Department for Business Innovation & Skills

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Insights from international benchmarking of the UK science and innovation system

A report by Tera Allas

JANUARY 2014

ANALYSIS

Contents

Acknowledgements

We are extremely grateful for assistance we received in compiling this report and the inputs from a large number of experts and from colleagues in the comparator countries, both those we were able to visit and those who provided input in other ways. The report has benefitted greatly. The full list of those we consulted is provided at Annex I.

We have given careful consideration to the information we drew upon and the various views that were expressed. The emphasis has been on basing our findings on the best available evidence. However, given the complexity of the science and innovation system, the challenges of international benchmarking and the mixed nature of the available data, the findings ultimately reflect the judgement and views of the project team.

Tera Allas
Director General, Strategic Advice
Department for Business, Innovation and Skills

Foreword

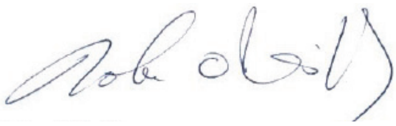

Britain's prosperity in a rapidly changing global economy depends critically on the quality and quantity of our science, innovation and skills. These are at the heart of the UK's Industrial Strategy and our work to build a successful knowledge-based economy.

To achieve sustainable growth we need to examine carefully the evidence of how others are approaching these challenges, to see what we can learn. This report rightly takes a longer-term, strategic view and provides a valuable contribution to our evidence base. As such it will help us to build on the UK's world class science base and innovation infrastructure to secure our future prosperity.

Martin Donnelly

Permanent Secretary

Department for Business, Innovation and Skills



Sir John O'Reilly

Director General, Knowledge and Innovation

Department for Business, Innovation and Skills

Executive Summary

1. Science and innovation are **at the heart of the UK's future success**. They are critical to growth in productivity and business investment, our comparative advantages in the global race and our ability to address societal challenges. The context is dynamic, however, as other nations also take this view and are investing accordingly – creating both opportunities and risks.

2. Success is built and sustained over time. The purpose of this report is to identify the UK's underlying strengths and weaknesses and to indicate the priority areas that need to be addressed if we are to capture the maximum benefits from science and innovation. We have found that science and innovation systems are **complex and made up of a large number of complementary elements**; that their effectiveness is crucially determined by how well the elements **interact within and respond to the demands of the broader economic and societal system**; and that different countries succeed with **different mixtures** of inputs and structures. International benchmarking is therefore challenging.

3. However, there is broad consensus and empirical evidence about the key **features of effective science and innovation systems**. These features are summarised in Table 3 in Chapter 2. Using this framework to benchmark the UK's performance, quantitatively and qualitatively, against relevant comparator countries produces a **mixed picture** (see Table 1 below). The UK exhibits:

- **world-class strengths in many aspects** of the system, such as research excellence, higher education institutions and the business environment;
- **concerning weaknesses in the talent base,** especially in terms of basic skills, science, technology, engineering and maths (STEM) skills and management skills; and
- a sustained, long-term pattern of **under-investment in public and private research and development (R&D) and publicly funded innovation.**

4. This under-investment is structural, not the result of any particular spending decisions. The UK's total **investment in R&D has been relatively static at around 1.8% of GDP** since the early 1990s and was around £27bn in 2011. In contrast, the US alone spends around £250bn (2.8% of GDP) on R&D per annum. China increased its R&D by 28% in 2009 and 15% in 2010, to roughly £125bn (1.8% of GDP), and South Korea doubled its expenditure between 2003 and 2011 to around £35bn (4.0% of GDP). France and Germany have consistently invested substantially more than 2% of their GDP in R&D, with aspirations to increase this to 3% or more. Public sector support for innovation is harder to compare, but such data as exist suggest that UK funding is very low.

5. Given that the UK only represents 3.2% of the world's R&D expenditure and that some 80-90% of innovation in advanced economies is based on technology transfer from foreign countries, a key priority for the UK is to increase its ability to exploit cutting-edge global research. In this context, the UK's consistent pattern of relatively **static and low R&D investment is a lost opportunity**: it risks jeopardising the breadth and depth of science excellence required to underpin our industrial success and the capacity of our firms to absorb and apply new knowledge and ideas (see Box A in Chapter 1); and hence missing out on the benefits available from the enormous, and growing, global investment in science and innovation.

6. There are no reliable estimates of an optimal level of expenditure in this area, not least given that science and innovation operate in a global system. What we can say is that comparator countries, who have been spending considerably more than the UK for some time, do not appear to get poor returns on their investment. To complement the UK private sector's strong investment into non-R&D innovation, a level of R&D spend consistent with securing future economic success is likely to be closer to the **2.9% average of our comparators.** Public sector expenditure may need to rise more sharply in the short-to-medium term, partly to develop the necessary talent and partly to catalyse private sector investment.

7. It is our judgement that incremental change will not be sufficient to tackle this structural gap: **a commitment to a long-term step-change in the UK's science and public sector innovation investment is needed if the UK wants to remain a global leader.** Such a step-change would bring tremendous benefits and should be at the heart of the government's future growth strategy.

Table 1: Summary of the main relative strengths and weaknesses of the UK's science and innovation system

Category	Assessment[1]	Key strengths[1]	Key weaknesses[1]
1. Money	**Medium/Low**	Strong foreign direct investment (FDI) and foreign funding into R&D, high private sector investment in intangibles, vibrant financial sector and capital markets (e.g. business angels, venture capital) relative to non-US comparators	Low levels of public and private R&D investment, low levels of public innovation support, short-term focus of capital markets, remaining issues in access to finance for innovative growth companies
2. Talent	**Medium/Low**	Relatively attractive to top global research talent, internationally recognised higher education system attracting high quality students, relatively high number of doctorate holders, average proportion of population with tertiary education	Relatively low basic skills (numeracy, literacy, ICT), insufficient domestic human capital to exploit science and innovation (domestic STEM talent and Masters/PhD graduates working in research), below-average management skills
3. Knowledge assets	**Medium/High**	Highly productive world-class research base (second only to US), world-class research institutions, high proportion of international research collaborations	Low number of academic / corporate co-authored publications, smaller number of patent applications (albeit unreliable as a metric of performance)
4. Structures and incentives	**Medium/High**	Competitive funding driving excellence, strong international collaboration by firms, effective university collaboration with R&D intensive businesses, relatively strong formal and informal knowledge networks, a number of strong clusters with critical mass, modern intellectual property regime, good mix of basic, applied and experimental research	Government procurement not seen to foster innovation, limited SME / university collaboration, potential tensions in academics' incentives (e.g. publications vs. collaboration and interdisciplinary research vs. teaching), possible issues around portfolio management (e.g. complementarity of broader system with science investments)
5. Broader environment	**Medium/High**	Open and competitive markets, positive business environment, attractive to multi-national corporations, good rates of new firm creation and entrepreneurial activity, strong citizen interest in science and technology	R&D concentrated in a small number of sectors and firms, low proportion of medium-sized growth companies, UK manufacturing relatively lower-tech and less skills-intensive, relatively low quality of demand (degree of consumer orientation and buyer sophistication), migration rules perceived to be cumbersome
6. Innovation outputs	**Medium (mixed)**	Comparative export advantage in relatively sophisticated products, strong knowledge-intensive services and creative sector exports, strong technology balance of payments	Lagging labour productivity, average-to-low levels of new-to-market innovations, low number of innovative SMEs

Source: *Literature review; expert interviews; BIS analysis*

[1] Strengths and weaknesses have been assessed relative to other leading comparator countries rather than on an absolute basis; the assessment reflects the project team's interpretation of the evidence and therefore involves an element of judgement

Chapter 1: Introduction

8. The UK is a global leader in science and innovation on many measures. However, the world around us is not standing still and we need to understand how to ensure the UK maintains and enhances its position and harvests the maximum economic and societal benefit from science and innovation. This is a long-term goal and this report's approach is consistent with that perspective.

9. The findings of this report are intended to provide a basis for future discussion with the science, research, innovation, higher and further education and business communities on the future shape and scale of the UK's science and innovation system. It addresses the following question:

> ***"What does international comparative evidence tell us about the key challenges we need to address in order to maintain and develop the UK's global leadership position in science and innovation?"***

10. What we mean by global leadership in this context is important: ultimately, we are interested in the value that science and innovation add to the economy and society. While measuring these ultimate outcomes – let alone what precisely drives them – is close to impossible, the conceptual thread of focusing on outcomes runs through our approach to the review.

11. There have been many comprehensive reports, studies and reviews in this area in recent years (a number of the key ones are referenced in Annex J). The purpose of the present document is not to re-do or restate this existing body of analysis and insight but rather to step back, take a long view, synthesise and identify strategic areas of priority for the UK. Whilst we identify issues for the next stage of the debate, we have avoided making specific recommendations.

12. The report is based on both hard evidence, such as statistics or academic papers, and more qualitative evidence gathered from experts and stakeholder interviews. Given the complexity of the system and imperfections in the evidence base, there is a substantial element of informed judgement underpinning the findings. By the nature of the exercise, this report focuses more on challenges than on strengths. This in no way implies that overall the UK's system is not performing well by international standards.

13. This introductory chapter briefly sets out three over-arching considerations that were emphasised regularly by experts and stakeholders and that underlie the discussion in the rest of the report. It also explains the definitions of research and development (R&D) and innovation that are used in this report and outlines how the rest of the report is structured.

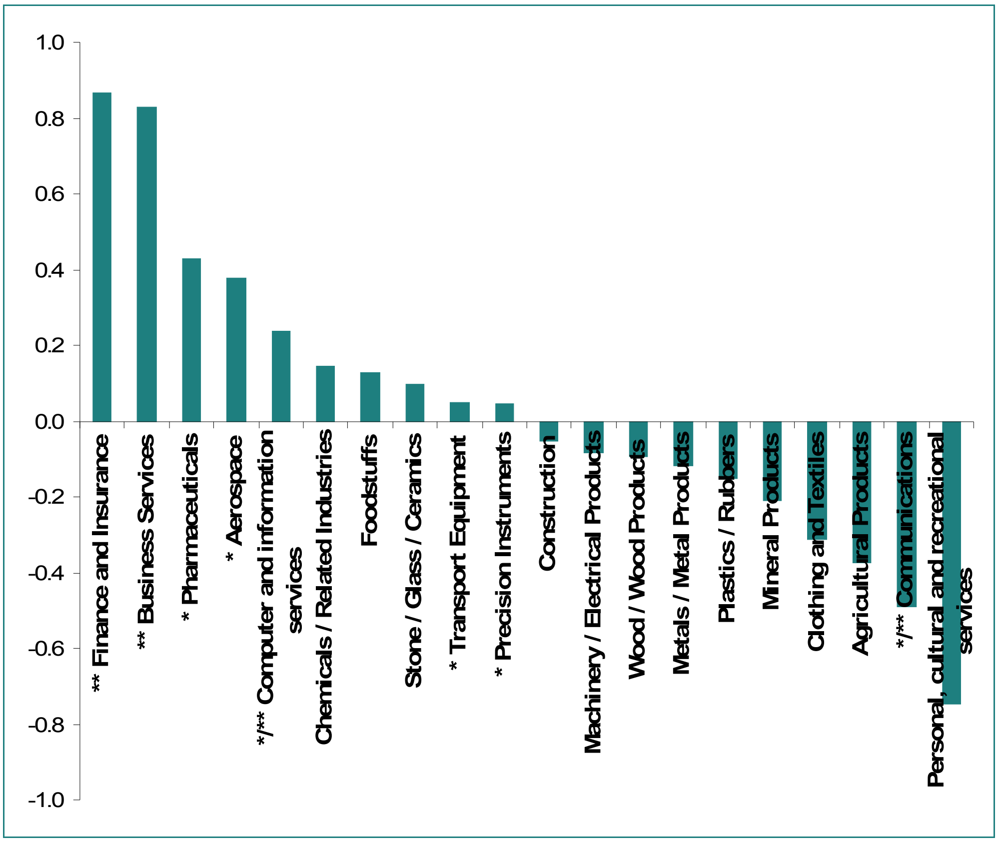
Science and innovation are at the heart of UK's future success

14. The UK has an enviable historical legacy and reputation in science and innovation, including the contributions of Newton, Faraday, Crick and Franklin. This tradition is still alive and the UK continues to have an impressively large number of Nobel laureates such as Higgs, Nurse and Geim. The UK has six of the world's top 20 universities, and 18 in the

top 100.[2] We also boast a significant number of world-class and highly innovative sectors including pharmaceuticals, aerospace and automotive, as well as vibrant new sectors like digital design, and exciting clusters such as Tech City.

15. This history matters, as the UK cannot compete on the basis of cheap labour, proprietary capital or natural resources – indeed it is increasingly unlikely that any country will be able to build sustainable and long-term prosperity simply from these factors. For the UK, this view is particularly pertinent due to two long-standing concerns about the wider UK economy: relatively low levels of productivity and low business investment. The UK therefore has to compete on the basis of its innovation capacity, not least because its comparative advantage is disproportionately derived from R&D and innovation intensive sectors, as illustrated in Figure 1.

Figure 1: UK's revealed comparative advantage[3] in selected sectors in 2011



Note: ** R&D intensive sectors; ** Innovation intensive sectors*
Source: *BIS analysis (calculations based on UNCOMTRADE and IMF data; BIS (2011) Figures 34 and 35)*

16. Indeed, there is a broad domestic and international consensus[4] that sustainable growth requires increases in productivity, and that a major source of productivity growth in

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[2] Times Higher Education (2013)
[3] A positive relative comparative advantage (RCA) value indicates that compared to the rest of the world, a sector represents a disproportionately large share of a country's overall exports; 1 would imply a country is completely specialised in a specific sector; -1 that the country has no exports in that sector; and 0 that the share of the sector in the country's exports is exactly the same as the world share of that sector.
[4] In line with the principle stated in paragraph 11, we will not demonstrate these points afresh since they are well established and generally accepted in the academic literature. The evidence is well summarised in Department for Business, Innovation and Skills (2011)

a post-industrial economy is innovation (in the broadest sense).[5] There is also evidence that public expenditure in the science and innovation space has a positive impact on private sector investment (see Chapter 4).

17. The need for on-going scientific discovery and innovation is further amplified by the vast social and environmental challenges and changes facing nations globally. In the market sector alone, manufacturing and services are blurring, new sectors and economic activities are coming into being, and all are massively impacted by the unfolding digital revolution.

This is an international game and there are no free rides

18. Like the applications and sectors they serve, science and innovation have always been international activities. Domestically created knowledge has rarely been the sole source driving innovation. Indeed, it is estimated that, in advanced economies, some 80-90% of productivity attributable to technology transfer derives from foreign research.[6]

19. It would be a mistake to conclude from this that the UK could derive greater economic benefit by creating less new knowledge itself and relying more on exploiting knowledge created overseas. Domestic research generates a hugely important by-product in the form of absorptive capacity:[7] the ability of businesses and researchers to exploit cutting-edge research carried out elsewhere in (see Box A for further details on absorptive capacity).[8] If we move away from the frontiers of knowledge creation, it is highly likely that our best researchers will go elsewhere, the world's talent will not come here, and consequently we will lose our ability to make the most of knowledge created elsewhere. This would make us significantly less attractive to inward investors. Furthermore, in a world where much applied research and development is increasingly commoditised, the UK has a huge advantage in its pre-eminent reputation for the quality of its research, which is not easily or quickly reproducible elsewhere.

20. Under-investing in the UK's absorptive capacity would mean missing out on the benefits available from the enormous, and growing, global investment in this area. While the UK's total investment in R&D has remained relatively static over time at around 1.8% of GDP (Gross Domestic Product), traditional comparator countries like France and Germany have consistently invested more than 2% of their respective GDPs and aspire to raise this level further.[9]

21. The contrast with emerging economies is even more striking, as many of these countries are significantly increasing their capabilities. China, for example, increased its spending on R&D by 28% in 2009 and by 15% to roughly £125bn in 2010.[10] It is also investing huge sums in seven new strategic industries (such as IT, energy conservation

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[5] Not all innovation is technologically based, but a strong science base is an indispensable component of an effective innovation system in a technological age (and this report will therefore generally refer to "the science and innovation system").
[6] Crafts (2012), citing Eaton and Kortum (1999). Note that Eaton and Kortum conclude that the UK is not particularly good at adapting innovation from overseas.
[7] Griffith et al (2003)
[8] Griffith et al (2004)
[9] This discussion focuses on R&D as there are meaningful comparable figures for R&D. Public support for innovation is harder to quantify reliably, and in many countries some element of this is included in R&D statistics. See further discussion in Chapter 4.
[10] This is based on an exchange rate of 1.6 USD = 1 GBP; figures remain in PPP (Purchasing Power Parity)

and environmental protection, high end manufacturing and biotechnology) and has set targets for them to grow from 2% of GDP to 8% by 2015 and to 15% by 2020. South Korea doubled its expenditure between 2003 and 2011 to around £35bn[10] (4.0% of GDP), a period when its economy grew 50% overall. It is also worth noting from our country studies (see Annex G) that emerging economies are in general less in awe of the UK's historical reputation in this area than are our traditional trading partners. The UK's science and innovation system needs to be considered in this international, highly dynamic context.

22. The most promising strategy for the UK is therefore to continue both to produce world-beating science and innovation and to seek to commercialise ever more consistently the best of what is produced in the rest of the world.

Box A: Absorptive capacity

What is absorptive capacity?

Absorptive capacity is the ability of a firm – underpinned by tacit knowledge embodied in people as human capital (skills, experience, etc.) – to recognise the value of new, external information, assimilate it and apply it to commercial ends. It is a function of the relationship between capabilities, structures, routines and policies particular to a firm.

Why is absorptive capacity important?

Absorptive capacity is important for innovation, with recent evidence finding positive impacts of absorptive capacity on growth and productivity outcomes.[7, 8, 11, 12] However, there are limited metrics for measuring either its contribution to innovation performance or how the UK performs. Some academics simply use the number of graduates as a proxy for human capital in this context.

Drivers of absorptive capacity

Many of the drivers of absorptive capacity are people-related. According to the UK Innovation Survey 2011, innovating firms tend to have a greater proportion of graduate employees, of whom the majority tend to be STEM graduates. This shows that highly skilled workers are important for innovation and emphasizes the importance of STEM skills. Diversity of skills is also important. For example, scientific and technical skills may be needed to absorb external knowledge whereas process, production and design skills may be required to create firm-specific innovations. It appears that innovating firms tend to have a higher proportion of skilled individuals employed in-house than non-innovating firms.[13]

Management quality is also regarded as a key driver of absorptive capacity, with good managers better able to lead firms to allocate resources (including human capital), recognise new ideas and undertake complementary investments to turn these ideas into new products and practices.

Investment in R&D increases a firm's innovative capability and may also increase absorptive capacity indirectly as employees engaged in R&D are likely to be more aware of external technological developments and their commercial potential.[8] In theory, better transport or communications networks should also impact on absorptive capacity, by making access to relevant sources of knowledge easier, and improve firms' ability and openness to draw in and use ideas.

Sectoral variation

Different sectors have quite different absorptive capacity with software and IT services, for example, having high innovation capability contrasting with relatively weak performance within the construction industry. This reflects differences in the skills mix within the sector, R&D intensity and the effects of the regulatory environment.

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[11] Mancusi (2004)
[12] Westmore (2013)
[13] Department for Business, Innovation and Skills (2011)

We need capacity to respond to unforeseen challenges and opportunities

23. It is not realistic for the UK to aim for world leadership in every scientific field and every sector, and this implies some element of choice on priorities. On the basis of current strengths and future trends, it is possible to make at least a reasonable estimate of the most promising pathways. The Industrial Strategy[14] and the Eight Great Technologies[15] reflect this approach.

24. It is, however, important to maintain the capacity to flex and adapt to unforeseen developments and opportunities. The future is uncertain, and we do not know what problems we will face; but we do know we will need science and innovation to solve them. This means maintaining capacity in a broad range of disciplines and an adaptive system, and accepting that this has a cost – partly as insurance and partly to be able to respond to opportunities when they arise. Over-specialism would limit this capacity. See further the discussion on taking a portfolio approach in Chapter 6.

We have used specific definitions of research and development and innovation throughout this report

25. These terms cover a wide range of activities, from basic research probing the limits of knowledge through to the application and commercialisation of products and services to create benefits to society and the economy.

26. Data is not always consistent or easy to interpret, particularly internationally. For the purposes of this report we are using the terms in the following ways. These are further defined in Table 2:

- **R&D**, as defined by the OECD (Organisation for Economic Cooperation and Development) Frascati manual,[16] is '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.' This includes basic, curiosity-driven science as well as application or market-orientated research.
- **Innovation** is harder to define, as the boundary between R&D and innovation is blurred and the definitions in the OECD's Oslo manual[17] are more recent and less settled than the Frascati definitions. We are using it in the sense of 'innovation beyond R&D' to record further activity that is new in its context, such as implementation of a new or significantly improved product, service or process, a new marketing method or new organisational methods.

[14] Department for Business, Innovation and Skills (Sept. 2013)
[15] Willetts (Jan. 2013)
[16] OECD (Dec. 2002)
[17] OECD (2005)

Table 2: Further breakdown of the definition of R&D and Innovation

Basic Research	Applied Research	Experimental Development	Innovation
Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without particular application or use in view.	Original invention undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific practical aim or objective.	Systematic work, drawing on knowledge gained from research and practical experience that is directed to producing new materials, products and devices; to installing new processes, systems and services; or to improving substantially those already produced or installed.	Activities including scientific, technological, organisational, financial and commercial steps, including investments in new knowledge, which actually, or are intended to, lead to the implementation of technologically new or improved products, services or processes.

Source: *OECD (Dec. 2002); OECD (2005)*

The rest of the report identifies a framework for analysis and benchmarks the performance of the UK system

27. In reviewing the evidence, we concentrated on the elements that are most relevant to raising our long-term ability to create and access knowledge and innovation in a competitive international environment and to remain responsive to the opportunities and threats of a future which is hard to predict.[18] The approach used was a combination of literature review, expert and stakeholder interviews and data analysis, with the aim of identifying a small number of the most critical issues to discuss in more detail. Given the complexity of the system and imperfections in the evidence base, the report findings include a substantial element of informed judgement.

28. The report is structured as follows:

- **Chapter 2**: Introduction to the **Six-Part Framework and comparators** used to benchmark the UK's performance
- **Chapter 3**: Discussion of the UK's mixed performance on **innovation outputs**, the closest proxy to the economic and societal outcomes that science and innovation should serve
- **Chapter 4**: Importance of **money** as one of the key inputs into science and innovation and analysis of the UK's apparent and significant **under-investment**
- **Chapter 5**: **Talent** and whether the UK has the right quantity, quality and mix of **human capital** to make the most of its own and the world's science and innovation
- **Chapter 6**: The UK's performance on the **remaining aspects** of the Six-Part Framework that drive successful science and innovation systems
- **Chapter 7**: **Looking ahead** to areas that need further analysis and debate

[18] It is important to note that this report is framed within the prevailing consensus that innovation is a complex and multi-directional phenomenon and not a linear progression from pure science to applied research to specific products, processes and services. In order to analyse the system, however, it has been necessary to create a framework that puts some structure around this system in ways that can be measured and compared. This should not be seen to imply any general assumption of linearity.

29. Annexes are provided in a separate document and are structured as follows:

- **Annex A: Mapping the science and innovation system** and the devising of the Six-Part Framework
- **Annex B:** Identification and **rationale for the indicators** used
- **Annex C:** Comparator countries' **performance on each indicator** identified
- **Annex D:** The **importance of money** to the science and innovation system
- **Annex E:** A summary of **comparator countries' expenditure on science and innovation**
- **Annex F:** Methodology behind the **estimation of total R&D and innovation spend**
- **Annex G:** Detailed **case studies on the comparator countries** and rationale for choice of comparator countries
- **Annex H:** A list of a**bbreviations** contained in the report
- **Annex I:** A list of **stakeholders and experts** that we have consulted and would like to acknowledge for their contribution
- **Annex J:** A list of **references** used in the report

Chapter 2: Comparisons and the Six-Part Framework

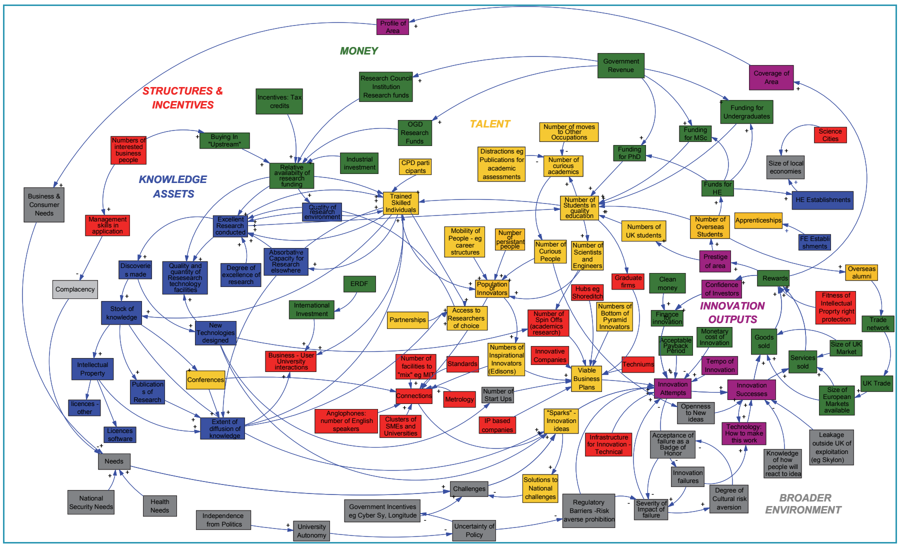
30. This chapter explains how we have made use of the international comparative evidence currently available in order to draw conclusions about the UK's underlying strengths and weaknesses. It introduces the Six-Part Framework used; identifies the features of an effective science and innovation system; and explains the indicators chosen to measure these quantitatively. Our choice of comparator countries is explained fully in Annex G.

A Six-Part Framework allows us to benchmark complex science and innovation systems internationally

31. It is commonly accepted that science and innovation function as a complex system that is highly interdependent, multi-faceted and non-linear. This applies both to the UK's domestic system, to other countries' systems and to their interactions within the international context.

32. In order to capture the key actors, elements, interactions and interdependencies of this system we undertook a systems mapping exercise that drew on literature and conversations with experts and stakeholders. The resulting systems map is illustrated visually in Figure 2. A full-size version of the systems map can be found in Annex A-Figure 2.

Figure 2: Map of the UK's science and innovation system[19]



Source: *Systems mapping exercise*

33. As expected, the map shows that the various parts of the system are dependent on each other and durable success requires a properly functioning set of inter-relationships.

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[19] The detail is not intended to be visible in this version of the systems map. It is included here as a visual illustration of the complexity and interconnections in the system. A full-size version of the systems map can be found in Annex A.

Equally, it illustrates the importance of a strong business population and dynamic public sector to create demand for ideas and allow their exploitation. Conversely, it also indicates that a strong science base creates a positive environment for the type of business population we need, including our attractiveness to inward investors.

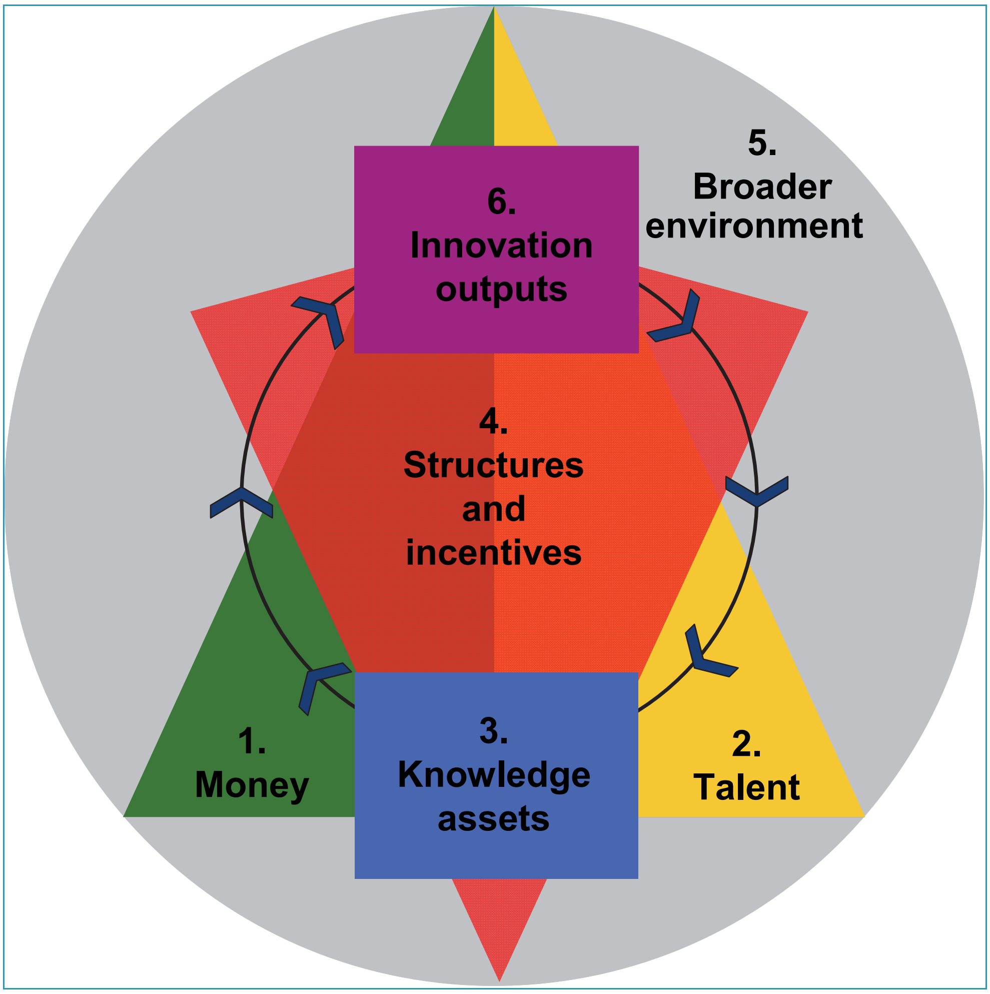
34. Other points that emerge are:

- the importance of **demand for innovative solutions** in the system;
- the need for a certain **level of scale** (actors, ideas and momentum) in the system to **sustain virtuous circles** of investment and return;
- **few single chains of cause and effect**, so attempts to raise the performance of the system must pay attention to the operation of the whole system; and;
- the framework cannot easily illustrate the importance of the time dimension of the system, both the time some activities take to have effect and also that some actions decay over time – reinforcing the point that **success in science and innovation requires sustained commitment over time.**

35. Given the complexities of the detailed system map, it was not feasible to quantify all the elements and interconnections in it. We therefore devised a simplified Six-Part Framework (Figure 3) to identify the broad categories of items within science and innovation systems that matter for economic and societal outcomes. While many elements of the system could fit into several categories, we felt that it was useful to analyse the science and innovation system's performance under the following headings:

1. **Money**: A key input into all parts of the system, used to invest in infrastructure, new knowledge, absorptive capacity and innovation
2. Talent: The human capital required to demand, develop, share and exploit new and existing knowledge
3. **Knowledge assets**: Intermediary outputs of the system that provide an indicator of its quality and potential and that are relatively easy to measure
4. **Structures and incentives**: The institutions and interconnections that determine how effectively the actors in the system work together to generate outcomes
5. **Broader environment**: The economic and societal context with which the science and innovation system interacts
6. **Innovation outputs**: Measurable outputs that can be used as proxies for the ultimate outcomes sought, i.e. economic and societal benefits

Figure 3: Science and innovation Six-Part Framework



Source: *Literature review; expert interviews; BIS analysis*

36. To keep the task manageable, we have not tried to map all the interactions between the multitude of actors, both individual and institutional, that are involved in producing positive science and innovation outputs. These actors include, at least, the government, public services, higher and further education, business and industry, financial markets, customers and citizens, learned societies and charities. However, where features of these actors or their interactions are critical to science and innovation performance, we have included relevant indicators in the framework.

There is broad consensus on "what good looks like" for effective science and innovation systems

37. Our research and expert discussions generated a rich picture of what the key success factors are for a high performing science and innovation system. While it is challenging to summarise these briefly and in only two dimensions, the most important features are captured in Table 3 using the Six-Part Framework.

Table 3: Key characteristics of an effective science and innovation system

Knowledge Creation	Knowledge diffusion and translation	Knowledge application and value capture
Money • Sufficient public sector funded research (often performed in HE institutions) • Strong private sector funded and performed research (relative to industrial structure) • Funding from other sources (charity/third sector and overseas) **Talent** • Ability to train, attract and retain world-class researchers • Population instilled with intellectual curiosity and inspired by science **Knowledge assets** • High-quality research infrastructure • World-class, internationally collaborative, highly cited published research **Structures and incentives** • Competitive excellence driven funding, with sufficient stable investment in new areas • Balance between curiosity-driven ("pure") and needs-driven ("applied") research • Balance between deep expertise and inter-disciplinary research • Meaningful (public/private) career paths for world-class researchers **Broader environment** • Sufficient number of companies willing and able to invest in knowledge creation	**Money** • Effective funding for applied research and innovation investment (public and private) • Foreign direct investment into R&D facilities and translational activity **Talent** • Sufficient quantity of individuals in firms and public sector with right absorptive capacity – Specific science and technology understanding across a broad spectrum – More generic basic, STEM, knowledge management and business translation skills **Knowledge assets** • High-performing clusters with world-class research institutions and critical mass • Strong business/academia co-authorship **Structures and incentives** • Attractiveness of research roles for and mobility of global talent • Incentives for and access to international collaboration • Incentives for business/researcher collaboration, co-creation and mobility • Sufficient co-ordination and strategic alignment among key actors **Broader environment** • Open markets and competition encouraging innovation as a source of competitive advantage • Mutually reinforcing activities within and links between science base and business population	**Money** • Timely access to risk capital (alongside advice, skills, networks, market disciplines) • Exit routes that provide access to markets and finance for growth companies **Talent** • Entrepreneurial aspirations and business building skills • General business skills (e.g., strategy, management, marketing, production) • Basic skills (literacy, numeracy, problem solving, ICT) relevant for business productivity **Knowledge assets** • Patents, trade-marks and other intellectual property that can be commercialised **Structures and incentives** • Sufficient intellectual property protection to incentivise innovation and capture value **Broader environment** • Productive dynamic between large firms and vibrant growth companies • Sophisticated demand, including from citizens and public sector (procurement) • Generally positive business environment (tax, regulation, planning, etc.) **Innovation outputs** • Revenues, exports, profits, productivity and growth derived from science and innovation • Improved societal outcomes due to better level and application of knowledge

***Source:** Literature review; expert interviews; BIS analysis*

From a challenging data set, we have chosen indicators that are most comparable and relevant

38. There are a large number of different metrics and datasets available, from numerous organisation such as the World Economic Forum, INSEAD and the International Intellectual Property Organisation, World Bank, Elsevier and the OECD, that describe different aspects of science and innovation systems. Some of these cover broader issues of economic competitiveness, but all include assessments of performance on science and innovation. The UK generally comes out well in these assessments and continues to be seen as a world leader in many areas.

39. Our approach has been to map the available data sets onto the Six-Part Framework described above, and identify the handful of indicators that are most comparable and relevant and best illustrate each of the areas in the framework. Whilst there are limitations in the data collected, we believe that those listed in Table 4 represent the most useful indicators for the purposes of this report.

Table 4: List of indicators used to benchmark science and innovation performance

Money	Talent
• M1: GERD (Gross Domestic Expenditure on Research and Development) as a percentage of GDP (Gross Domestic Product) • M2: BERD intensity (Business Enterprise Research & Development) as a % of GDP • M3: Government financed GERD as a % of GDP • M4: Percentage of GERD financed by abroad • M5: Government financed BERD as a % of GDP • M6: FDI (Foreign Direct Investment) and technology • M7: Seed/start-up/early stage venture capital as a % of GDP on Research and Development transfer • M8: Later stage venture capital as a % of GDP • M9: Financing through local equity markets • M10: Investment in fixed and intangible assets as a % of GDP	• T1: Literacy proficiency among adults (mean score) • T2: Numeracy proficiency among adults (mean score) • T3: Proficiency in problem solving in technology-rich environments among adults • T4: Population that has attained tertiary education • T5: Percentage of total first university degrees in science and engineering • T6: International students as a percentage of total enrolment • T7: Doctorate holders per thousand employed • T8: Researchers per thousand employed • T9: Individuals with tertiary level STEM qualifications • T10: Firms' leadership and management capabilities
Knowledge assets	**Structures and incentives**
• K1: Share of 1% most highly cited papers • K2: Patent application per million of population • K3: Academic/corporate co-authored publications • K4: Quality of scientific research institutions	• S1: Attractiveness to researchers and scientists • S2: Intellectual Property Protection • S3: Cluster Development • S4: Government procurement of advanced technology products • S5: SME collaboration with Higher Education institutions • S6: International collaboration on innovation by firms
Broader environment	**Innovation outputs**
• E1: Ease of Doing Business • E2: Total Early-Stage Entrepreneurial Activity (TEA) • E3: Intensity of local competition • E4: Firm-level technology absorption (2013-2014) • E5: Quality of demand conditions • E6: Interest in science and technology	• O1: Labour Productivity • O2: Sales of new to market and new to firm innovations as % of turnover • O3: Economic complexity index • O4: Knowledge-intensive services exports as % total service exports • O5: Technology balance of payments: surplus as % of GDP • O6: SMEs introducing product or process innovations as % of SMEs • O7: SMEs introducing marketing or organisational innovations as % of SMEs

Source: *Literature review; expert interviews; BIS analysis*

40. Further details on these indicators and the selection process can be found in Annex B and Annex C, and the main conclusions derived from them are set out in the following chapters.

A comparison of the UK's performance against other leading countries highlights strengths and weaknesses

41. Given the timescale of the report it was necessary to select a short-list of countries to compare the UK against. Countries were chosen following an initial trawl of the available indicators from the OECD Science, Technology and Industry Scoreboard, INSEAD Global Innovation Index and World Economic Forum Competitiveness Rankings. This resulted in a short-list of countries that offered meaningful comparison to the UK, based on their overall performance in science and innovation.

42. The countries that we chose to look at in detail were Australia, Canada, Finland, France, Germany, Japan, South Korea and the United States. Annex G provides further information on why these countries were short-listed, our methodology and an overview of our findings from each country. Notes on a small number of other countries that were of interest, but not scrutinised in detail, are also included.

43. It is important to note that many countries take different approaches to the UK, partly for cultural reasons as well as due to differences in the underlying institutions, economic structures and historical development. For this reason we have avoided drawing inferences for UK policy from specific overseas institutions or initiatives. Moreover, because the comparator set was drawn up from other leading countries, the UK's **relative performance** is, almost by definition, only average overall. Were one to look at a larger set of comparators, the UK's relative performance in many areas would be stronger.

44. The results of comparing the UK's performance against the chosen indicators to that of the countries above are discussed in detail in the rest of this report and summarised in Table 5. Note that Table 5 also includes key points from expert interviews that were raised regularly and for which evidence exists, even when this evidence has not been included in the detailed indicators.

Table 5: Summary of the main relative strengths and weaknesses of the UK's science and innovation system[20]

Category	Assessment[21]	Key strengths[21]	Key weaknesses[21]
1. Money	Medium/Low	Strong foreign direct investment (FDI) and foreign funding into R&D, high private sector investment in intangibles, vibrant financial sector and capital markets (e.g. business angels, venture capital) relative to non-US comparators	Low levels of public and private R&D investment, low levels of public innovation support, short-term focus of capital markets, remaining issues in access to finance for innovative growth companies
2. Talent	Medium/Low	Relatively attractive to top global research talent, internationally recognised higher education system attracting high quality students, relatively high number of doctorate holders, average proportion of population with tertiary education	Relatively low basic skills (numeracy, literacy, ICT), insufficient domestic human capital to exploit science and innovation (domestic STEM talent and Masters/PhD graduates working in research), below-average management skills
3. Knowledge assets	Medium/High	Highly productive world-class research base (second only to US), world-class research institutions, high proportion of international research collaborations	Low number of academic / corporate co-authored publications, smaller number of patent applications (albeit unreliable as a metric of performance)
4. Structures and incentives	Medium/High	Competitive funding driving excellence, strong international collaboration by firms, effective university collaboration with R&D intensive businesses, relatively strong formal and informal knowledge networks, a number of strong clusters with critical mass, modern intellectual property regime, good mix of basic, applied and experimental research	Government procurement not seen to foster innovation, limited SME / university collaboration, potential tensions in academics' incentives (e.g. publications vs. collaboration and interdisciplinary research vs. teaching), possible issues around portfolio management (e.g. complementarity of broader system with science investments)
5. Broader environment	Medium/High	Open and competitive markets, positive business environment, attractive to multi-national corporations, good rates of new firm creation and entrepreneurial activity, strong citizen interest in science and technology	R&D concentrated in a small number of sectors and firms, low proportion of medium-sized growth companies, UK manufacturing relatively lower-tech and less skills-intensive, relatively low quality of demand (degree of consumer orientation and buyer sophistication), migration rules perceived to be cumbersome
6. Innovation outputs	Medium (mixed)	Comparative export advantage in relatively sophisticated products, strong knowledge-intensive services and creative sector exports, strong technology balance of payments	Lagging labour productivity, average-to-low levels of new-to-market innovations, low number of innovative SMEs

Source: *Literature review; expert interviews; BIS analysis*

45. In line with the outcomes focus of this report, the next chapter first looks at the final part of the Six-Part Framework, namely innovation outputs, and how these compare to other countries. Subsequent chapters then consider the other parts of the Six-Part Framework which might explain some of the reasons for the UK's performance on the outputs.

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[20] Note: this table is also presented in the Executive Summary as Table 1.

[21] Strengths and weaknesses have been assessed relative to other leading comparator countries rather than on an absolute basis; the assessment reflects the project team's interpretation of the evidence and therefore involves an element of judgement.

Chapter 3: Innovation outputs

46. This chapter begins the detailed analysis of the UK's relative performance by looking at the sixth element of the Six-Part Framework: **innovation outputs**. This is the closest we get to understanding how the UK performs against the ultimate outcomes we are interested in: benefits of science and innovation for society and the economy.

47. Whilst outcomes and outputs are most naturally depicted at the end of the science and innovation system, it is important to emphasise that they are not simply an end point, given that the system is non-linear (as illustrated by Figure 2 and the systems map in Annex A). They also feed back into the wider system at a number of points including:

- generating an **expectation of continually improving** products and services and hence a demand for science and innovation;
- **creating new funding** for innovation from profits on previous innovative endeavours;
- **stimulating confidence** in the wider environment, both for people with ideas and for people with money;
- feeding new processes and techniques back into the system that **improve efficiency**; and
- **increasing human capital**.

Innovation outputs are the closest we get to measuring ultimate economic and societal outcomes

48. Research and innovation do not exist for their own sake. Ultimately we are interested in whether they produce beneficial outcomes for the economy and for wider society. Importantly, sustained economic growth can only come from increased productivity, and innovation is a key driver of increases in the trend growth rate of productivity.[22] Beneficial outcomes deriving from higher productivity and economic progress in turn include: people being better off because of better or cheaper products or services; better public services; lower taxes; meaningful employment; increased health, longevity, mobility or other aspects of increased quality of life; and easier communications and more rewarding social interaction.[23]

49. There are many metrics that can be used to compare the economic and societal well-being of nations. For this report, however, we have decided that it would be inappropriate to focus on these metrics, for two reasons. Firstly, there are a vast number of drivers of these outcomes and the effectiveness of science and innovation is only one of many determining factors. Secondly, the contribution of science and innovation systems, or their constituent parts, to ultimate outcomes is notoriously difficult to measure.

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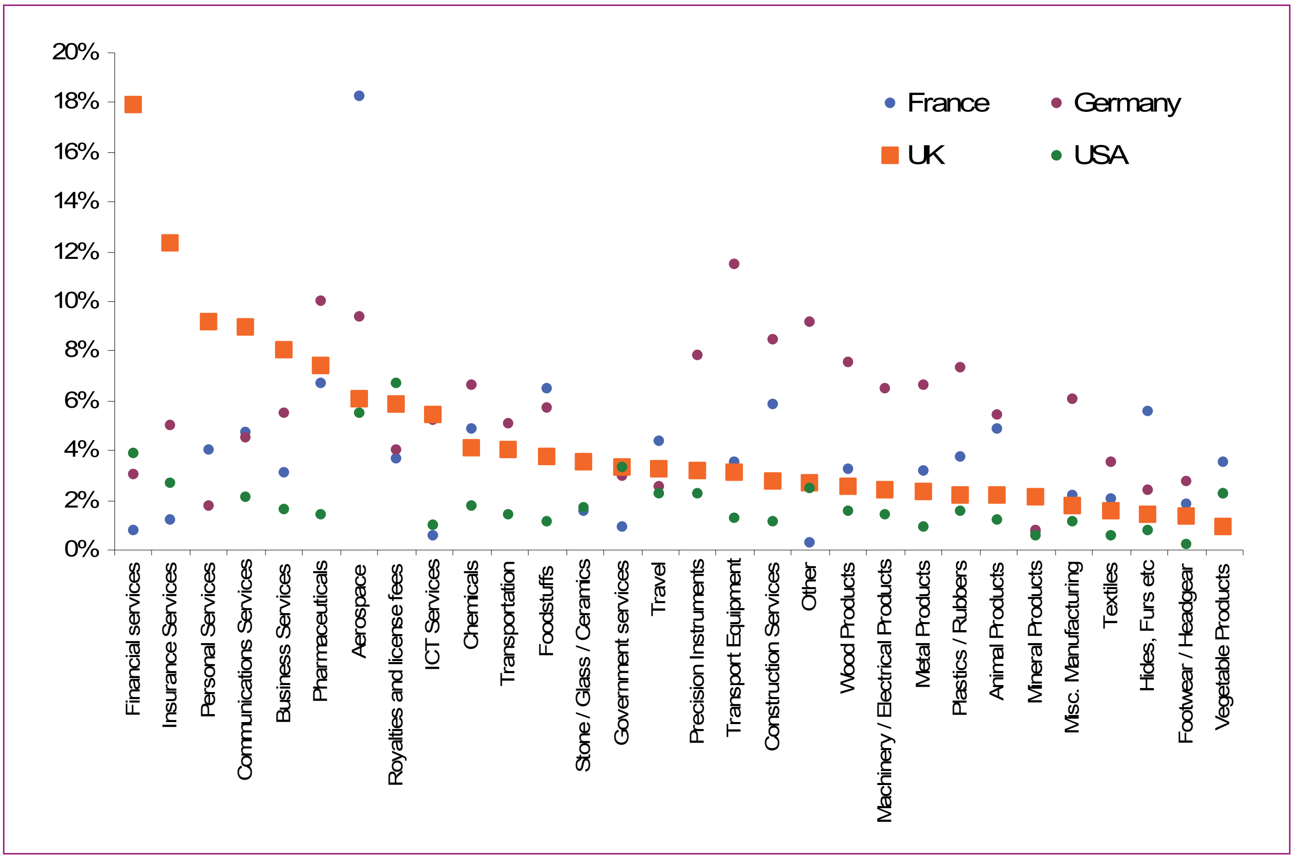
[22] Department for Business, Innovation and Skills (Dec. 2011)
[23] This is known as 'welfare' in economics terminology, and represents the sum of consumer surplus and producer surplus, plus or minus any externalities. Gross Domestic Product, or GDP, is a reasonable proxy for welfare as a whole, but clearly does not directly capture all the beneficial outcomes in which society has an interest.

50. This report is therefore focused on a set of metrics we call **innovation outputs**: things which we can more confidently attribute to science and innovation and which are clearly beneficial for economic and societal outcomes. Whilst at a remove from the ultimate goals, they are nonetheless more straightforward to compare, and valid metrics exist in some important areas. An example of such an output is the UK's strong performance in knowledge-intensive services, illustrated in Figure 4.

Figure 4: Share of global exports by sector weighted by the size of economy in 2010



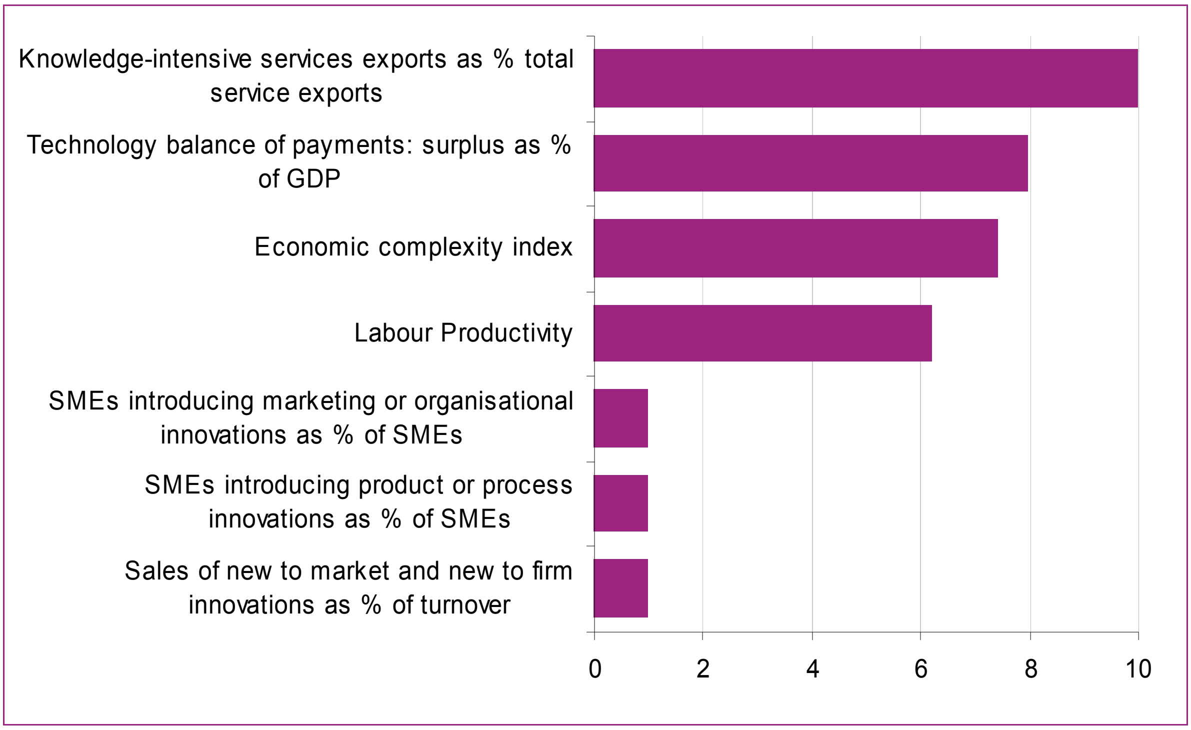
Notes: *Export share calculated as share of global exports in that product / service category, adjusted for relative size of economy; measured in US dollars (current prices)*
Source: *BIS calculations based on International Trade Centre data and IMF World Economic Outlook data*

51. The indicators were chosen according to the criteria set out in Annex B, which also describes the rationale for each individual indicator. The indicators and associated data are set out in full, with commentary, in Annex C (indicators O1-O7). They try to measure the productive application of science and innovation: are we increasing our productivity, are other countries buying technologically sophisticated products and services from us, are our small and medium-sized businesses updating the processes they use and the products and services they sell?

The UK's performance on innovation outputs is mixed

52. Overall, the UK's performance comes out around the middle of the pack. However, it is important to note that this reflects some items of very strong performance and some of very weak performance, rather than average performance across the board. The key findings from the indicators are summarised in Figure 5.

Figure 5: Relative UK score on a number of innovation output indicators



Note: *10= Highest raking comparator country, 1= Lowest ranking comparator country*
Source: *BIS analysis; see Annex C indicators O1-O7 for further information*

53. The significant points that stand out are:

- the **UK scores well on the exporting and importing of technology** and also on knowledge-intensive exports, suggesting an area of comparative advantage;
- the UK scores **poorly on sales and introduction of product and process innovations by SMEs** (small and medium enterprises), as well as marketing or organisational innovations (though the number of comparators is limited);
- **labour productivity, as measured by GDP (Gross Domestic Product) per hour worked, does not look as flattering** against our comparator countries as it does when measured in the more usual way against the rest of the world.

54. The findings on SMEs and productivity are important areas of weakness as they suggest that a large proportion of firms are not innovative (given that SMEs are 99.9% of all businesses in the UK) and that we are not managing to pull innovation sufficiently into productivity growth and therefore our ability to win the global race. These findings also suggest that the demand from business that acts as a key stimulus to innovation system

may be under-developed.[24] This view is consistent with earlier studies which note that UK policy and practice give insufficient attention to innovation as a means of improving the competitiveness of existing sectors and businesses (as opposed to creating entirely novel ones).[25]

It is likely that other parts of the Six-Part Framework explain some of this mixed performance

55. On one level, the UK's mixed performance on innovation outputs is not particularly surprising: the summary table at the end of the previous chapter shows that the UK has strengths and weaknesses across the Six-Part Framework as a whole, and the parts of the framework are closely interconnected and interdependent. It is, however, hard to pin down what exactly causes the mixed outputs, as we found no analysis that provided a compelling explanation.

56. There are, however, some plausible areas to examine. It is likely, for example, that talent and people issues are a particularly important factor. If the UK underperforms internationally on leadership and management capability, it is not surprising that there are not enough SMEs that know how to innovate effectively (in the broadest sense) in order to grow. Equally, if the UK does not have sufficient numbers of science, technology, engineering and maths (STEM) graduates, and does not pay enough attention to combining STEM skills with a wider (and changing) set of professional skills, then we may have insufficient numbers of people in businesses who can spot the potential of the knowledge assets created by the science and innovation system or alternatively define an imaginative practical problem for the science and innovation system to solve. These points are explored in more detail in Chapter 5. Additionally, a hypothesis worth testing would be that the UK's business population is not optimally compatible with the rest of the science and innovation system. This is discussed further in Chapter 6.

57. The following chapters look at the other parts of the Six-Part Framework in turn.

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[24] See Chapter 6 regarding the Broader environment and indicator E5 on quality of demand conditions
[25] Department for Business, Innovation and Skills (Dec. 2012)

Chapter 4: Money

58. This chapter looks at investment in the UK science and innovation system.[26] It considers what the evidence tells us about the importance of investment in research and innovation. Following this, it looks at the specific evidence on UK expenditure relative to comparator countries (both for research and development (R&D) and for broader innovation). The final section of the chapter pulls out a handful of key points for follow up and further work. In this chapter we use the terms R&D and innovation in the senses described in Chapter 1. Further data on science and innovation expenditure and financing can be found in the Money section of Annex C (indicators M1-M10) and Annex E.

59. R&D and innovation expenditure includes paying for researchers and other people in the system.[27] A key by-product of R&D is the tacit knowledge and expertise that it builds in the people who undertake it. This investment in human capital increases a country's absorptive capacity and ability to maximise the benefits of science.[8] While money and talent are therefore intimately interlinked, specific indicators and the UK's performance on talent are covered separately in the following chapter.

Competitive levels of R&D and innovation investment are important for beneficial outcomes

60. Chapter 1 emphasises that effective science and innovation systems are critical to growth in productivity and business investment. It is clear that money, in the form of expenditure on R&D and innovation, is a key input into this system. The evidence on the role that money plays in achieving success is reviewed in more detail in Annex D. The following points are worth highlighting here, before comparing the UK's expenditure with comparator countries:

- **The returns to investment in R&D are high,** with a social rate of return typically estimated to be in the range of 20-50 per cent. A 50% social rate of return implies that a one-off £1 investment in science or innovation delivers a return of £0.50 a year in perpetuity. However, returns can be significantly higher than this.[28]
- Academic studies find a **positive link between R&D investment and economic growth**, with public funding of business R&D providing the best returns.[29] This holds across a broad set of countries, even where investment is likely to be relatively ineffective.[30]
- **Public funding plays an essential role**, particularly where the risks are too high or the returns too remote for the private sector. Public sector investment creates knowledge assets, the absorptive capacity and international collaborative links to access and apply other countries' knowledge assets.

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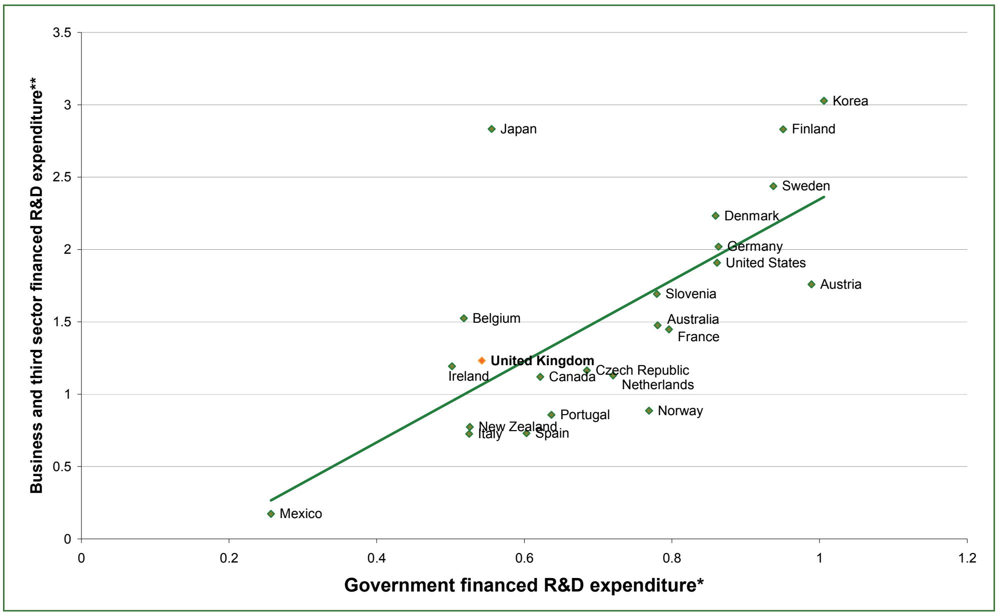
[26] Investment in R&D and innovation are clearly not the only money elements of a successful science and innovation system (see Table 3 in Chapter 2). However, given time limitations, we have not conducted a detailed analysis of other issues such as access to finance. Indicators on these other aspects are, though, included in Annex C.
[27] The rest is spent on facilities, equipment, infrastructure, raw materials and other inputs.
[28] Salter et al (2001)
[29] Guellec et al (2001)
[30] See fuller discussion in Annex D.

- Public and private funding are inter-dependent and complementary. Whilst the causal links are complex and path-dependent, the pattern of spending shows **a marked correlation between public and private investment in R&D** (Figure 6). There is potential for public investment to drive virtuous circles of private investment and innovation, as quality of research attracts international talent which in turn attracts global companies – all of which results in further advances in both new knowledge and exploitation.[31]
- There is **little evidence that comparator countries that spend more than the UK get poor returns on their investment.** Indeed, most perceive significant positive value in continued investment and are aiming to increase their expenditure further.
- The existence of strong positive feedbacks points to the **possibility of increasing returns** to scale. Economic evidence does not provide clear guidance on this point, however. One study suggests that returns may taper off beyond a certain point,[32] but the UK's current expenditure is well below this level.

Figure 6: Government and private sector financed R&D as % of GDP in 2011



***Note:** *Government financed R&D expenditure based on OECD statistics, **Total expenditure on R&D (GERD, Gross Expenditure on R&D) minus government financed GERD*
***Source:** OECD; BIS analysis*

UK's overall investment in R&D and innovation is not at the level of other global leaders

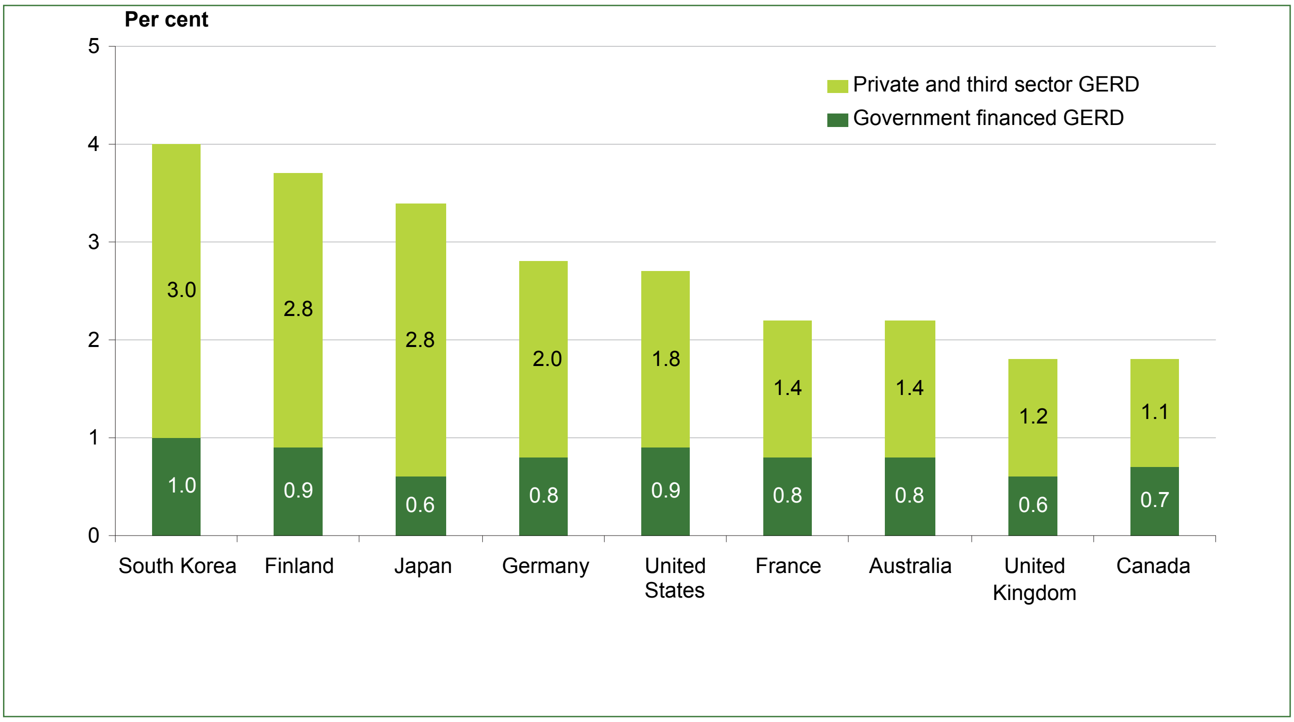
61. Having reviewed what the evidence says in general about the importance of sufficient levels of investment in R&D, we now consider the evidence on the UK's relative performance (bearing in mind the caveats on international comparisons in Annex B). We look first at **total expenditure on R&D**, and then separately at the **public and private sector components**. After that, we assess the limited evidence on the total, public sector

[31] See Box A in Annex D- 'What does public sector R&D buy? A potential virtuous circle'
[32] Coccia (2009): Coccia estimates the optimal to be around 2.3-2.6% of GDP. UK R&D expenditure in 2011 was 1.8% of GDP.

and private sector expenditure on **broader innovation**. For a comprehensive set of tables on expenditure by country, see Annex E.

62. **Total R&D investment** by the public, private and third sectors (GERD; Gross Expenditure on R&D) is lower in the UK than in most of our comparator nations, in many cases considerably so. As Figure 7 shows, GERD as a percentage of GDP (R&D intensity) in the UK was 1.8% in 2011. This contrasts with an average of 2.9% of GDP in comparator countries. Moreover, the UK's percentage has been consistently below that of comparator nations, including Germany and the United States, throughout the 1990s and 2000s.[33] This is a structural gap in investment, not the result of any particular spending decisions (which generally recognise the importance of science and innovation).

Figure 7: Total Gross Expenditure on Research and Development (GERD) as % of GDP in 2011



Note: ** Private and third sector GERD = Total R&D expenditure (GERD) minus government financed GERD*
Source: *OECD; BIS analysis*

63. If the UK's relative expenditure was low at the start of this period, competing nations are now pulling further ahead. This does not, however, reflect a reduction in UK spending in absolute terms.[34] The UK intensity rate has been broadly stable, but other nations have outpaced us. South Korea has been the most dramatic case, moving from an intensity level of below 2% in 1992 to 4% in 2011. Finland and Japan have also increased their levels substantially. As the pack has spaced out, the UK would now have to increase its expenditure very substantially to get closer to the average of comparator countries.

[33] For a comprehensive comparison of expenditure levels, including time series, see Annex E and indicators M1-M5 in Annex C
[34] As the time series chart for indicator M1 in Annex C shows, UK's expenditure has kept broadly in line with GDP growth. Indeed, in cash terms, UK's expenditure has consistently grown in this period.

64. Furthermore, UK's absolute spending on R&D (£27bn in 2011) is around one tenth of the United States (approx. £250bn PPP),[35] and is well below spending in Japan (approx. £90bn PPP)[35] and Germany (approx. £60bn PPP).[35] The UK's size means it is never likely to be among the top spenders in absolute terms,[36] but it is important to bear in mind that the group of those spending significantly more than us is likely to grow.

65. Having looked at the overall intensity of R&D, we now consider the levels of intensity in the public and private sectors respectively.

The UK's R&D expenditure levels are low relative to comparators both for public and private investment

66. A measure of **public sector R&D investment** in this area is Government financed GERD as a percent of GDP. This was 0.6% in the UK in 2011, contributing about 30% of gross R&D expenditure. This includes research carried out directly by government and grants to other organisations to carry out research. This is likely to include some expenditure on innovation support, though not all. As Figure 7 shows, this public sector intensity level is below those of key comparators with the exception of Japan (although Japan more than makes up for this with its level of private sector investment). It has, however, been relatively stable over the period, in line with policy intentions.[37]

67. The UK's **private sector R&D investment**, measured by Business Enterprise R&D (BERD) was 1.1% of GDP in 2011.[38] As Figure 8 shows, this puts the UK below key comparator nations, in many cases by quite a significant margin. The UK level has reduced slightly in the past decade.

68. There are **few compelling explanations for the low levels of private sector R&D** in the UK. Industrial structure, which we discuss in paragraph 70, only explains a small proportion of the gap, though there appears to be a particular issue with low R&D intensity in larger medium- and low-tech industries.[39] Investment in non-R&D intangibles and innovation may also contribute, but should not be seen as a substitute for R&D (see paragraph 82). Indirect support for R&D, such as tax credits, may provide an additional explanation. However, more research on this issue is warranted.

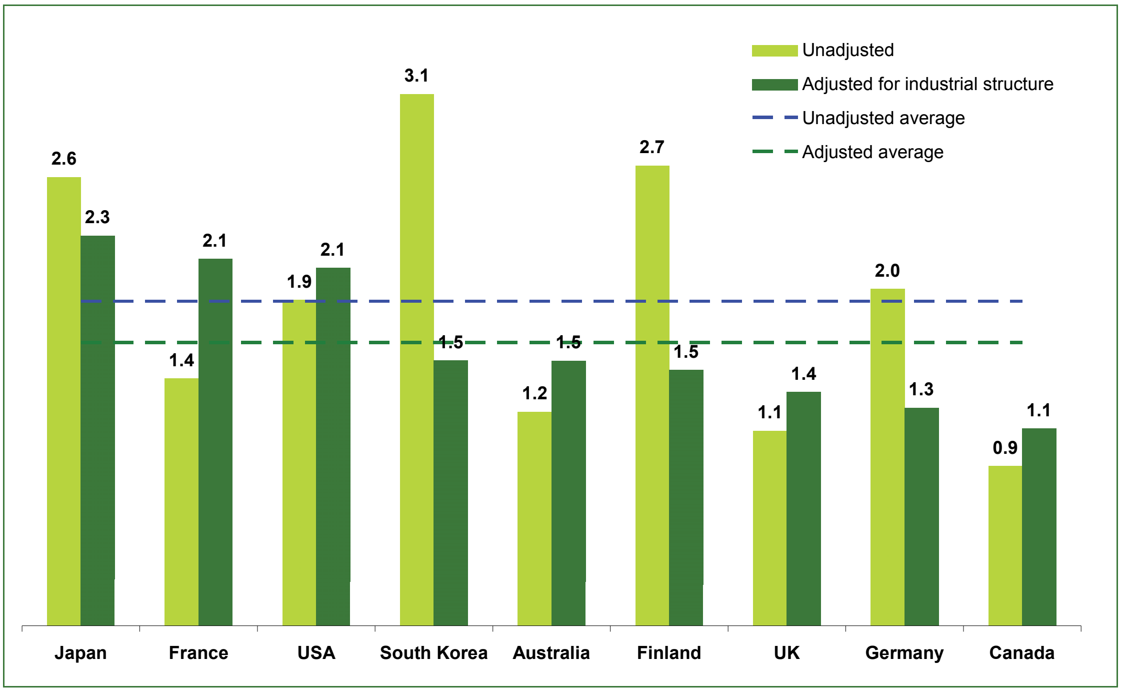
69. In **summary**, therefore, the UK's overall R&D intensity has been consistently below that of key comparator nations, and this reflects low R&D intensity in both public and private sectors.

[35] This is based on an exchange rate of 1.6 USD = 1 GBP; figures remain in PPP
[36] For a comprehensive table on absolute figures, see Annex E.
[37] For a time series, see indicator M3- Government financed GERD as a % of GDP in Annex C.
[38] Technically, BERD refers to R&D *performed* by the private sector and is therefore not entirely comparable to the previously discussed R&D *financed* by government. It is, however, the most commonly used benchmark for private sector R&D. It is also a good proxy: 90% of BERD is indeed funded by private sector sources. Table 2 in Annex D provides a cross-tabulation of UK funding sources and performing sectors.
[39] Department for Business, Innovation and Skills (Dec 2011), p. 36. Smith and Estibals note that the UK's R&D intensity is reasonably good for high tech sectors (such as pharmaceutical, aerospace and ICT) but weak compared to Germany, Japan and Korea for larger medium-and low-tech sectors (such as vehicles, metal products and food processing).

There are more benign interpretations of the R&D data, but none are fully reassuring

70. There are ways of contextualising the R&D spending statistics that present a less stark picture of the UK's relative position. If we adjust international figures on business expenditure on R&D to reflect industrial structure (see Figure 8), the UK's intensity level moves closer to the OECD average, while Finland, South Korea, Germany and Japan's intensity declines. This suggests that UK firms' spending is not as far below international norms, once industrial structure has been accounted for. It does, however, imply that the UK has fewer firms in research-intensive sectors.

Figure 8: Business Enterprise R&D (BERD) as % of GDP in 2011, unadjusted and adjusted for underlying sector composition of GDP



Source: *OECD; BIS analysis*

71. It is also the case that the UK is emerging from a recession, and business spending on R&D generally only grows significantly during periods of high, sustained economic growth.[40] In this context, business R&D in the UK has held relatively steady during a challenging period[41]. This does not, however, change the picture of consistently low intensity of business spending. The United States has also experienced a recession, and while its business expenditure on R&D as percentage of GDP has remained largely flat, it has done so at a level well above the UK's.

72. Thirdly, the comparatively low level of R&D expenditure (and in particular, public sector funded research) could be partly explained by the very high productivity of the UK's research base. As illustrated in Box B, for a relatively small absolute investment, the UK produces an exceptional quantity and quality of scientific articles and citations. However, these metrics do not take into account the benefits of investment in building absorptive

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[40] European Commission (2011)
[41] See time series chart of indicator M2 in Annex C

capacity or collaboration, both of which are instrumental to deriving economic and societal benefits from science (see Annex D for a fuller discussion).

BOX B: The UK punches above its weight as a research nation
Whilst the UK represents 0.9% of global population, 3.2% of R&D and 4.1% of researchers, it accounts for 9.5% of article downloads, 11.6% of citations and 15.9% of the world's mostly highly cited articles.

73. Therefore, while these considerations provide helpful context, they do not fully neutralise concerns that there is a persistent structural gap in the amount of investment the UK and its firms are devoting to R&D. It was certainly clear from our conversations with other countries for this study that this is a fairly widespread perception of the UK seen from abroad. The next section moves on to consider the UK's performance on broader innovation investment.

UK public sector support for innovation is low, while the private sector performs strongly in international comparisons

74. Chapter 2 noted some of the definitional issues associated with innovation (in the particular sense of "innovation beyond R&D"). Whilst it would be desirable to follow the same pattern as for the R&D statistics and compare total innovation spending, and its public and private sector constituents, no estimate of **total innovation spending** across nations has been identified.

75. It is similarly challenging to produce a definitive view on the amount of **public sector funded innovation spending**. Our best interpretation of the different data sources is that, for most comparator countries, some public sector support for innovation (such as, for example, the expenditure of the Technology Strategy Board in the UK) is already included in the R&D figures. Annex E considers different proxies for innovation expenditure in more detail.

76. Overall, the picture from these proxies is mixed and is not easily reconciled with the more anecdotal evidence gathered from country sources. For example, the US is known to provide significant support to the commercialisation activities of innovative firms,[42] but has the lowest Government expenditure on Industrial Production and Technology (IPT) as a % of GDP of all comparator countries.[43] While the IPT data for the US does not appear to be credible, the relative position of other countries on this indicator is roughly in line with expectations.

77. In the absence of reliable statistical sources, we have looked at comparable innovation bodies in the UK, Germany and Finland (Table 6). This comparison indicates that the UK's public sector support for innovation is very low. Our conversations with other countries reinforce this message: even where they admired UK initiatives (particularly the Catapult Centres), other countries were surprised at the relatively modest scale.

[42] Mazzucato (2013)
[43] See Table 7 in Annex E

Table 6: Comparison of innovation bodies in the UK, Germany and Finland

Country	Innovation body	Budget 2013, £m*	Budget as % of GDP
UK	Technology Strategy Board	440	0.03
Germany	Fraunhofer Institutes	1600	0.07
Finland	TEKES	490	0.29

Note: *Average exchange rate for 2013 used €1=£0.86*
Source: *Innovation bodies' websites; Eurostat (for GDP and exchange rates)*

78. The best practical proxy for **private sector funded innovation** is expenditure on intangible assets. Box C sets out some background notes on the measurement of intangibles.

Box C: Measuring intangible assets[44]

The term intangible assets covers a broad range of investments that firms make to enhance their competitiveness. It includes design, organisational improvement, training and skills development, advertising and market research. All of these can contribute to what is termed "innovation".

Intangible assets are an important complementary metric to consider alongside R&D expenditure for three main reasons.

First, intangible investment is an important proxy for innovation expenditure and hence significant in its own right; second, it is possible that BERD is under-recorded in service sectors and looking at intangibles provides an alternative perspective; and third, an assessment of investment in intangibles might also indicate more broadly an environment that is able to absorb new ideas and use them.

79. Our preferred metric (see Figure 9) indicates that the UK performs well on its private sector investment in intangible assets. However, not all investment in intangibles is on innovative activities. For example, a firm purchasing a software license to operate standard office applications, or an organisation training a new hire on health and safety measures, is unlikely to contribute to innovation. Our best estimate is that roughly 50% of the recorded intangibles investment could be considered expenditure on innovation.[45]

80. On this basis, the UK private sector invested 4.8% of GDP in innovation in 2011, second only to the US at 6.1%. Both were at a considerably higher level than other countries for which figures exist: France at 4.2%, Finland at 3.4% and Germany at 3.3%. (These are figures calculated by the report team, rather than derived directly from an existing source. The methodology and assumptions are detailed at Annex F.)

81. It has not been possible to do a sector adjustment on these data – but we would expect the effect to be the reverse of the R&D BERD adjustment in paragraph 70 above: since intangibles are particularly prevalent in the service sector, an adjustment to take account of the UK's relative strength in the services sector is likely to reduce the UK's lead over other countries in Figure 9.

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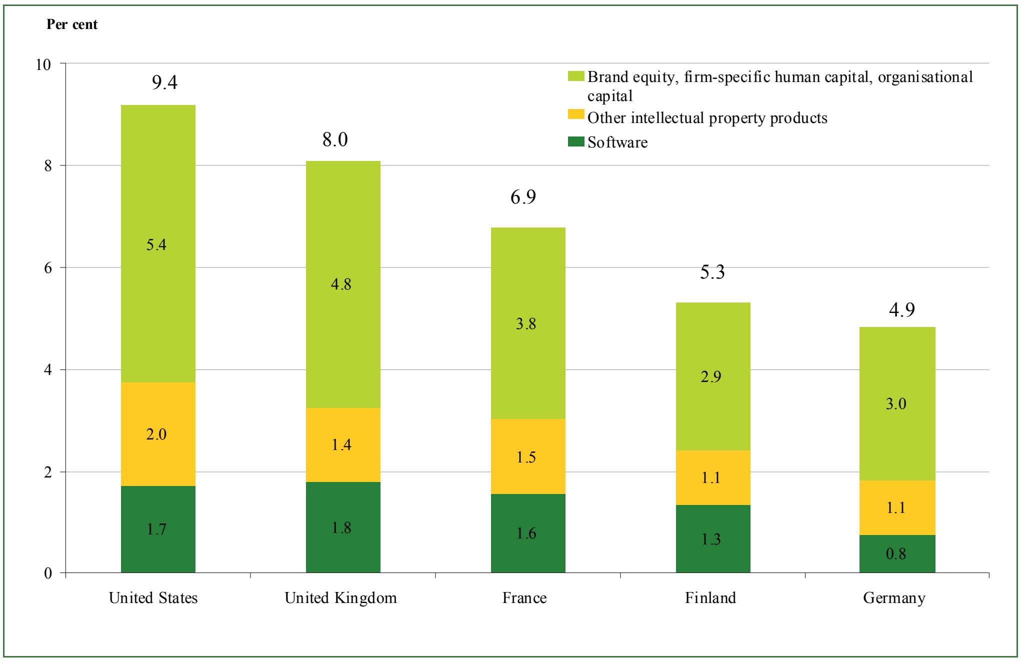
[44] Corrado et al (2012)
[45] See Annex F for explanation of the methodology employed to arrive at this estimate

Figure 9: Non-R&D intangible investment as a % of GDP in 2010



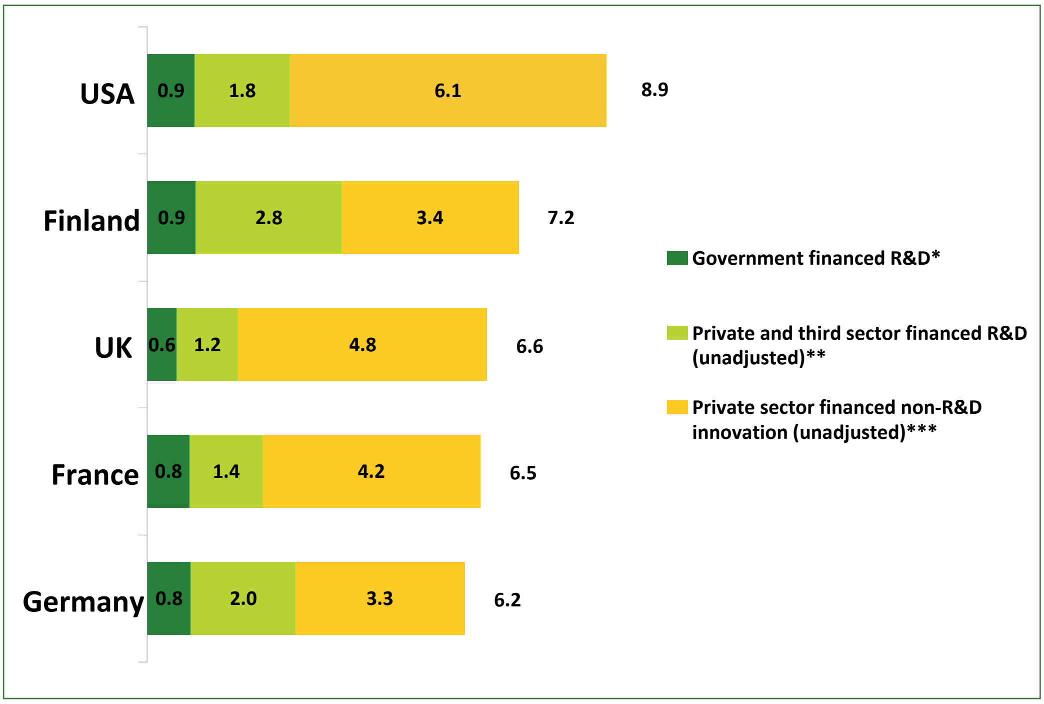
Note: *R&D expenditure has not been included in order to avoid double counting compared with previous indicators in the report*
Source: *Corrado et al (2012); BIS analysis*

The UK's high private sector innovation investment does not fully offset its low expenditure on R&D

82. In **summary**, therefore, it is harder to draw firm conclusions on innovation than it is on R&D. Innovation cannot substitute for research and development, as the key difference is that R&D involves an appreciable element of novelty and the resolution of scientific or technological uncertainty. But even with that proviso and with the limitations of the data, the pattern that emerges is that the UK as a whole appears to do well on private sector innovation expenditure but not so well as to fully offset its pattern of low expenditure on R&D. A very rough comparison of the total level of R&D and innovation expenditure, put together, is provided in Figure 10.[46]

[46] This estimate intentionally does not adjust for industry structure, given that we have no robust way of adjusting the intangibles investment numbers and it is reasonable to assume that the adjustments for R&D and innovation would roughly cancel each other out (see paragraph 81).

Figure 10: Rough estimate of total R&D and innovation spend as % of GDP in 2011[47]



Source: *Corrado et al (2012); OECD; BIS analysis*

83. It is our judgement that, all things considered, **this overall level is unlikely to allow the UK to maintain or develop its leadership in science and innovation**; and that higher levels of investment would likely provide very substantial returns in terms of benefits to the economy and society.

How best to increase investment is a critical question for follow-up work

84. The fact that science and innovation systems differ so much in different countries and that data are notoriously hard to compare makes it difficult to make firm recommendations for specific areas that might need more funding. There is some evidence[48] to suggest that further government support for innovation might be particularly valuable, but this would need to be verified by further study. Were there to be an increase in public sector investment, care would of course need to be taken to ensure the money was spent efficiently and effectively, and in a way that resulted in an optimised portfolio. As we discuss in Chapter 6, the structures and incentives operating in the current UK system appear broadly capable of delivering this.

85. There are two other crucial issues for follow-up work, both relating to how the UK might further boost private sector investment in R&D and innovation:

- a more granular and compelling evidence-base on the root causes of the UK's low level of private sector R&D is required; and

[47] The details of the methodology used to derive estimates for the components of total R&D and innovation expenditure are provided at Annex F
[48] See paragraphs 77 and Table 6

- for a country whose economic performance is heavily reliant on knowledge-intensive services, our understanding of the dynamics of R&D and innovation in these sectors needs deepening.

86. All of this has to be seen against points made in Chapter 1 that there are no obvious or sustainable ways to free-ride in this territory. To be competitive in an increasingly international economy, and to benefit from the massive, and growing, research investments of other nations, the UK has to maintain its core capacity both to create its own knowledge assets and to interpret and apply those of others. This is largely a matter of talent and human capital, which is the subject of the next chapter.

Chapter 5: Talent

87. Talent was the second main area that stood out from our international benchmarking exercise and which showed some areas of success for the UK but also some concerns. Experts and stakeholders in the UK and in comparator countries consistently emphasized the importance of this area and the increasing competition to secure international talent. In this chapter we firstly consider why talent matters, and then look at some areas of strength and weakness, and identify issues that merit further attention.

Talent is vital as it determines our absorptive capacity and therefore ability to benefit from science

88. Talent in the science and innovation system can be determined at a number of levels, all of which are both inputs and outputs within the wider systems map (described in Annex A). Particularly important elements are:

- **researchers**: in universities, public labs and industry;
- **graduates** more generally: across the economy;
- **teachers:** in higher and further education institutions but also further down the education system inspiring the next generation;
- those in **vocational roles**: lab assistants and technicians ensuring smooth running of infrastructures;
- **managers**; and
- **entrepreneurs**.

89. Government also has a key influence through the policies it sets and through the provision of funding. In addition, the point made in Chapter 1 about the inherently international nature of science and innovation is particularly important in respect of talent. The attractiveness of the UK to international researchers is captured under the Structures and incentives part of the Six-Part Framework (Chapter 6).

90. A sustainable pipeline of skilled people from home and abroad is needed if the UK is to have the necessary talent not just to generate new knowledge but also to build absorptive capacity. Talent is the dominant determinant of absorptive capacity: as noted in Chapter 1, absorptive capacity is the ability of businesses and researchers to understand and exploit cutting-edge research in areas critical to our economic and social wellbeing (see Box A in Chapter 1 for more detail). Much of knowledge resides in journals and text books, but a significant proportion of it is tacit and resides in the people and communities within the science and innovation system (in the broad terms outlined above). Talent, or human capital, – from home and abroad – is therefore at the heart of making the most of our science and innovation system.

91. Science, technology, engineering and mathematics (STEM) skills are obviously important in this context. High-level STEM skills (which include data analysis and interpretation, research and experimental design, understanding of social and behavioural impact, testing hypotheses, analysis and problem solving and technical skills) enable researchers to carry out high-level research but also enable businesses to spot the need

for innovation or the potential of an idea. A strong base of vocational STEM skills equally allows innovative products, processes and services to be produced in the UK. Our discussions with comparator countries systematically emphasised the need to instil STEM in students from an early age and indicated that they are making significant efforts to train, attract and retain STEM talent.

92. But too narrow a focus on STEM skills can be detrimental. For example, the creative and digital industries, in which the UK is a global leader, account for 6% of all employment in the UK and are projected to be among the fastest growing sectors in the coming decade.[49] These sectors have a high technical content in many cases but depend for their success on combining a wide range of professional skills. Most importantly, a solid base of business management and entrepreneurial capability is needed to bring innovation to market effectively and profitably. Sir Andrew Witty and Lord Young have both recently made recommendations on how universities and further education colleges can support the creation of a culture and the skills for entrepreneurship.[50]

93. In the broader population, it is also vital to have a good foundation of basic literacy, numeracy, ICT and problem solving skills. Clearly, a well educated, flexible, adaptable and creative work force across all organisations is key to productivity and growth in general terms. [51] It is also essential for the exploitation of science and innovation and the implementation of new ideas. Arguably, high skill and education levels in all citizens also create domestic demand conditions that reward innovative businesses.

94. Talent, therefore, is not just about researchers or STEM – important as they are – but about the full range of skills needed to realise the potential of the science and innovation system.

The UK's performance on talent raises concerns on a number of key measures

95. The evidence from a number the key indicators is set out in detail in Annex C (see indicators T1-T10). The indicators aim to cover the breadth of talent described in the previous section (though it is important to note that there are issues of data availability and reliability). The results are summarised in Figure 11. This shows a mixed picture for the UK with some apparently strong areas but most well below average.

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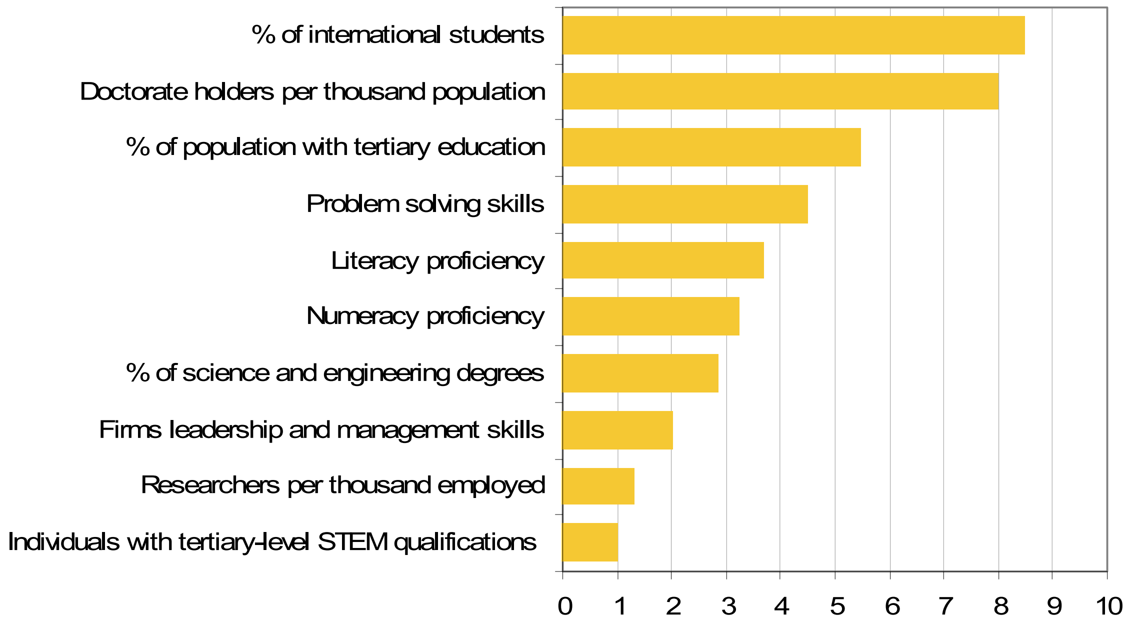
[49] UKCES (2012)
[50] Witty (2013), Lord Young (2013)
[51] The Economist (Jan. 2014)

Figure 11: Relative UK score on a number of talent indicators



Source: *BIS analysis; see Annex C indicators T1-T10 for further detail*

96. Issues of particular concern are:

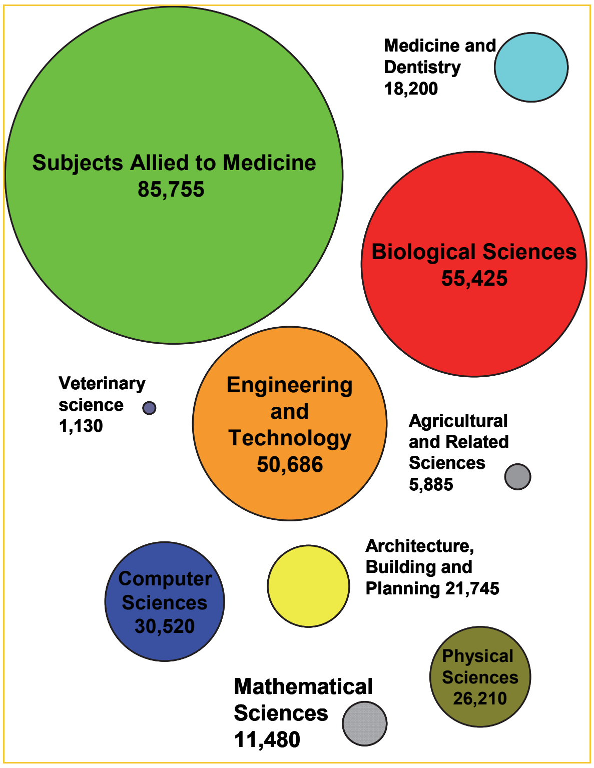
- **negative perceptions of the visa system** and the impact this has on international researchers coming to the UK;
- **the numbers of science and engineering degrees** – whilst the number of students studying STEM subjects to first degree level has remained consistent, it is still low against our comparator group and the number progressing to further study is falling;
- **the numbers of researchers** – the UK is only just above the EU28 average for the number of researchers per 1000 in employment; as discussed in paragraph 100, a large proportion of the doctorate holders (a UK strength) do not end up working as researchers;
- the **low scores on management skills**, which will limit our ability to capture economic value from science and innovation; and
- the **low figures on basic skills** – the UK has consistently underperformed in recent OECD-PIIAC studies relative to comparators, which is likely to have negative long term effects.

97. A common perception in conversations we conducted for this review, both in the UK and abroad, was that career pathways in the UK were not as clear or as secure as they might be. One country we spoke to noted that it managed to lure significant numbers of well trained researchers from a neighbouring country because it was able to offer them reasonably paid, permanent positions and career options that were not available at home.

98. Within the STEM figures, it is also important to note that there is a heavy concentration in the medical, pharmaceutical and biological sciences. Additionally, the

growth in recent years has been in the softer sciences rather than the traditional core disciplines.[52] The breakdown by discipline of UK STEM graduates in 2011- 2012 is shown in Figure 12.

Figure 12: University qualifiers in STEM subjects 2011-12



Source: *Witty (2013)*

99. Whilst this is reflective of the UK's traditional strengths and industrial structure, as well as the influence of organisations such as the NHS, it raises questions as to whether the UK needs to expand the number of people available in other STEM disciplines, at all levels of qualification. The recent Perkins Review has restated the case for additional engineering skills, not just in the form of new graduates but also (given the varied pathways into engineering) via the technical route. [53] In addition, more than 50%[54] of those taking higher degrees in STEM subjects are of overseas origin and many of them are likely to leave the UK on finishing their course. The best available estimates for the UK suggest that around 80% of non-EU students have left the UK five years after graduating.[55]

100. Caution is similarly needed in interpreting the figures on doctorate holders. Three and a half years after completion, over 60% of PhDs are working outside of higher education although the qualification remains primarily focused on training people for academia.[56] There may also be issues of expectation on the part of many undertaking PhDs: the most recently published postgraduate research experience survey found that 46% of PhD students and 40% of research staff aspired to a career in academia, and that

[52] Witty (2013)
[53] Perkins (2013)
[54] House of Lords (July 2012)
[55] Home Office (2001)
[56] Vitae (2013)

35% thought they would follow such a career.[57] So although the numbers of PhDs produced are strong, and the flow of PhDs out into the wider economy has many benefits, we cannot necessarily assume that the UK is deriving the maximum benefit from this important qualification.

Three other talent weaknesses were identified but the evidence is not good enough to be definitive

101. First, a concern was put to us that the UK does not have sufficient quality and quantity of general talent available to its science and innovation system and, whilst STEM skills are important, that the issue is a broader one. However, some studies suggest either this not to be the case or that the issue is localised (either in particular regions or with respect to certain specialist skills).[58] All such studies have found it hard to get accurate figures on flows and future demand, and this limits our ability to make a sensible judgement. It would be helpful to have more accurate figures on: the numbers of people coming here to study, teach and work in science and innovation; the numbers of UK citizens leaving for abroad to study, teach or work in science and innovation; and therefore a feeling for our net available pool of talent. This would help us clarify how reliable our apparent strengths are and help us better understand and address our weaknesses

102. Second, some experts and stakeholders emphasised that Master's degrees are particularly important in the science and innovation space (as they act as a key practicing certificate for many technological roles) and they were concerned that the UK does not have enough people qualified to this level. It was hard to find evidence to confirm either of these propositions, and indeed we heard countervailing claims that in fact we have too many Masters as people are increasingly using them to differentiate themselves from those with Bachelor's degrees. There were also claims that Master's courses are sometimes seen as cash cows by universities and do not really impart cutting edge knowledge.

103. Third, there are a large number of jobs in the UK which broadly fall into the technician category, and the route to many of these is via further education rather than universities, in particular apprenticeships. The availability of technician skills has a major impact on our attractiveness to inward investment as well as helping determine the ability of UK businesses to exploit ideas. These skills issues can also impact on business performance by limiting technical capacity and therefore inhibiting growth potential.[59] Anecdotal evidence from the further education sector indicates that many young people are unaware of the existence of this large category of jobs with good rewards and prospects and therefore overlook it in considering their career options. This suggests that a higher and more explicitly aspirational profile may be needed for this category of employment. But this depends on verifying the underlying proposition first.

[57] Bennet and Turnet (2013)
[58] Bosworth et al (2013)
[59] Kelly (2013)

While many of the talent issues are not new, resolving them requires further work

104. In summary, the UK's performance on most talent indicators is not encouraging and there are reasons to be cautious of taking our areas of strong performance too much at face value. Overall, however, it is hard to reach definitive, specific and policy relevant views on many issues because of the poor or limited data.

105. We therefore suggest a number of areas for further work:

- clarifying how reliable our apparent strengths really are – we need better data on international flows, particularly for Masters and Doctorates, and where this leaves the net position for the UK;
- exploring ways to increase numbers of people with STEM degrees to help increase our absorptive capacity[60] – including whether there are particular disciplines where growth needs to be encouraged;
- considering whether there are problems with awareness of science and innovation related careers and whether careers advice needs to be improved; and
- building the science and innovation perspective into the wider work on boosting managerial, entrepreneurial and basic skills.

106. The issues that we have identified are not new but they remain important and unresolved and given the importance of talent to the success of our whole economy, this is not an area we can afford to get wrong. It is an open question whether changes, for example, in higher and further education, such as a renewed emphasis on management and entrepreneurial skills and increased support for apprenticeships, will bring about the desired changes. The effectiveness of UK talent is also dependent on funding for science and innovation, discussed in Chapter 4 and influenced by the structures and incentives and broader environment, discussed in Chapter 6.

[60] Considering the poor performance of UK SMEs on innovation (see Chapter 2), particular attention may need to be paid to how to get more SMEs to employ STEM graduates.

Chapter 6: The remaining parts of the Six-Part Framework and other issues

107. This chapter reviews the remaining three elements of the Six-Part Framework described in Chapter 2: Knowledge assets, Structures and incentives and Broader environment. This is a relatively high-level review, as our discussions with experts and stakeholders, and analysis of the indicators described in Annex B and C, suggested these elements of the system raised less pressing concerns. The chapter also considers the role of portfolio management in ensuring, in particular, that the long-term effectiveness of public sector investment in science and innovation is maximised, another issue flagged up by experts and stakeholders. The overview of UK performance below is followed by considering, at the end of the chapter, a number of other issues that could not be covered in the time available but are relevant for the UK's future success.

The UK performs resonantly well on knowledge assets generated by the science system

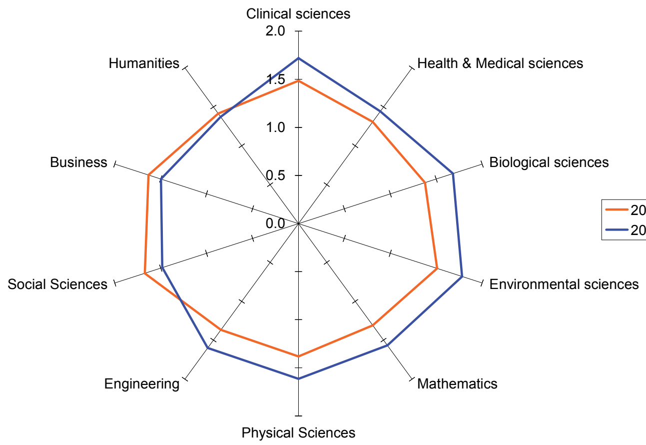
108. Knowledge assets represent the initial products of the science and innovation system and are a first measure of output and potential. They provide a complementary set of metrics to consider alongside Innovation outputs (Chapter 3). Knowledge assets include some relatively tangible outputs, such as science infrastructure and institutions, academic papers and patents, and many intangible ones, such as reputation and international links.

109. The UK generally performs well on a number of the key indicators for knowledge assets. These are discussed in more detail in Annex C (see indicators K1-K4), but the main points are:

- the UK is second only to the United States in numbers of most-cited papers, and there continues to be an upward trend; this suggests continued world-class quality of research produced in the UK;
- UK institutions are recognised as the highest rated for research quality amongst the comparator countries analysed;
- the UK has a relatively low level of patent applications and academic/corporate co-authored publications, even though these metrics may say more about our industrial structure than the economic potential of UK knowledge assets.

110. As noted in Box B in Chapter 4, strong performance on most-cited papers and research institutions, considered alongside the UK's relatively low expenditure on research and development, suggests a very high level of research productivity. Moreover, as shown in Figure 13, the UK's science excellence is strong across the entire breadth of research fields.

Figure 13: UK's field-weighted citation impact across ten research fields in 2002 and 2012



Source: *Elsevier (Dec. 2013)*

The UK compares relatively favourably on the structures and incentives operating in the system

111. As we have emphasised throughout this report, the most effective science and innovation systems consist of both strong individual components and strong complementarity between them. The structures and incentives that operate within the system – and regulate how the various actors interact – are therefore key.

112. Much of our science and innovation system has developed organically over time, particularly our learned societies and charitable sector. Our structures are often held up internationally as a good example of a strong system with a positive mix of academia, industry, small and medium enterprises (SMEs), public organisations and charities. These structures and incentives are increasingly adaptive to the international environment in which they have to operate. For example, as discussed in Chapter 5, our universities attract the second highest number of international students after the United States.

113. Overall, the structures and incentives within the UK system appear relatively fit-for-purpose. (The key quantitative metrics on this are detailed in Annex C indicators S1 –S6) Key areas of strength that emerge from our analysis are:

- the English language is a major advantage to the UK, though this is eroding as more countries move to teaching at high levels in English; this is also a major enabler of international collaboration;
- the UK's excellence-based competitive funding regime is seen as a strength and partially responsible for the quality of science outputs (as measured by published articles and citations);
- the UK is seen to have a strong intellectual property protection regime, which incentivises investment in R&D and innovation;

- the UK has strong formal and informal knowledge networks that work across academia and industry as well as internationally, and are particularly strong at our various cluster locations; and
- countries that we spoke to whose systems were dominated by large public sector research organisations tended to admire the greater flexibility and responsiveness of the UK's university-led approach.

114. However, there are a number of areas where the current structures and incentives might need refinement. Based on both quantitative metrics and more anecdotal information, these are as follows:

- many countries see government procurement as an important driver of innovation – the UK ranks poorly in this area, though no country performed particularly strongly;
- while collaboration between universities and business is perceived as strong,[61] the UK ranks as average on collaboration between higher education institutions and SMEs; this may explain some of the low levels of innovation among SMEs;
- some concerns have been raised about the incentives facing academics, with respect to the appropriate balance between focusing on world-class publications, interdisciplinary research, collaboration with businesses and teaching; and
- as we discuss in more detail below, there may be a case for considering a more conscious approach to enhance portfolio management across the UK's science and innovation system.

115. The government plays an important role in any science and innovation system, and the UK system is no different. The government strives to promote the UK system by:

- ensuring excellence driven research and funding through Research Councils and the Technology Strategy Board (TSB); and
- promoting international collaboration by various means including Free Trade Agreements (FTAs) and bilateral visits (such as the recent Prime Ministerial visit to China).

116. A frequent theme in many conversations conducted for this study, both in the UK and abroad, was the importance of stability in the system. A wide-spread perception is that the UK has good structures and governance for its research activities but tends to make frustratingly frequent changes to its innovation support.

The UK's broader environment is generally positive but there is room for more complementarity

117. The science and innovation system does not sit in isolation, and is significantly affected by the underlying business and social environment of the UK. This can include factors such as tax, law, regulation, the state of the economy and the wider culture of the country. These are all important considerations that a business or researcher will take into

[61] See WEF (2013) indicator 12.04 University-industry collaboration in R&D

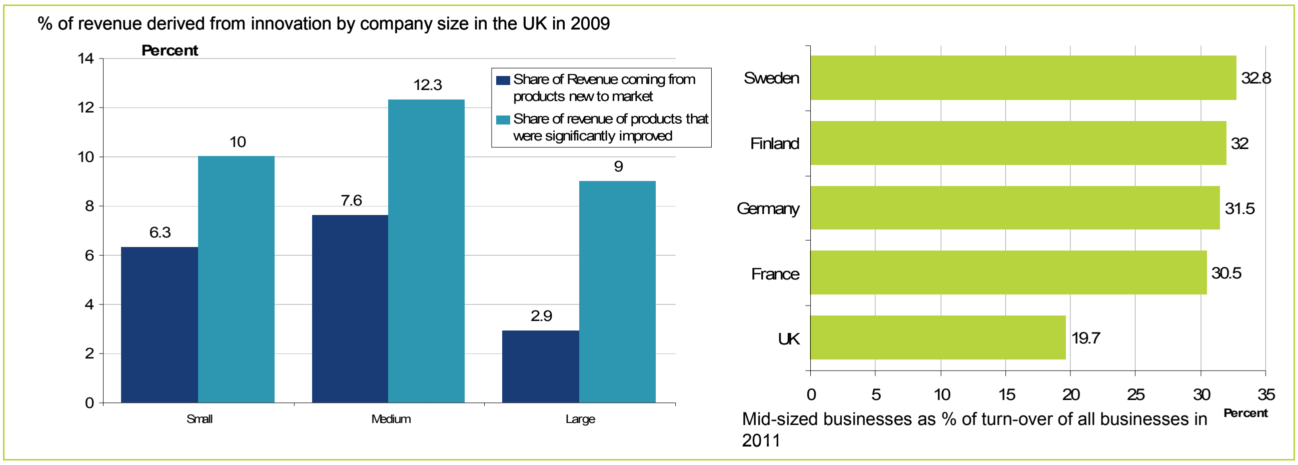
account in their investment and location decisions. The results from the quantitative analysis in this area are set out in more detail in Annex C indicators E1-E6.

118. Overall, the UK benefits from many positive factors and is seen as a good place to start and run a business with good export potential and access to the EU Single Market. This is reflected in positive indicators on general business environment:

- the UK ranks high overall and highest amongst our European comparators on ease of doing business, indicating that our regulatory system is conducive to the starting and running firms;
- the UK also scores high overall and highest in Europe for early stage entrepreneurial activity (the percentage of 18-64 year olds in the process of starting or running a new business);
- the UK ranks highly and highest in Europe for intensity of local competition, which encourages firms to get closer to the technological frontier and to demand more innovation from their supply chain;
- the UK scores highest (for those countries with data) for interest in science and technology, indicating positive of attitudes towards new technologies.

119. However, we can only maximise the benefits from our science and innovation system if the UK's business population is complementary to it. For example, the CBI have pointed out that while mid-sized businesses make up a smaller proportion of the UK's business population than in comparable countries, they also tend to be the most innovative in terms of revenues generated from new products or services[62] as illustrated in Figure 14.

Figure 14: Role of mid-sized businesses in innovation and business population in the UK in 2009



Source: NIESR (2011); Department for Business, Innovation and Skills (2011)

120. From a sectoral perspective, services are particularly prominent in the UK but are not generally seen as a strong user or stimulator of R&D (though there are exceptions, such as financial services). Even within the proportion of GDP represented by

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[62] CBI (2011)

manufacturing and production, only about a quarter of this is medium to high tech manufacturing [63] and manufacturing is less skills-intensive in the UK than many other countries.[64] In addition, lower-tech sectors' investment in R&D is particularly low in the UK.[65]

121. These underlying structural issues are also likely to contribute to the main perceived weaknesses we found in our analysis:

- UK firms are perceived to have low levels of new technology adoption, compared to other countries, with a relatively stable ranking over the last 7 years; and
- The UK also ranks relatively low on its quality of demand conditions, based on how well customers are treated by companies and how the buyers make their purchasing decisions; lack of sophisticated demand is likely to limit the UK's innovation potential and outputs.

122. These factors of economic structure and competitiveness lie behind the emphasis in the Industrial Strategy on creating a positive framework for innovation and upgrading capacity in key sectors.

There is a view that a greater degree of conscious portfolio management in the UK should be considered

123. In addition to reviewing the three remaining areas of the Six-Part Framework (above), this chapter is an opportunity to comment on a set of suggestions that emerged from expert and stakeholder discussions on portfolio management, i.e. the way the overall system of science and innovation is managed, coordinated and assessed in the UK. While we had limited time to scrutinise the evidence, the messages were sufficiently compelling for us to conclude that a further exploration of these ideas should be undertaken.

124. The argument was made that a medium-sized country like the UK cannot excel in every single field of activity or type of research, which implies some element of rational choice in where to concentrate effort nationally. Many experts and stakeholders felt that the returns on science and innovation investment could be further enhanced if they were considered explicitly in the context of the whole system.[66] Some expressed the view that there should be a greater element of conscious coordination; and that greater alignment with the UK's existing absorptive capacity and industrial strategy should be sought. Points were also made about the use of mission-oriented, challenge-led programmes (See Box D); and the way the returns from science and innovation are assessed.

125. The returns to science and innovation are substantial, but they are unpredictable and highly skewed, in that the bulk of the economic returns tend to come from a small number of successful outputs.[67] Successful ideas can also occur at some distance in time from the original discovery and be applied in areas far distant from any conceived at the

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[63] Department for Business, Innovation and Skills (Sept. 2012)
[64] Department for Business, Innovation and Skills (Oct. 2012)
[65] Department for Business, Innovation and Skills (Dec 2011), p. 36
[66] This might involve, for example, individual decision makers incorporating in their criteria a consideration of the fit with other actors' and institutions' activities, including in the commercial sector.
[67] Hughes et al (Aug 2012), e.g.paras 23 and 49

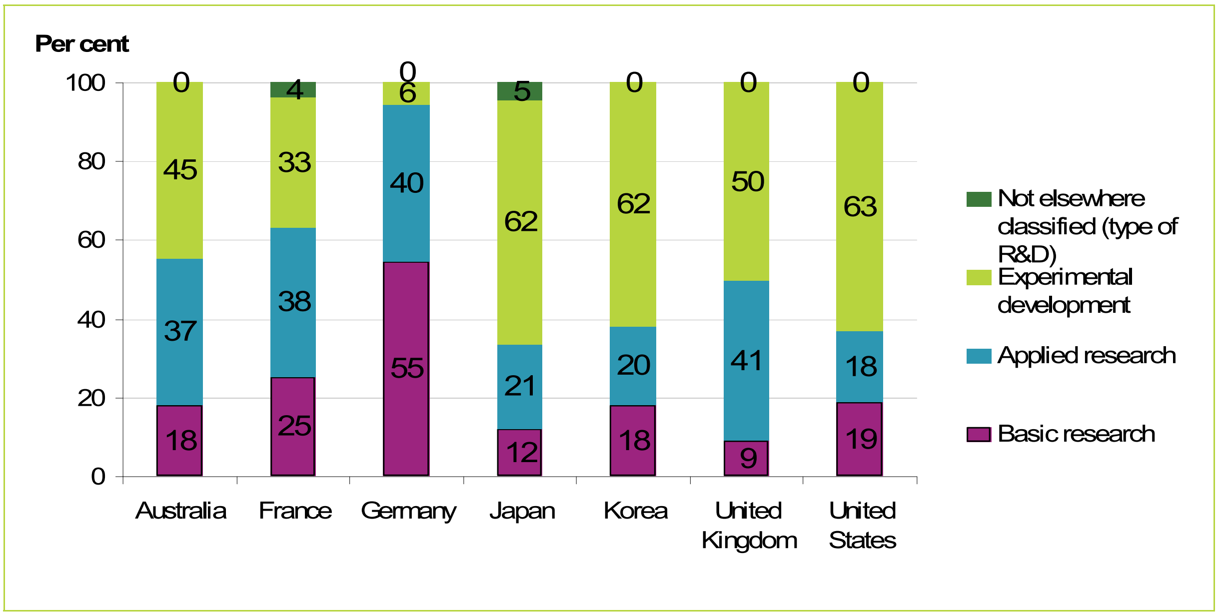
time of development (e.g. lasers). Therefore, the objective should be to maximise returns from the overall portfolio, rather than individual investments.[68] An ideal portfolio would avoid sub-scale activity on the one hand and over-concentration on a small number of areas on the other, consider the complementarity and option-value of different investments dynamically, and aim to achieve an appropriate balance between the following factors:

- **experimental or curiosity driven basic research** (which has the highest social returns) and more **applied research and innovation** (which appears to have the biggest positive effect on leveraging in private sector R&D investment);
- **longer-term inquiry** (with stable funding for potentially highly challenging mission-driven programmes) and **shorter term problem-solving** (with more immediate applications **and** value capture);
- **competition** to stimulate ideas and drive quality (e.g., encouraging several institutions and researchers to pursue a similar area) and **collaboration** to avoid wasteful duplication of effort; and
- **deep expertise** that confers global leadership in a particular field and **inter-disciplinary** research that creates novel new insights.

126. There was, however, no clear view on what might be deficient in the UK's current system. We therefore interpret these suggestions in the spirit potential further refinements that might make UK even more successful, rather than major criticisms of how things currently work. As Figure 15 shows, the UK's current portfolio (at least on this metric) is not obviously out of line with international comparators, and we did not find any countries that manage to balance all the relevant factors in a strikingly better way than the UK. Indeed, practice in the countries studied covered the full spectrum of approaches, from strong involvement of the political system to absolute freedom for researchers.

[68] This principle should also feed into how investments are assessed. Whilst careful appraisal and evaluation of investment opportunities will remain essential, it should be the portfolio as a whole that needs to make a positive return, not every single constituent investment.

Figure 15: Gross Expenditure on R&D by type in 2010



Note: *1) United States - only provide breakdown by current costs and latest data relate to 2009; 2) Japan and France have around 5% of their spend unclassified; 3) Australia - split only available for the HE and Business Enterprise sectors; 4) Germany - split only available for the government sector 5) Finland and Canada - no data available on type of R&D undertaken. .*
Source: *OECD Main Science and Technology Indicators; BIS analysis*

127. There is of course considerable uncertainty with regards to future needs. This requires the UK to maintain a broadly-based and flexible science and innovation capability. Commentators we spoke to were therefore anxious to avoid too much top-down control, not least since the strongly responsive and bottom-up approach in the UK is seen as a strength internationally. Moreover, the government's Industrial Strategy seeks to signal areas for attention without implying top-down planning. The Eight Great Technologies identify some particularly promising areas of opportunity which cut across a number of different sectors and which require a mixture of funding and structures.

128. Our view is therefore that the impact of the Industrial Strategy and the influence of the Eight Great Technologies on future science and innovation needs longer to become apparent, at which point it would be sensible to take stock as to whether the balance this gives rise to is optimal.

Box D: Mission-driven research and innovation

In addition to more traditional technology push (e.g., commercialisation and spin-off opportunities for university research), there is a wide-spread recognition of the importance of sophisticated demand for science and innovation (technology pull). As part of this, our analysis of comparator countries revealed a trend towards gearing research to solve specific societal challenges. Various terms are used to describe such initiatives, including “grand challenges” and “mission-led programmes”.

For example, a country might launch a mission to drastically reduce the costs of a certain health care intervention and then engage actors across the science and innovation system to stimulate solutions to deliver that outcome. In some cases, missions are explicitly linked to procurement: the government might commit to a future contract for the solution that has been developed. The US has traditionally used mission-led programmes to generate technology pull; and Japan has recently moved from a sectoral to a societal challenge approach to allocating funding. The newly-launched EU research and innovation funding programme Horizon 2020 contains one "pillar" (out of three) which focuses on seven specified "Societal Challenges" and accounts for around 36% of the total budget; and the relevant Ministries in France, Germany and Finland are all either considering or implementing similar schemes.

Whilst some use of this method is already made in the UK, we suggest that there needs to be a debate about the benefits and downsides of its wider implementation. This would require a cross-government approach both to identify the challenges in a sufficiently strategic and cross-cutting way and also to co-ordinate the deployment of all the necessary levers across departments and organisations in order to deliver the mission. Given the number of existing cross-cutting initiatives, it might also be necessary to streamline or amalgamate these to maintain coherence and focus.

There are a number of important areas that fell outside the scope or timescale of this report

129. Given the timescales of this report it has not been possible to consider all issues that affect science and innovation. Three of the most important areas outside of the scope of the report were **access to finance, procurement and international collaboration**, all of which would warrant reports in themselves.

130. In addition, during the course of the report a number of interesting points were raised that we have not been able to give sufficient focus to but that are worth recording here. These are summarised below:

- There is a perception that the UK often overlooks the innovation potential of embedding **standards** in international agreements and a need to ensure that standards do not entrench existing technologies at the expense of better replacements.

- **Legal systems** associated with contracts, licensing and intellectual property, were seen by some to be too cumbersome and costly and therefore act as a barrier to innovation. Memorandums of Understanding and non-disclosure agreements are beginning to be used more widely as a faster and more flexible alternative.
- UK business groups observe that many parts of government **procurement over-specify** the way in which the need is to be met, thus limiting the scope for innovative responses. The Strategic Business Research Initiative (SBRI) seeks to address some of these concerns, but remains on a smaller scale than other countries and focuses on health-related issues.

131. Many of these points back up the ideas proposed in this report that the science and innovation system is intimately bound up with the profile, capacity and attitudes of our business population and the effectiveness of the business environment in which it operates. The final chapter presents some issues that we have identified that merit further attention.

Chapter 7: Looking ahead

132. This report has drawn on a wider variety of both qualitative and quantitative sources and has looked at the broad science and innovation system currently operating in the UK. Overall, we have found that many aspects of the UK science and innovation system compare favourably to other leading countries. However, the UK significantly under-invests in research and development and public sector innovation support; and its talent base has weaknesses that stop it from maximising value from science and innovation.

133. We will not reprise the detailed findings here: they are summarised in the Executive Summary and Table 1, and discussed throughout the document. We would, however, like to draw attention to the most important issues that we did not have either sufficient evidence or time to pursue or which fell outside the scope of the report. These are areas in which we believe further work, discussion and debate is warranted in order to maintain and develop the UK's global leadership in science and innovation.

134. Many of these areas are, of course, already being actively pursued by the government. This list should serve as a reminder of their significance for future success.

- **Quantifying science and innovation outcomes:** As noted in Chapter 3, the international comparative evidence on meaningful innovation outputs and outcomes is sparse and gives a mixed picture of the UK's performance. A more granular and comprehensive picture would help pinpoint potential priority areas for policy action.
- **Low private sector R&D investment:** As noted in Chapter 4, even after adjusting for industrial structure, the UK's businesses invest less in R&D than comparator countries'. Given that private sector performed R&D is more than half of GERD, understanding the root causes of this is critical to addressing the UK's overall under-investment in R&D.
- **Dynamics of service sector innovation:** Services make up almost 80% of the UK GDP and 40% of exports, so a better grasp of the preconditions and drivers of innovation in these sectors would be reassuring. It would likely identify areas – for example in talent and incentives – that require serious further consideration.
- **Poor innovation performance in SMEs:** A theme throughout the indicators in Annex C is the poor performance of the UK's science and innovation system vis-à-vis SMEs. This applies both to SMEs' own activity and linkages with research institutions. As SMEs account for almost 60% of private sector employment, this is likely to be a significant drag on productivity.
- **Quantity and quality of "net talent":** The discussion in Chapter 5 concludes that comparative data on international flows of science and innovation talent are not available or sufficiently granular to draw definite conclusions. Yet, addressing talent weaknesses in a targeted and cost-efficient manner would require such insight. A first step may be refining and testing a set of specific hypotheses with employers.
- **Access to finance for innovative growth companies:** It seems clear that the private sector will not provide the socially optimal level of financing for the constant and often risky experimentation that characterises highly effective science and innovation systems. The question to ask is whether the quantum and targeting of existing government interventions, notably the Business Bank, is sufficient to address this issue for the UK.

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