact on educational outcomes in a way that allows managers to compare the costs and benefits of the various options at a glance.

- Departmental implementation and operational delivery has a need to access technology development to ensure policies are implemented effectively, for example creating market conditions to facilitate implementation, or meeting statutory requirements and operational delivery for example, deployment of science for environmental monitoring. Examples include Food Standards Agency (FSA) collaborative programmes with industry partners (both large and small) in areas such as Internet of Things, blockchain and use of sensors to develop more efficient and effective approaches to Food Chain Information and the Collection and Communication of Inspection Results (CCIR).

- Science builds resilience in order to respond effectively to emergencies and crises. Most prominently, this is the role of the Scientific Advisory Group in Emergencies (SAGE) at times of particular need, but there is a very extensive network of relevant capability across government. This is critical for the protection of the UK population, but also in providing global leadership. For instance, the expertise of Public Health England (PHE) in epidemiology was critical in supporting the government’s work to tackle Ebola. MOD capability at Porton Down has again demonstrated its importance in response to the Salisbury and Amesbury poisonings.

- Science provides a valuable element of the government’s international partnerships. It is a key element of “soft diplomacy”. There are many areas where relationships with other governments are taken forward through direct scientific collaboration between governments: work with our closest allies on the sciences of security are a familiar example. As the UK prepares to play a more independent role in respect of trade policy, technical expertise will form an essential part of our ability to settle on the standards which underpin our trade agreements.

- Government science can also promote prosperity, innovation and productivity in the wider economy. Businesses work with the Health and Safety Laboratory (HSL), for instance, drawing on its expertise and experience on the safety of technologies in the workplace, helping solve common problems in the transition of new products to market.
- Government science has an important role to play in the delivery of public services, including justice. For example, the Forensic Explosives Laboratory within the Defence Science and Technology Laboratory (DSTL) has been important in providing expert evidence to secure convictions of the Parsons Green bomber, amongst others. The scope, quality and strengthening of the UK's forensic science capability is important more generally, and forensic analysis, in its many forms, can be applied more effectively to assure us of the provenance and authenticity of the goods and services that we buy and use, as has been highlighted recently by the Government Office for Science.[14]
- Government science also has a role in sustaining excellence in the UK academic science base. The Met Office Hadley Centre has partnerships with a number of universities on climate science, and itself has a first-class track record in the publication of cutting-edge climate science.
- Government science also improves operational processes: for instance, the application of mathematical modelling to improve queuing systems at the 2012 Olympics and at airports. Science can also be used to challenge existing policies and process.

13. This diversity of purpose is reflected in the diversity of departments' specific science needs. One of the lessons of this review is the widely divergent circumstances – from the scientific and technological point of view - within which Departments operate.

The attributes of a successful science system

14. Science leadership sits within a system. This report addresses the various aspects of this. It would be useful to outline the components of a well-managed programme of science, evidence-gathering and research and development.

15. To be successful, a department's science system needs to:
    - Establish an ambition and a vision, and its policy and operational priorities for those areas where directed investment in research and implementation will drive transformational change for government and its operations.
    - Gather evidence and make it useable for decision-making – by the commissioning, and conduct of, effective evidence synthesis.
    - Be highly connected internally – working towards the development of a common language between Ministers, policy officials, scientists and analysts,

[14] https://www.gov.uk/government/publications/forensic-science-and-beyond

to ensure that the possibilities and limitations of science are well understood; a shared sense of what science brings to the department, and clarity about its role in meeting the government's objectives.

- Understand what data we and others already have and how this could aid government – valuing data as an asset (amongst others) which can both leverage external capability and be used to help test and implement policy.
- Be well connected externally – with other government departments as well as the world outside government – to seek new ideas and ways to implement them.
- Be able to challenge itself on its own ideas – finding mechanisms that provide peer review, challenge group-think, test internal capability, and bring diversity into its thinking;
- Have a clear set of requirements from science users that do not change on a timeframe that is inconsistent with the discovery process – allowing research to be commissioned effectively whether internally, externally or through other intermediaries.
- Discover things – identify new policy options, the art of the possible, evidence on what works.
- Choose and implement from discovery into a development process – be able to take ideas and enable their use by government, the public and industry.
- Be clear about proprietary information, what must be accessible and what must be done in-house – it must have a clear idea where government must invest to maintain national security, secure key alignment with allies etc., and where existing markets are not strong enough to deliver government policy/needs.
- Manage value for money. The system should be effectively managed, and open to meaningful scrutiny.

16. All of these point to the importance of a well-developed **science strategy and leadership within government departments**, with the following components:

- A CSA who champions the role of scientific evidence, provides strategic direction on balance of investment in research and development, and who is accountable for research investment and its application to policy-making.
- Communication – in two directions: reaching out to scientists beyond government to build partnerships and understanding, and an effective approach to the synthesis of the latest evidence and presenting this in ways that are most effective in informing decisions at all levels, and clarity around the purposes to which science is, or ideally should be, put.

- Governance - assuring R&D governance structures are fit-for-purpose, both in relation to research delivered within the department and through partnership with others.
- Delivery – assuring excellence in the delivery of R&D and quality in its products.

17. This might be seen as encompassing a number of functions:

- **A strategic leadership function** – as described above.
- **A Commissioning function**– being an Intelligent Customer (and Partner) for work commissioned internally or externally, capturing and translating and helping customers develop their needs – developing senior user relationships and understanding our customers' needs to inform the design of research and development programmes.
- **A function for building and retaining in-house expertise** – retaining institutional knowledge about R&D previously undertaken, and established relationships across the science base - government undertaking measurement and monitoring, R&D too sensitive for government to be outsourced, fields where the government possesses world-leading capability (e.g. the Met Office Hadley Centre's climate modelling).
- **A function for building external relationships** – with Scientific or technical analytic services, Universities, procuring science services, and Mission-Driven Programmes.
- **A specialist capability function to support external engagement and harnessing innovation** – enablers such as venture capital, business development and scouting and accelerator type functions.
- **Direct support (where appropriate) to operations of government** – including frontline engagement across a range of operational capability (i.e. national security, courts and justice etc).

A key function: Needs capture

18. The ability to identify need is an essential element of all this. **Science leaders** have a key role in:

- Understanding the breadth of a department's responsibilities, both in policy and operational terms;
- Identifying areas where evidence, research and development are of potential use in supporting the department's work
- Fostering meaningful conversations between the staff responsible for the development of policy and other functions (finance, human resources,

operational delivery), and the world of research – both internal and extramural; and

- Brokering solutions and partnerships to address those evidence and research questions.

19. A central function of the government science system is the ability to **capture departmental science requirements** (particularly from policy officials and Ministers) from those who may not themselves have a close understanding of the relevant technical areas. There are a range of models across departments. For example, MOD has a particularly well-developed system, which was put in place following a review of its own capability in 2015: see the text box below. This includes an S&T policy function to work with and mediate between deep technical / subject matter experts and key decision-makers.

20. This can be particularly complex where parts of government's science capability address the needs of multiple government departments. For instance, the Met Office (which is owned and sponsored by the department for BEIS) provides forecasting and modelling in many different contexts for customers across MOD, the Department for International Development (DfID), Defra, and BEIS to name but a few.

21. One possible approach (which addressed some of the potential weaknesses of outsourcing science and technology capability) is that adopted by MoD:

MOD as a customer for commissioning science from its arms' length body

A review of the health of scientific capability in MOD in 2015 identified areas where capability could be strengthened, but also noted problems in the way MOD had established the commissioning function for science with its arms' length body, DSTL.

The report by the previous GCSA noted:

- "There is a confusion between the customer and provider of S&T, with a blurring of the role of DSTL, which acts as both customer and provider for the MOD and Armed Forces"
- "in the absence of a clear S&T strategy from the customer/ funder it is very hard for DSTL to allocate its resources in the most effective and responsive way"
- "it creates invidious choices for DSTL to decide how to allocate resources between its internal programmes and external providers",
- "the customer cannot hold the provider to account for the quality of its work if it is effectively one and the same organisation", and
- "furthermore, the way S&T requirements are increasingly refined and interpreted into the programme across this blurred customer-provider split potentially drives out opportunity to access new S&T capability and to provide technology-push for new innovative solutions."

In response, MOD has established a robust commissioning mechanism. The existing strategy directorate was strengthened to introduce a clear separation between customer and provider, including an additional customer engagement function, a strategy function to identify and translate requirements and develop capability needs, and a portfolio office which undertakes commissioning and portfolio design of programmes. Existing project management and stewardship of capability remains in DSTL.

The customer engagement function works closely with end-users in the Armed Forces to identify where science can solve problems, fill gaps in capability and meet their needs. This involves having a knowledge of the programme, relevant new and emerging science and technology, as well as individual end-user priorities.

MOD's programme is substantial and involves a wide variety of technologies, natural sciences and engineering. The portfolio function draws on best practice for commissioning and rebalancing the portfolio, managing successful programmes, and developing coherent mandates for programmes of work to be developed by DSTL for internal and external delivery. Programme Boards allow key stakeholders to assess delivery and progress.

22. Other examples of good practice include the FSA, where clear governance structures surround biannual discussions by the FSA Board on the basis of reports by the CSA and chair of the Agency's independent scientific advisory council. In many Departments, however the articulation of need and the process of planning how those needs will be met is fragmented and conducted in silos.

23. Where commissioning is excessively diffuse, this can get in the way of effective oversight. As one senior official explained to the Review, it was unclear to whom they should turn in their department to determine whether the overall amount of science activity was right. There is an important leadership function here, and it is a core part of the CSA's role to give the assurance to Ministers and the Permanent Secretary that such a plan is in place and that it meets the relevant scientific needs. In some departments if may not be the role of the CSA to run the plan or even necessarily to make use of it, but the CSA should provide the overall assurance and approval that such a plan is in place, and that the department has the scientific resources it needs to implement it.

Recommendation 1 – *Every department should have a clearly defined science system. A central role here is leadership in the articulation of the entire range of a department's science needs in a single document which is endorsed by the department's Executive Committee. This should form an integral part of overall business planning within departments: unlike Areas of Research Interest (see below) it should address the whole range of science activity conducted within the department and at arm's length from it. It should also include mechanisms for how non-government funded R&D will be used and incentivised. A core part of the departmental Chief Scientific Adviser's role is to be accountable for the existence of such a plan, signing off on issues including prioritisation, ensuring that it addresses the key science issues facing the department throughout its operational work and policy cycle and that these will be tackled in the most appropriate way.*

Areas of Research Interest

24. There has been a significant new development since 2015, with the publication of departmental Areas of Research Interest (ARIs). This was a recommendation of the Nurse Review[15], which recommended Statements of Research Need be developed as a means of dialogue with the Research Councils.

25. The effective articulation of a department's research and evidence needs is not a straightforward proposition and many departments have found it difficult. Both Defra's and the Department for Work and Pensions' (DWP) documents were the product of two years' intensive work. The ARIs should be regarded as a vehicle for a deeper culture change, placing an awareness of science and research at the centre of strategic policy thinking. This is not currently the case in most of government, and further iterations of the documents will require persistence and leadership to take this forward. Ideally ARIs should set out more enduring needs of research, rather than ad hoc and tactical needs. However, regular updates (ideally yearly in line with departmental plans) should be undertaken to ensure these documents remain fresh.

26. Many of the existing documents have a "bottom-up" character, constituting an aggregation of multiple issues relevant to many specific policy areas. Further work is needed to clarify the really major areas where sustained R&D investment would be most transformative for government and the society it serves. This will require greater involvement from the policy profession. As an example, MOD has worked across policy teams to develop and publish a 'Defence Technology Framework' to prioritise investment[16].

[15] A review conducted with the UK research councils, to explore how they can support research most effectively. The aim was to ensure that the UK continues to support world-leading science. https://www.gov.uk/government/publications/nurse-review-of-research-councils-recommendations

[16] Defence Technology Framework available here: https://www.gov.uk/government/publications/defence-technology-framework

27. To date, 15 government departments have published ARIs. The research questions and statements in this body of documents draw on a broad range of themes and disciplines, even from within a single department. These documents already illustrate a number of areas where there is a need for more capability in future areas of policy and operational delivery that cut right across government. These crosscutting themes include:

- Behavioural Science (a very wide range of topics relating primarily to lifestyles, and the way in which people interact with public services);
- Data (data science, digital services, open data);
- Many health issues that have significant impact on lifestyle, and therefore upon the government's ability to manage public services effectively across the whole range of its responsibilities (mental health, disability, well-being and chronic disease);
- Demographic issues relating to the UK population, including the combination of the multiple vulnerabilities which characterise prolific users of public services;
- Security; and
- The environment, climate change and its implications.

28. This is the start of a process that is already bringing benefits: both in developing departments' internal capability for understanding the scientific and technical context within which policy and delivery mechanisms are developed, and (through publication) leveraging the work of external communities of interest to develop research and evidence. The example from Japan at beginning of this chapter (paragraph 3) illustrates the potential if this process is done well. Two examples illustrate how departments are doing so.

DWP and Defra: using ARIs to build wider research capability

DWP carried out a series of half day workshops at several UK Universities to disseminate their research questions to academics. They called this their "ARI Roadshow". The universities which hosted these workshops included the Universities of Bristol, Cambridge, Sheffield, Manchester, Newcastle and Durham and further workshops planned for Universities of Leeds, Essex, Kent and East Anglia. The structure of the workshops was co-developed with members of the universities, but all included presentations and discussions with academics whose current research was relevant to the DWP ARIs; future work which DWP could contribute or advise on; and evaluating the ARI as a tool for fostering collaboration. The DWP ARI Roadshow has resulted in an expansion of DWP's network of interested academics and the submission of research grants which related directly to questions framed in the ARI.

Following the publication of **Defra**'s ARIs in March 2017, Defra worked with the Royal Society to hold a two-day science and analysis conference where the ARIs (and science in Defra more broadly) were discussed with nearly three-hundred academics, government scientists, analysts and policymakers. The conference helped build on and further develop strong links between academia and Defra policy and evidence officials. The conference now takes place annually, where strategic science and analysis issues across the Defra group are explored. This provides an important opportunity to maintain an effective dialogue between academia and the Defra policy and evidence community.

29. As well as considering the content of the ARIs, the review commissioned advice from the Government Office for Science Horizon Scanning team regarding the global trends that will require the development of new forms of government science capability as a whole in coming years.

30. The key themes echo many of those in the ARIs:

- Technology and data (algorithms, big data, automation)
- Norms and institutions (e.g. new regulatory frameworks, changes in consumption patterns, new and emerging issues relating to privacy and security in the context of rapid communications technology change)
- Environmental and resource stress (e.g. climate change, demographics), and
- Economic shifts (e.g. globalisation).

31. Very few of these trends align precisely with the responsibilities of any single government department, and yet the complexities resulting from them are significant to many departments' work.

32. Government should actively seek to promote a culture of research and continuous learning within the civil service to address these challenges and opportunities. This necessarily entails better networks with specialists inside and outside government. One Permanent Secretary said that the further development of **ARIs should be at the centrepiece of this, and there is a need for closer dialogue between the CSA, departmental analysts, and Heads of Policy Profession in departments around them to help develop this culture**.

33. The ARIs represent the first generation of a set of documents which will continue to be refreshed. Some already have been. There are a number of improvements which would increase their impact. Some are not consistently presented. The balance between truly strategic and more tactical issues needs to be clearer; with a clearer statement of the challenges and problems departments face. Some are more focused on the natural sciences, whilst some are more focused on other disciplines, including economics. Their consistency and user friendliness could be improved: for instance, references and guides to relevant datasets would increase

independent researchers' ability to go beyond the questions themselves and be guided to resources that would help consider how those questions might be addressed. This would bring more minds to help address key government R&D questions. ARIs should be available through department websites and a single webpage hosted on the Cabinet Office website.

Recommendation 2 – *All Departments should publish, and refresh annually, Areas of Research Interest documents with a view to encouraging extra-mural activity and collaborations and the commissioning of key R&D. They should be co-developed by Chief Scientific Advisers, Analysts, and Heads of Policy Profession in departments, putting scientific thinking at the centre of departmental processes, including policy and operations. The Government Office of Science, with CSAs, should make the documents consistent and ensure they provide potential collaborators with the key information (including the availability of data) that they need to engage effectively with the relevant research questions.*

Chapter 3

Government science: methods of delivery

1. Science for government may be delivered through a wide range of mechanisms. The following outlines at a high level the main vehicles whereby government's science, research and development requirements are met in practice, and the circumstances in which these forms are appropriate.

2. This chapter is intended to give a broad overview of the entire range of activity, and some recommendations for government in relation to specific approaches. It is not suggested that all the approaches (or even most of them) are relevant to any given government department's work.

3. The ability to determine which approach is appropriate, and to provide the relevant level of managerial and frontline resource to it, is itself a form of capability. It is important to note at the outset the critical importance of retaining **internal scientific capability within government to perform an effective commissioning function**– with a view to government being an Intelligent Customer for work commissioned internally or externally. Part of this role relates to the issues addressed in the previous chapter: developing senior user relationships with the department and understanding those customers' needs to inform the design of research and development programmes. The function additionally entails:

   - Developing expert interlocutors within the policy and procurement professions– increasing the understanding and knowledge of our customers and key stakeholders on the value of S&T,
   - Developing exploitation – driving the exploitation of science and technology by our customers and reporting the 'golden thread' from identifying customer needs, through the commissioning and delivery of science and research through to its deployment – working with end-users at the outset to improve implementation,
   - Providing a gateway – integrating expert scientific advisers across the department and acting as a simple, single entry point to internal and external science and research,

- Understanding the latest activity in HEIs and the private sector, and how this might be leveraged, and
- The capacity to build and develop effective research partnerships (with UKRI and elsewhere) for applied and commissioned research, including full participation in research governance mechanisms, and retaining the ability to stop work promptly if it looks unlikely to deliver what is needed.

4. **In-house expertise**. Historically, this was the primary source of science, research and development and innovation for both public and private sector organisations. Internal government science capability remains important in many areas.

5. In practice, departments adopt a variety of organisational models for strictly internal expertise:

   - In some departments there is a centralised science team, line managed by specialist professionals;
   - In others, scientists are embedded in teams which are organised around a specific departmental policy area;
   - Elsewhere, arm's length models of administration are adopted. The Centre for Environment, Fisheries and Aquaculture Science (Cefas), is for instance an executive agency of Defra; similarly, PHE is an executive agency of the Department for Health. Under this model, the scientists employed are civil servants, but the organisation has substantial operational autonomy from its parent department. Similarly, DSTL is an executive agency of MOD, comprising more than 3500 staff with key capabilities in amongst others Chemical Biological Radiological and Nuclear weapons, Counterterrorism and Cyber. It absorbed the Home Office's Centre for Applied Science and Technology (CAST) in April 2018.

6. Whatever approach is adopted, the key requirement is to manage scientific staff in a way that secures all the advantages of a coherent, separate, profession, while maintaining effective partnerships with the other civil service professions which work with, and use, scientific output.

7. There are a range of specific circumstances where the retention of in-house expertise is advantageous, if not essential:

   - Some areas of science will be too sensitive for government to outsource, and as such must be done in-house.
   - Where the questions involved are relatively clear, relate directly to an immediate need, and the continuing need for the expert advice over time means that the retention of internal capability represents good value for money. To take an analogy from a different civil service profession, it is widely recognised that economic analysis is integral to policy development and the government retains in-house experts, working at all grades, for this purpose.

- Often the government needs to undertake routine measurement and monitoring, and this forms a substantial part of many departments' science programmes. This work is typically insufficiently attractive in commercial or purely academic terms for independent bodies to undertake, but it is critical to the effective conduct of a department's work.
- In some cases, government has a role for setting standards that underpin more ambitious innovation programs elsewhere, seen for example in the work of the National Physical Laboratory (NPL) in defining fundamental units of measurement.
- In addition to science work that is done in-house, much is directly commissioned with organisations that have established relationships with government (and commonly were formerly parts of government). Notable examples of this exist in the relationship between QinetiQ and MOD, and FERA (a joint venture owned by Defra and Capita).

8. Where science and research is conducted in-house, this should be of sufficient quality. This requires a strategy for the retention of research skills, and for conveying to potential applicants the relevance and quality of work within government. The review's comment on the importance of PSREs as leaders of directed research, below, are relevant.

9. An additional and critical role of in-house science capability is to help develop the science and data knowledge needed within the policy profession to ensure effective policy- and decision-making within government. There are further comments on areas of skills shortage within government's in-house science base, in Chapter 4 below.

10. **Public Laboratories, sometimes referred to as Public Sector Research Establishments (PSREs)** occupy the very diverse and complex territory between purely internal and external capability.

11. Public Laboratories – agencies supporting government in the conduct of directed programmes of research and development – play a prominent role in most countries' research and innovation systems. They frequently have a role in the delivery of mission-based programmes (archetypically, NASA in the Apollo mission) and in "de-risking" the early stages of innovation which would otherwise be unattractive to private investors.

12. They are prominent in many research ecosystems. In the United States, government laboratories are a very prominent force in the federal science funding landscape. Several relevant agencies have an annual expenditure of over $1billion. Spending plans agreed earlier this year include the following allocations, for instance, including (for the last financial year) NASA's science programmes, $6.3 billion, the National Oceanic and Atmospheric Administration, $5.9 billion,

and the US Geological Survey, $1.1 billion[17]. Funding is allocated by Congress. In Germany, an Institute model is well-established as the centrepiece of national expenditure on research and development, with both Helmholtz and some Fraunhofer Institutes providing support to government on translational and directed research. This includes work in developing policy advice. Funding here is sourced from both the federal and *lander* governments.

13. One characteristic of the research and development performed by many such laboratories is its strongly "directed" character – activity is planned with a view to the achievement or testing of a particular outcome, and research is managed as part of a programme, with multiple workstreams contributing to their development. The work tends to be programme managed to ensure consistency with the desired outcome. This contrasts with the principal investigator (PI-led) model which (rightly) underpins most curiosity-led research. These attributes are not unique to public laboratories, but it means that they can form an important part of a diverse research and development system - particularly in relation to the 'D' side of R&D - but they have not featured prominently in in UK policy. The dominant focus here has been more narrowly focused on value for money: in particular, frequent review to consider (i) whether the body needs to continue to exist and (ii) the appropriate legal status for it. There has been very little work considering their place in the round as part of larger research system serving key national priorities (with honourable exceptions in specific areas, notably a 2014 review of work on Animal and Plant Health[18]).

14. There have been a number of reviews and reports with findings relevant to Public Laboratories in general in recent years. Some themes of these reviews (all of which are consistent with the findings of this Review) have been:

- the importance of understanding the asset base that Public Laboratories hold and maintain, and the need for care in handling changes in status, particularly privatisation, in order not to lose core capability, or sign over assets which might be exploited more fully by government;
- the need for a more co-ordinated approach to the management and stewardship of Public Laboratories across government, given the multiple reporting lines involved;
- their role as repositories and stewards of key scientific skills, infrastructure and know-how (whose importance to government often comes to light most strongly where it is needed in response to emergencies);

[17] https://prd-wret.s3-us-west-2.amazonaws.com/assets/palladium/production/s3fs-public/atoms/files/Fact%20Sheet%20-%20USGS_0.pdf
[18] *Animal and Plant Health in the UK: building our science capability,* available at: https://www.gov.uk/government/publications/animal-and-plant-health-in-the-uk-building-our-science-capability

- their value in supporting wider research and innovation systems, above and beyond the provision of services direct to government. This can be particularly important for local links to business;
- their potential role as hubs for economic growth and activity, particularly outside London and the South East; and
- the case for allowing those Public Laboratories which are owned by government departments to compete for research funding on a level playing field with universities and other research institutions (subject to the important proviso that this should not dilute research excellence)

15. In addressing Public Laboratories' functions, we should emphasise their value in the provision of strategic directed R&D leadership. They have an underexplored potential to play a key part – alongside universities and the private sector – in the delivery of mission-based funding, which is becoming increasingly prominent in government innovation policy.

16. The following table lists some of the various Public Laboratories' more narrowly focused *service* functions:

Table 1 – Some of the general functions of Public Laboratories

Customer-focussed functions	Additional functions, positive externalities and wider benefits
To provide services to government • Statutory/regulatory functions • Information to departments e.g. monitoring developments in the human or natural environments for policy making • Policy-related research • Improving public services **To provide strategic capacity to the government** • Addressing a market failure • Emergency Response • National Security • Custodians of critical collections (e.g. data or specimens)	• Scientific advancement • Innovation • Supporting businesses • Local economic growth • Knowledge transfer • Developing skills

17. Some specific examples of what this means in practice follow.

The work of Public Laboratories in practice

Leading a trailblazer apprenticeship for DfE – The National Physical Laboratory led a consortium of 30 employers to design a new Level 3 standard that sets out the knowledge, skills and behaviours required by Metrology Technicians across a wide range of industries. This is the first nationally recognised apprenticeship standard in metrology; it will ensure apprenticeship training is relevant and beneficial to the future of the metrology industry.

Increased international collaboration on nuclear research - The National Nuclear Laboratory (NNL) is a leading player in raising the profile of UK nuclear skills and capability, driving innovation for economic growth. In September 2018, NNL facilitated the signing of the Nuclear Energy Research and Development Cooperative Action Plan between the Department of Energy in the US and BEIS. The plan recognises the important role civilian nuclear energy serves both now in the future for clean energy, and builds on a long-established history of civil nuclear cooperation between the two nations. This increases the attractiveness of the UK as a hub for nuclear research and innovation, attracting international researchers and inward investment, core objectives of the Industrial Strategy.

Supporting SMEs to scale up – as a vital part of all new product developments, The National Physical Laboratory supported 76 companies with end-to-end measurement health checks and subsequent support across the advanced manufacturing value chain, as part of its through product verification programme. Within 45 of these companies £10.5M of quality improvements were identified and two companies have received £27M worth of orders attributable to this support.

Helping UK industry win international business - The UK Atomic Energy Authority (UKAEA) plays a leading role in the world fusion programme, and runs the UK's national laboratory for fusion energy R&D. UKAEA can therefore advise UK industry on overseas opportunities, and provides UK companies advance notice of contract opportunities and specialised advice on technical requirements. Through UKAEA's support, the UK industry has won over €500M of business from ITER, the French-based global £10bn+ project to build an experimental fusion power station.

18. Representatives of a number of departments raised with us the complexity of the commissioning process relating to some of these bodies. With longer standing research providers, some departments have developed procurement frameworks which reduce the administrative obstacles involved allowing commissioning to happen to a timescale that reflects the demands of the policy cycle. There is scope to develop this approach to embrace more of these bodies.

19. Not all of the international institutes treated here as "research organisations" resemble Public Laboratories in the UK context. Nevertheless, the figures are indicative of what one recent commentator has described as a decline in the perception of Public Laboratories as participants and leaders in research excellence (particularly important in areas of development and application) in the UK over the last sixty years.[19]

[19] Hill, Edward (2018) The place of research institutes in science and innovation.

20. Their profile with policy-makers (most of whom will know the university system from first-hand experience) is also considerably lower than that of universities, even though many form part of government. The scientific assets (both physical and human) that Public Laboratories contain can be insufficiently understood, and therefore are insufficiently exploited for purposes that go beyond their sponsoring department's immediate needs, e.g. key longitudinal expertise, know-how, data and resources. These benefits can take many forms, for instance:

- reaching out to local communities in the provision of science education;
- building collaborative partnerships with foreign government agencies (this has been particularly important in the co-ordination of emergency response);
- making data and other research assets open to the wider research community; and
- engaging in activity with businesses to promote innovation and economic growth.

21. Public Laboratories in practice do many of these things, but in an ad hoc, uncoordinated way, and this is not widely recognised when the government is developing cross-cutting strategies in pursuit of these wider objectives. A further difficulty arises as the department responsible for the government's broader science and innovation strategy, BEIS, only has responsibility for the sponsorship of a small number of the bodies. More needs to be done for stronger cross-government communication with Public Laboratories, with a view to: (i) intelligence-sharing on research opportunities and other managerial issues, and (ii) for greater engagement with this important part of the research sector in the development of broader government strategies.

22. The focus of this review is activity funded directly by government spend, but in this respect public laboratories need to be seen as part of the wider research and development system. It is critical that government engage closely with UKRI (which has direct responsibility for a number of internationally significant research institutes) as it works on this.

> **Recommendation 3** - *The Government should create a policy-focused Forum for Public Laboratories, to raise their profile within government and to create greater knowledge exchange about their role amongst policy-makers. The Government Office for Science should lead on this, working closely with department sponsors. An early task for the forum will be to advise on the development of a framework for evaluating their performance and value.*

23. UKRI has opened up a number of excellence-based competitions to subsets of Public Laboratories, the rules of which are based on competition, and in particular the Research Councils' rigorous system of peer review, which is widely recognised as having been an important factor in driving the high quality of curiosity-driven

UK science. It is desirable that PSREs should be incentivised to develop excellent and competitive proposals with an outcome-focused, directive character.

24. Excellence – and ensuring that funds allocated on the basis of excellence are protected for that purpose – is paramount. Competitive processes for access to funds by PSREs should be no less rigorous than they are for universities, and it is incumbent on departments to ensure that laboratories' core funding for key services to government is assured through the normal routes.

25. Work by Julia Goodfellow (as yet unpublished) highlights the potential for Public Laboratories to contribute significantly to local growth through the development of partnerships with local businesses, particularly in innovative sectors. It argues that the approach taken with the Higher Education Innovation Fund, which supports local growth through universities, might be extended to the (BEIS owned) Public Laboratories within the scope of her work. With the government's commitment to raising the proportion of R&D in the economy as a whole to 2.4% of GDP, there is a case for extending such an approach more broadly.

Recommendation 4 - *The Government should make greater use of Public Laboratories as leaders in directed R&D programmes, and in supporting innovation through intermediate technology readiness levels. Government should give greater support to them in this role. This should include: a) departments ensuring that they have adequate long-term funding for the pursuit of their core missions for government; b) research funders opening up excellence-based competitions to Public Laboratories, where they might compete with universities and other research institutes, c) the creation of a specific fund geared to the work of Public Laboratories, for which they can compete for funds for innovation activities to be conducted in partnership with business, and d) clear processes for the protection and maintenance of intellectual property generated. BEIS as part of its 2.4% roadmap should address the role of Public Laboratories across government in supporting and enabling research and development in the private sector, and the accountability to deliver this should rest in the department in charge of that sector.*

Science Commissioning Function

The principles of a science commissioning function are that it should:

- Provide a clear distinction between the end-user and those setting the requirement of science, and the supplier
- Set out a clear strategy for science and its procurement, including understanding of supplier long-term capability
- Provide a framework for assessing the quality of work.

Key functions that departments must develop or maintain are:

1. A function to understand the needs of policy-makers, operational delivery and corporate functions of departments
2. A function for translating needs into programmes, commissioning and co-commissioning, and contracting with suppliers (internally and external)
3. A function for assessing output, translating and transmitting this to department users of science
4. Access to business development functions, including scouting, capability to deploy a range of business relationships, equity, strategic partnerships and contracting research.

Responsibility for the commissioning function must be maintained and managed effectively, this should be accountable to but independent from the Chief Scientific Adviser's role and advice to the Department. Central departments need to maintain specialists in-house, in order to be able to commission R&D effectively.

26. **External capability – commissioning.** The development of research and evidence can also be commissioned (usually under contract) from strictly external providers. Most government departments commission work in this way. Providers of research may come from the private, not for profit, or HEIs. This can be appropriate where there is well-established external expertise on a topic, where the question involved is sufficiently clear and defined for it to be set out in a contract, and where the need is unlikely to recur.

27. The above approaches all relate primarily to areas where the evidence or research question is clearly understood, and government is competent to take a primary role in the day-to-day management of the research (an Intelligent Customer). Different approaches, calling on a wider pool of leadership and innovation as well as on another sector's capability for research, are appropriate where government is either:

    - seeking to develop an active independent academic research programme in support of its objectives; or
    - (and this may be an objective only for a handful of departments), government is seeking to promote the development of cutting-edge innovation to be deployed in the direct pursuit of its policy objectives.

28. In these cases a variety of approaches involving various forms of joint governance – both with the higher education and the private sectors – are appropriate.

External capability – work with universities, university researchers and funders of university research

29. Beyond simple commissioning, government has many standing partnerships with universities and individual academics, and regularly commissions work from researchers employed in universities. These can take a variety of forms. Many individual academic experts are members of government Science Advisory

Committees (SACs). The Committees' responsibilities range from high-level strategic advice (like that of the Prime Minister's Council for Science and Technology (CST)), to specialised technical support (for instance, the UK Advisory Committee on Pesticides). The SACs clearly provide an important aspect of scientific capability to departments. There will be some instances where issues arising from the UK's exit from the EU will lead to additional roles for and need of SACs, and such areas will need careful consideration by the relevant departments to ensure the scope and governance of any new or existing SAC is appropriate. The Government Office for Science maintains a Code of Practice for Scientific Advisory Committees (CoPSAC 2011) and can provide advice in establishing any new SAC whether or not they are related to EU-exit.[20]

30. But SACs are not the only model in practice. DfID, for instance, has a very wide-ranging research programme and as well as maintaining a Research Advisory Committee, employs seven Senior Research Fellows on a part-time basis who provide permanent expertise across the disciplines while continuing to work in universities.

31. Short-term policy fellowships and internships are becoming more common. These can allow for working researchers to come into government for a short period (UKRI runs a range of these), or take the form of fellowships for policy-makers (like the University of Cambridge's Centre for Science and Policy's fellowships, which give individual civil servants exposure to a range of experts). Sometimes the government funds programmes of work by university departments over a longer period. The use of such mechanisms is uneven across government however. The Policy Profession Board and Government Office for Science will be launching a joint programme of work shortly to put this onto a more systematic footing across government.

32. The UK's universities are world leaders, and it is unsurprising therefore that the review found many examples of outstanding practice in the development of research and evidence relationships with universities, for instance:

- Work initially supported by the Department for Trade and Industry (DIT) at the London School of Economics (LSE) Spatial Economics Research Centre in the 2000s has utterly transformed, over a decade, the way in which economists think about the geographic aspects of growth. Related work is now at the core of the government's Industrial Strategy.
- The model adopted in the Government Communications Headquarters' (GCHQ) funding for the Heilbronn Institute in partnership with the University of Bristol (whose fellows spend half their time working on government projects, half on their own undirected research in mathematics) has allowed the government to secure access to world-class thinking on issues in pure mathematics that have vital applications in cybersecurity.

[20] https://www.gov.uk/government/publications/scientific-advisory-committees-code-of-practice

Both cases illustrate the potential that government research leadership has in catalysing the development of research communities in areas of work that are potentially interesting from a purely scientific perspective but might otherwise be neglected.

33. Government departments commonly enter partnerships with other research funders, in cases where there is an interest not only in the direct objects of research for a given programme, but also in catalysing the development of wider research programmes.

34. The Nurse Review of the Research Councils recommended that government's own research leaders should be represented on the individual Research Councils with a view to representing the interests of government's research interest as a whole. This is now in place, with CSAs members of all seven Councils and Innovate UK. Further work is needed to ensure that policy-makers and the other analytical professions are made aware that this resource exists.

35. There is a perceived tension between the need for academic independence and the need to ensure that work which was funded in part because of its promise in taking forward a government priority delivers on this potential. It is appropriate however that where funding is explicitly granted based on its relevance in pursuit of the government's objectives then there is a case for continuing engagement with government throughout the course of the specific work programme, in a way that does not prejudice the independence of the research findings themselves.

36. There are a number of existing models. DfID, for instance, is a long standing collaborator with the Research Councils, and has developed with them a strong joint governance model in relation to projects that are jointly funded by the Department and Research Councils.[21] This allows for joint governance in regard to co-funded programmes, including collaboration on appointments to peer review panels, with an emphasis on closer management of programmes with a view to ultimate impact than would ordinarily be the case.

37. UKRI's Strategic Priorities Fund (SPF) was launched in 2018, and one of its aims is to fund projects that support research and development relevant to the government's wider priorities. At the time of writing, a number of SPF wave 2 programmes have been announced, with CSAs playing a key role in articulating government's areas of priority need. Funds have yet to be distributed, and there is a need for delivery structures that are appropriate to the Fund's objectives.

Recommendation 5 – *UKRI should lead development of tailored forms of governance for research programmes relating to government strategic priorities taken forward under the Strategic Priorities Fund and related areas.*

[21] A summary of the DfID Concordat, which relates to work with all the Research Councils, is available here: https://www.ukri.org/research/international/international-collaboration/ukri-dfid-concordat/

External capability – open innovation approaches

38. One of the most important things government can do in unlocking the economic and social potential of the digital space is to make their data open.[22] By making data publicly available external actors can engage in open innovation, developing new products and solutions for market. However, simply making the data open and leaving it in a repository is not enough to realise the potential economic and democratic benefits of open data. Rather, government must adopt a more engaged and curated approach and must explore novel business models to capitalise on the benefits. This is exemplified in the Singapore government's open data platform.[23]

39. The significant efforts by the Singapore government to facilitate engagement have paid great dividends. In 2016 there were over 30,000 downloads from Data.gov.sg, and over 2 million Application Programme Interface (API)[24] calls per month. Coupled with public engagement with the data, the Singapore government also employs a significant data science capability to address public and policy needs. In the UK, many departments already make their data open however, it is sometimes the case that not enough thought is given to making this data usable.

40. We may compare this with Ministry of Housing, Communities and Local Government (MHCLG), who have adopted many of the principles seen in Singapore's approach, producing an accessible open data platform equipped with useful data visualisations and APIs.[25]

41. Departments providing academics with links to relevant government datasets in their ARIs could further support open innovation, as set out in Recommendation 2.

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[22] M. Chui, D. Farrell and K. Jackson, "How government can promote open data and help unleash over $3 trillion in economic value," *McKinsey: Government designed for new times,* 2014, and World Bank, "Open Data for Sustainable Development," 2015.
[23] Government of Singapore: https://data.gov.sg/, and C. M. Chan, "From Open Data to Open Innovation Strategies: Creating e-Services Using Open Government Data," 2013.
[24] An API is the description of the computer code that allows users to interrogate and display data from remote databases.
[25] Ministry of Housing, Communities and Local Government: Open Data available at http://opendatacommunities.org/home.

Open Data: MHCLG's open data platform

MHCLG engages extensively with open data initiatives. Particularly noteworthy is the MHCLG open data platform which is linked through the ARI document. This provides access to over 200 datasets in open and linkable formats, data from all 15 million Energy Performance Certificates and an interactive mapping tool for exploring the 2015 indices of multiple deprivation. Data is provided in machine-readable format, is coupled with useful data visualisations and helpful APIs have been produced to facilitate developer engagement. This more curated approach to open data is vital in fostering engagement, and opportunities exist across government for departments to develop similar open data platforms.

42. In addition to using government data to improve access to external innovation, government should explore how its own knowledge assets (KA) including intellectual property can be used to help open innovation. The government has undertaken a 'balance sheet' review of KA, which it published alongside the budget Red Book on 29 Oct 2018 as *'Getting smart about intellectual property and other intangibles in the public sector: Budget 2018'*[26]. KA in the form of intellectual property (IP), software, data, technological expertise, organisational know-how, and other intellectual resources, are of large and growing importance to both the UK and global economy.

43. Knowledge assets are both undervalued and underexploited in the public sector in the UK. Despite considerable investment in research, software, data, and expertise, the value of KA and other intangible assets reported in government accounts is just £34.5 billion or 2% of total public-sector assets in 2017. Given KA and other intangibles account for between 52% and 84% of the value of publicly listed companies today, the true value of KA in the public sector is likely many multiples of this. Realising the full value of knowledge assets in the public sector requires careful consideration of the balance between immediate financial returns and the wider economic and social benefits of longer-term financial benefits that these assets can generate. It also requires a series of deliberate actions to generate, protect, develop, deploy and scale the asset.

External capability – drawing on more innovative and private sector approaches: Mission Research, Venture Capital and Business Development based approaches

44. The following models are particularly relevant to those departments which have a direct need for the development and procurement of innovative technologies in the course of their core business: notably DfID, the Department for Health and Social Care (DHSC), MOD, and the UK National Security community, but will also be

[26] 'Getting smart about intellectual property and other intangibles in the public sector' published at https://www.gov.uk/government/publications/getting-smart-about-intellectual-property-and-intangible-assets

relevant to many departments, which aim to improve performance through innovation. An additional benefit of such approaches is their role in promoting innovation and R&D in the wider economy.

45. There are a variety of ways in which government can work more closely with the private sector on innovation programmes, than in a system purely determined by contractual arrangements. The exact approach to be used here depends on a number of factors including the extent to which the relevant R&D “question” is well-defined, and the maturity of the technology involved. Three main approaches are highlighted here: mission-driven, government venture capital, and business development approaches.

46. **Mission-driven research** where the problem is more developed. The most widely emulated example of this comes from the US, the Department of Defense’s Defense Advance Research Projects Agency (DARPA) model. At the heart of the DARPA model is the role of fundamental scientific research being used to address pressing societal needs. DARPA has developed truly ground-breaking innovations, with a portfolio including the precursor to the modern internet (ARPANET) and Global Positioning System (GPS) technology. DARPA projects must be ambitious, requiring significant advancement in the underlying science if they are to succeed.

47. **Key considerations of any DARPA approach should include:**

- **A significant up-front investment in problem definition**. DARPA functions with a high degree of independence from the US Department of Defense, having autonomy to select and run projects. It brings in temporary project teams, coupled with a competitive bidding process, to work on strictly time-limited projects. Using temporary teams allows DARPA to bring in large numbers of specially selected individuals to work collaboratively, with the time-limited projects creating an intense focus. Alongside this there is typically a very closely managed approach to projects. DARPA also functions with significant independence from the US Department of Defence, having the autonomy to select and run projects. To find leaders, DARPA leverages its extensive network and historical prestige.

- **The issue of talent acquisition for any new DARPA-like programme to succeed**. Another potential factor in DARPA’s success is the size of both domestic civil and military markets in the US to drive demand and pull-through of technology. The role of intelligent innovation focused public procurement is key. Several attempts have been made over the years, within the US government and beyond, to replicate the DARPA model with mixed success. The UKs Mission Orientated Innovation approach, together with recent work the Government Office for Science undertook on key factors in leadership and governance for the successful delivery of missions. A link to public procurement is key to the success of mission-driven approaches.

48. A **Government Venture Capital (GVC)** function, which rather than invest in specific research or solutions, provides capital to grow and develop small and start-up firms to a level that potentially provides these solutions in the future. Looking to successful examples of GVC, such as the US In-Q-Tel (the Central Intelligence Agency funded VC, which led to Google Earth) and DfID's Global Innovation Fund (GIF), **there is a significant effort and expertise placed on contractual due diligence**, before investment, significantly more than merely contracting research. In-Q-Tel employs around 200 senior people to work on this. Both In-Q-Tel and GIF draw up contracts where they work closely with the partner organisations to develop their innovations, dropping the investment if it is not progressing sufficiently. GIF possesses a tiered funding model focusing on scale, where the partner is only allowed to progress to the next stage having provided evidence of success at the current scale and funding level. Further details on the UK National Security Strategic Investment Fund (NSSIF), which supports long-term investment in advanced technologies, can be found in Annex D. Some of these funds are a mix between VC funding and collaborative research models.

49. **Successful GVC requires a detailed understanding of start-up culture, and a deep technical knowledge of the field on the part by the VC fund**. Studies of GVC programmes have found that GVC only really succeeds when there is also significant private VC activity, and often investments are syndicated. Before exploring GVC, thought must be given as to how to develop the start-up culture and greater leverage of private VC. There may be opportunities to leverage US experience and expertise and while it is easy to downplay the UK's experience when comparing to star performers such as Silicon Valley and Boston, London and the South East generally, remains a major draw for VC across Europe. This also requires a new way of thinking about procurement: understanding and helping make the best technology ready for government, rather than simply procuring technology exclusively for government. Particularly in the defence and security environment, there are opportunities to build a 'five-eyes' approach to have more global coverage for both VC and business development and science scouting functions.

50. **Business Development** (BD) involves capability for scouting for new and relevant technologies, the engagement of relevant experts for peer-review and validation, and commercial expertise to develop effective beneficial partnerships. Typically, the private sector use BD approaches to identify companies or innovations that can do something that is needed for developing their overall R&D objectives and for challenging their own internal R&D organisations. Typically, this function is more a department rather than government accelerator and research procurement programmes. The BD function may "compete" as well as collaborate with the internal R&D capability, helping to drive more rapid innovation and value for money. The BD model is of growing importance in several R&D intensive sectors, including pharmaceutical and many areas of engineering, where it provides a wide range of options for the firm to pursue as these develop (**including buying out**

companies if they are successful or taking equity stakes). It is linked to a venture capital approach but is driven much more by need (short and long-term) rather than the prospect of financial return specifically.

51. Adopting BD in government will require a more concerted effort to define clear research problems and will need government to systematise a culture where, at each stage of the R&D process, there is continuing review of how much work needs to be done internally and how much can or should be externally procured or partnered. Significant investment in "scouting" – intelligence-gathering from rapidly developing private R&D market places – and in the appropriate forms of financial control are also important. Such an approach could be very beneficial in national security, health services, and infrastructure projects.

52. These models could be applied more extensively in government.

Recommendation 6 - *The Government Office for Science should work with the UK Government Investments and the British Business Bank to explore the use of government venture capital and business development models in innovation, and to provide expert resource to support departments in developing these.*

Recommendation 7 – *The Government Office for Science should develop proposals for the implementation of business development functions, including experience from similar approaches taken from defence and security, to identify wider applicability. This will ensure that the landscape of small and large company activities is well understood, and we have good links with those companies and their backers and are able to exercise a range of business partnerships effectively. This work should then be taken forward within the centre of excellence. (See recommendation 13 below).*

Chapter 4

The right amount of science

1. This chapter will address the scale and balance of science activity within government.

2. A further critical **function** of an effective system of science and research leadership relates to decisions about the **scale and allocation of resource**. This is a complex judgement, and there is no universal, or ultimately correct, answer. It will reflect a number of variables, including (within a department) different departmental strategies. As a function, this has several components:

   - assessing the amount of activity required to meet a given department's needs as defined by the department's overall strategy set by ministers, and the most cost-effective methods of meeting those;
   - assessing the type of expenditure required (which is the appropriate delivery method, see chapter 3, where in the scale of research and development this sits);
   - making a case to other decision-makers within the department, whether ministers or officials, to ensure that adequate resource is allocated amongst other competing priorities.

3. The role that should form a part of core business planning, and – here as in other key areas – the relevant responsible official should sit on the relevant department's executive committee.

4. Research and development expenditure is recorded according to an internationally agreed standard, which is derived from the so-called Frascati definition:

   "Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge,

including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications."[27]

5. Not all science constitutes research and development, and may not be included within these figures, but the best proxy that we have for the scale of scientific activity is the ONS dataset "Government expenditure on science, engineering and technology" which is published annually. The latest published data are for the calendar year 2016.[28] Unless otherwise stated, the data in this chapter relate to that year.

6. First, it is important to note the very wide range in the scale of departmental budgets: the bulk of expenditure sits with four departments (particularly where there is a stronger element of international collaboration), and there is a long "tail" of departments where spend is of a lower order of magnitude. This is a long-standing pattern.

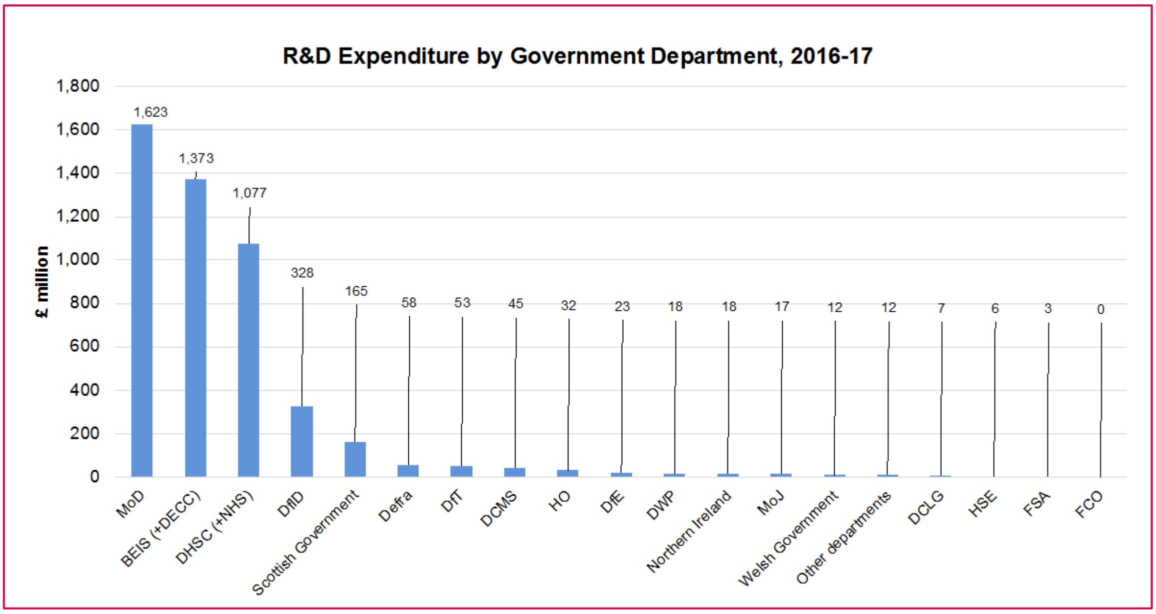


Figure 1 – Research and Development expenditure by UK government department 2016/17. Note that the "BEIS (+DECC)" column includes expenditure via Innovate UK, which is not within the scope of this review. Note this is departmental and does not include Research Councils funding through UKRI, but in 2016-17 did include Innovate UK.

7. The difference in scale to some extent reflects different departmental circumstances. The very largest budgets belong to those departments which sit at the centre of very significant public service delivery functions and need direct control over a wider range of research and development activities that relate

[27] A fuller definition is given in Annex A.
[28] These, and comparable data back to 2005, are available at https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/datalist

directly to their ability to deliver services directly. The position is quite different for those departments – for instance with the Department for Transport (DfT) or BEIS with regard to its energy functions – whose responsibilities relate to sectors where the relevant services are predominantly provided from within the private sector. The position is again different again for those departments (for instance Defra and BEIS with their responsibilities relating to climate change and the environment) where there is a general need to promote significant natural sciences research to inform decision-making.

8. Whatever the background to specific departmental allocations, it is clear that this pattern of spend has not come from any systematic review and is not obviously related to need. The scale of the relevant budgets reflect factors that have very little to do with scientific need: most importantly, the fiscal pressures confronting the relevant departments in general, and historical patterns of spend. There has been no attempt to assess the relative scale of the relevant opportunities and risks facing departments, nor an allocation of funds to secure research activity that reflects that scale. As the government reaches decisions at Spending Reviews in future, a zero-based approach founded on objective need and an understanding of the ever-changing scientific and technological context will be important.

9. The data is not uncontested. Several interviewees expressed the view that there is a risk, particularly within areas where R&D expenditure has been protected, that some borderline activity which may not represent research and development in the strict sense is included. The Review has some relevant observations below on how this tendency ought to be controlled.

10. The starting point for this review was a clear trend towards reduction in some of the smaller budgets, which raises some questions about the resilience of the government's science system.

11. In gathering our evidence, we explored in particular the implications of fiscal consolidation with representatives of the relevant departments, and the extent to which this endangered departments' resilience to future requirements. This brought forward a range of views. In some departments there was a sense that budgetary pressures had focused activity on statutory requirements and short-term tactical research in a way that was undermining government's ability to prepare for issues in the longer term. This was particularly marked in one department, where by the end of the current Spending Review, the amount of money available to conduct discretionary research[29] would have declined by 93% to about £1.8 million from a starting point of £27.7 million.

12. Strategically targeted investment made at the right time can have a powerful positive effect on the government's ability to perform its policy and operational

[29] i.e. science not required by statutory obligations or by short-term policy necessity.

functions. DWP's investment in a pensions model in the early 2000s is a case in point.

13. In other contexts, there was a view that recent reductions had been accompanied by a step change in controls over the quality of research commissioned by the department.

Some specific areas where more strategically focused expenditure is required

14. The Review identified several areas where additional provision should be seriously considered within the context of Spending Reviews. We explored the possibilities with two departments where budgets for strategic research have become particularly weakened. Our emphasis on Defra and the Home Office should not be taken to imply that comparable important work might not be undertaken elsewhere. Similar opportunities exist in other departments, but are perhaps less well understood – understandably so in those departments that do not currently have CSA.[30]

Scope for additional strategic research: Home Office and Defra

Home Office:

The review highlighted several areas of focus, where further STAR (Science, Technology, Analysis & Research) investment could support transformational improvement in performance across the Office:

- Data, data architecture, analytics and data science: E.g. invest in infrastructure to support mature data architecture systems capable of meeting cross-cutting data science departmental needs
- Enhanced technology, systems and capability to support operational needs: e.g. enhancing technology at the border (Future Border), including possible Brexit related technology and collaboration with Industry
- E.g. Expanded futures capability linked to strategic planning to enable us to get ahead of the threat, better understand the impact of emerging risks and opportunities to proactively shape strategic planning and investments, including - future threats, technologies and innovative approaches to Chemical Biological Radiological and Nuclear weapons and public protection, and
- Work to understand harder to research/measure phenomena: E.g. hidden harms and vulnerabilities such as to extremism and radicalisation, child sexual abuse and exploitation, modern slavery,

[30] At the time of writing, all Departments have a recruited CSA. The role is performed by the Director of Science and Analysis (usually appointed through internal government recruitment) at DWP, MoJ and DfE.

serious violence (knife crime via DASA being an example of this), serious and organised crime

Defra:

Additional funding would enable Defra to partner and strategically lead across the science community to develop new, self-sustaining, approaches to addressing strategic R&D needs across research funders.

Specific areas include:

- investment in research to tackle bovine TB;
- exploring how technology and innovation could be used to grow the food sector, build in long-term resilience for national food security and help the UK to meet its objectives for the environment. For example, understanding how unproductive agricultural land in the UK could support other functions, such as carbon storage, recreation and other public goods; and
- how new disruptive technologies could transform food manufacturing and processing. This could include exploring the feasibility and effectiveness of vertical farms within cities.

15. In a number of areas, departments have acquired substantial new responsibilities and the appropriate levels of R&D expenditure needs to be reviewed to match the amount of activity to the relevant levels of need. The Department for Digital, Culture Media & Sport (DCMS) for instance, has acquired responsibility for digital policy in the period since the last Spending Review, but has an R&D budget of approximately £2.5 million, which is primarily limited to the conduct of a survey dealing with participation in sport and culture ('Taking Part'). DIT faces a unique challenge, in the need to encourage the creation of an academic community geared to addressing the many challenges represented by the repatriation of trade policy. The capability to foster new research centres, for example in academia, would make a significant difference to its work.

16. In other areas technologies and the changing human and natural environments are changing in ways that require a step change in capability – namely **resilience, national security,** and **data**: Research is required to remain ahead of new and emerging threats. These are areas, for example, which cut across departments and where new and emerging issues can have a significant impact on national security. For example, the Animal and Plant Health Agency (APHA) have recently drawn attention to a number of emerging animal or plant health problems which might be heading to the UK because of climate change or greater mobility.

17. For **data,** there are needs for basic capabilities to ensure accuracy, integrity and quality across all departments. Increasing demand for wide-ranging data for data science and analytics, where up to 80% of time can be spent on finding,

organising, verifying and cleaning data, and use of these methods to support decisions, outline the importance of accurate and reliable data availability.

18. A common perspective was that where budgets (which for the most part represents expenditure on workforce) had been reduced most, the capability to deliver core science leadership and administration functions effectively is becoming lost. To do science today requires time and expertise in managing relationships through complex delivery chains, and contracts. An injection of funds alone is insufficient. There is a need for access to expert resource (be it centralised or led by a specific department of best practice) in facilitating the better management of expenditure.

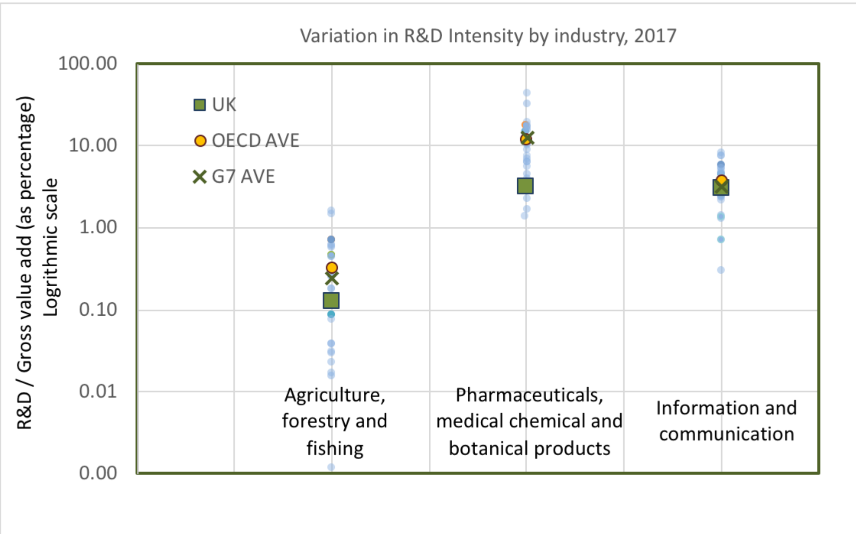
Protecting science expenditure

19. The vulnerability of R&D expenditure, particularly in times of financial restraint, is widely recognised. The implications of decisions about expenditure often go wider than those of the relevant department: for instance, where it is expected that a government need can be met from elsewhere in the government's research funding system. The need to manage both these risks was recognised in 2010 when a joint letter from the Government Office for Science and HM Treasury instructed departments to consult with them where a significant reduction was being considered. This has not been observed in practice. There is a need for greater accountability, particularly given the government's ambitions to increase the scale of the UK's research and development expenditure as a proportion of GDP. A public statement of R&D allocation will allow further external scrutiny.

20. Where ring-fences or other controls designed to protect research and development exist, there is sometimes pressure to redefine borderline work in such a way that it falls within the definitions. Clarity of definition is essential if the distinctive character of research is to be maintained. DfID has developed a manual – Research Spend Methodology and Reporting – which starts with the existing definitions used by the OECD and UK research funders and gives greater clarity on the boundaries between research and other work. Policy research papers, for instance, or literature reviews would not be included within the department's definition. This may be applicable in other areas; the departmental CSA should have considerable discretion and independence in making judgements at the boundary. The definition of government science provided in chapter 1 above should guide this. It is critical that work that does not create new knowledge (which is the essential aim of research and development) is not included.

Recommendation 8 - *Submissions by departments to HM Treasury ahead of Spending Reviews should incorporate a statement of research and development need and costed plans for meeting those needs (including an assessment of the percentage of overall departmental expenditure they aim to spend, in absolute terms, on science) and how this compares with international benchmarks for R&D spend in their policy areas. Departments should include a clear statement of where particular R&D work streams fit within the spectrum from basic to applied R&D. In support of the government's objective to spend 2.4% of GDP on R&D, departments should also set out plans for stimulating wider economy investment in R&D in industries of relevance to their policy portfolios. Consultation with the GCSA and HM Treasury should take place if there are significant deviations from planned expenditure.*

International benchmarks for R&D spend in representative sectors



When benchmarking departmental R&D spend, comparisons should consider the degree of uniformity with trends within the overall sector, as well as the role of the department in incentivising non-government funded R&D. *(from https://www.oecd-ilibrary.org/science-and-technology/oecd-science-technology-and-industry-scoreboard-2017)*

Clarity of purpose in planning expenditure: research vs development

21. A further decision in relation to the allocation of expenditure relates to the type of activity involved – in particular, where this sits on a spectrum ranging from the analysis of existing data, through basic research, to development.

22. To date there has been minimal aggregated data to inform any decisions that might be taken across government about the appropriate focus of government expenditure within this range. Such decisions need to be informed by a close understanding of the work of other parts of the system – which reinforces the

importance of the *scouting* function which is relevant to partnerships with the private sector, highlighted in the previous chapter.

23. This year, the ONS has started publishing a breakdown of the relevant expenditure according the following classifications that departments submit when making their returns: [31]

Basic research	is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.
Applied research	is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.
Experimental development	is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed. R&D covers both formal R&D in R&D units and informal or occasional R&D in other units.

24. The (simplistic and misleading) tendency persists to see this spectrum as the embodiment of an essentially linear process whereby an idea conceived in the abstract is processed through a series of set procedures and ultimately brought to market. However, it is not a linear process. The Nurse Review, when considering expenditure by the Research Councils, underlined the considerable complexity of the process, and the indistinct boundaries between all three forms of activity. It did, however, highlight the importance that there should be funding for each, and establishing the right balance should be established between them, in any national programme of research. Government has rather different objectives, but comparable decisions need to be made about the balance of research funding which is appropriate to government itself.

25. What does the data tell us about government's own expenditure on this spectrum? Statistics, prompted by this review, have only been published for one year, 2016. Departmental breakdowns are given on the following pages. The focus of government expenditure, as one might expect, has little focus on basic research, and is made up predominantly of what is defined as applied research or experimental research. It is unclear how rigorously data is collected and classified as there are some anomalies in the figures,[32] but prima facie one would expect

[31] These are taken direct from the OECD's Frascati manual. Further details are given in Annex A.
[32] The tendency of some departments to use only two categories, and others the entire range, suggests that the way data is treated varies in practice.

more work to be carried out at the "experimental development" end of the spectrum, where much research in the direct support of a particular policy would fit in, according to the definitions above. Whatever the true position, there is a case for clearer and more explicit decision-making about the precise role of government's interventions across this spectrum, particularly in the light of work that is already being conducted, or might be catalysed, in academic and private research contexts. Allocations need to be kept under constant review as new technologies, disciplines, and markets emerge.

26. The approach adopted by a government department should aim to complement activity funded by other agencies: note the focus of work by the National Institute for Health Research (NIHR), compared to the Medical Research Council (MRC), which funds more basic research:

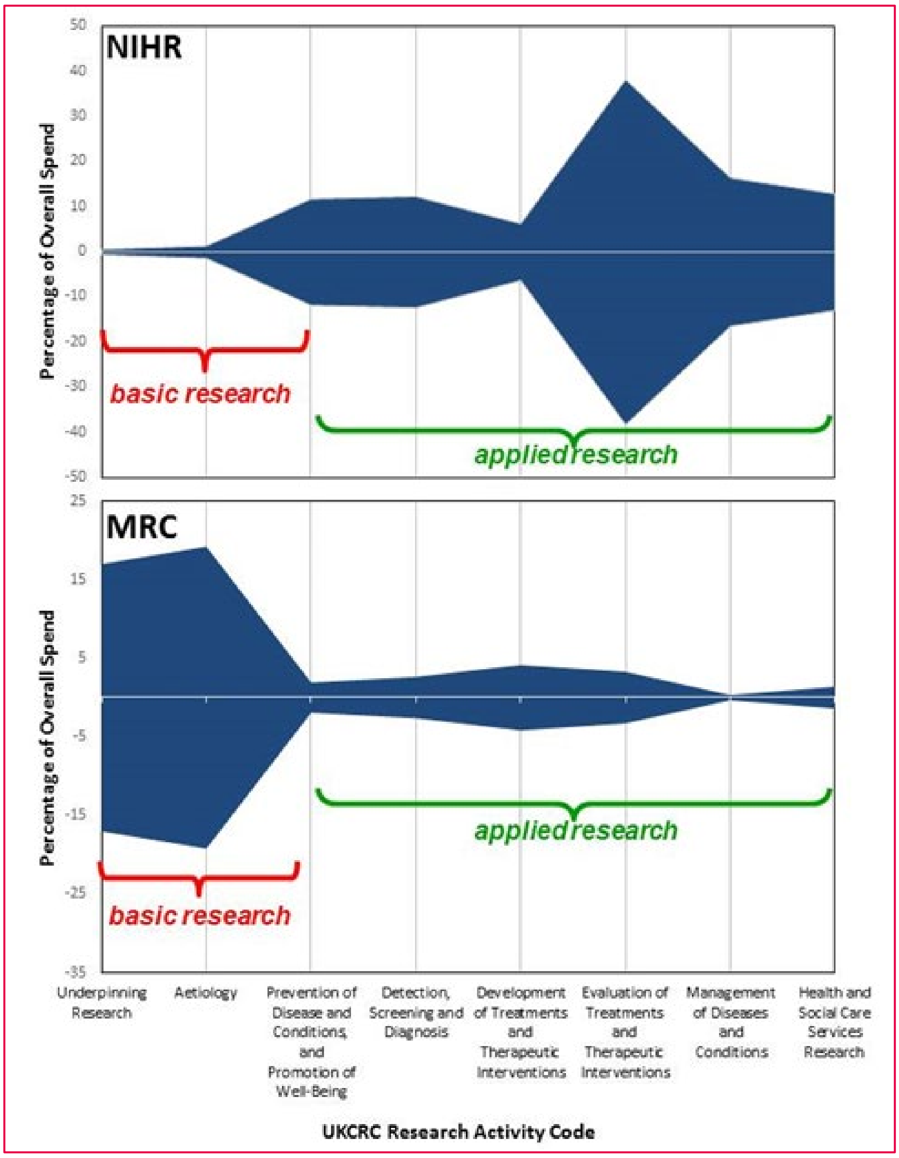
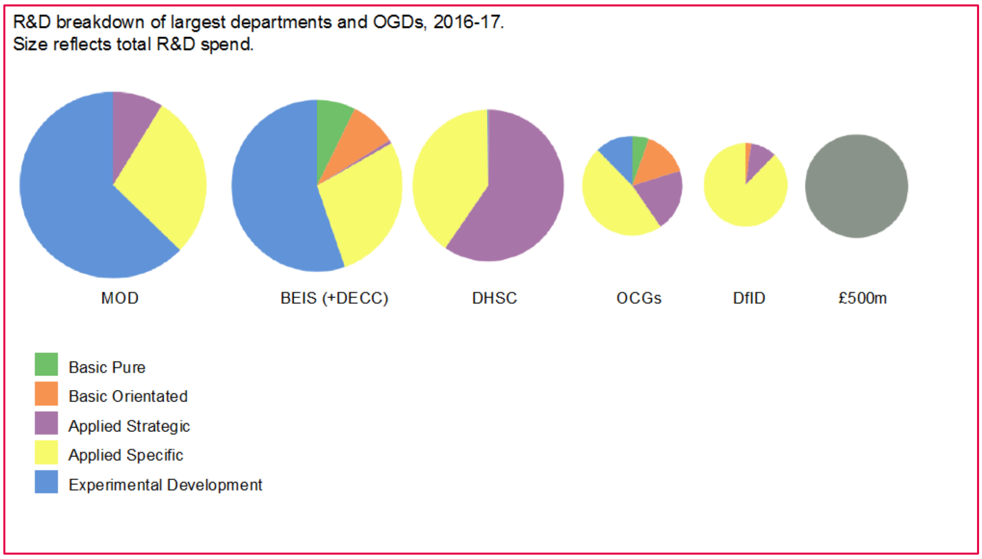
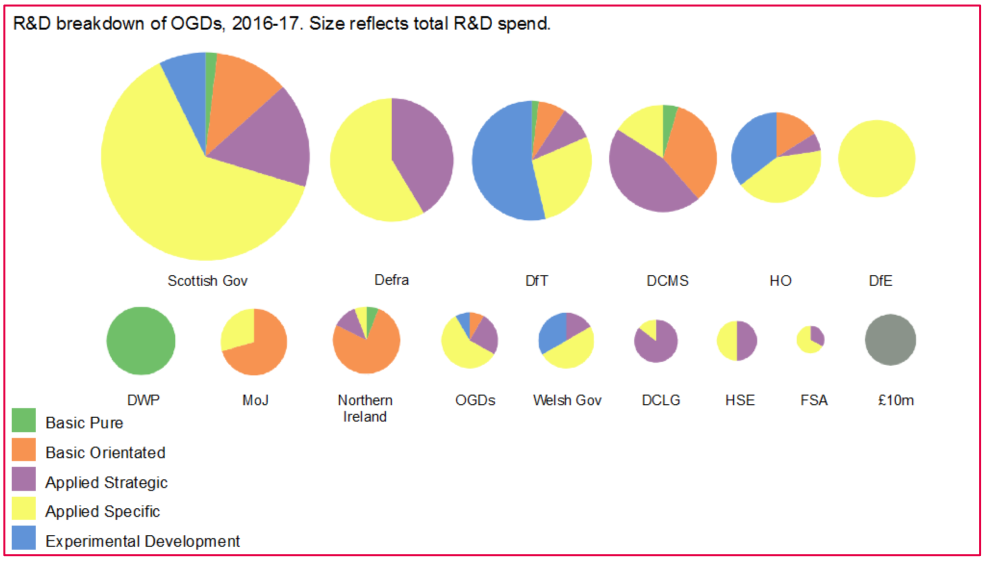


Figure 2 - Proportion of NIHR and MRC Expenditure by UKCRC Research Activity Code in 2014/15

27. Whatever the position in a given department, there needs to be a clearer rationale for the precise intentions behind a particular R&D programme. This should be underpinned by a clear understanding of the research currently being conducted in the department's particular context (both in academia and elsewhere) and accompanied by a clear rationale for the government's need to act to ensure that its needs are met. At times this will involve encouraging basic research where a particular problem has not been picked up by the academic world. This should usually be done through UKRI and suitable academic pursuit. More commonly for departments seeking to promote innovation in a given market, it will involve expenditure at higher technology readiness levels (TRLs) helping transform a promising idea into reality. Much of the time, government will need a very focused and applied piece of work in direct support of a particular policy or public service delivery need. The important thing is that these aims should be clearly articulated as part of a comprehensive science and innovation strategy.

> **Recommendation 9** - *The Government Chief Scientific Adviser should work with HM Treasury and the Office for National Statistics (ONS) to ensure that government expenditure on research and development is transparently reflected in public expenditure statistics, so that in the future there will be comprehensive data on which to assess spending on science within government.*





In both diagrams, the grey circle illustrates the scale of the total for the relevant department.[33]

The need for greater alignment of activity across departments and between government professions around skills

28. For many departments the main challenge in capability is less a matter of funding than one of people and skills. Some skills shortages are commonly reported, such as research commissioning, and data science. The discipline of systems engineering will become increasingly important as government seeks to equip itself to make effective investment decisions in environments that are marked by the interaction of complex interdependent technologies. This is particularly relevant to infrastructure of all kinds. Dame Judith Hackitt's Review of the Building Regulations and Fire Safety, which followed the Grenfell fire, emphasised the importance of a systems approach to regulation.[34] Comparable issues will confront DfT as it takes forward plans for an integrated transport system.

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[33] The Frascati Manual also allows for further breakdown of basic research into subcategories, as well as the long-standing UK practice of subdividing applied research:

- **Pure-basic research** is carried out for the advancement of knowledge, without working too long-term economic or social benefits and with no positive effects being made to apply the results to practical problems or transfer the results to sectors responsible for its application;
- **Oriented-basic research** is carried out with the expectation that it will produce a broad base of knowledge likely to form the background to the solution of recognised or expected current or future problems or possibilities;
- **Strategic-applied research** is directed towards practicable aims, but has not yet advanced to the stage where eventual application can be clearly specified; and
- **Specific-applied research** will have quite specific and detailed products, processes, systems etc. as its aims.
- **Experimental development** is systematic work to installing new processes, systems and services, or to improving substantially those already produced or installed.

Note – not all departments have applied this additional breakdown within the current published statistics, for example DWP research is not 'basic pure'.

[34] *Building a safer future: independent review of building regulations and fire safety*, available at: https://www.gov.uk/government/collections/independent-review-of-building-regulations-and-fire-safety-hackitt-review

29. The complexity of many of the new technologies that determine how policy is made has meant that some departments have had to invest in additional skills. Before it became a part of BEIS, DECC invested in the recruitment of approximately 30 engineers to help address some of the complexities arising from technologies including "smart" energy systems. DCMS is contemplating a comparable recruitment of engineering specialists to address its new digital responsibilities and has recently recruited an expert in this area as its CSA.

30. More needs to be done to promote greater science literacy within the policy profession. It is welcome that "science and technology" has been identified as one of 18 areas where all policy-makers within the UK civil service ought to have some familiarity.[35] However, the number of employees with a science degree or declaring themselves to be members of the science and engineering profession in the civil service's early development scheme is remarkably low:

Science and engineering fast streamers / total number on fast stream schemes	24/1200
Fast streamers with a science degree / number on the generalist scheme	45/400
GSE Professionals on the Future Leaders scheme (Grades 6 and 7) / total participants	3/400
GSE Professionals on the Senior Leaders Scheme (SCS Payband 1) / total participants	1/95
GSE Professionals on the High Potential scheme (SCS Payband 2) / total participants	Data not available

31. Work for the GSE Profession has highlighted a number of areas of specific skills shortage within it. The issues behind these reflect a number of factors: weaknesses in the talent pipeline, (e.g. nuclear engineering), or the competitiveness of the wider jobs market, and the existence of much more attractive pay packages in the private sector, like scientific software engineering. The GSE Profession Board through implementation of the GSE Strategy, will be working on specific proposals to address those shortages, and to promote greater awareness of and embed scientific thinking and evidence within the policy profession.

[35] *Policy Profession Standards: a framework for professional development*, available at: https://www.gov.uk/government/organisations/civil-service-policy-profession/about#policy-professional-development-framework https://www.gov.uk/government/organisations/civil-service-policy-profession/about#policy-professional-development-framework

32. "Data science" is remarkable for the extent to which it spans the disciplines that underpin separate government professions: it embraces the work of scientists, engineers, statisticians, operational and social researchers, and digital specialists. The government is likely to see further convergence of the work of analytical disciplines around data science, and the government will be recruiting for such skills at a time when demand in the whole economy will be growing. Here in particular there is a case for a cross-government and cross-profession strategy that matches resource and expertise to areas of greatest need.

Recommendation 10 - *The GSE Profession Board should work with the Analysis Function Board to ensure that the civil service as a whole has the scientific skills it needs and the mechanisms to deploy them effectively through the wider civil service functional agenda being led by the Cabinet Office. Plans should be developed to remedy any shortages (working with UKRI and DfE where appropriate), reporting early in 2020.*

Chapter 5

Ensuring value for money

1. Conventionally, value for money is defined through its three components – to use the succinct language of the National Audit Office – efficiency (spending well), economy (spending less), and effectiveness (spending wisely). Therefore, value for money in its fullest sense cannot be treated separately from other priorities in the effective management of government science.

2. Other chapters of this report address forms of capability which permit government to make the most of its expenditure in science:

   - The role of customer focus in identifying policy and operational needs and translating these into terms that are tractable in research terms;
   - The role of competition, publication and openness in driving excellence in research quality;
   - The need to reduce administrative overheads and other forms of waste through the development of a strong and effective commissioning function, with real scientific knowledge;
   - Government's powerful ability to leverage wider science activity and investment in the academic and private sectors; and
   - The importance of an effective "scouting" function in enabling government to understand better the latest developments in other sectors, allows its own approach to be under constant review with a view so identifying better, more cost-effective ways of getting the best results.

3. This chapter addresses some specific issues which relate to the effective, efficient, and economical management and governance of the government's own research programmes. In particular, we cover the role of the departmental CSA in oversight and governance of good process and better co-ordination across departments, ways to improve impact, as well as options for improving access to science through procurement.

Chapter 5: Ensuring value for money

Effectiveness - Better alignment, oversight and governance of science and research activity within departments

Sign-off

4. Each department is different in the scope and scale of its needs and the capability it funds and accesses. It is unsurprisingly, therefore, that approaches to science and research governance – in particular the processes where official level sign-off and strategic direction is given to a department's whole programme of activity – diverge strongly across departments.

5. In some departments, research proposals are systematically captured and referred to a Board, chaired by a research specialist, for sign-off. This is the case in Defra, for instance, where and Evidence Budget Allocation Board chaired by the CSA makes funding decisions founded on initial proposals prepared by a variety of Defra business areas. In some departments, as with DfE, the CSA has direct oversight over a specific research budget, but discretion over the expenditure of other funds is retained by policy teams. In some departments there is no central oversight. Where possible, the Defra approach should be adopted and applied consistently across all department research budgets (and not limited to specific programmes or those with direct oversight by CSAs).

6. In a number of cases, governance includes a significant role for non-executive members. The GCSA, for instance, chairs BEIS's Energy Innovation Board; DfT has established a similar approach through the Transport Research and Innovation Board (TRIB); and in the FSA (a non-ministerial department) science proposals, like all investment proposals, are overseen ultimately by the Board.[36]

7. The ideal governance structures will necessarily vary by departmental context, but, in many departments, there needs to be clearer accountability for the delivery and approval of departmental science and research programmes and stronger involvement with academia through non-executive membership. This should include clear lines of accountability from those undertaking the science through to the Permanent Secretary. In the first instance the Government Office of Science should develop a map of boards and scientific advisory committees/councils.

8. This is a more straightforward proposition in some departments than others. For larger departments the role of a separate R&D Director should be considered for example, MOD has a Director of S&T which reports to the MOD CSA. In some cases, however, the role of CSA and R&D Director may be one and the same. Whatever the position, CSAs should have access to resource which is commensurate with this important role. The CSAs should remain the Permanent Secretary's key source of advice in ensuring that Ministers are

[36] MOD has a Defence Technology & Innovation Board chaired by the principal military customer, the Vice Chief of Defence Staff (VCDS).

equipped with the science capability that they need in meeting their objectives. As a minimum CSAs must be accountable for the quality and oversight of planning and appropriate spend on science in their departments. The CSA also needs to be able to report quality and oversight issues through to the GCSA, enabling overall assurance and oversight across government. Direct line management of programme and commissioning teams is not essential and potentially detracts from the accountability and assurance role the CSA brings.

Recommendation 11 - *All departments should have a clear sign-off mechanism for science expenditure, involving joint accountability for the Director of Finance and Chief Scientific Adviser, in reporting to the departmental Executive Committee and to Ministers.*

Standards, publication and impact

9. The baseline for scientific quality control is independent peer review. For basic and applied research this is most often through independent publication in editorially reviewed journals or books.

10. In the academic context, competitive processes informed by peer review (informing decisions on whether to publish, or fund, particular research programmes publication or to make funding decisions), is the most important mechanism for securing research quality. This entails openness to challenge by those with the experience and knowledge to do so effectively in any given area of research. Government commonly uses peer review mechanisms in relation to the research that if funds. Evidence summaries for the Government Office for Science's Foresight programmes, for instance, are subject to peer review before publication. A policy of publishing all science work (an approach adopted by Defra for instance) is helpful in providing for external scrutiny in a way that will drive quality over time.

11. The standards applied to the publication of research vary not by department, but by profession. Much of the work of the government's statistics profession is governed by statute. Social research which is conducted outside that legal framework is governed by a separate publication protocol, which is owned by the relevant professions. There is no comparable framework for the conduct of research by the GSE profession. However, researchers within departments or funded by departments should be encouraged to publish their work as far as it is possible.

12. As well as skills, quality research also requires access to the right tools for the job. A very widespread source of frustration raised with the review team by those who provide science (as well as other forms of analysis) was the lack of access in most departments to some of the basic online tools of research that

are available only on subscription, including research databases, academic journals, and many forms of analytical software.

Recommendation 12 – *CSAs should work to ensure (and have support from their departments in doing so) that science specialists have access to the tools and research journals that are essential to understanding, evaluating and undertaking excellent research.*

13. Research Integrity – ensuring quality and robust practice in research is essential. The internet has brought closer scrutiny to published scientific work, raising questions about the extent to which published findings are reproducible by others. Basic good practice in terms of the investigation of forms of research misconduct (including plagiarism and the falsification of findings) is now enshrined in a document co-owned by Universities UK and major research funders (the Concordat to Support Research Integrity). An important part of the government's research machinery – the NIHR – is already a signatory to the Concordat. The Concordat has been updated to reflect recommendations by the House of Commons Science and Technology Committee. Departments conducting scientific research programmes must seek to conform to its standards and make this policy public.

14. The recommendations in Chapter 3 relating to further work to open up excellence-based competitions to government agencies, are also important in this context.

Recommendation 13 – *The Government Office for Science should work with UKRI to develop guidance for government departments on best practice for a) improving peer review and research integrity and b) benchmarking of quality and outcomes.*

Including:

- *Annual reporting processes on the statistics relating to government expenditure on science, engineering and technology need to be more rigorous, with a lead role for Chief Scientific Advisers and Directors of Analysis within departments. The Government Office for Science should work with the National Statistician to develop guidance.*
- *Adopting systematic policies for peer review and considering options for bringing stronger competitive pressure to government's own research, for instance, departments to develop their own "challenge funds" against which their own laboratories and others might compete.*
- *Clearer, more consistent, standards for quality in research and development practice across government. This should include a public commitment to upholding relevant standards, including the Concordat to Support Research Integrity.*

> **Recommendation 14**- *A centre of excellence should be created to support those departments with smaller science and evidence budgets in areas of basic capability that underpin the conduct of an effective research programme, such as data quality and integrity, research procurement, research governance, best practice in the use of grant and contract, and the use of financial instruments and business development approaches in the development of R&D programmes.*

15. Science and science capability is only a means to an end. Effectiveness only comes if the science is put to good use; the impact of science must be measured and assessed in order to ensure continuing effectiveness.

16. There should be better evaluation of R&D, assessing the impact into developing and implementing policy, economy or wider government needs – comparison of practice across departments.

17. Assessing the outcomes of any research is challenging (note the amount of resource involved in the Research Excellence Framework process) and government research no less so. However, examples of impact already exist. For example, an independent report, commissioned by the DHSC NIHR Clinical Research Network (NIHR CRN), demonstrates the economic impact of the NIHR CRN's activities to support clinical research in the UK.[37]

Efficiency - Better co-ordination of research programmes between departments

18. The NAO report on cross-government funding of research and development (15 Nov 2017) highlighted the need for more strategic leadership and co-ordination across areas of cross-cutting research and the efficiencies this brings.

19. Co-ordination within government is vital as is co-ordination with external partners. Cross-cutting mechanisms should be further nurtured and supported by departments.

20. While there are good examples of co-ordination with academia and independent R&D funding (e.g. OSCHR[38] in health, the Animal & Plant Health Partnership and DfID research concordat) these tend to reflect areas where a single department is clearly in the lead, the relevant partner organisations have sizeable budgets and therefore have a strong stake in participating in

[37] KPMG. NIHR Clinical Research Network: Impact and Value Assessment (September 2016): https://www.nihr.ac.uk/documents/partners-and-industry/NIHR_Impact_and_Value_report_ACCESSIBLE_VERSION.pdf

[38] Office for Strategic Coordination of Health Research

leadership and co-ordination. Boards or groups which allow more effective co-ordination with academia and industry should be explored, if departments are to leverage the benefits from the commitment to increase national R&D to 2.4% of GDP by 2027, the majority of which will be funded within industry and UKRI.

Recommendation 15 – *For important cross-government areas of science, shared governance models consistent with the recommendations of the National Audit Office (NAO) report on cross-government research and development should be established to improve co-ordination and to maximise funding opportunities. To support this, the Government Digital Service should work on a platform to allow important R&D projects to be logged within a single database.*

21. A Public Accounts Committee report based upon the NAO report recommended that "UKRI should work with other Departments to determine options for developing a cross-government database of research projects." In response, the government said it would do so, citing existing work by the Government Office for Science to support departments in developing and publishing their ARIs, the Research Council's database "ResearchFish", and work by BEIS to improve tracking of R&D expenditure on energy for the Energy Innovation Board.

22. A number of departments have databases describing their research activity: for instance, DfID brings its published research together in one place (https://www.gov.uk/dfid-research-outputs), while Defra has a searchable site detailing current projects (http://sciencesearch.defra.gov.uk/). Both approaches are to be commended, and a cross-government database would provide greater clarity for government and its stakeholders.

23. However, the resource entailed in the development of and maintaining a single database would be considerable, and certain initial steps would be necessary before it could be developed effectively: i.e. consolidating the ARIs as comprehensive statements of government research need, and the development of improved cross-government governance, including developing the representative roles of those CSAs who are members of Research Councils. In addition, complementing other ongoing programmes on data records and archiving (e.g. the Better Information for Better Government programme) will be essential. Government should return to this question once these and the recommendations of this review have been implemented.

Economy – better ways of contracting and obtaining faster access to science

24. A number of departments highlighted procurement of research (particularly small and timely pieces of analysis) was difficult and that procurement mechanisms tended to delay the overall process. Competition remains an

effective way of ensuring value for money and enabling selection of the most appropriate and best suppliers; visibility and access to the widest possible range of appropriate suppliers is essential.

25. Framework agreements and pre-qualification arrangements such as MOD's R-Cloud[39] (which is based on the G-Cloud commercial framework) offer alternative approaches where suppliers compete upfront before tasking, allowing pre-qualification compliance and terms and conditions to be set and agreed before areas of work are commissioned. This can reduce tasking to a number of weeks rather than months. It can also allow improved supplier engagement – sharing of outcomes, maintenance of capability and expertise – which can be included within the initial competing of the framework. Development of frameworks should be done in conjunction with the Government Commercial Organisation to enable sharing of best practice and drive through further efficiency through common approaches. As part of the wider government procurement commitment of spending with SMEs, departments should remain open to the benefits of working with smaller research suppliers, where appropriate.

26. Traditionally, government departments tend to contract for research outcomes while UKRI and research funding bodies provide grants. While contracts reduce risk and uncertainty around outcomes, where the aim is to sustain capability or where the research outcomes are less certain, a grant-based approach could be more beneficial. The grant-based approach should be investigated further particularly where greater leverage of UKRI funded capability in academia is sought.

[39] Accessed here: https://rcloud.dstl.gov.uk/

Annexes

The Frascati definition of research and development

The following, internationally recognised, definition is taken from the Frascati Manual[40], an OECD publication.

> Research and experimental development (R&D) comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man, culture and society, and the use of this stock of knowledge to devise new applications.
>
> The term R&D covers three activities: basic research, applied research and experimental development.
>
> These are defined as follows;
>
> - **Basic research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.
> - **Applied research** is also original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.
> - **Experimental development** is systematic work, drawing on existing knowledge gained from research and/or practical experience, which is directed to producing new materials, products or devices, to installing new processes, systems and services, or to improving substantially those already produced or installed. R&D covers both formal R&D in R&D units and informal or occasional R&D in other units.
>
> R&D must be distinguished from a wide range of activities relating to R&D with a scientific and technological basis; such activities are excluded from the definition of R&D unless they are carried out solely or primarily for R&D purposes. Pure R&D activities should have an element of novelty and the resolution of scientific and/or technological uncertainty, i.e. when the solution to a problem is not readily apparent to someone familiar with the basic stock of common knowledge and techniques for the area concerned.

General exclusions

Reference to the Frascati Manual should be made for detailed analysis of exclusions, but general exclusions to highlight are:

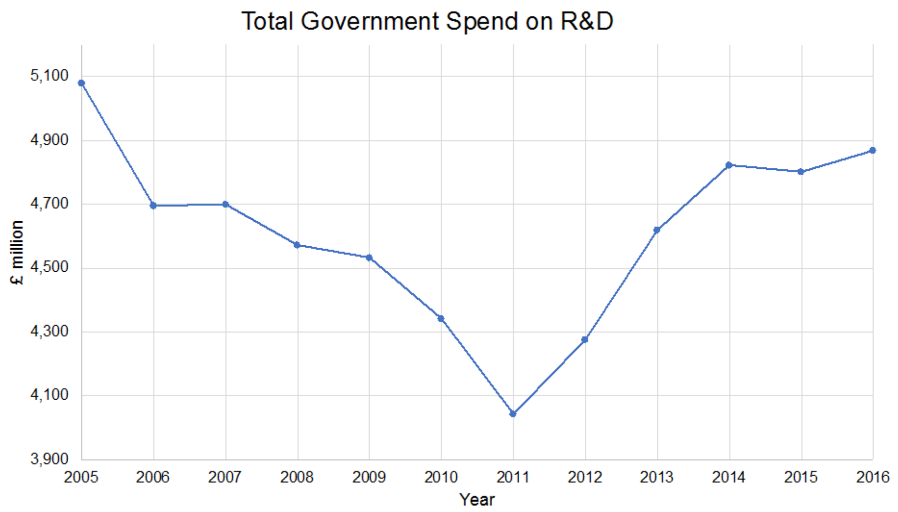
- education and training other than PhD research
- general purpose data collection (such as recording weather statistics)
- routine testing and analysis of materials, components, products, processes, etc.
- feasibility studies
- policy-related studies
- phase IV of clinical trials (unless they result in a further scientific or technological advance).

[40] Available at: http://www.oecd.org/sti/inno/frascati-manual.htm

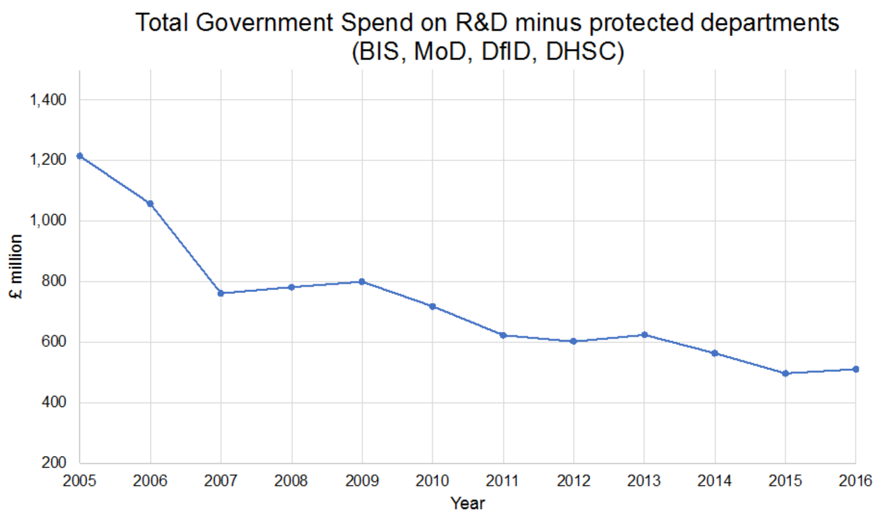
Annex B

Key trends in overall and individual department spend of R&D over time (since 2005)

Total R&D expenditure since 2005

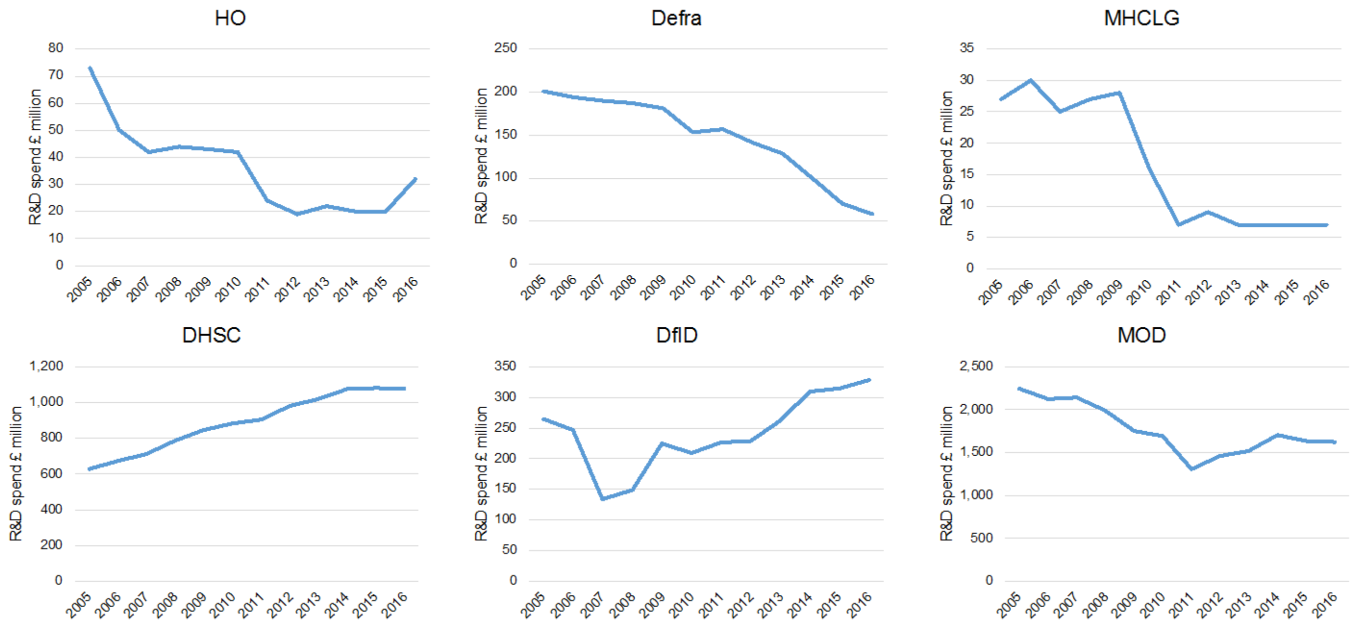


Total R&D expenditure since 2005



Annex B

Total Departmental R&D spend 2005-2016



Annex C

Drivers affecting demand for science capability in the UK government

Context

The aim of this work is to begin to understand the drivers of the demand for developing science capability in the UK Civil Service. In general terms, the demand for science capability is driven by the desire to do things better, faster, cheaper, safer and more efficiently. Below are examples of current drivers to achieve this. These drivers affect many different aspects of society, and although individual drivers may be cross-cutting and arise for multiple reasons, they are grouped into five general areas; technology/data, norms/institutions, economics and environmental, in addition to trends related to Civil Service organisation.

The following drivers were determined through input from officials in "town hall" meetings and in-house expertise from the Government Office for Science Horizon Scanning team, in addition to desk research. The drivers detailed in this appendix were those most commonly mentioned. Other drivers exist but were rarely mentioned and had fewer implications.

List of drivers – what is driving the development of science capability in government?

Technology and data

1. Computing power (increasing function for decreasing cost)

Many analytical fields require large amounts of computing power to analyse data, and this is often the limiting factor in their progression. Whilst cost is decreasing, available computing function is increasing rapidly – currently doubling every 2.5 years – and new technologies with vastly more computing power, such as quantum computing, are becoming a realistic possibility. With increasing computing power there is more demand for the capability to make use of the consequential possibilities.

Substantial computing power is used within government departments such as the Met Office, where weather patterns are predicted daily using a supercomputer, enabling quicker and more accurate results. With increasing data production, computing power can enable government to increase time efficiency through automation of processes, targeting response to customers or collating information on an individual to ease applications and improve customer services.

Increasing computing power and the associated analysis of big data requires specialist knowledge. However, higher renumeration in the private sector contributes to this skill shortage within government. Changing relationships with other countries may increase this shortage.

2. Platforms and Networks

Platforms or networks facilitate connections and interactions between people, either digitally or physically. They may be used to provide information, services or products. Digital platforms are becoming increasingly common, along with the associated demand within government for the skills required to make use of them. A platform is a location where software can be implemented. Examples include websites, Microsoft Windows or Mac OS, Android or iOS. Social networking sites such as Facebook and Twitter are also platforms, enabling software to be built out of components hosted by the provider as opposed to the software developer.

Government is increasingly using platforms to improve public services and their efficiency. The Government Digital Service has created Government As A Platform, a method of building digital services that can be used across government, enabling sharing of digital services, processes, data and technology. For example, GOV.UK Pay was created to simplify the large number of different payment systems within government.

Government has also used a common digital platform to improve the efficiency and effectiveness of the courts and tribunals system, with the aim to fully assimilate the criminal justice system[41].

3. Big data

Previously, large datasets were mainly limited to a few areas of science research, such as climate science and particle accelerators such as CERN. However, there are increasingly large volumes and types of data available, concerning numerous aspects of our lives. These data are collected by increasingly numerous methods and are progressively available to government as new methods of analysis arise. Big data may increase science capability within government by allowing more targeted response, automation and enabling a larger evidence base on which to create policy, thereby increasing both time efficiency and accuracy. For example, health and lifestyle data are collected continually from a wide range of people using fitness devices such as smart watches, opening up a huge data source for health and infrastructure requirements.

Big data is increasingly used within government. In 2017 ONS established the Data Science Campus, with the aim of using new big data sources to improve decision-making within government for public good, and to increase the UK capability for data science. DSTL launched the Data Science Challenge in 2017, offering prizes for the solution of real-world big data problems, such as the identification of vehicles using aerial imagery[42].

However, there remains uncertainty and a lack of technical knowledge of how to deal with this increasing availability of data. There is an associated skills shortage within

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[41] https://www.gov.uk/government/publications/spending-review-and-autumn-statement-2015-documents/spending-review-and-autumn-statement-2015

[42] https://www.gov.uk/government/news/making-sense-of-big-data-to-improve-the-nations-defence-security-and-prosperity

government because the required skills are often valued more highly in industry and business. There are also ethical issues with the use of people's health and lifestyle data. Government has previously published a report detailing the skills shortage in big data analytics and highlighting the need for government investment in its digital capability to increase, enabling increased big data usage.[43] [44]

4. Algorithms (disembodied AI)

Artificial Intelligence (AI) is the automatic carrying out of tasks that requires some level of intelligence. Different tasks have different capacity for the use of AI, and this is not always intuitive. For example, the development of a robot to beat the world champion at chess was significantly simpler than the development of a robot that could walk. The surge in capability has been made possible by the increased amount and availability of data and computing power. With increased data, AI can be more accurate.

AI may increase science capability within government in a number of ways - perfectly remembering large amounts of data and learning from more data than a human could manage, faultless execution of logical reasoning, near perfect execution of probabilistic reasoning, more rational learning from small amounts of data and significantly faster extraction of data from extremely large numbers of scientific papers.

The use of AI in science could enable faster scientific discovery, since thousands of hypotheses may be tested simultaneously. AI also can reduce the cost of experimentation in terms of both time and money and may work continuously without need for breaks or holidays. AI also allows for more reproducibility and faster and easier training, and the source of value gained in the UK is shown in Figure 2 [45].

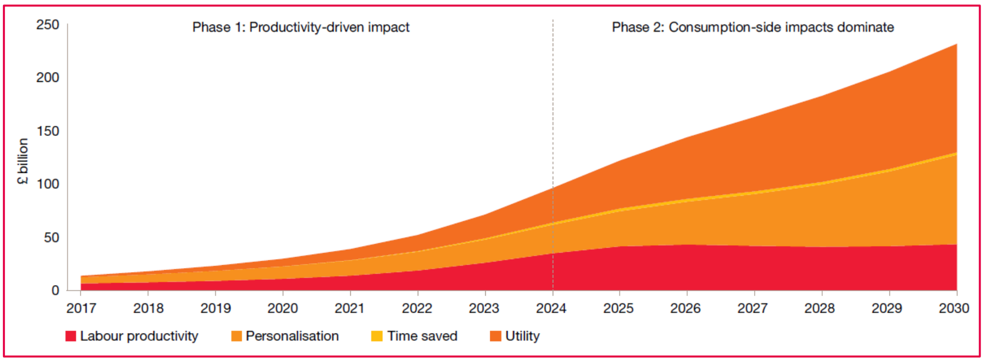

Figure 1 The source of value gained in the UK from AI.

5. Automation (embodied AI)

Automation describes the process of using technology to carry out procedures without human influence. Although automation as a general concept has existed for many years, there has been a surge in recent technologies and applications[46].

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[43] https://publications.parliament.uk/pa/cm201516/cmselect/cmsctech/468/468.pdf
[44] https://www.sas.com/content/dam/SAS/en_gb/doc/analystreport/cebr-value-of-big-data.pdf
[45] Graph taken from The Economic Impact of Artificial Intelligence on the UK Economy. Reprinted with permission from PwC. All rights reserved https://www.pwc.co.uk/economic-services/assets/ai-uk-report-v2.pdf
[46] https://www.pwc.co.uk/economic-services/ukeo/pwcukeo-section-4-automation-march-2017-v2.pdf

There is significant opportunity for automation within government, and significant uptake has already been achieved in HMRC, who carry out over 11,500 procedures automatically, in almost 60 different processes. Contact centre advisors in HMRC now use dashboards to bring information directly to a computer screen and files are opened automatically, increasing accuracy and time-efficiency (call times reduced by 2 minutes, and only 10 mouse-clicks required compared to 66 previously). Registration of new employees is another area where automation is already used within HMRC; data is automatically validated, and applications process, leading to the procedure being three times faster and around 80% cheaper.[47]

Increased automation can extend science capability within government by allowing more time for human skills to be used where they are important, such as areas of customer support and communications. Automation, as with AI, allows for extremely fast and accurate reasoning, efficient extraction of data from vast sources, and the ability to carry out multiple tasks at the same time. To make use of these benefits, there is demand for the associated technological skills within government.

6. Blockchain

Blockchain is a technology that creates an absolute and permanent public record of historical transactions. The data in blockchain cannot be edited or deleted, hence the commonly quoted application of banking. Within science and government, blockchain has the potential to increase reproducibility and the peer review process by allowing permanent data trails and secure records of publishing decisions, shown in Figure 3 [48].

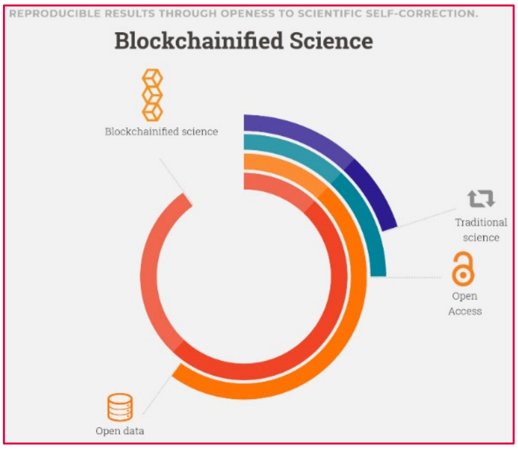

Figure 3 - Blockchain to improve reproducibility and reliability of science.

Blockchain has the potential to help to avoid the common issue of multiple teams working on the same problems, which costs both time and money. Better collaboration can be achieved using blockchain to enable a decentralised approach through incentivisation, enabling collaboration between departments and academics, but also with non-scientists or those simply with an interest.

Within government, blockchain could be used to create and store digital identities for individuals or businesses (including for example, birth certificates, passport/visa applications or health records), and would reduce the possibilities for identity theft. Blockchain can also be used to facilitate financial services within government, record land registry, automate eligibility assessments for benefits, and manage contracts, supply chains and energy grids. Blockchain also has the capacity to transform voting, through increased validation and auditability.

[47] https://quarterly.blog.gov.uk/2018/03/28/robots-lend-government-a-helping-hand/
[48] https://www.blockchainforscience.com/ Reproduced with permission from Blockchain for Science.

To achieve these benefits, there is demand within government for the associated technological skillsets. However, there are also potential ethical problems associated with blockchain, for example in health tracking technologies; if a patient decides to withdraw from a scientific research trial, their data cannot be deleted.

7. Genetic technologies

Over the past 70 years, rapid developments in genetic technologies have enabled many breakthroughs, ranging from the genetic engineering of insulin to treat diabetes in 1982, to trials of human gene therapy in 1990. We are now also capable of sequencing the human genome in 3 days and for less than $1000. However, this rapid development has generated many issues - ethical, environmental and economic – for which we still have no solution, and it may appear that the limit to these technologies is political, rather than technological. Policy questions remain, including regulation, affordability and whether the technology will be available to everyone.

Current applications of genetic technologies include genetic testing to determine which variant of a gene is inherited, to diagnose rare diseases, to provide specific care, or to aid those currently suffering from otherwise incurable diseases. On the larger scale, genetic technologies may aid understanding how genes affect us, by analysing the DNA of large numbers of different people. Targeted healthcare arising from genetic research has the potential to enable significant cost savings in healthcare, however there is a cost associated with genetic testing which reduces the availability of funds for other parts of the NHS.[49]

In order to realise the benefits of genetic technologies, there is demand for the associated scientific knowledge and capability within government in order to correctly remove the political barriers to its uptake. The significant ethical issues associated with genetic technologies require specialist knowledge within government to ensure the safety and health of the UK population.

Norms and institutions

8. Demand for renewal of regulatory frameworks

New technologies may lead to novel uses for existing infrastructure, leading to redundancy and new functionality from a regulatory framework. The changing use and applications of technologies, along with new technologies, can result in existing regulatory frameworks becoming less fit for purpose. Demand exists for renewal of infrastructure and a changing nature of existing infrastructure given digitisation and increased consumer choice. This emphasises the need for agile and responsive regulation.

9. Changing workplace and the gig economy

The nature of work is changing in terms of contracts, ways of working and sourcing work. Currently we are trending towards a gig economy, characterised by more short-

[49] https://royalsociety.org/topics-policy/projects/genetic-technologies/infographic/

term contracts and freelance work. Benefits of such work include increased flexibility for both employers and employees, and so the gig economy is particularly favourable to those with other responsibilities such as childcare or part-time education, or a carer. However, there are downsides to this type of work, particularly as current employment legislation is not adapted to a gig economy, and such workers' rights are less protected.[50]

Implications for government are varied; self-employed workers pay less income tax and national insurance. This is predicted to reduce tax income over £6 billion per year by 2020.[51]

10. The UK's international relationships

The changing nature of the UK's international relationships is driving a need for data and evidence that was previously unnecessary. For example, significant policy areas used to be almost entirely based in Brussels, but we now require a UK approach. The UK may therefore be lacking in the capability to analyse data and do work that was previously done in Brussels.

11. Consumer choices

There is currently a consumer drive towards the personalisation of everything. Consumers are also looking increasingly for portability, reliability and cost-effectiveness. At the same time, advertising is becoming increasingly dematerialised and demonetised due to the rise of AI and social networks – if all shopping is done automatically by AI, it is not influenced by adverts.

12. Uncertainty and methods of governance

There is increasing uncertainty in many different aspects of life. This has arisen for many reasons, including the implications of new technologies (e.g. automation and work), changing international relations (e.g. Brexit and the role of America and China) and changing methods of governance (e.g. large number of elections leading to common upheaval of government). There exists an environment of continuing change and uncertainty, leading to a need to adapt. Trust in authority is also changing, with high standards and values required of those with positions of authority, and increasingly valued security and privacy.

Current trends show a rise in populism and anti-establishment voting trends. In 2017, anti-establishment parties were in power in a quarter of EU member states. This

[50] https://www.cps.org.uk/blog/q/date/2017/04/24/implications-of-the-new-gig-economy/
[51] https://www.telegraph.co.uk/business/2017/02/22/uber-deliveroo-seek-reforms-provide-benefits-self-employed-claiming/

compares to zero in 1985. Currently, a fifth of voters in the EU vote for a left- or right-wing populist party, shown in Figure 4 [52].

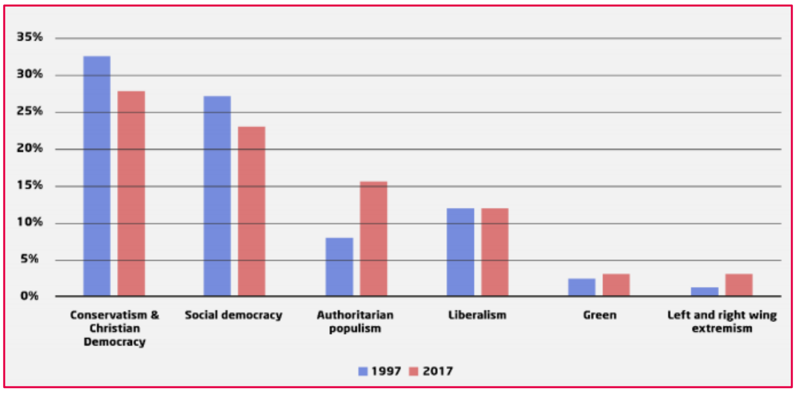

Figure 4 - Changing voting trends from 1997 to 2017.

In terms of government science capability, this uncertainty and regular change makes continuity difficult. Science priorities commonly change between governments, which can lead to a lack of progress. There is a need for science capability to be resilient to government change.

13. Privacy and security

Although data sharing has existed for years, with the rising amounts of data produced there is growing concern about how individuals share data and how this data can be used. Rising levels of cybercrime coincided with our increasing creation and usage of data, and the growth of internet and mobile banking[53].

In 2018 the EU General Data Protection Regulation (GDPR) came into force. GDPR was designed to unify data privacy laws and protect data privacy across the EU. Key changes include the right for an individual to know how their data is being used, and to delete it.

This increasing demand for personal data privacy and security requires the capability to do this within government. Technical skills are required within the Civil Service in order to stay ahead of the increasing volumes of data and the resulting increase in cybercrime.

Economic shifts

14. Globalisation; shifting centres of economic power and global technology

The UK, along with most other highly-developed countries, is tending to become more negative about globalisation, believing that it is not a 'force for good', although millennials tend to be more positive about globalisation than older generations. At the same time, the centres of economic and technological power are shifting to the East. In terms of the technology industry, following current trends China will equal the USA within 5-10 years, and has already overtaken the USA in e-commerce and mobile payments. In terms of economies, China is expected to be the world's largest economy

[52] https://timbro.se/allmant/timbro-authoritarian-populism-index2017/ Reproduced with Permission from Timbro.
[53] https://www.pwc.co.uk/forensic-services/assets/gecs/global-economic-crime-survey-2018-uk-findings.pdf

by 2050, whilst six of the largest seven economies may be from emerging economies. At the same time, the share of world GDP held by the EU27 may reduce to under 10%.

In order to remain globally competitive as the centres of economic and technological power shift to the East, the UK requires the technological capability within government to ensure the full benefit of scientific breakthrough is achieved. Scientific capacity within government could help to bridge the gap between the UK's high capability for scientific research, and commercialisation of these technologies.

Environmental and resource stress

15. Global warming and energy consumption

Global warming caused by increased greenhouse gas emissions has a large number of consequences, ranging from decreased biodiversity to more extreme weather patterns and food and water shortages. As we become more aware of the causes and consequences of global warming, more policies exist to attempt to limit the possible outcomes. The number of laws relating to climate change has increased by approximately 20 times in the last 20 years, although only 40% of countries have explicit reference to climate change in their plans for development.

Technology and innovation must follow changing public/academic views on what is good for the environment. As our awareness of climate change increases, and as we experience more of the consequences, it is likely that more regulations will exist to limit the negative outcomes. This is expected to drive innovation away from traditional oil and gas-based sources of energy, to renewable sources.

Climate change is also predicted to have significant effects on food and water security, pests and diseases, and cause disruption to supply chains. This is likely to lead to increased research into food alternatives (e.g. marine protein or genetic technologies), agri-engineering and different methods of sustainable food or water production.

Plastic pollution is a growing concern, potentially leading a drive to biodegradable plastics or alternative packaging. These factors are driving the need for scientific capability within government, in order to create suitable policies for the environment, whilst maintaining global competitiveness.

16. Demographics and ageing population

The UK population is predicted to increase due to births outnumbering deaths and net migration. At the same time, the number of children being born in the UK is decreasing, leading to an ageing population.

These factors are driving a demand within government for the scientific capability to overcome the infrastructural and technological issues associated with the changing UK demographic.

Civil Service Organisation

Factors affecting supply: Development, attraction and retention
Certain attributes of government and the Civil Service result in further drivers for science capability that are specific to government.

1. Status and pay

There is a need within government for certain scientific knowledge and skills (e.g. data analytics), however these are more highly paid in alternative industries, leading to a lack of scientific knowledge within government. Government typically finds it easy to recruit entry-level positions in such fields, but retention after training is difficult.

2. Education

The blend of skills required in the modern workplace is changing, and government today requires different mixes of skills in order to remain competitive. There is increasing demand for behavioural psychology and sociological insights. Shortages in specific skills mixes has implications for improving government services.

3. Translational

Science capability within government is often focused on industry requirements and is therefore skewed away from SMEs and academic research. There is a requirement for close work between industry and academia to ensure no regulatory barriers to the uptake of research into industry and the commercial sector. There may also be ethics associated with the uptake of technologies.

A barrier exists for transmitting research from academia or industry to government, caused by difficulties in networking and access to expertise. No one system provides all solutions to scientific problems, so issues are generated by structural trade-offs between academia, industry and government. An industry procurement model is difficult for partnering with universities, whilst UK government departments face difficulty in carrying out research due to their inability to receive UKRI funding. Academic scientists (or those in industry) need to understand policy – a science translator role would aid this knowledge transition, for example.

Within government itself, the complex model of numerous departments makes creating solutions to cross-cutting problems difficult. Where issues do not fit neatly into a single department, capability may be reduced due to communication issues and lack of a clear leader.

Conclusions

Many factors drive the UK government demand for science capability, but these cannot be treated in isolation as linkages exist between them all. For example, the increasing amount of data available stems from the increased connectivity of devices and the Internet of Things. Data itself enables more accurate artificial intelligence, of which automation is one illustration, or it can be applied, for example within blockchain.

The interconnectivity and convergence of these drivers creates a level of complexity that is challenging for policy-making in terms of understanding the current situation as a whole. This complexity makes communication between academic scientists and policy-makers increasingly difficult.

To overcome these difficulties in practice, government requires capability in horizon scanning, to take advantage of opportunities and challenges, and to mitigate against risks. Capabilities in data science and systems thinking skills are also required, to enable improved engagement between policy and scientific research. This capability can lead to better understanding of what is currently important and can ensure that science can respond to policy questions in an understandable and useful format. Government also requires the capability to leverage external expertise, such as academia and industry, or to develop in-house expertise if this is not practical.

Grand Challenges and Missions, and critical factors in leadership, NSSIF

Mission Orientated Innovation: UK Industrial Strategy Grand Challenge missions

The UK Industrial Strategy[54] sets out four clear and ambitious Grand Challenges to drive innovation and investment: Artificial Intelligence and data; ageing society; clean growth; and the future of mobility. Missions represent one of the approaches to tackling these Grand Challenges.

Missions address important, highly challenging societal problems and take a different approach to conventional policy making – they set out to tackle a problem without defining the approach or outcome, with the emphasis being on the achievement of the desired impact. A mission sets strategic aims with ambitious, stretching and measurable goals which are to be delivered within a set timeframe.

Successful missions focus the efforts of industry, researchers and government; and achieve the mission goal by catalysing innovation across multiple economic sectors, increasing rates of investment and growth, building new markets, accelerating transitions from incumbent to emerging technologies, and developing sources of long-term industrial competitive advantage.

Missions are open to a range of potentially competing solutions and encourage collaboration across sectors and disciplines which may not otherwise come together, to develop innovative approaches to address the mission challenge. Innovation and the development of fresh ways of thinking about problems are central to achieving the transformational change missions aim to deliver.

The Prime Minister announced four initial missions in May 2018, one under each of the Industrial Strategy Grand Challenges:

Ageing Society – 'Ensure that people can enjoy at least five extra healthy, independent years of life by 2035, while narrowing the gap between the experience of the richest and poorest'

Growth – 'At least halve the energy use of new buildings by 2030'

AI & Data – 'Use data, Artificial Intelligence and innovation to transform the prevention, early diagnosis and treatment of chronic diseases by 2030'

Future of Mobility – 'Put the UK at the forefront of the design and manufacturing of zero emission vehicles, with all new cars and vans effectively zero emission by 2040'

[54] https://www.gov.uk/government/topical-events/the-uks-industrial-strategy

Critical factors in leadership, governance and delivery of Missions as part of UK Grand Challenges

1. **An empowered and accountable mission leader (ML)**
   a) A single, accountable ML, appointed by the Perm Sec of the lead department, whose role (on which they will be assessed) is to lead the mission.
   b) The ML has the authority and autonomy to make decisions, within agreed risk parameters as laid out in the governance structure.
   c) The ML is directly supported by a core team of sufficient critical mass.

2. **A flexible and empowered core team of** sufficient **critical mass**
   a) A dedicated full-time core team of no more than 8-10 people, with appropriate expertise that spans the breadth of the mission and exists for the lifetime of the mission.
   b) The team consists of members from the key departments involved in the mission to ensure representation and buy-in from departments.
   c) Each department should have a senior sponsor (e.g. Perm Sec or DG) to act as a mentor and unlock resources when required.
   d) The team is formed solely to deliver the mission and therefore has a lifetime that spans the duration of the mission.

3. **A whole systems approach to delivering the mission**
   a) Teams should include dedicated systems capability to ensure a holistic systems approach to scoping the problem at the start of the mission and to prioritising the options and solutions.
   b) Agile project management to ensure that the mission takes account of new evidence and changing situations and can change direction when necessary.
   c) Utilise a multidisciplinary approach to help deliver innovative solutions and break new scientific ground.
   d) Mission teams should engage with relevant enabling technology platforms, to ensure join up and aligned timelines.

4. **Resources to deliver transformative change**
   a) Departments to commit sufficient ring-fenced funding for missions to ensure success – this includes both programme/capital budget as well as admin budget to access talent and skilled professionals.
   b) Each mission team should have a dedicated communications resource to ensure that the vision is clearly communicated to stakeholders (and those within the team).
   c) The team is supported by dedicated HR and financial functions to deliver these resources quickly and flexibly.

5. **Clear and simple governance structures**
   a) Simplified governance, with a clear escalation route, which holds the mission leader to account without stifling risk-taking.
   b) A governance structure which has representation from relevant departments giving it authority to operate across departments.

c) A governance structure that defines key decision points and allows autonomy and risk-taking by the team in between these points.
d) Governance is responsible for collective ownership of the vision, objectives and outcomes.

6. **Well defined delivery plans**
   a) The team is accountable for delivering the mission against the delivery plans and is rewarded for success.
   b) Delivery plans are focussed on measurable outcomes/deliverables and not specific policy outputs.
   c) Delivery plans and ambitions should be stretching and transformative – therefore there needs to be an anticipation and acceptance that not all objectives will succeed.
   d) Deliverables are time-bound, to drive progress at pace.
   e) Delivery plans include short-, medium-, and long-term deliverables with clear milestones to help drive and track progress against the aims of the mission.
   f) Mission teams should use best practice from previous large, successful projects e.g. the 2012 Olympics; as well as lessons learned from less successful projects.
   g) Clear stakeholder engagement plans to ensure private sector/industry/wider public contribute and buy in to the mission and support delivery of mission outcomes.

7. **Access to expertise**
   a) Access to expertise or specific skill sets that can be drawn from departments or from outside the Civil Service to support delivery.
   b) Access to an advisory board that provides advice to the team when required and requested. This should include external representation to provide challenge and peer-review and to advise on a change of approach or direction if warranted. It should also include specific industry sector knowledge relevant to the mission and input from non-Whitehall stakeholders to challenge the cultural approach.

National Security Strategic Investment Fund (NSSIF)

The National Security Strategic Investment Fund was established in the 2017 Budget to support long-term equity investment ("patient capital investment") in advanced technologies which will contribute to the national security mission.

This announcement followed an extensive consultation published as the Patient Capital Review. The term Patient Capital is used to describe long-term equity investment for fast-growing, innovative companies and is required by these businesses to enable them to scale-up and prosper.

The major barrier holding back the continued development of young innovative firms continues to be access to longer-term investment. The lack of such investment slows these firms' growth, dampens their ambition and means that some firms are sold on rather than growing to maturity in the UK. Overall levels of productivity are reduced as a result as some firms do not fulfil their economic potential.

The 2017 Budget made available over £20 bn of Patient Capital over the next 10 years. The £85m NSSIF Programme is one element of this. Additional investment capacity builds on and is channelled through the existing Enterprise Capital Funds (ECF) and British Patient Capital (BPC) programmes dependent on each applicant's eligibility under either of these schemes. The NSSIF Programme has additional objectives to the ECF and BPC, namely:

1. to support private sector led investment into the UK's world class security technology sector, by increasing the amount of private early stage venture and growth capital available to innovative, high-potential UK companies in this sector
2. to attract venture and growth capital into investment strategies which will support government's national security mission by investing in dual-use advanced technologies, and
3. to facilitate the faster adaptation and adoption of private sector commercial security technologies by government.

Annex E

List of recommendations

Recommendation 1 – Every department should have a clearly defined science system. A central role here is leadership in the articulation of the entire range of a department's science needs in a single document which is endorsed by the department's Executive Committee. This should form an integral part of overall business planning within departments: unlike Areas of Research Interest it should address the whole range of science activity conducted within the department and at arm's length from it. It should also include mechanisms for how non-government funded R&D will be used and incentivised. A core part of the departmental Chief Scientific Adviser's role is to be accountable for the existence of such a plan, signing off on issues including prioritisation, ensuring that it addresses the key science issues facing the department throughout its operational work and policy cycle and that these will be tackled in the most appropriate way.

Recommendation 2 – All Departments should publish, and refresh annually, Areas of Research Interest documents with a view to encouraging extra-mural activity and collaborations and the commissioning of key R&D. They should be co-developed by Chief Scientific Advisers, Analysts, and Heads of Policy Profession in departments, putting scientific thinking at the centre of departmental processes, including policy and operations. The Government Office of Science, with CSAs, should make the documents consistent and ensure they provide potential collaborators with the key information (including the availability of data) that they need to engage effectively with the relevant research questions.

Recommendation 3 - The Government should create a policy-focused Forum for Public Laboratories, to raise their profile within government and to create greater knowledge exchange about their role amongst policy-makers. The Government Office for Science should lead on this, working closely with department sponsors. An early task for the forum will be to advise on the development of a framework for evaluating their performance and value.

Recommendation 4 - The Government should make greater use of Public Laboratories as leaders in directed R&D programmes, and in supporting innovation through intermediate technology readiness levels. Government should give greater support to them in this role. This should include: a) departments ensuring that they have adequate long-term funding for the pursuit of their core missions for government; b) research funders opening up excellence-based competitions to Public Laboratories, where they might compete with universities and other research institutes, c) the creation of a specific fund geared to the work of Public Laboratories, for which they can compete for funds for innovation activities to be conducted in partnership with business, and d) clear processes for the protection and maintenance of intellectual property generated. BEIS as part of its 2.4% roadmap should address the role of Public Laboratories across government in supporting and enabling research and development in the private sector, and the accountability to deliver this should rest in the department in charge of that sector.

Recommendation 5 – UKRI should lead development of tailored forms of governance for research programmes relating to government strategic priorities taken forward under the Strategic Priorities Fund and related areas.

Recommendation 6 - The Government Office for Science should work with the UK Government Investments and the British Business Bank to explore the use of government venture capital and business development models in innovation, and to provide expert resource to support departments in developing these.

Recommendation 7 - The Government Office for Science should develop proposals for the implementation of business development functions, including experience from similar approaches taken from defence and security, to identify wider applicability. This will ensure that the landscape of small and large company activities is well understood, and we have good links with those companies and their backers and are able to exercise a range of business partnerships effectively. This work should then be taken forward within the centre of excellence.

Recommendation 8 - Submissions by departments to HM Treasury ahead of Spending Reviews should incorporate a statement of research and development need and costed plans for meeting those needs (including an assessment of the percentage of overall departmental expenditure they aim to spend, in absolute terms, on science) and how this compares with international benchmarks for R&D spend in their policy areas. Departments should include a clear statement of where particular R&D work streams fit within the spectrum from basic to applied R&D. In support of the government's objective to spend 2.4% of GDP on R&D, departments should also set out plans for stimulating wider economic investment in R&D in industries of relevance to their policy portfolios. Consistent with existing practice, consultation with the GCSA and HM Treasury should take place if there are significant deviations from planned expenditure.

Recommendation 9 - The Government Chief Scientific Adviser should work with HM Treasury and the Office for National Statistics (ONS) to ensure that government expenditure on research and development is transparently reflected in public expenditure statistics so that in the future there will be comprehensive data on which to assess spending on science within government.

Recommendation 10 - The GSE Profession Board should work with the Analysis Function Board to ensure that the civil service as a whole has the scientific skills it needs and the mechanisms to deploy them effectively through the wider civil service functional agenda being led by the Cabinet Office. Plans should be developed to remedy any shortages (working with UKRI and DfE where appropriate), reporting early in 2020.

Recommendation 11 - All departments should have a clear sign-off mechanism for science expenditure, involving joint accountability for the Director of Finance and Chief Scientific Adviser, in reporting to the departmental Executive Committee and to Ministers.

Recommendation 12 – CSAs should work to ensure (and have support from their departments in doing so) that science specialists have access to the tools and research journals that are essential to understanding, evaluating and undertaking excellent research.

Recommendation 13 – The Government Office for Science should work with UKRI to develop guidance for government departments on best practice for a) improving peer review and research integrity and b) benchmarking of quality and outcomes.

Recommendation 14 - A centre of excellence should be created to support those departments with smaller science and evidence budgets in areas of basic capability that underpin the conduct of an effective research programme, such as data quality and integrity, research procurement, research governance, best practice in the use of grant and contract, and the use of financial instruments and business development approaches in the development of R&D programmes.

Recommendation 15 – For important cross-government areas of science, shared governance models consistent with the recommendations of the National Audit Office (NAO) report on cross-government research and development should be established to improve co-ordination and to maximise funding opportunities. To support this, the Government Digital Service should work on a platform to allow important R&D projects to be logged within a single database.