Department for
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& Industrial Strategy

Evidence for the UK Innovation Strategy

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Any enquiries regarding this publication should be sent to us at:
enquiries@beis.gov.uk

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Executive Summary

In the long-term innovation in technologies, production processes, supply chains, and business models determine the ability of a country to raise its economic growth and productivity. The UK's future depends on it.

The UK innovation system has many strengths: it is ranked 4th in the Global Innovation Index, it has an unrivalled status in research impact amongst the G7 and is a partner of choice for international collaboration. However, the UK faces significant competition and challenges. UK R&D investment is 1.7% of GDP while average spend in OECD countries is 2.4%. The proportion of innovation active businesses in the UK has decreased from 49% in 2014-2016 to 38% in 2016-2018[1].

The UK Innovation Strategy outlines an ambitious approach to make the UK a global innovation hub by 2035. This paper complements the Strategy with evidence against its four pillars on the current strengths and areas for improvement for the UK to reach this overarching goal.

This evidence paper provides an overview of a non-exhaustive range of factors that influence the pace and direction of innovation. These factors give a fuller understanding of how finance, the supporting regulatory and intellectual property (IP) systems, and global collaborations unleash innovation opportunities for business (Pillar 1). Investing in people and talent is crucial to unlocking new areas of innovation activities (Pillar 2), and supports the adoption and diffusion of new ideas, knowledge and processes across all regions of the economy (Pillar 3). The final two sections (Pillar 4) set out how mission-based policy and identifying technological advantages, underpinned by analysis, can achieve outcomes that support UK economic growth and prosperity, and tackle major societal challenges. The paper concludes with a summary of the findings from each Pillar.

Pillar 1: Unleashing Business

Businesses need access to finance to fund innovation activities. While the UK compares favourably in many access-to-finance indicators, there are gaps around early-stage investments in innovation, coordination between institutional investors and venture capital, and challenges in the scale-up of innovative UK businesses. The evidence suggests that the UK needs to address equity finance gaps across the funding landscape and increase supply of capital to match demand.

Regulations, standards, the IP system and other framework conditions have a significant impact on innovation. However, the evidence shows that this impact varies between sectors,

[1] BEIS 2019. UK Innovation Survey 2019.

markets, and timescales, and there is not a one-size-fits-all rule around how they impact innovation. The UK can further improve framework conditions to unleash innovation.

Despite the UK's strong research base, its performance in adoption of ideas and technologies is weaker in comparison with competitors. Although the UK ranks 4th in the Global Innovation Index overall, it ranks 11th in the world in terms of knowledge diffusion and 27th for knowledge absorption. There is good evidence that current and future economic growth depends on an economy's ability to adopt innovations—technology diffusion explains 44% of the difference between GDP per capital across countries. Improving the adoption of innovative ideas and technologies among UK firms, as well as the process of taking these to commercial markets, could have a large impact on UK productivity, job creation and economic recovery.

The UK is a partner of choice for innovation collaboration across the global and collaborations have contributed to UK's unrivalled research status. Evidence shows that international research and innovation collaboration achieves higher scientific impact. To future proof national innovation, the UK needs to build on its advantageous position with continued support to our collaborative innovators.

Pillar 2: People and Talent

Businesses increasingly report lack of qualified people as a barrier to innovation. If the UK does not address the shortage of qualified people, it will experience major gaps in digital, management and STEM (science, technology, engineering, and mathematics) skills in the UK. It is vital that the UK's workforce, and the training and education system that feeds it, has sufficient scale, diversity and breadth to meet the challenges and opportunities of a more innovative economy and society.

Pillar 3: Institutions and Places

The UK holds three of the most science and technology intensive clusters in the world in Cambridge, Oxford and London. Overall, innovation activity in the UK is concentrated. This reflects a virtuous circle with a high concentration of research-intensive organisations, skilled people, and availability of investment in those areas.

Evidence indicates that investing in places with existing and emerging strengths in the factors needed for R&D, would benefit both regional and UK-wide productivity. This applies to clusters of public and private R&D activity that need to achieve a scale where they can attract their own private investment and global talent, and also at firm level because all UK regions host innovative firms that see productivity gains from R&D and innovation output.

Pillar 4: Missions and Technology Advancement

Mission-oriented policies direct innovation to tackle complex technological and societal challenges. Following publication of the UK Innovation Strategy, we will identify a suite of ambitious and inspiring missions determined by the new National Science and Technology Council. Evidence suggests that the UK needs to set the direction and co-develop these missions with the private sector, drawing upon the UK's own experience as well as best practices from around the world.

National competitiveness, security, growth and productivity depend on technological advancement. The UK needs to identify and focus on technologies with market potential and strategic interests. Horizon scanning has identified commercialisation potential in seven technology families[2]. In the future there is a role for government and businesses to unleash technology innovations and wide-spread adoption across businesses and the wider economy.

Evidence in this paper shows UK strengths in innovation outputs as reflected in the 4th ranking in Global Innovation Index and its unrivalled status in science and research. Comparison, however, also shows that if the UK wants to become a global hub for innovation it needs to invest more in R&D, unleash businesses who want to innovate, nurture innovation talent, and ensue the innovation system serves the needs of the businesses and places across the UK.

[2] The seven technology families of identified to have UK strength and opportunity are: Advanced Materials and Manufacturing; AI, Digital and Advanced Computing; Bioinformatics and Genomics; Engineering Biology; Electronics, Photonics and Quantum; Energy and Environment Technologies; and Robotics and Smart Machines. Access report here

Introduction

To build back better and lead the advanced economies of the world, the UK needs to innovate. New jobs, new products, new services are built on ideas, scientific discoveries, research, experimentation, and wide-scale adoption and diffusion. More importantly, global and local challenges, such as climate change and levelling up, require bold and evidence-driven policies to unleash innovation across the economy.

In July 2020, the BEIS R&D Roadmap[3] reaffirmed the UK government's commitment to increase R&D investment to 2.4% of GDP and to increase annual public investment to £22 billion. Build Back Better: our plan for growth[4] published in March 2021 reiterated this commitment to innovation, "tackling long-term problems to deliver growth that creates high quality jobs across the UK". The UK Innovation Strategy takes this vision forward. It identifies actions that are necessary to make the UK a global hub for innovation by 2035, and its four pillars set out key actions in wide-ranging areas.

This paper complements the policy direction set out in the UK Innovation Strategy. It presents evidence on the current strengths and areas for improvement to address bottlenecks to innovation. A range of sources have influenced this paper, including reviews of existing literature, policy studies, analysis of UK and international databases, evaluation studies of existing policies and round tables with experts, academics, and industry.

This paper highlights and explores a selection of issues discussed in the Strategy and is complemented by a range of existing publications from other government departments and the academic community which provide more in-depth coverage on specific issues.[5]

Why is innovation important?

Technological innovation, scientific research, computing technologies, medicine, new business models, cleaner sources of energy, among numerous other innovations, have improved health and wealth. While earlier generations lived shorter, harder and more precarious lives, "living standards have increased by many times, life spans have more than doubled, and people live fuller and better lives than ever before"[6].

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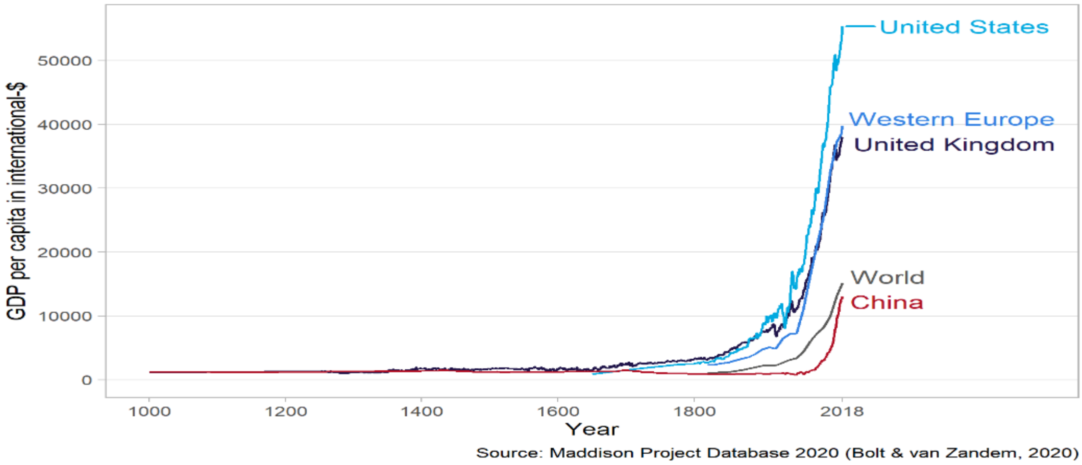
[3] UK Research and Development Roadmap, 2020. https://www.gov.uk/government/publications/uk-research-and-development-roadmap
[4] Build Back Better: our plan for growth, 2021. https://www.gov.uk/government/publications/build-back-better-our-plan-for-growth
[5] To give but a few examples, the British Business Bank research features studies on how to make the finance market work better; NESTA's compendium of evidence on the effectiveness of innovation policies offers a detailed discussion of policy issues; and UKRI and its research councils publish details of R&D and innovation programmes and impact these programmes generate .
[6] Deaton, A. 2013. The Great Escape: health, wealth, and the origins of inequality. Princeton: Princeton University Press.

Innovation is vital for economic growth and productivity improvements as well as creating more and better-paid jobs.[7] Significant changes in per capita income took a clear turn upwards around the time of industrial revolution, thanks to innovation in technology, business models and ideas. In the last 100 years alone, GDP per person in the UK has increased by 340% – largely thanks to innovations enabled by technological progress like electrification, transportation advances, new industries and new jobs. The chart below shows GDP per person since 1000 AD for selected regions and leading prosperous nations.

Figure 1.1: GDP per capita, 1000 to 2018



Source: Maddison project Database 2020 (Bold and van Zanden 2020)

Innovations in medicine have doubled the average persons' life span; electricity and household machines have made it possible to enjoy leisure saved from gruelling household work; technology and innovative business models made it possible for ordinary citizens to travel around the globe; the internet has enabled us to engage with the world from our homes; and our scientific research, entrepreneurship and inventiveness led, amongst other things, to the development of vaccines for Covid-19 in record time.

This section does not aim to cover the full impact of innovation and technological progress on growth and quality of life, but it presents a few selective examples to put the long-term impact of innovations in perspective.[8]

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[7] There is a positive relationship between product innovation and revenue productivity and firms that increase innovative sales see increased productivity. Hall, Bronwyn H. (2011). Innovation and productivity. No. w17178. National bureau of economic research; Hodges D. (2010). Investigating the links between innovation and productivity: an analysis of UK firms, BIS, 2010; Criscuolo C. (2009). Innovation and Productivity: Estimating the core model across 18 Countries, in OECD, Innovation in Firms – A Microeconomic Perspective, Paris: OECD (2009).

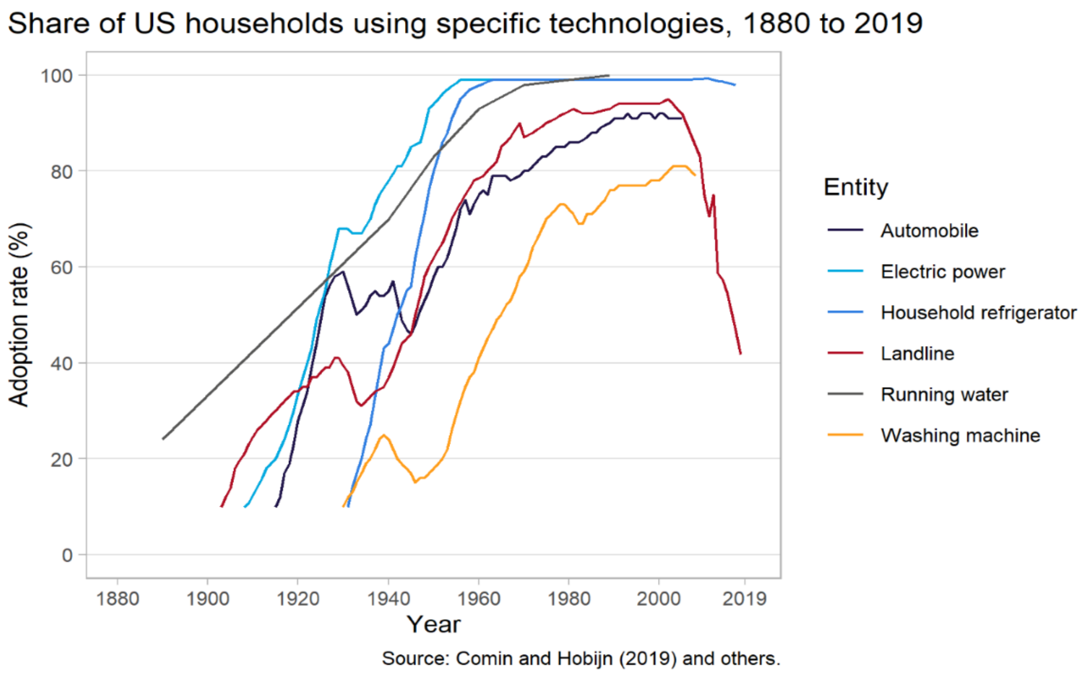
[8] Robert Gordon provides a comprehensive coverage of how "great inventions create a revolution inside and outside the home" in his book "The Rise and Fall of American Growth". Joel Mokyr's "A Culture of Growth: The Origins of the Modern Economy" explains how ideas, intellectual innovation and technological progress paved the way for the modern economy.

Household appliances have transformed our lives inside the house

Most of the UK population in 1900 hauled wood or coal for cooking and heating, bought candles or oil for internal lighting, spent hours in washing and cleaning and could not even imagine refrigerators, television and the internet. Technological progress has transformed the inner life of our houses.

Innovation has made everyday technologies more accessible and affordable to households. This has increased productivity, created jobs and saved people from hours of hard work. While the data below is for the US, the trends would be similar in the UK and Europe. This shows not only a transformation in the use of household appliances but also in comfort and leisure brought in by innovations.

Figure 1.2: Share of US households using specific technologies, 1880 to 2019



Source: Our World in Data and Comin and Hobjin and Others9

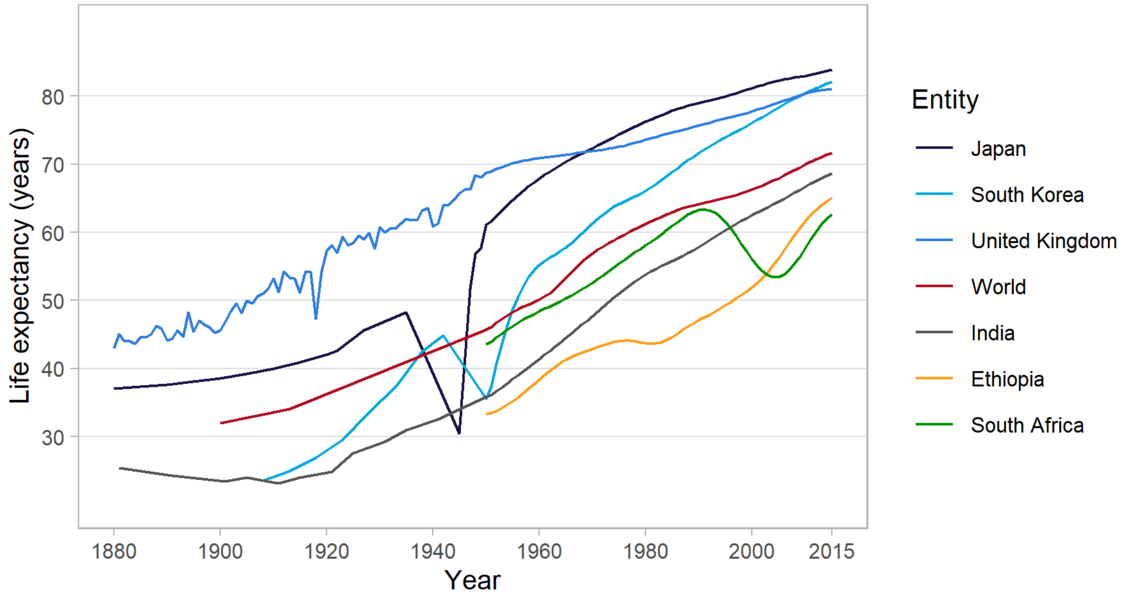
We live longer and better-quality lives because of innovations

If we focus on one single metric to understand the impact of new ideas, technologies, advances in health care, increase in income, this will be the impact on life expectancy. Life expectancy has generally increased across the world. Early industrialized countries saw a rapid increase in life expectancy while it stayed low in the rest of the world. Largely thanks to

[9] For full list of sources see: https://ourworldindata.org/grapher/technology-adoption-by-households-in-the-united-states

innovations in bio pharmacy, many diseases which were once considered incurable are now treatable[10], leading people to lead healthier, more productive, longer lives.

Figure 1.3: Life Expectancy, 1880 to 2015[11]



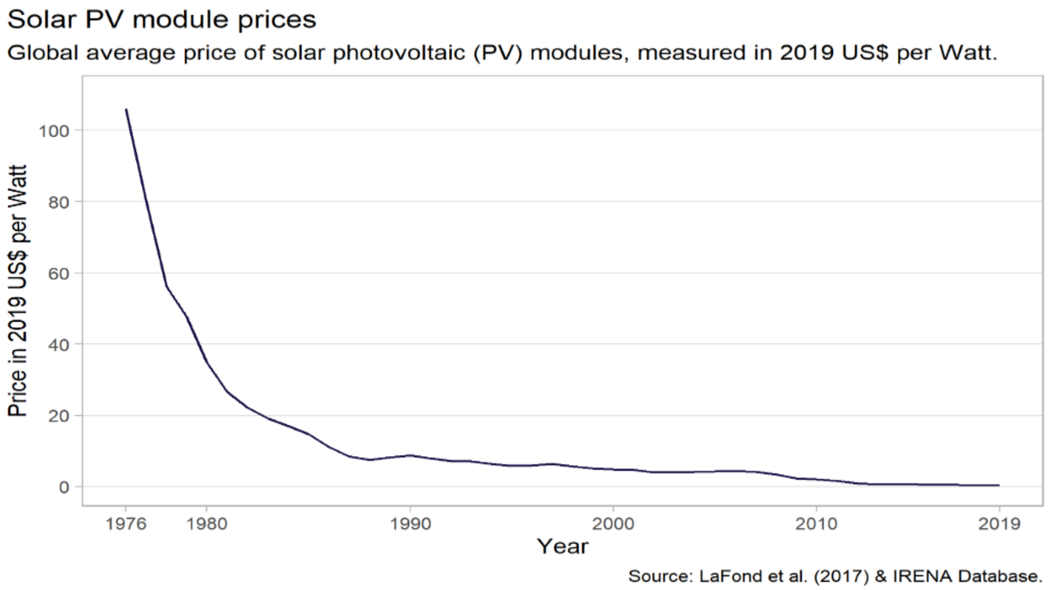
Source: Riley (2005), Clio Infra (2015), and UN Population Division (2019).
Note: Shown is period life expectancy at birth, the average number of years a newborn would live if the pattern of mortality in the given year were to stay the same throughout its life.

Solar PV modules have become cheaper

When alternative sources of energy first become technologically viable, their high cost required heavy state subsidies because compared to conventional energy sources they remained commercially unviable. This is yet another example of innovation making socially desirable products commercially affordable. Dramatic reduction of the cost of solar photovoltaic (PV) modules is one such example in this area. The cost has fallen by 99% over the last four decades and is often touted as a major success story for renewable energy technology, with clear implications for climate change. Improvements in technology is one of the key factors that has led to the fall in the cost of solar PV. Innovations in solar cell technology has meant that cells have become more efficient at converting sunlight to electricity, leading to the observed costs reductions.

[10] Frank R Lichtenberg, 2019. How many life-years have new drugs saved? A three-way fixed-effects analysis of 66 diseases in 27 countries, 2000–2013, International Health, Volume 11, Issue 5, September 2019, Pages 403–416, https://doi.org/10.1093/inthealth/ihz003
[11] For full list of sources please see: https://ourworldindata.org/grapher/life-expectancy-at-age-10

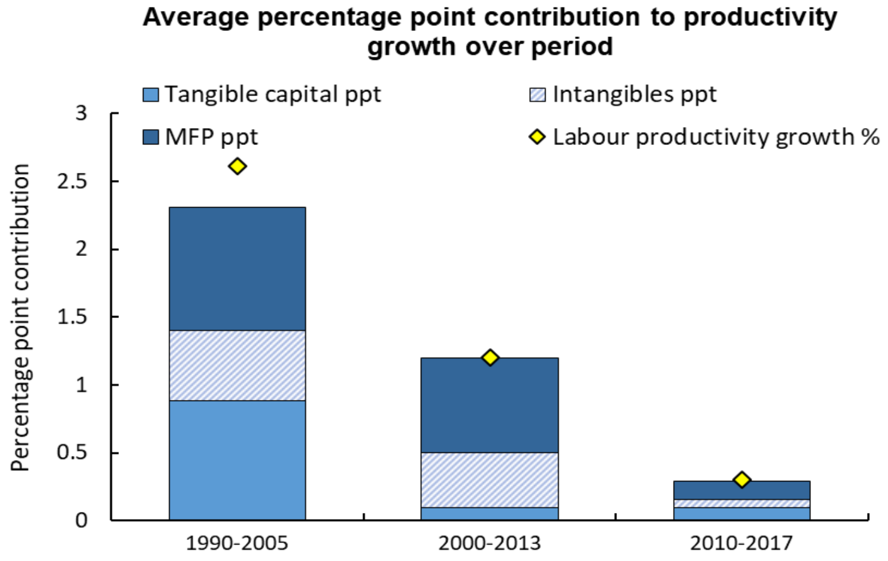
Figure 1.4: Solar PV module prices, 1976 to 2019



Innovation and the macroeconomy

Improvements in technology and innovation are a fundamental source of productivity and economic growth. Long-term productivity improvements are strongly correlated with innovation and R&D activities. For example, investments in intangible capital[12], which is a good proxy for

Figure 1.5: Average percentage contribution to UK productivity growth, 1990-2017



Source: Goodridge (2016), Corrado (2016), OECD (2019)

[12] Such as computerised databases, R&D, design, brand equity, firm-specific training, and organisational efficiency

innovation related activities, contributed 33% to UK labour productivity growth between 2000-2013[13].

The creation of new ideas, new technologies, new organisational practices, and their diffusion increased per-capita income in the last two centuries. It is the application of advances in several technologies simultaneously, in conjunction with entrepreneurship and innovative approaches to the creation and delivery of goods and services, which translates scientific and technological advances into more productive economic activity, new sectors and new jobs[14].

More recently, the importance of innovation has been reinforced both by globalisation and by rapid advances in new technologies, notably Innovation and Communication Technologies (ICT) related, which have enabled new forms of competition and opened new markets. Its importance has only increased as intangible capital and assets have become more important and valuable in the modern economy.

Though plants and machinery (the most obvious type of tangible capital) are still important, investment in intangibles assets (such as software, design, R&D and organisational capabilities) have increased in importance with total intangible investment surpassing tangible investment in 2018[15]. Advances in digital technologies hold considerable potential to lift the trajectory of productivity and economic growth, and to create new and better jobs to replace old ones.

Innovation and business growth

Innovation is central to starting, growing and scaling-up businesses. Entrepreneurs take ideas and transform them into products and services which create growth and jobs in the process. Innovation enables businesses to create new sectors, enter new markets, reduce production costs, and produce more output with the same inputs. Many UK businesses are at the cutting edge of technology, but too few businesses currently excel in adopting existing innovations. As such, the percentage of UK businesses that were innovation active declined to 38% in 2016-18 from 49% in 2014-16[16].

The evidence consistently shows significant benefits of investing in new and existing technologies. Businesses that consistently invest in R&D are 13% more productive than firms that do not invest in R&D and 9% more than firms which occasionally invest in R&D[17].

While investment in technologies and innovation bring benefits, many more businesses benefit when they adopt existing technologies. Businesses gained between 7% to 18% improvement in productivity when they adopted a range of common technologies[18]. Similarly, those who

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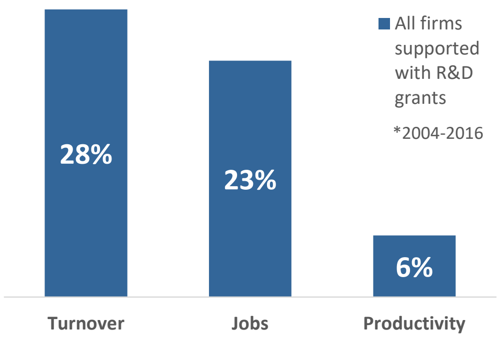
[13] Corrado, C., Haskel, J., Jona-Lasinio, C. Iommi, M. 2016. Intangible investment in the EU and US before and since the Great Recession and its contribution to productivity growth. Access here.
[14] OECD, 2007. Innovation and Growth: Rationale for Innovation Strategy. Access here.
[15] Office for National Statistics (ONS) 2018. Investments in intangible assets in the UK: 2018. Access here.
[16] World Intellectual Property Organization (WIPO). https://www.wipo.int/
[17] Cefis, E., and Ciccarelli, M. 2005. cited in BIS 2014. Innovation Report. Access here.
[18] State of Small Business Britain (2018, 2020). Access here.

adopted ICT with good management practices achieves a 20% productivity improvement compared to just a 2% uplift when adopted with poor practices[19].

Figure 1.6: Firm level impact of Innovation Grants (ERC 2017)



Analysis from the Enterprise Research Centre shows that firm turnover, job creation and productivity increases much more in firms that receive innovation grants compared to those that do not receive innovation grants[20]. Furthermore, innovative high-growth firms contribute to local economic growth through their positive spillover effects, for example on the growth of firms in their local area. Innovative firms have been shown to grow twice as fast, both in employment and sales, compared to firms that do not innovate[21].

COVID-19 impacts on innovation

Adapting to Covid-19 has seen accelerated innovation activity and workplaces have adopted technology to facilitate changes in working patterns. However, the lockdown and slowdown of economic activity has also impacted innovation and research activities negatively. Most of the available evidence on Covid-19 shows negative impact on innovation inputs such as investment intentions, adoption of technology and innovation activities. However, long-term impacts of Covid-19, especially on innovation outputs, will take time to appear in data.

As an increasingly greater number of people began working from home, workplaces innovated to facilitate online and remote working. A survey of 375 UK businesses indicated greater innovation rates than might have been expected in the absence of Covid-19[22]. Over 60% of respondents adopted digital technologies and new management practices during the crisis, 38% adopted new digital capabilities and 45% adopted a new product or service. While these results are not directly comparable with the large-scale UK Innovation Survey, the rate of product innovation is significantly higher than 18% as reported in the recent 2019 survey. Surveys that focused on investment intention often show a negative impact of lockdown and change in business activity.

Innovate UK surveys of its award holders between June 2020 and February 2021[23] show R&D investment patterns vary significantly between firms, with 63% of firms still

[19] Grous, Alexander, 2016. The Power of Productivity: An Assessment of UK Firms and Factors Contributing to Productivity Enhancement. London School of Economics and Political Science.
[20] Enterprise Research Centre, 2017. Assessing the business performance effects of the receiving publicly-funded science, research and innovation grants. Access here.
[21] NESTA, 2009. Business Growth and Innovation: The wider impact of rapidly growing firms in the UK city regions. Access here.
[22] LSE and Confederation of British Industry (CBI), July 2020. Innovation in the time of Covid, https://cep.lse.ac.uk/_NEW/PUBLICATIONS/abstract.asp?index=7514
[23] ERC, Innovation Caucus Assessing the impact of Covid-19 on Innovate UK award holders, Wave survey and case study evidence (Wave 1, 334 respondents, June 2020), (Wave 2, 242 respondents, October 2020), (Wave 3, 274 respondents, February 2021)

classifying R&D capacity as “disrupted”. Future concerns include supply chain disruptions, cash flow constraints, weak collaborations with R&D-intensive institutions and workforce effects meaning around 16% of firms have made redundancies during the three months to February 2021. The most recent wave of the survey however offers a slight improvement. Businesses reported marginally optimistic outlook compared to October 2020, though cash flow remained a limiting factor for many companies (1 in 6 reported cash flow to be critical).

Like businesses, Covid-19 disrupted research and innovation activity in university research. BEIS and Vitae carried out a survey of over 10,000 researchers in May and June 2020 to understand the nature and degree of disruption[24]. Survey results show restrictions affect early career researchers to a greater extent as compared to established researchers. The overall findings highlight:

- Researcher hours became more extreme, with around 40% reporting a decrease in working hours and 20% reporting an increase.
- Almost 100% of lab work was stopped, but also to a lesser extent, academic networking, dissemination of research and business collaboration.
- There was an increase in writing papers and desk-based research, though most experienced research or publications being delayed.

Going forward, continued monitoring is needed to understand the effect of Covid-19 restrictions as the full impact flows through the innovation system. Any negative impact on the innovation activity across the UK will affect the Strategy’s ambition “to make the UK a global hub for innovation by 2035”.

Social returns from innovation

While innovation benefits businesses directly, consumers and society at large also benefit indirectly from better quality, affordable products. Society also benefits through, for example, better health outcomes resulting from innovative treatments, improved environmental quality, energy efficiency, and the general advancement of knowledge. It is the presence of high social returns from innovation to the wider society that provides the rationale for government investment in innovation. Evidence shows social returns from R&D and innovation investment are higher than private returns.

Social returns, based on spillover benefits from R&D conducted by one agent to the productivity or output of other agents, are typically 2 to 3 times larger than private returns[25]. A study using US firm level data concluded that the ratio of marginal social returns to private returns for R&D investment is a factor of 4[26]. Not only are the social returns high for innovation investment but government investment also attracts additional private investment. Evidence

[24] BEIS and Vitae, 2020. Survey results
[25] Rates of return to investment in science and innovation, 2014. Access here.
[26] Nick Bloom, Brian Lucking and John Van Reenen, 2018. Have R&D spillovers changed?, CEP Discussion Papers dp1548, Centre for Economic Performance, LSE.

suggests that, on average, each £1 of public investment leads to an additional £2 of investment from private sources over fifteen years[27].

UK innovation in global context

The UK has a strong position in science, research and innovation. It is ranked 4th in the Global Innovation Index[28]. Four of its universities are in the top 10 global universities and 18 are in the top 100[29]. The UK draws in proportionally more internationally mobile R&D than other large countries[30], with a total of 14% of UK R&D investment financed from abroad[31] and over half of UK R&D performed in business is by overseas-owned businesses[32].

With less than 1% of the world's population, the UK accounts for 4% of researchers, 7% of the world's academic publications, and 14% of the world's highly cited academic publications[33]. The UK's field-weighted citation impact (FWCI), an established measure of research impact, has been higher than any other G7 country every year since 2007[34].

However, the global context is changing fast. Competition in new technologies has been intensifying, with emerging economies and their businesses increasing their innovation investment substantially[35]. In 2018, the last year for which official data is available, the UK invested slightly over 1.7% of GDP on R&D while the OECD average was 2.4%, and many emerging economies spent much higher than 3% of their GDP on R&D. Out of the top 2000 R&D investor companies globally, just over 100 have their headquarters in the UK, while only 3 of the top 100 global R&D investors[36] locate their headquarters in the UK.

The proportion of innovation active businesses[37] has decreased in the UK from 49% in 2014-16 to 38% in 2016-18. Figure 1.7 provides a comparison of different types of innovation activities. Most significant change are seen in the proportion of innovation active and wider innovation categories.

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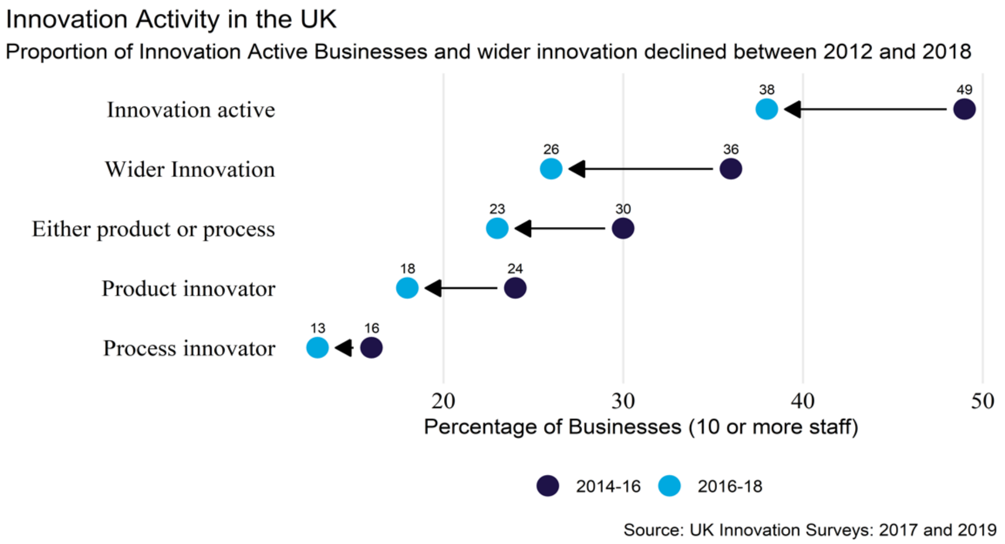
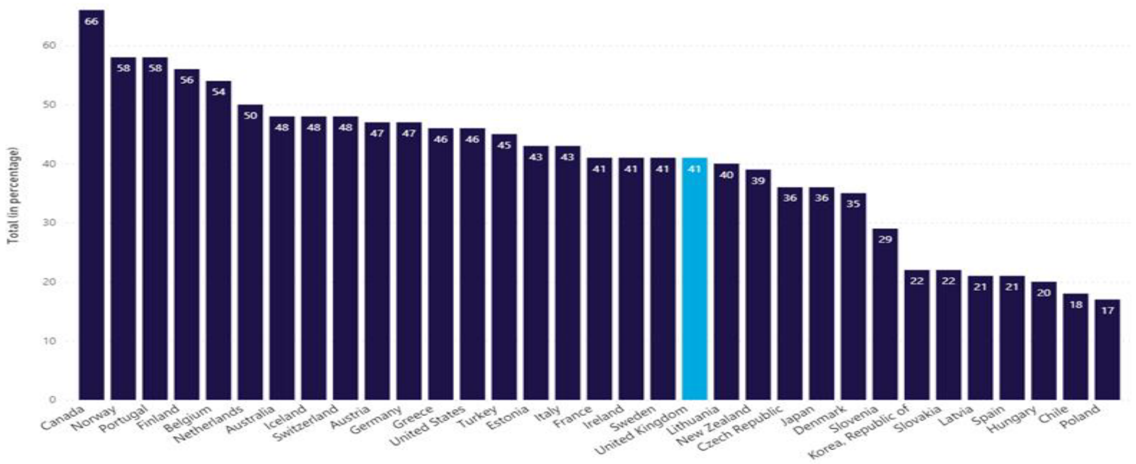
27 Oxford Economics, 2020. The relationship between public and private R&D funding. Access here.
28 https://www.globalinnovationindex.org/analysis-indicator
29 QS 2020. QS World University Rankings
30 OECD 2019. Main Science and technology indicators (MSTI). (2016 data point used, Percentage of GERD funded by rest of the world). Access here.
31 ONS 2019. UK Gross domestic expenditure on research and development.
32 ONS 2018. Business enterprice research and development Access here
33 https://www.gov.uk/government/publications/international-comparison-of-the-uk-research-base-2019 Researcher line from Elsevier, 2017. Most up-to-date available.
34 BEIS 2019. International comparison of the UK research base. Access here.
35 2020 Business Insights report by the OECD Emerging Markets Network and Global focus in this strategy. Access here
36 Dernis H., Gkotsis P., Grassano N., Nakazato S., Squicciarini M., van Beuzekom B.,Vezzani A. 2019. World Corporate Top R&D investors: Shaping the Future of Technologies and of AI, A joint JRC and OECD report. EUR 29831 EN, Publications Office of the European Union, Luxembourg, 2019.
37 An innovation active business either introduces a new or significantly improved product (good or service) or process; or engages in innovation projects not yet complete, scaled back, or abandoned; or introduces new and significantly improved forms of organisation, business structures or practices, and marketing concepts or strategies.

Figure 1.7: Innovation active firms: Change from 2014-16 to 2016-18



In the global context, the UK has a lower proportion of innovation active businesses than other countries. This implies that the UK could significantly increase the proportion of innovation active businesses through more business investment in R&D and other innovation activities and higher adoption of existing innovations.

Figure 1.8: Innovation active firms across countries 2014-16.



Source: OECD

Business innovation statistics and indicators

R&D investment

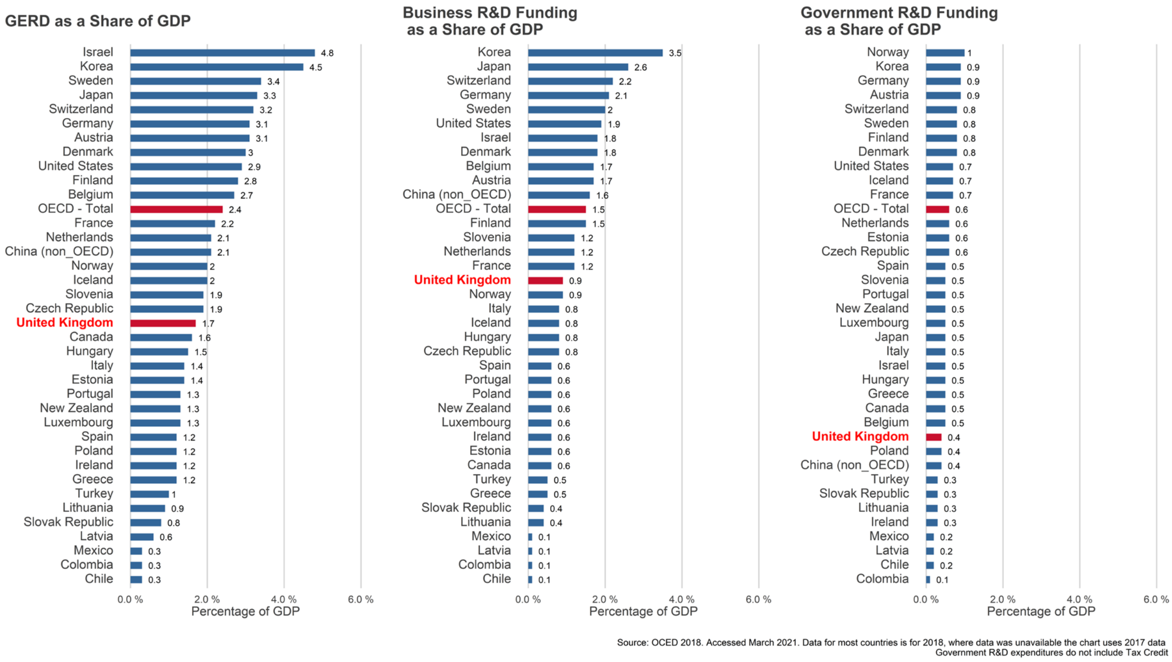
R&D is a major part of innovation. The UK's total national R&D investment has increased over time, both nominally and after adjusting for inflation, but it has varied little as a share of GDP. For example, between 2008 and 2018, R&D investment increased from over £26 billion to £37.1 billion in 2018 prices, while for the same period R&D as a share of GDP moved from 1.6% to 1.71%[38]. The OECD data shows (Figure 1.9) total R&D investment as a share of GDP

[38] ONS, 2019. Gross Expenditures on R&D

in the UK stands behind the leading R&D nations of Israel and South Korea who each spend over 4%, and countries like Austria, Japan, and Switzerland, who all spend over 3%.

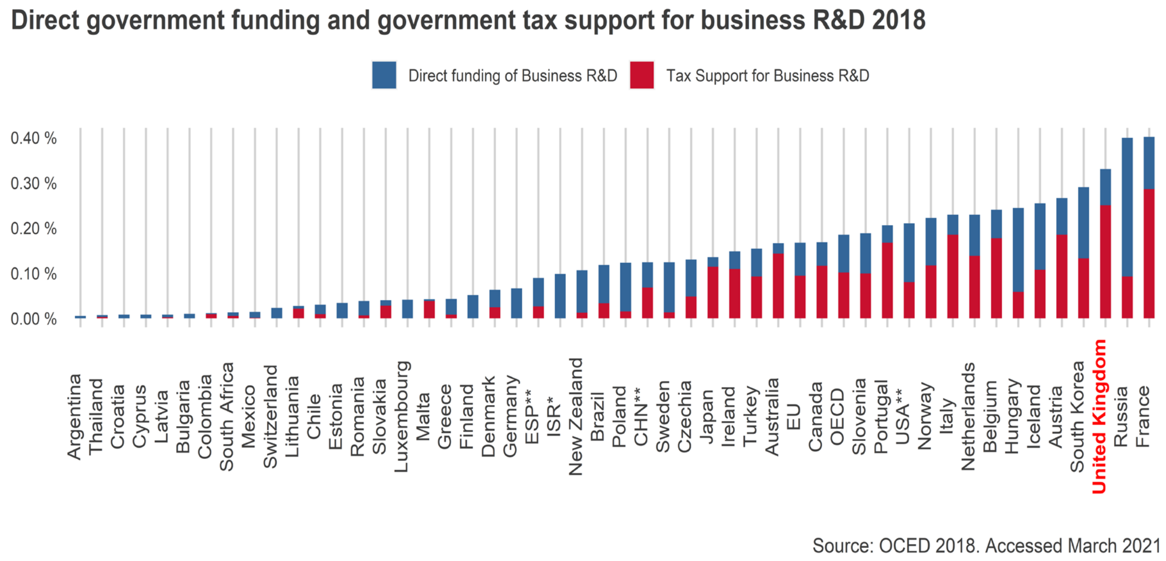
Out of the four main sectors of the economy – business enterprises, government (including UKRI), Higher Education and the private non-profit sector – business enterprises performed 68% of the total £37.1 billion R&D investment in 2018. Investment by business enterprises is integral to achieving the government's objectives of raising investment in R&D to 2.4% of GDP by 2027 and unleashing innovation across the UK.

Figure 1.9: UK Comparative Position in R&D Expenditures



The UK investment is lower than total OECD average, however when comparing countries on direct government funding and tax credits (Figure 1.10), the UK ranks in the top three funders.

Figure 1.10: Direct and Tax support for Business R&D



Finance to Unleash Innovation

The UK has a vibrant financial sector and capital markets. They enable businesses to access finance, be it through loans, grants, equity or other financing mechanisms[39]. Evidence suggests businesses are both more likely to have developed new products and improved processes if they use external finance and continue using external finance[40].

However, evidence also shows gaps in accessing finance. Market failures mean businesses are not able to access external finance either because it is unavailable or too expensive. Access may differ depending on the sector, location, and stage of growth. Innovative firms often seek finance to fund innovative ideas which have higher technical, business model or commercialisation risks and rewards. Greater risks and returns require additional due diligence to assess these risks and lead to higher cost for financiers. When this happens, promising ideas may remain unfunded.

Under the UK Innovation Strategy, government will continue to bring together effective private markets with well-targeted public investment. The Strategy will also focus on crowding-in private investment and stimulate innovation at the pre-market stage through grant funding. As part of incentivising private R&D investment, it will encourage large asset-holders, such as pension funds, to invest in innovative businesses and make the funding system easier to navigate.

[39] Global Innovation Index 2020. Access here: https://www.globalinnovationindex.org/Home
[40] BVA BDRC's SME Finance Monitor

Equity and debt market failures affect highly innovative start-ups

Positive externalities: innovation benefits innovators through sales revenues but also benefits other businesses and society at large through spillover benefits. Private investors do not take into account wider benefits. As a result, projects with high social value remain underfunded and, if left only to market forces, innovation investment will be below the socially optimal level. Theoretical and empirical research show social returns from R&D outpace private returns. BEIS research shows that the annual private rate of return from R&D and innovation averages around 20 to 30%, but the social returns are two to three times higher[41]. Research also suggests that "the knowledge spillovers from firms financed by venture capital (VC) are at least nine times larger than the spillovers from corporate R&D"[42]. The inability of the market system to capture the value of spillover benefits particularly affects start-up in highly innovative sectors such as Life Sciences and CleanTech[43].

Imperfect information: financiers and businesses have access to different information on the risks and returns of innovation. Lenders and financiers fill this gap with due diligence. Due diligence for highly innovative companies operating in R&D-intensive sectors may require highly trained experts. This incentivises VC funds to invest in relatively less-complex sectors or deals with shorter exit periods and lower transaction/ scaling costs. Over time this will skew activity away from companies developing complex technologies or risky but high return innovations.

Coordination failures: Large institutional investors, such as pension funds, have minimum investment sizes[44] when making allocations to VC funds[45]. Because most VC funds are currently too small to attract institutional investors, the supply of capital through VC funds is limited - funding on which many highly innovative companies rely. HMT's Patient Capital Review identified the presence of "too few large VC funds" as one of the four main reasons for low allocations by institutional investors. Previous research found that although the UK performs strongly compared to European counterparts, UK VCs lack the deep pools of risk capital seen in US equivalents[46]. As a result, UK companies struggle to raise follow-on funding rounds at sufficient scale.

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[41] BIS, 2014. Rates of Return to Investment in Science and Innovation: A Report Prepared for the Department for Business, Innovation and Skills (BIS). Access here

[42] Schnitzer, Watzinger 2017. Spillovers from venture capital investment. Access here: https://voxeu.org/article/measuring-spillovers-venture-capital

[43] An example of this is graphene which came out of The University of Manchester but has a multitude of applications across various sectors.

[44] Institutional investors generally have minimum investment sizes of around £300m-£450m - HMT's Patient Capital Review. Industry Panel Response. 2017. Pg. 11. 2.3. Access here

[45] The average size of UK VC funds in 2020 was £150m according to British Business Bank analysis of Preqin

[46] Internally commissioned research for the Life Sciences Industrial Strategy found that US PE and VC funding in life sciences is 20x that of UK.

Funding gaps faced by highly innovative start-ups

The health of the pre-seed and seed funding environment is vital to the wider innovation ecosystem, as it provides the pipeline for later stage investment. Data on pre-seed funding is relatively incomplete, however BEIS research found that the funding gap is felt most acutely at the seed stage[47]. Evidence also shows that over recent years funding gaps faced by highly innovative start-ups have worsened. The number of initial equity rounds in UK-based SMEs peaked at 1,008 in 2015, but fell to 909 in 2020.[48] Over the same period, the SME equity market as a whole grew substantially. This means that first fundraisings as a proportion of total deals fell significantly, from 63% of all SME equity deals in 2015 to 44% in 2020.[49] The UK Business Angel Market 2020 report found that seed stage funding fell by an average of £27,000 in 2020 as compared to 2019. Covid-19 and the following economic disruption and uncertainty has affected the personal investment capacity of many angel investors.

Innovate UK and UKI2S's grant and finance options play an important role for businesses in this area, businesses that are critical to the innovation landscape. Venture and growth funding for spinouts rely on institutional funds.

The early-stage funding environment also has a strong geographic angle. Agglomeration economies mean that clusters develop, primarily around prominent universities in London, Oxford and Cambridge. These ecosystems have strong early-stage funding environments, established over time, with established links between key ecosystem participants such as universities, business angels, and tech transfer offices.

This leads to regional differences in the ability of universities to successfully spin out companies, attract external equity capital and ultimately commercialise their research and technologies. For instance, in 2019 five universities accounted for 74% of overall private external equity investment into SME university spinouts[50]. As outlined in Figure 2.1 below, many of the regions are underrepresented in terms of getting equity investment into university spinouts.

[47] Work has been undertaken by Prof. Nick Wilson to conduct a quantitative assessment of the SME equity finance gap in the UK. The total equity finance gap in the UK (determined by unmet potential demand and supply) was estimated at around £10.5bn per year (for 2017), with the equity gap found to be felt most acutely at the seed deal stage.

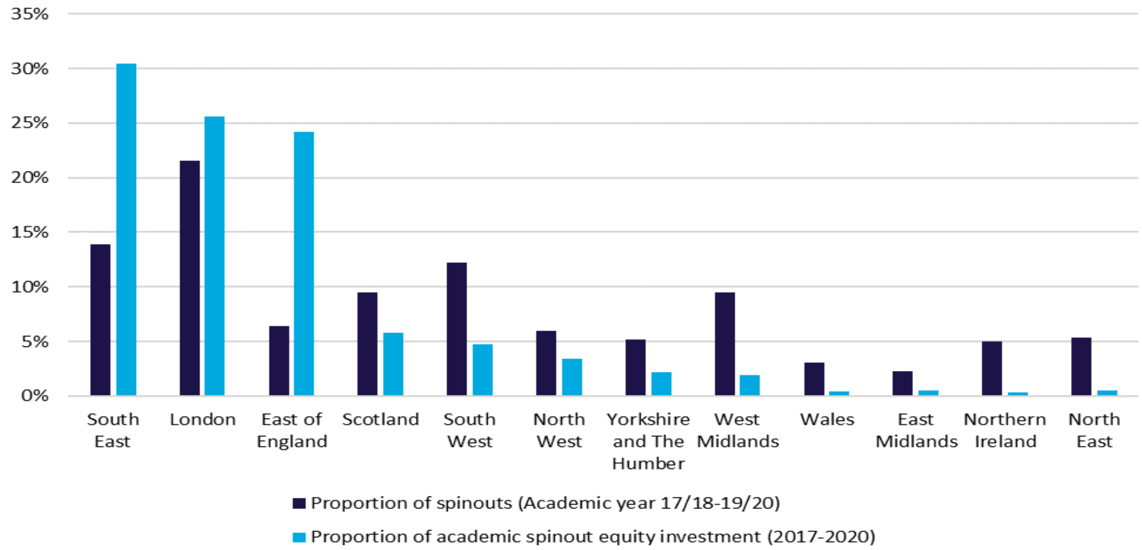
[48] British Business Bank analysis of Beauhurst

[49] British Business Bank, 2020. Small Business Finance Markets Report 2020.

[50] British Business Bank, 2020. Equity Tracker 2020

Figure 2.1: Proportion of formal HESA university spinouts (17/18 – 19/20) compared to proportion of private external equity investment into university spinout SMEs (2017-2020)[51]

Source: Higher Education Statistics Agency (HESA)



Scale-ups and late-stage equity: International comparisons

Once companies move beyond the seed-stage they face the "second equity gap" [52] which is commonly dubbed as the "second valley of death"[53]. NESTA estimate that only around 2% of entrepreneurs are likely to overcome the demand-side hurdles to seeking finance for growth, which include a lack of a growth mindset, little awareness of finance options and a lack of time and confidence to speak to investors and raise capital[54].

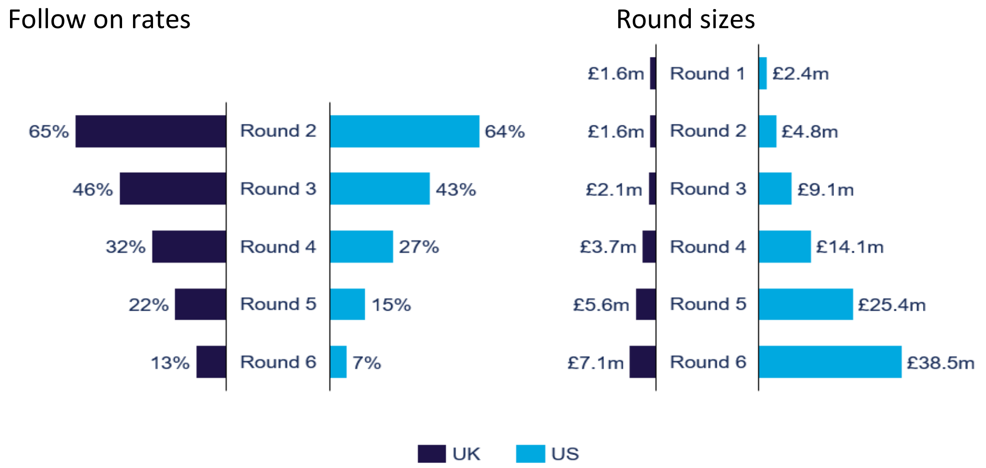
International comparisons suggest that the UK VC market, overall, is strong relative to the EU, but weaknesses remain when compared to the US market, particularly when considering companies in R&D-intensive sectors. Overall VC investment in the US between 2018 and 2020 equated to 0.65% of GDP, compared to 0.46% of GDP over the same period in the UK[55]. However, substantially more VC capital in the US goes to highly innovative firms in R&D-intensive sectors – 48% of overall VC funding in the US between 2018 and 2020 went to companies in R&D-intensive sectors, compared to just 37% in the UK. Of companies in the UK's R&D-intensive sector, those part of the 'Deep Tech' (companies, often start-ups, founded on scientific discoveries or engineering innovation) subset received a fifth (19%) of total VC investment in 2020[56]. Separately, Software as a service (SaaS) and Fintech verticals are other

[51] University spinouts in this case refers to either companies with some Higher Education Provider ownership, or formal spin-offs, not HEP owned. Graduate/ staff start-ups are not included.
[52] Murray, G.C., Lott, J., 1995. Have UK venture capitalists a bias against investment in new technology-based firms. Res. Policy 24 (2), 283–299
[53] N. Wilson et al 2018. The equity gap and knowledge-based firms. Journal of Corporate Finance 50 (2018) 626-649.
[54] Nesta 2021. Motivations to Scale
[55] British Business Bank. Small Business Equity Tracker 2021
[56] The differences between R&D intensive companies and deep tech companies: deep tech companies are founded on tangible scientific discoveries or meaningful engineering innovation, while R&D intensive are those attempting to commercialise technologies with long and costly processes.

popular destinations for VC capital, accounting for £3bn and £1.6bn of the £8.8bn total equity investment in 2020 respectively[57].

Although the US attracts more funds (1.8 times more than the UK), the UK receives more deals when weighted by GDP. This implies a significant difference in average round sizes between the UK and US, where UK companies in these capital-intensive sectors raise smaller rounds on average. Figure 2.2 below compares the follow-on funding rates and average deal sizes between UK and US companies operating in R&D-intensive sectors that raised an initial round in 2012 or 2013, and subsequently progressed into further rounds over the next eight years. The data clearly shows that funding rounds in the UK do not scale in line with US rounds as a company progresses through the fundraising pipeline.

Figure 2.2: Comparison of UK and US VC follow-on funding rates and round sizes for companies in R&D-intensive sectors

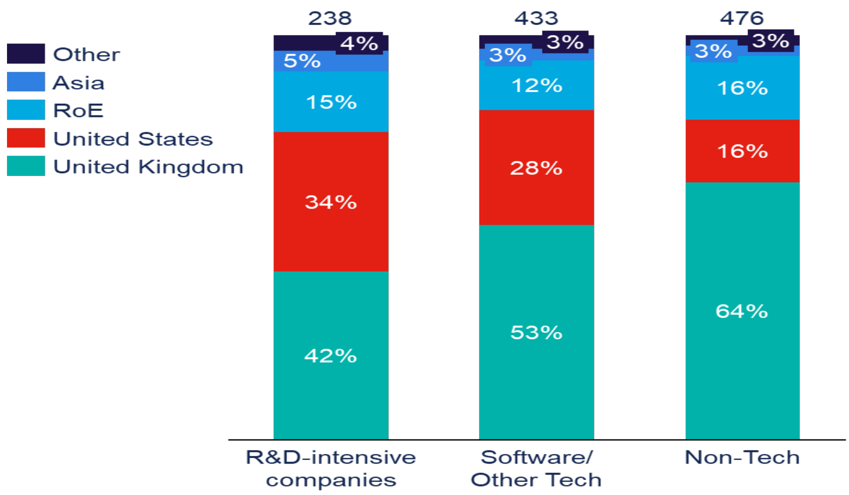


Source: British Business Bank analysis of PitchBook data as at 10/05/2021

A lack of suitable scale-up capital in the UK, especially for highly innovative businesses, results in such companies relying on overseas capital, and ultimately looking overseas for exit opportunities. The sheer scale of overseas pools of capital as well as the other financing opportunities available mean that some firms see the best prospect for taking their business further outside the UK. Figure 2.3 shows a large proportion of acquisition exits of UK-based, VC-backed companies were undertaken by overseas companies, particularly in R&D-intensive sectors. This may result in UK R&D activity relocating elsewhere, at a cost to the UK economy.

[57] British Business Bank. Small Business Equity Tracker 2021. Software as a service and fintech verticals are classified as being distinct from the R&D intensive sector. Beauhurst also offer an alternative way to classify companies based on the market the company serves, the technology they employ or the delivery model of the company. It is important to acknowledge that companies can be in more than one vertical e.g., software-as-a-service (SaaS) and fintech, and so it is not possible to aggregate these verticals together.

Figure 2.3: Location of acquiring company in UK-based, VC-backed acquisition exits (2011-2018)

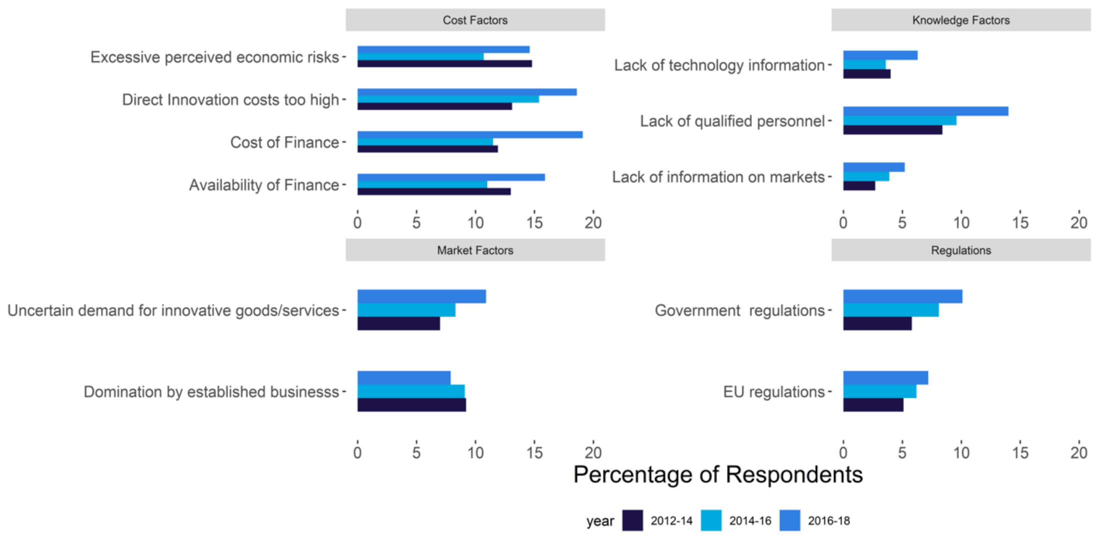


Source: British Business Bank analysis of Beauhurst

Barriers facing established companies looking to raise capital to innovate

As highlighted above, firms' propensity to use external finance and their innovation activity are closely associated. However, market failures, such as cost of risk assessment, limit firms' ability to access finance, especially for smaller, IP-rich companies. UK Innovation Survey data in Figure 2.4 shows that the availability and cost of finance are two of the biggest innovation barriers faced by businesses.

Figure 2.4: Innovation barriers faced by businesses



STIA analysis based on UK Innovation Survey 2019 Data

Like the UK's innovation activity, the financing ecosystem is geographically concentrated. In 2020, London received around half of all UK equity deals and two thirds of all equity investment despite containing only 21% of the UK's high-growth businesses[58]. Government policy has sought to address this imbalance, for example through the regional funds overseen by the British Business Bank. But a combination of general and place specific market failures drive regional imbalances in access to finance for SMEs based outside of mature entrepreneurial ecosystems such as London.

Conclusion

While the UK has a vibrant financial sector and capital markets, evidence points to gaps in access to finance for innovative businesses that arise due to market failures. These gaps constrain highly innovative start-ups, scale-ups and other innovative businesses to raise finance to innovate. In addition, the UK's financing ecosystems are characterised by regional disparities in terms of access to finance.

The UK Innovation Strategy sets out plans for Innovate UK and the British Business Bank to reduce complexity and make finance and available support more accessible for firms. Other specific actions include targeting the growth-stage funding gap faced by UK life science companies through the British Business Bank's £200m Life Sciences Investment Programme.

[58] BBB's 2020 Small Business Equity Tracker. https://www.british-business-bank.co.uk/small-business-equity-tracker-2020/

Supporting the Innovation Ecosystem

To boost innovation in the UK, a set of supportive institutions need to create conditions that allow new ideas to emerge and create value. UK's innovation ecosystem includes a set of supportive institutions that boost innovation. These include: the legal and regulatory frameworks, physical and digital infrastructure, and incentive setting through regulation, standards, competition and intellectual property.

Many elements of the ecosystem set incentives for innovators. For example, a dynamic regulatory system attracts firms that want to test their business model and products in a safe environment. Digital and physical infrastructure enables start-up firms to translate their ideas into products without investing in labs and testing kit. An effective intellectual property system enables innovators to reap the returns from their investments and incentivises further innovation. In short, a well-functioning ecosystem supports innovation and a poorly functioning system stifles innovation.

Regulations and innovation

The 2016-2018 UK Innovation Survey reports that 12% of UK firms, engaging in some form of innovation activity, consider UK regulations a barrier to innovation. Yet regulation can stimulate new ideas, provide certainty to reduce investment risk, create consumer confidence, steer development of new products, and enable rapid but safe adoption of new technologies. 32% of innovative businesses reported that the meeting of regulatory requirements was of 'high' importance to their decision to innovate[59]. Similarly, 29% of UK businesses believe that the government's approach to regulation supports them in bringing new products and services to market.

The 2020 Business Perception Survey shows that firms' perspectives on regulation do impact innovation activity and innovative businesses report a higher burden from complying with regulations. 61% of businesses consider that regulators' approaches affect their willingness to invest in innovation and 66% reported that regulations slowed the introduction of new products or services to market. The most common prohibitive factors include costs (14%) and ambiguous guidance (10%).

More innovative businesses perceive regulatory compliance to be costly when compared to non-innovative businesses – 49% of innovative businesses identify regulatory compliance as a burden compared with 29% of non-innovative businesses. Similarly, on average innovators spent 9.2 staff days per month on regulatory compliance as compared to 7.5 days for non-innovators. Finally, innovative businesses used external advice for regulatory compliance and spent over £10,000 per year.

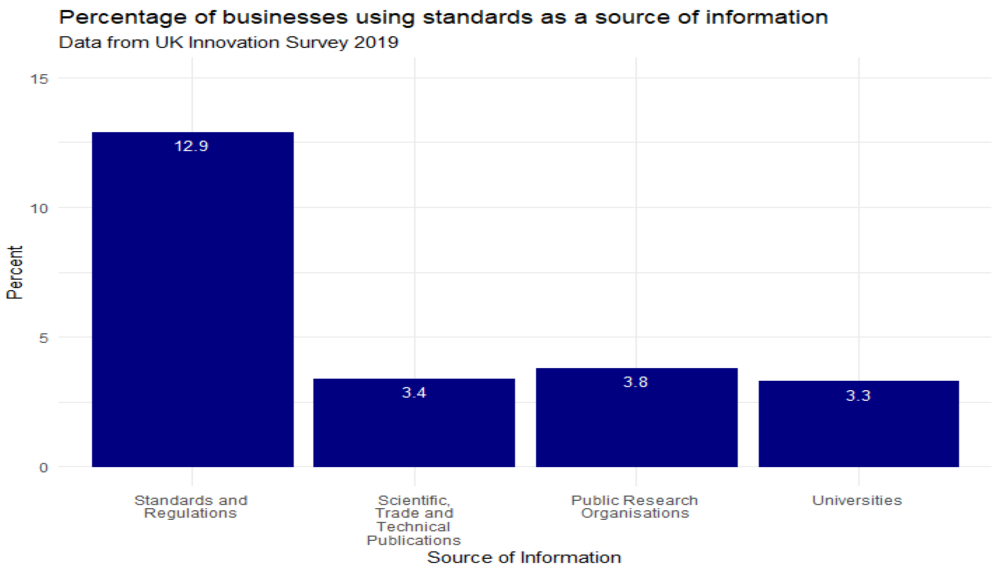
[59] UK Innovation Survey 2019. Main report

The UK Innovation Strategy sets out plan to commission the independent Regulatory Horizons Council to develop a set of high-level pro-innovation principles to guide regulation. This will ensure regulations are not an unnecessary barrier to innovation.

Standards and measurement role in innovation

Effective standards minimise the cost of trading by providing an agreed way of making a product, managing a process, delivering a service, or supplying a material. Standards are part of the infrastructure for innovation. They codify technological knowledge and act as a source of information. Innovative firms use standards and regulations as a source of information more often than alternatives such as scientific, trade, and technical publications, public research organisations, and universities[60], as shown in Figure 3.1.

Figure 3.1: Sources of information for innovative firms – UK Innovation Survey



One study suggests that standards contributed over 25% of the change in productivity that has occurred after 1948[61] through enhancing organisational efficiency, boosting trade, and facilitating innovation. However, this result needs to be interpreted cautiously, because standardisation acts in connection with a host of other factors that underpin technological growth (such as the discovery of new fields of research that lead to new technologies or wider improvements in education and human capital). Standards for new technology are particularly important in areas with high uncertainty. Evidence from German firms shows that standards

[60] UK Innovation Survey 2019. Statistical Annex, 2016-18 data. Access here: https://www.gov.uk/government/statistics/uk-innovation-survey-2019-main-report
[61] P. Temple, R. Witt, and C. Spencer, 2005. Project 1: Standards and Long-Run Growth in the UK, The Empirical Economics of Standards.

have a positive effect on innovation in cases of high uncertainty while regulation leads to lower innovation efficiency[62].

Standards also require effective measurement to check that the standards have been met[63]. The UK Measurement Strategy, to be published this Summer, will outline how the UK will provide the measurement infrastructure that the UK needs. Measurement supports innovation through:

- Accelerating innovation: An agreed method for measuring technology performance, serves as an independent criterion against which to demonstrate and test improvements on existing technology.
- Bringing confidence to investment decisions: Common and reliable measurement standards for assessing performance provide confidence in the data used to evaluate a technology’s potential. Providing this reassurance can help speed up investment decisions.
- Safeguarding competition on quality: The development of agreed testing protocols supports product certification activities. Having agreed and reliable testing protocols for demonstrating conformance to quality standards in turn makes the comparative advantage associated with such knowledge more resilient and secure.
- Enabling the use of performance-based standards: the existence of established measurement protocols is fundamental to implementing more flexible and less prescriptive approaches to regulation and associated standard-setting.

Competition policy and innovation

Competition incentivises innovation. Various theories argue firms create new products and services to outcompete rivals and capture market share. However, evidence on competition and innovation relations is complex, with no consensus about the exact relationship.

Mergers in the Digital sector are characterised by high levels of innovation and can evolve rapidly. Mergers and acquisitions can drive positive outcomes where knowledge/resource sharing and other synergies yield efficiencies and innovations[64]. However, a considerable body of empirical evidence links mergers to lower R&D effort and lower innovation activity[65].

Competition can impact innovation and should be considered when setting competition policy, particularly in highly innovative and fast-moving digital markets. The UK Innovation Strategy

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[62] Knut Blind, Sören S. Petersen, Cesare A.F. Riillo, 2017. The impact of standards and regulation on innovation in uncertain markets, Research Policy, Volume 46, Issue 1, pp. 249-264.
[63] J. Barber 1987. Economic rationale for government funding of work on measurement standards in Review of DTI work on measurement standards, memo, The Department of Trade and Industry (DTI), London, UK.
[64] See Federico, G., Langus, G., & Valletti, T. 2018. Horizontal mergers and product innovation International Journal of Industrial Organization, 2018, vol. 59, issue C, 1-23
[65] See Kerber (2017) which cites De Man/Duysters (2005), Ornaghi (2009a), and recently Haucap/Stiebale (2016); as overview see Kerber/Kern (2014, 13-15).

sets out plans to consult on reforms that will ensure the competition framework is effective for an innovative modern economy, and that set up a new, pro-competition regime for digital markets.

Intellectual Property and innovation

Intellectual property (IP) enables investors to appropriate the return of their investments by providing legally enforceable rights on the use of their inventions and innovations. The UK has a well-developed IP system. It ranks 2nd in the Global Intellectual Property Centre (GIPC) International IP Index 2021[66]. The GICP highlights the UK's strengths as a strong and sophisticated national IP environment, with strong cross-sectorial enforcement of IP rights upheld with cross-industry and government co-operation.

With the increasing importance of intangible assets (design, software, R&D) in determining competitive advantage for businesses, the IP system has become increasingly more important. Intangible assets, also referred to as knowledge assets, pertain specifically to intellectual resources used in the creation of new knowledge. In 2016, firms in the UK market sector invested an estimated £134.3bn in knowledge assets such as software, R&D, of which £63.8bn was protected by IP rights, equating to 6.8% and 3.2% of total GDP[67], respectively according to ONS data.

Use of IP has been linked with an increase in firm performance. The European Patent Office (EPO) found that ownership of IP rights is strongly associated with improved economic performance at firm level, especially for SMEs. SMEs with registered IP rights were round to have 68% higher revenue by employee than SMEs without. For all firms, this result is 55%[68].

Improving awareness of and access to IP is an important tenet of business support and the UK levelling up agenda. The ability to identify IP in research is critical to achieving impact, and as part of the UK Innovation Strategy the IPO will expand its IP education programme for researchers to fully leverage their IP to commercialise their ideas.

The European Union Intellectual Property Office (EUIPO) 2019 SME Scoreboard found that for SMEs without registered intellectual property rights the main reason for not registering was a lack of knowledge about the IP and its benefits (38% of respondents)[69]. Data from the EPO complement the EUIPO findings, with evidence suggesting that barriers for SMEs include the cost and complexity of securing IP protection, as well as a lack of awareness of the benefits of IP[70].

[66] GICP International IP Index. 2021. Access here. https://www.theglobalipcenter.com/ipindex2020/
[67] Developing experimental estimates of investment in intangible assets in the UK: 2016. ONS, Access here.
[68] IBID
[69] Intellectual Property SME Scoreboard, 2019. EUIPO. Access here
[70] EPO Patent Commercialisation Scoreboard 2019. Access here

Conclusion

The relationship between innovation and the various regulatory frameworks is complex and varies by sector, time scale, or market. Modifications to regulatory frameworks can have significant influence on how innovation occurs in a country[71]. Government or industry need to be forward-looking and consider the wider innovation impacts when developing and setting regulatory frameworks and the interplay between them.

The UK Innovation Strategy sets out plans for high-level innovation-supportive principles to guide regulation through the independent Regulatory Horizons Council, and with the Regulators' Pioneer Fund (RPF) which will enable regulators to test and pilot ambitious and experimental pro-innovation approaches to regulation.

[71] Blind, Knut, 2012. The influence of regulations on innovation: A quantitative assessment for OECD countries, Research policy 41.2: 391-400.

Adoption: Supporting Business and Universities

Adoption and diffusion of innovation determine their impact on economic growth and prosperity. Economic benefits from innovation largely accrue from incremental innovations arising from the diffusion of knowledge and wider applications of technologies, rather than the introduction of completely new products or services[72]. Evidence indicates that technological diffusion explains 44% of the difference between GDP per capita across countries[73].

There are significant gains at firm and national level from adopting existing innovations. McKinsey Global Institute estimates that for developed economies like the UK, 55% of future labour productivity will come from adopting best practice technologies, whilst 45% comes from creating new innovations[74]. The Confederation of British Industry calculate that the UK economy could gain £100 billion by adopting tried and tested technologies and closing the productivity gap between the most and least productive UK firms.[75] Innovation adoption and productivity have a positive and significant relationship which has been empirically proven.[76]

The UK exhibits strong leadership as an innovative nation globally, ranking 4th in the 2020 Global Innovation Index, and by the same index ranked 10th for knowledge impact[77]. This shows the UK is a world leader and performs well in terms of innovation at the forefronts of ideas and technologies[78]. Yet the ‘trickle down’ of ideas to non-frontier firms is weak; by the same index the UK ranks 11th in the world in terms of knowledge diffusion and 27th for knowledge absorption[79]. This illustrates the UK’s disparity in innovation activity and its outcomes, further evidenced by drops in innovation-active firm numbers below rates of other countries[80].

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[72] Additional reading: Nesta 2008. Innovation by Adoption, 7.8 Knowledge Diffusion in Firms
[73] Cormin, D. and Mestieri, M. 2013. Technology Diffusion: Measurement, Causes and Consequences
[74] CBI 2017. From Ostrich to Magpie
[75] IBID
[76] Surinach et. al 2009. The Diffusion / Adoption of Innovation in the Internal Market, Economic Papers 384, European Commission. https://ec.europa.eu/economy_finance/publications/
[77] This sub-pillar of the Index measures increases in labour productivity, new firm creation, spending on computer software and industrial output of high- and medium-tech manufacturers.
[78] Global Innovation Index 2020. https://www.globalinnovationindex.org/Home
[79] Knowledge absorption (an enabler) and knowledge diffusion (an output) are sub-pillars of the GII. Knowledge diffusion includes measures of intellectual property receipts, proportion of high-tech net exports of total exports, ICT services exports and net outflows of FDI as a percentage of GDP. Knowledge absorption measures the mirror opposite of indicators: IP payment, high-tech imports, ICT services imports and FDI new inflows. Percentage of research talent was added in 2016 to measure professionals engaged with elements of innovation.
[80] UK Innovation Survey and European Community Innovation Survey (equivalent)

Figure 4.1: Adoption and diffusion journey of businesses as innovations spread

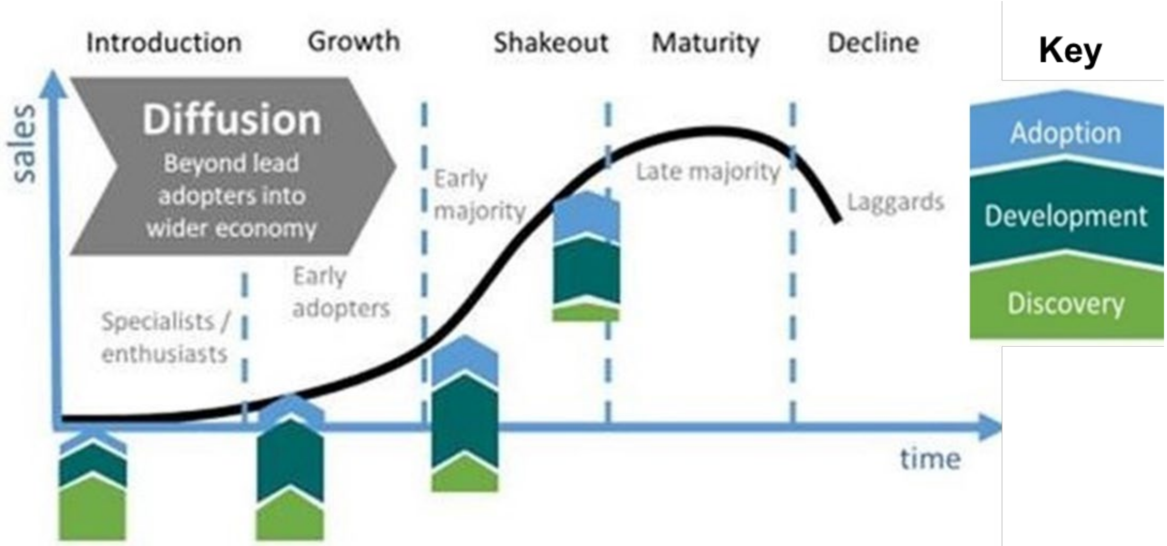

Figure 4.1 illustrates how different businesses will adopt innovations over time. Adoption affects how widely groups share and utilise products, services, processes, and behaviours. Adopters can be categorised according to their tendencies to adopt – innovators, early adopters, early majority, late majority and laggards[81]. Each group ideally requires a different diffusion approach[82], from supporting the acceleration of diffusion of cutting-edge innovations to business support programmes for firms who are simply trying to stay competitive through foundational measures. The UK Innovation Strategy sets out ways in which organisations such as UKRI and Innovate UK will support ideas and products to come to market to bring about innovation benefits.

Business adoption of innovations

Business leaders' mindset is key to a firm's propensity to innovate, often affected by the level of understanding and the terminology used around innovation. Exploring these attitudes to adoption, Kantar research found an innovation mindset, industrial awareness and business capability are enabling factors influencing the adoption of innovations[83]. Thus, the journey to successful adoption goes through increasing awareness, assessing business capability to introduce new products/processes, and addressing business leaders' mindset to decide to adopt new products/processes.

Interim evaluation evidence of the BEIS funded £20 million Made Smarter North-West pilot launched in 2019 – supporting to date over 12,000 manufacturing SMEs to invest in digital transformation projects – suggested this programme changed participant mindset, strategy and

81 Rogers, 1983.
82 ESRC UK Centre for Evidence Based Policy and Practice 2002. Learning from Diffusion of Innovations, Working Paper 10
83 BEIS 2019.Attitudes to Adoption

capability of firms. 84% of those surveyed and supported firms reported increases in their productivity, 60% were better able to participate in digital supply chains, 25% reported export benefits, with modest job creation found[84].

Technology adoption is associated with a productivity improvement of between 7% and 18%, depending on the technology[85]. Despite this, limiting factors affecting the pace and extent of adoption include technical feasibility, cost of developing and deploying solutions, and expected economic benefits[86]. Government has a role in giving businesses the confidence to invest, acting to unshroud information on best practice, thus accelerating the deployment of new productivity-enhancing technologies. To achieve this, the Help to Grow: Digital voucher scheme will look to support 100,000 businesses to overcome barriers of adopting basic technologies.

Firms state barriers in adopting digital technologies include a lack of skills or expertise. There is strong evidence that even small improvements in management practices can lead to a 10% increase in productivity[87] and that small and medium size business are less likely to use formal management practices than international competitors[88]. To overcome skills access barriers, the Help to Grow: Management programme offers 30,000 businesses the opportunity to build strategic skills in financial management, innovation and digital adoption.

Diffusion between businesses

Evidence widely suggests that technologies and knowledge from the highest productive firms in the UK are not diffusing effectively enough or rapidly enough to less productive firms (commonly termed 'adoption laggards'). Increasing the productivity of laggards to the median (average) firm would increase aggregate productivity by 6%[89].

Businesses rarely innovate in isolation, often drawing in information and knowledge from external parties, utilising skills and networks, and collaborating with other firms or universities. This means the dissemination to utilisation of innovations is reliant on (creating or existing) networks and infrastructure. The Knowledge Transfer Network facilitates and accelerates innovation through collaborations between businesses, entrepreneurs, academics and funders, facilitating the exploitation of R&D to capture more UK value from innovation. Innovate UK's Innovation to Commercialisation of University Research (ICURe) aims to build skills and business capability and has been shown to draw economic benefits. An evaluation of ICURe in 2020 showed that the programme has created £3.94 of economic benefits for every £1 invested to date[90].

[84] Steer Economic Development, July 2020. Evaluating the North West Made Smarter Pilot
[85] McKinsey Global Institute, 2017. A Future that Works: Automation, Employment, and Productivity
[86] IBID
[87] ONS, 2016. Management and Expectations Survey
[88] Bryson and Forth, 2018.
[89] OECD, March 2020. Laggard firms and Technology Diffusion and its Structural and Policy Determinants
[90] Ipsos Mori 2020. ICURe Evaluation Report. Access here

The effective diffusion of productivity-enhancing innovations requires demand for these innovations among businesses. Given current evidence, this requires continued efforts to overcome fixed mindsets of business leaders, business cultures to adopt new ideas and processes and an understanding of the value of innovation.

Knowledge exchange and commercialisation

Commercialisation – the process of taking new ideas and technologies to market – can be seen to be underpinned by the UK's world-leading research base, measured through patents, spinout, and income from IP. UK universities play a key role at all stages of commercialisation (of new innovations), adoption and diffusion (of existing ideas and technologies). They often facilitate this via technology transfer offices[91] [92] managing the translation of new knowledge to market, through collaborative research partnerships with business and others, and by providing infrastructure through access to specialist facilities and equipment, incubators, and accelerators. Activities including IP licencing, contract research, and investment into spinouts have all increased between 2014/15 and 2018/19[93].

Funding programmes are shown to facilitate and drive impact by making knowledge-based linkages between universities and businesses in the UK; examples include the Higher Education Innovation Fund (HEIF) and the Connecting Capability Fund (CCF). Modelling for HEIF indicates the average returns to an additional £1 of funding would generate an additional £8.3 in knowledge exchange (KE) income[94], and £9 return on investment[95]. An interim evaluation of the CCF indicated good outputs and outcomes of the programme spanning training and skills; commercial readiness; spinouts; industry engagement; and investment[96]. These evaluations illustrate strengths of the UK's higher education sector in generating innovation outputs.

Commercialisation activities by firms, backed by government's ability to coordinate and facilitating networking, can improve the flow of information to boost the adoption and diffusion of innovations. Programmes such as Knowledge Transfer Partnerships (KTPs) are shown to improve flows of knowledge through connecting firms and researchers to deliver strategic innovation projects across a range of sectors. A 2015 review of over 7,000 partnerships found that every £1 of KTP grant invested resulted in up to £8 of net extra GVA[97].

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[91] TTOs are a part of a university responsible for protecting and commercialising intellectual property developed at the university. https://www.imperialinnovations.co.uk/media/uploads/files/Technology_Transfer_in_The_UK.pdf
[92] https://www.praxisauril.org.uk/resource/university-knowledge-exchange-ke-framework-good-practice-technology-transfer-mcmillan-2016
[93] HE-BCI 2018/19. Access here.
[94] HEFCE 2015. Assessing the Economic Impacts of the Higher Education Innovation Fund: a mixed-method quantitative approach. Access here.
[95] https://re.ukri.org/sector-guidance/publications/assessing-the-gross-additional-impacts-of-the-higher-education-innovation-fund-heif/
[96] IP Pragmatics for Research England, 2015. Update to the interim review of the connecting capability fund programme. Access here.
[97] https://www.gov.uk/government/publications/the-knowledge-transfer-partnership-programme-an-impact-review

Conclusion

The UK has the potential to greatly improve the adoption and diffusion of innovations across sectors and the economy. This is aided by signposting and facilitating commercialisation activity, networking opportunities and seeing innovation as core to business activity.

Evidence shows the returns to strengthening and promoting programmes that further incentivise collaboration activities, including ICURe, which targets entrepreneurs bringing ideas to market, and KTPs that ensure a flow of expertise between academia and business. Innovate UK’s EDGE programme facilitates deployment and adoption (new to market innovation) for businesses that wish to exploit innovation, source funding and expand into new international markets[98].

To support this and overcome barriers highlighted, the UK Innovation Strategy sets out actions to ensure all business can reap the benefits of innovation, by aiding business technology and skills adoption, as well as promoting commercialisation.

[98] Innovate UK EDGE. https://www.innovateukedge.ukri.org/

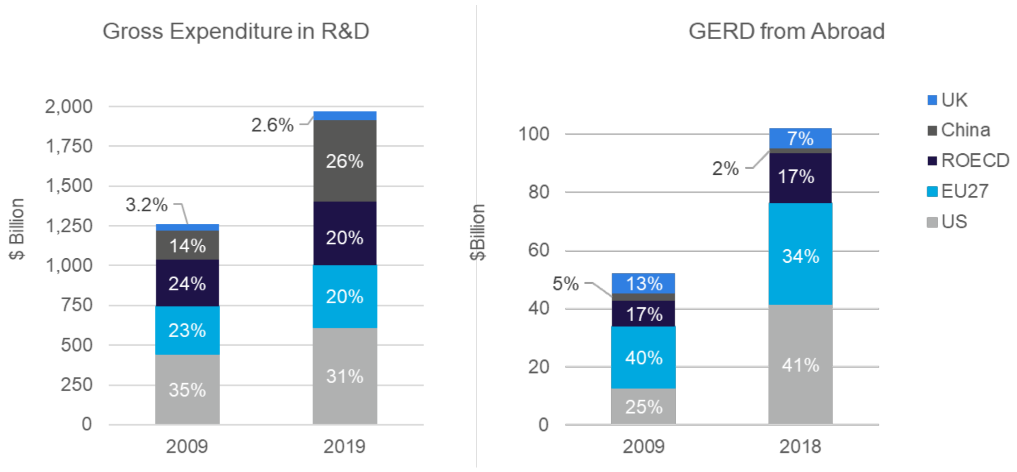
Global

International research and innovation (R&I) activities are widespread and increasing globally. With higher R&D activity worldwide, the shares of global inputs for R&D are falling for established R&D nations such as the UK, the US and the EU27. Despite this, the UK maintains a leading position on indicators of outputs of R&I globally and is a partner of choice for an increasing number of international collaborators in business and in academia.

Figure 5.1 shows UK's R&D expenditure in an international context. The UK increased its expenditure from $41.3bn in 2009 to $51.7bn in 2019, but this growth is slower than in countries like China, leading to a fall in the UK's share of worldwide R&D: the left panel shows that China's share nearly doubled from 2009 to 2019 while the UK's fell from 3.2% to 2.6%. In the same period, the UK's share of worldwide foreign investment in R&D fell from 13% to 7% (right panel)[99]. At the same time, the UKs share of the world's count of patents with international co-authors also fell from 5% in 2009 to 3% in 2018[100].

The UK remains a partner of choice for researchers: 57% of all UK academic publications were with international co-authors in 2019, compared to only 21% for the World, 36% for the US or 23% for China[101].

Figure 5.1: Levels and shares of global R&D investment performed in UK, China, EU27, US and Rest of OECD.



Source: OECD Main Science and Technology Indicators. Note non-OECD countries except China are not included. Figures in international purchasing power parity $.

99 OECD Main Science and Technology Indicators Database, accessed March 2021. Data for business enterprise only to 2018. https://www.oecd.org/sti/msti.htm
100 World Intellectual Property Office database, accessed March 2021. PCT patents only.
101 Elsevier's Scival database, accessed March 2021.

These falling shares of R&D inputs alongside high-quality outturns speaks to the excellence of existing partnerships, including those supported through Horizon Europe and ODA programmes.

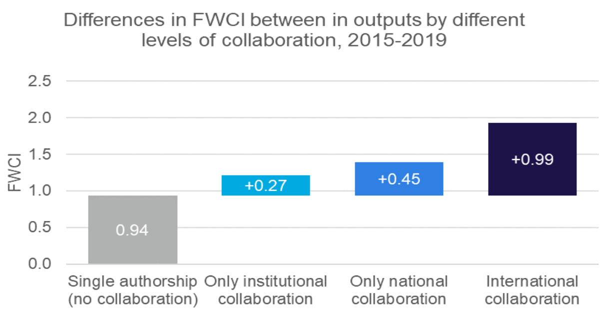
The Strategy is committed to building a long-term inward investment approach that targets specific areas of strength and aims to slow down, and potentially reverse, the UK's falling shares of foreign investment in R&D.

Returns to international research and innovation

International R&I accrues benefits for the collaborating partners who engage in it and for society. It has been shown that the spillover benefits of international R&I activities accrue higher rates of return than those achieved in domestic innovation, despite the fact that, for international applications, uncertainty and sunk costs are also higher[102].

Evidence also shows that international R&I collaboration achieves higher scientific impact, as indicated by citation measures such as FWCI.[103] Figure 5.2 suggests that the further afield the collaboration, the higher the scientific impact. International-collaborative publications with UK authors have 99% higher citation impact than the world average.

Figure 5.2 Differences in FWCI by different levels of collaboration



International mobility of researchers and innovators has additional academic and economic benefits. Internationally mobile researchers publish twice as much and achieve 30% higher citation impact compared to the publication records of researchers who do not move. The co-location of experts together achieves higher academic productivity than digital collaboration alone[104]. The immigration of experts can improve knowledge diffusion and lead to innovation outputs in the migrants' specialism[105].

To make the most out of these benefits, international cooperation requires governance and regulation that go beyond the national scope to cover international R&I tools and standards, such as intellectual property rights (IPRs). The case of medical supplies during the Covid-19 pandemic illustrates the importance of governance for success in global value chains[106]. The

[102] CESIfo 2016 International R&D spillovers and marginal social returns on R&D, find significantly higher returns from international than from domestic R&D spillovers
[103] FWCI is Field-Weighted Citation Impact. 1 is the average global level of citations in the field of research, so values above 1 represent higher-than-average citation impact.
[104] https://www.aeaweb.org/articles?id=10.1257/aer.98.4.1578
[105] A 10% increase in immigration from exporters of a given product is associated with a 2% increase in the likelihood that the host country starts exporting that good 'from scratch' in the next decade https://onlinelibrary.wiley.com/doi/abs/10.1111/ecoj.12450
[106] Gereffi, 2020. What does the Covid-19 epidemic teach us about Global Value Chains: the case of medical supplies. Access here: https://link.springer.com/article/10.1057/s42214-020-00062-w

importance of an internationally connected innovation system is reflected through the UK Innovation Strategy as it sets out initial steps to utilise diplomacy and trade to strengthen innovation.

Mechanism of impact

With the right balance of national and international R&I activities the UK will achieve a higher impact academically (international collaborations achieve higher citation impacts than national ones) and economically (international R&I investment achieves higher returns than domestic).

Enablers of impact

Business enterprises play a key role in the economic impact of international cooperation for R&D, drawing returns through two channels: expansion of markets (exports) and access to foreign knowledge (innovation).

Direct access to foreign knowledge assets (skills, funding, facilities) results in direct benefits for innovation activities[107] and businesses will generally engage in international cooperation provided the costs of access do not exceed the private benefits. Public support subsidises the private costs of international cooperation so that firms engage more than they might otherwise in the presence of market failures or other barriers that limit this socially beneficial activity.

Export activity accrues indirect benefits on innovation: Aghion et al. (2019) show that the demand diversification of export markets increases sales and employment immediately. This in turn induces other firms to enter the export market causing a competition effect that leads the more productive local firms to increase their innovation activity to keep their competitive edge. This shows there is higher patenting by the more productive firms 3-5 years after the initial expansion of export demand.

Not all firms use both channels at the same time: in 2018 35% of UK innovation active firms also exported (i.e. used both channels) but conversely 65% used innovation only, whereas 12% of non-innovators exported, thus used the markets not the innovation channel[108].

Barriers to impact

There are many reasons why not all firms utilise both international channels at the same time. Both innovation and export channels incur direct and indirect costs (financial as well as other costs including information, skills, knowhow) that make them unprofitable for some firms. The uneven distribution of these costs across firms leads to differences in how many firms engage with innovation and with exports across countries, depending on which types of firms prevail in each country (e.g., sectoral distribution).

[107] Aghion et al 2019. The heterogeneous impact of market size on innovation: evidence from French firm-level exports. Access: https://www.nber.org/papers/w24600
[108] UK Innovation Survey 2019, Table 7

International evidence suggests there is scope for improvement in the UK: in France and Germany more than half of innovative firms export (57% and 51% respectively), and over a third of non-innovators export (35% and 33% respectively). These proportions are even higher in smaller countries such as Belgium where 75% of innovators are active in foreign markets[109].

The logic chain below shows how policies, such as funding, non-pecuniary actions such as help with identifying partners, and instruments of governance such as agreed property rights and standards, can boost R&I activities, innovation assets and mobility. There is also scope to increase the proportions of exporters among innovators, and of innovators among exporters, leading to higher productivity for the UK.

Table 1: Logic chain for Global chapter actions

Inputs	Activities	Outputs	Outcomes
Direct Funding Opportunity identification Orientation/Guidance Governance (IPRs, Standards)	Projects, Programmes, Partnerships, Networks Talent Mobility & Development/Training Access to facilities (inc. new build) Framework for prioritising partnerships	Research proposals, matched funding Knowledge co-creation (papers, patents, code) Knowledge exchange (international, inter-sectoral) More integrated global value chains	Improved scores GII, especially output Reverse falling R&D investment trend Higher proportions of innovators/ exporters among business, leading to higher UK productivity Knowledge diffusion (citation, co-invention)

Evidence and insights

There are already funding opportunities for international cooperation that are well understood and deployed successfully including Horizon 2020, Eureka and UKRI programmes such as the Fund for International Collaboration or the Global Expert Innovation Programmes. There are also non-pecuniary actions in place, such as the Global Entrepreneur Programme and the Innovator Visa to facilitate inward mobility of high-growth firms and innovators.

As noted in the Integrated Review[110], there are many other policies that support R&D cooperation: Science Diplomacy (SIN Network), Big Science (European Spallation Source), International Development (Newton Fund, GCRF). Not all of these policies are as visible as others and there is scope to better inform national resources about foreign opportunities and foreign resources about national opportunities.

International coordination and transparency matter to all innovators. Across all firm sizes, 95% of innovators are in cooperation agreements with overseas partners (including public and private sector partners) because all involved benefit from cooperation. The top two groups of collaborators are the up and downstream of the value chain: 75% of innovators cooperate with

[109] Community Innovation Survey 2016-18 data portal https://ec.europa.eu/eurostat/web/science-technology-innovation/data/database?node_code=inn (inn_cis11_mrkt)
[110] https://www.gov.uk/government/collections/the-integrated-review-2021

suppliers and 64% with customers suggesting that innovation cooperation agreements build upon Global Value Chains[111].

Global value chains rest on regulatory frameworks that allow resources to move across the chain from creation to sale, with minimal friction, such as those underpinning the production and distribution of the Covid-19 vaccines[112]. The top R&D investing sectors in the UK, pharma, automotive, aerospace, and digital, rely heavily on global value chains for the production and distribution of their innovations. Their success relies on integrated international activities, from basic research to transport logistics, structured around a bespoke governance that enables globally dispersed members to cooperate internationally within the boundaries of their domestic regulatory environment.

The international practices of already successful Global Value Chains can inform the overarching aim of global-oriented actions set out in the UK Innovation Strategy, whereby international R&D policies align around the seven priority technologies and accelerate delivery of the four innovation missions, all of which have global scope.

Trade liberalisation has also been found to increase innovation effort in potential future exporters[113] and to release trapped factors that restrain innovation[114]. The inclusion of innovation chapters in Free Trade Agreements (FTA) aims to reap the benefits of innovating for exporters and exporting for innovators with transparency, market expansion, and a levelled playing field for innovators.

Conclusion

The UK is a global innovation leader as shown in the GII and other international standards and there are large benefits to be gained from further exploiting global R&I collaboration opportunities.

To future proof national innovation, the UK needs to build on its advantageous position with continued support to our collaborative innovators. The proposals embedded in the UK Innovation Strategy will support the UK's position as a global leader by providing guidance and better coordination and transparency of opportunities to partner, both for domestic and foreign businesses.

[111] OECD Global Forum on Productivity, 2017. The Relationship between Global Value Chains and Productivity. Access here: http://www.csls.ca/ipm/ipm32.asp

[112] Gereffi, 2020. What does the Covid-19 epidemic teach us about Global Value Chains: the case of medical supplies. Access here

[113] Burstein, Ariel, and Marc Melitz. 2013. Trade Liberalization and Firm Dynamics. Access here: https://scholar.harvard.edu/melitz/node/14403

[114] Bloom et al. 2013. A trapped factors model of innovation, American Economic Review, 103 (3).

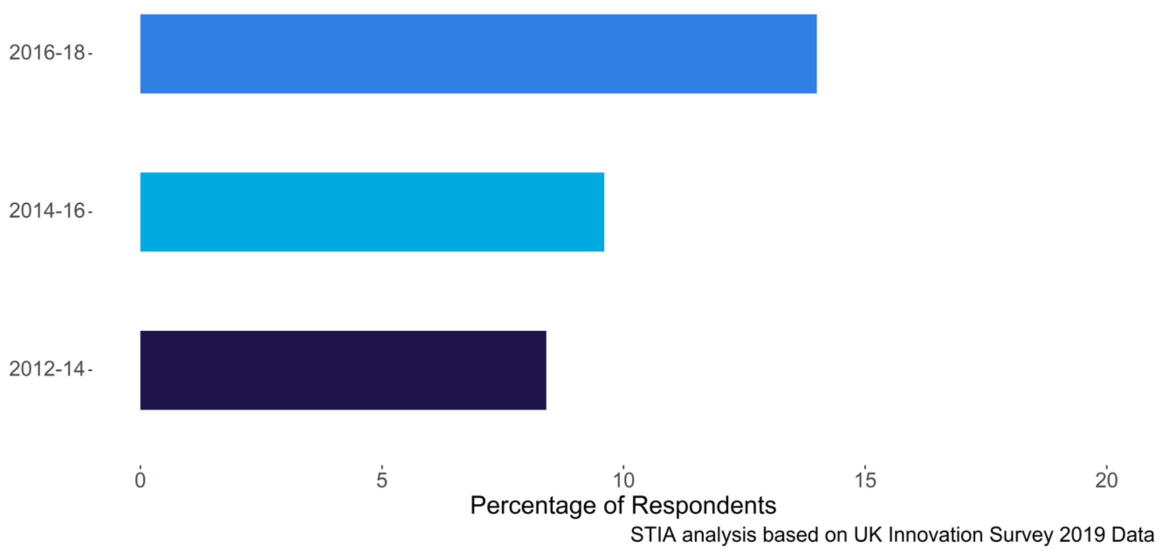
Talented People and Skills for Unleashing Innovation

Businesses need a talented workforce with the necessary skills to develop ideas and translate them into products and services. In 2018 roughly 10 million employees in the UK worked for an innovation-active employer in the private sector[115]. While not all employees of innovative businesses currently contribute to innovation activities, it shows that the workforce needed for innovation is far wider than the workforce needed for R&D[116], and in theory every worker can be 'innovative'.

Skills

The lack of qualified personnel is increasingly cited as an important barrier to innovation by businesses, seen in Figure 6.1, the fifth greatest barrier in 2016-18[117].

Figure 6.1: Barriers to business innovation: the **percentage of business reporting lack of staff as a barrier** has increased over time



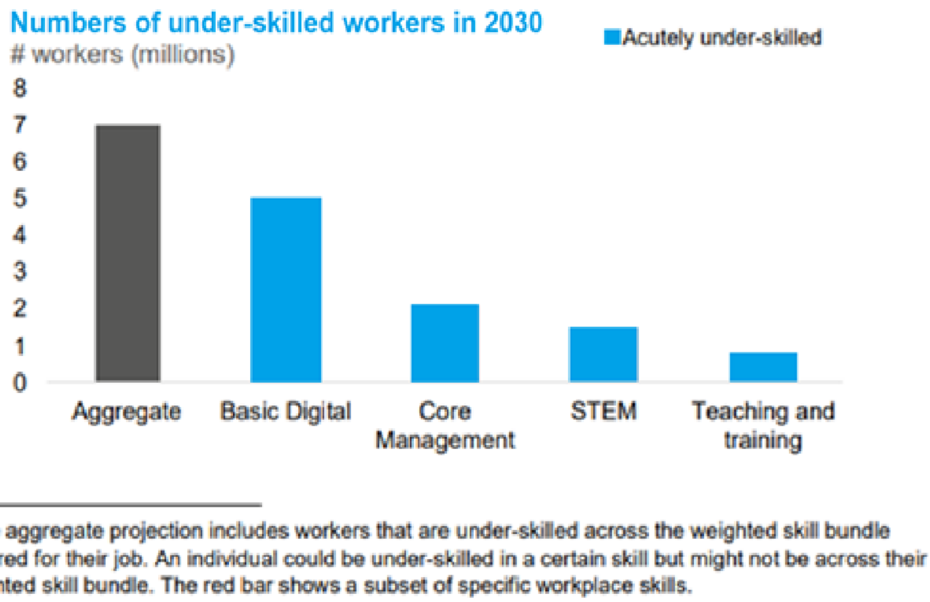
[115] Conversely, roughly 16 million people work for UK businesses which are not innovation active - defined as a business having introduced a new or improved product, process, business structure or strategy (UK Innovation Survey 2019). These figures are rough approximations. Source: UK Innovation Survey 2019, internal calculations.
[116] 0.5 million using OECD Frascati definitions, or 1m using a wider Labour Force Survey data a wider set of occupations needed for R&D and technology innovation
[117] UK Innovation Survey 2019. Main report.

The proportion of people who do not possess basic skills is high, particularly when compared with the UK's peers[118]. Basic skills include numeracy, literacy and problem solving within a technology rich environment.

It is important to distinguish the UK skills gap from UK academic achievement levels, which have been increasing steadily[119]. Many workers struggle to find suitable jobs because of limited work experience accumulated whilst studying[120], highlighting the value of work placements during academic education.

In 2019 the UK Industrial Strategy Council estimated that by 2030, 7 million additional workers could be under-skilled for their job requirements[121]. Figure 6.2 shows the most wide-spread under-skilling is in basic digital skills[122]. Core management skills are also expected to be lacking while being very trainable[123]. Business managers and leaders can stimulate innovation in their teams through, among others, psychological safety, sharing information, incentivising staff[124].

Figure 6.2: Forecasts for the numbers of workers under-skilled for their job requirements in 2030 (millions)



Source: UK Skills Mismatch 2030, Industrial Strategy Council

118 BIS, 2015. International Evidence Review of Basic Skills: Learning from High-performing and Improving Countries, BIS Research Paper No 209. Access here
119 ONS 2015. Analysis of the UK labour market - estimates of skills mismatch using measures of over and under education: 2015. Access here
120 Internal analysis using Employer Skills Survey
121 Industrial Strategy Council. UK Skills Mismatch in 2030
122 Industrial Strategy Council. UK Skills Mismatch in 2030
123 Channing, J., 2020. How Can Leadership Be Taught? Implications for Leadership Educators. International Journal of Educational Leadership Preparation, 15(1), pp.134-148. Access here
124 Enterprise Research Centre, 2021. Leading for Creativity and Innovation: A Review of the Current Evidence, ERC SOTA Review NO 48. Access here.

STEM skills are valuable. Employing STEM staff is strongly associated with higher innovation[125] and absorptive capacity[126]. However, by 2030 STEM demand is also expected to exceed supply. As of 2021 it may be more accurate to talk of the UK having a mismatch of STEM skills rather than a shortage overall: some STEM skills are oversupplied and some undersupplied (e.g. shortage of technicians, excess of biological science graduates)[127].

With 80% of the 2030 workforce already in the workforce today, reskilling the existing workforce will be the major challenge between now and 2030, providing opportunities to many. Innovative companies continue to experience problems finding talented candidates particularly with technical, social, critical thinking and service orientation skills[128]. In addition to hiring more talented staff, companies benefit from providing in-house training[129]. This relationship is particularly well documented for technicians, with training leading to an increase in innovation (a causal effect)[130]. Despite this, STEM workers are less likely to receive training than those in other roles[131].

Transferable (non-technical) skills and outlooks associated with greater innovative output can also be developed throughout the pipeline: this includes belief that one has the capacity to be creative, greater openness to experience and intrinsic motivation[132]. Transferable skills of low-skilled staff are also a key driver to their contribution to an organisation's innovation output[133].

The relevance of skills to employer needs is impacted by the responsiveness of vocational, educational and training (VET) institutions to employer needs, with adjustments to British Business Bank (BBB) apprenticeship and other training syllabuses accordingly[134]. There may be space to further support such institutional links and their responsiveness to other parts of the UK's "innovation infrastructure" (employers, other VET institutions, universities). In addition, various routes towards STEM roles can mean that young people require career guidance.

There were roughly 1,500 high skilled migrants who moved to the UK in 2020 including 200 via the Innovator route (requiring sponsorship by an incubator). Skilled migration can have a positive impact on innovation[135]. Migrants bring culturally unique, complementary skills as well as knowledge of processes and ideas to the workplace. A diverse workforce with a global outlook can identify opportunities and new openings. Significant benefits arise where migrants

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[125] UK Innovation Survey 2019. Main report.
[126] Jones and Grimshaw 2012. The Effects of Training and Skills on Improving Innovation Capabilities in Firms, Nesta Working Paper No. 12/08. Access here
[127] NAO 2018; (ERC unpublished). What are the main barriers to increasing the UK's business R&D workforce?
[128] Scale Up Review, 2020. https://www.scaleupinstitute.org.uk/scaleup-review-2020/introduction/
[129] Jones and Grimshaw, 2012. The Effects of Training and Skills on Improving Innovation Capabilities in Firms, Nesta Working Paper No. 12/08. Access here
[130] Jones and Grimshaw, 2012. The Effects of Training and Skills on Improving Innovation Capabilities in Firms, Nesta Working Paper No. 12/08. Access here
[131] Employer Skills Survey
[132] ERC, 2021. Building a creative work force: What is the current evidence on individual predictors of creative performance? Access here
[133] Aghion et al
[134] Paul Lewis, 2020. Innovation, Technician Skills, and Vocational Education and Training: Filling a Gap in the Innovation Systems Literature. Access here
[135] BIS, 2015. International Evidence Review of Basic Skills: Learning from High-performing and Improving Countries, BIS Research Paper No 209. Access here

assist business' expansion by sharing insights and connections to new international markets, suppliers and client relationships. The UK Innovation Strategy looks to enhance this route and the UK government will introduce a new High Potential Individual route to make it as simple as possible for internationally mobile individuals who demonstrate high potential to come to the UK.

Diversity

Diversity of thought and personal characteristics are shown to increase innovation. Similarly, diversity of nationality, subject of study and gender can increase the innovative strength of a firm[136] and increases the talent pool.

As such, ethnic diversity has a particularly positive impact on innovations in knowledge-intensive and internationally-oriented sectors[137]. Similarly, gender diversity is associated with greater innovation in businesses[138] and higher efficiency in knowledge-intensive industries[139]. A diversity of backgrounds also seems to increase innovation[140].

Detailed data is often not available to assess innovation impacts on all protected characteristics, but we have clear evidence of gender and racial disparities existing at many stages of the innovation process, and evidence that these are costly to national productivity and growth. One example is estimates of closing the gender patent gap in the US result in an increase in GDP per capita of 2.7%[141].

More women than men are lost throughout STEM education (from GCSEs to A Levels, and undergraduate to postgraduate) [142], shrinking the pool of potential innovators: STEM skills are strongly associated with higher innovation[143].

There are also disparities in entrepreneurship, with women half as likely as men to start their own business[144], and with larger businesses being less likely to be chaired by women. Women are also under-represented in innovation and commercialisation activity: disproportionately low levels of funding and finance go to businesses led by women[145].

[136] Enterprise Research Centre, 2018. Diversity in Innovation Teams. Access here
[137] Ozgen et al. 2013.
[138] Østergaard et al. 2011. Does a different view create something new? The effect of employee diversity on innovation, Research Policy, Volume 40, Issue 3. Access here.
[139] Garnero et al. 2014.
[140] Østergaard et al. 2011. Does a different view create something new? The effect of employee diversity on innovation, Research Policy, Volume 40, Issue 3. Access here.
[141] National Bureau of Economic Research, 2012. Why Don't Women Patent?, NBER working paper 17888,
[142] This is the case for the most, but not all, STEM subjects (e.g. Biology has higher female representation) Source: HESA
[143] UK Innovation Survey 2019. Main report.
[144] Global Entrepreneurship Monitor 2018. GEM
[145] https://www.british-business-bank.co.uk/uk-vc-female-founders-report/

Conclusion

The Industrial Strategy Council estimates that by 2030 the UK is expected to be under-skilled in several key domains: digital, leadership and specific STEM skills. To meet the skill gaps expected by 2030, it is critical to upskill the existing workforce to meet the UK's innovation potential, as well as increasing the skills of new entrants.

In the longer-term, increasing equality of gender and other protected characteristics across STEM students and graduates will be essential, as well as attracting international talent, to ensure talented people in the UK contribute to innovation workforce. This will help raise UK competitive advantage to push forward the frontiers of innovation.

Research, Development and Business Innovation by UK Places

This chapter is a brief overview of spatial analysis on business R&D and innovation (RD&I) in the UK. It examines the distribution of business RD&I activity across subregions to show that it is clustered around major cities, and more concentrated in the Greater South East (GSE). We also use recent research on the return to different R&D investments by region, and examine the comparative advantage in different R&D-intensive sectors by region. The key message is clear – different places require tailored RD&I interventions and precise analysis is imperative to identify opportunities.

Recent research for BEIS[146] confirmed the importance of regional business RD&I to drive regional productivity in the UK. This evidence found a statistical link between regional business R&D investment and innovation outputs which lead to increased regional productivity. More precisely, this study found that on average for the UK a 10% increase in R&D investment leads to a 0.5% increase in firm productivity – with each UK region benefitting from R&D investment – but with the magnitude of innovation and productivity increases from R&D varied by UK region as well as by industry. For example, firm R&D investment has a strong positive effect on firm productivity in high-tech manufacturing industries and knowledge-intensive services sectors, meaning that R&D based productivity rises were particularly relevant for regions with a greater proportion of such industries and firms.

This and wider studies confirm two important findings: a) business innovation outputs are primarily driven by firms' internal capabilities to generate innovations, and b) R&D collaborations with external organisations, both public institutions and private companies, are beneficial for the creation of knowledge and new innovations.

It is important to note, that R&D in a location does not necessarily have a linear relationship with UK firm innovation in that location. In other words, increases in local R&D will not always lead to increases in local firm-level innovation, as innovation is dependent on other factors (which we discuss below). Furthermore, all innovation policies (not just R&D) have a place dimension. This means that the policy solutions to increasing innovation in UK regions are required across the themes highlighted in the UK Innovation Strategy, for example access to finance, talent attraction and retention, skills supply and demand, and innovation adoption are all critical factors for increasing innovation within UK regions (as well as the wider conditions observed in strong regional economies such as high quality physical and digital infrastructure, housing, and local government collaboration).

[146] IBID

Business R&D and innovation vary by place, so precise place-based policy interventions are needed

The spatial patterns in business R&D and wider innovation activity in the UK reflect a virtuous circle for clusters of RD&I activity where research-intensive private and/or public organisations are relatively close in distance and attract talent and investment, and these innovative clusters have become the preferred destination for innovative people and firms.

The UK hosts globally competitive R&D and innovation clusters, but there are few of these and they are smaller in output than R&D clusters in some of the UK's global competitors across the world. This is illustrated by global Science and Technology cluster rankings[147] where the UK holds the top two most science and technology intensive clusters in the world when controlling for populations in UK cities[148] – Cambridge and Oxford, which host highly productive research organisations in relatively small urban agglomerations[149]. These clusters cover areas with a small proportion of the UK population, but produce a high volume of internationally significant research, attract global talent, produce highly skilled people, and attract large amounts of domestic and foreign private sector R&D investment.

The levels of overall R&D activity in each region also reflects the lack of many global R&D-intensive clusters. Given the UK's target of increasing total R&D investment to 2.4% of GDP (OECD R&D intensity average), too few regions are currently above the OECD R&D average. For example, in the UK 6 out of 41 (15%) subregions spend more than the OECD R&D average, compared to 16 out of 38 (42%) German subregions. Analysing UK and international evidence suggests that interventions could drive more places and regions into a virtuous circle of attracting and retaining talented and highly skilled people, global R&D investment, and innovative firms. Growing both emerging and existing R&D intensive places is needed to reach the 2.4% of GDP target. Growing R&D intensive places outside of the GSE is especially valuable to the UK given the need to 'level up' regional economies, and there are some indications that places outside of the GSE are under-potential given they hold many of the wider factors needed for R&D in place.

Business Expenditure on R&D (BERD) is concentrated in the GSE with 52% of the total spend in the region, and provisional data[150] on R&D tax credits[151] show that over 60% of R&D tax credits by value are claimed by firms in the GSE. However, this may be partially due to the headquarter effect, meaning the actual R&D activity could be taking place elsewhere. Notably, Innovate UK[152] funding shows a different picture of where firm R&D takes place (64% outside of the GSE and 36% within the GSE), indicating that businesses engaging in RD&I are spread

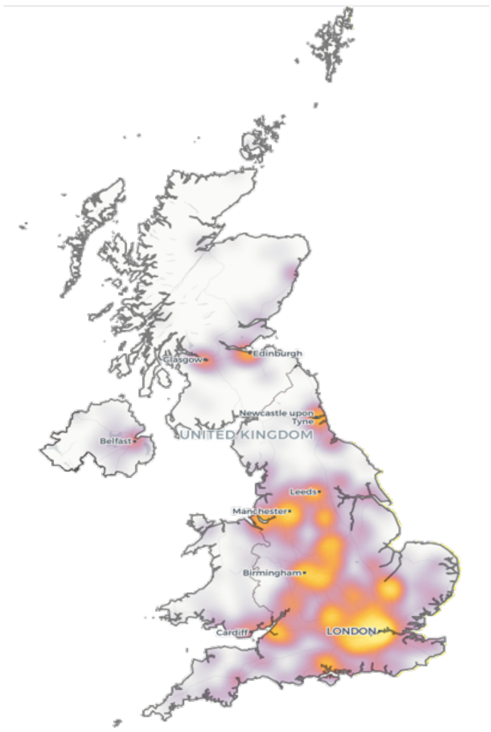
[147] The top 100 Science and Technology Clusters, World Intellectual Property Organisation 2020
[148] S&T intensity is the sum of patent and scientific publication shares associated with a cluster, divided by its population.
[149] The top 100 Science and Technology Clusters, World Intellectual Property Organisation 2020
[150] https://www.gov.uk/government/statistics/corporate-tax-research-and-development-tax-credit
[151] For financial year 2018/19
[152] Using FY18/19 spend data, available at: https://www.ukri.org/about-us/what-we-do/funding-data/regional-distribution-of-funding/

throughout all UK nations and regions more than overall Gross R&D expenditure suggests (see Figure 7.1).

Table 2: UK R&D expenditure in 2018 with a break down by selected sectors or funders by region

R&D by sector/funder[153]	Greater South East	North England[154]	Midlands & South West[155]	Devolved Nations	Total (£m)
Business R&D sector expenditure	52%	14%	25%	9%	£25,048m
Tax credits funding	60%	13%	19%	9%	£5,330m
Innovate UK funding	36%	17%	37%	10%	£941m
Total UK R&D (public and private) expenditure	53%	14%	22%	11%	£37,072m

Figure 7.1: **Places in receipt of Innovate UK funding 2018/19[156] (£610m)**

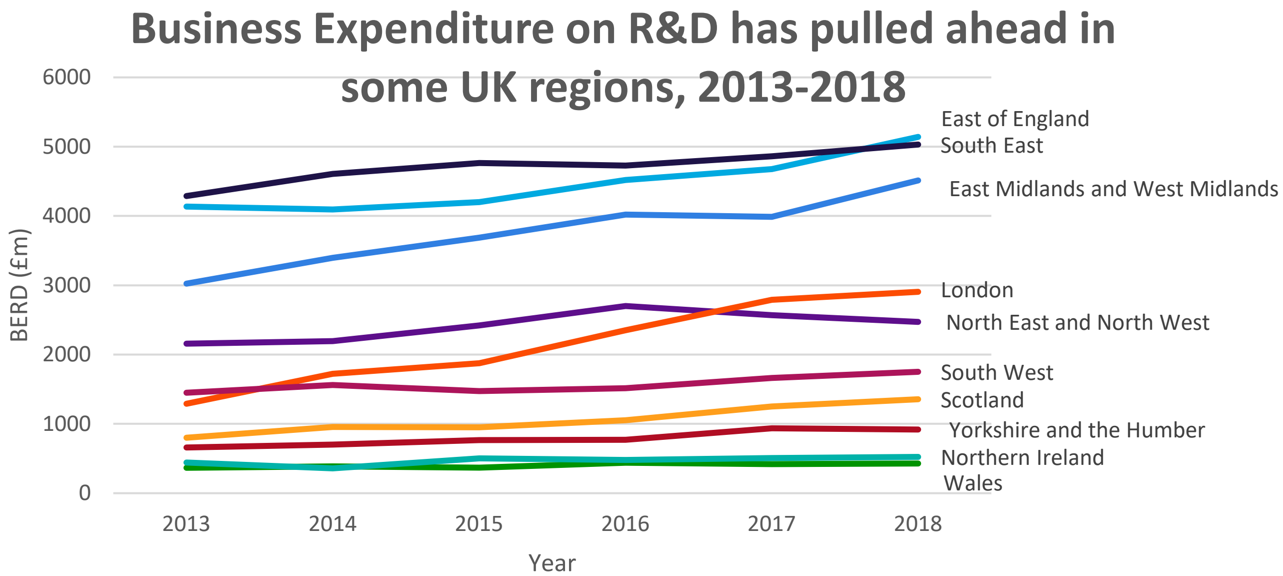


Source: BEIS analysis using UKRI funding data

153 Based on ONS definitions.
154 Defined in this document as the combined NUTS1 regions of North West, North East and Yorkshire and the Humber.
155 Defined in this document as the combined NUTS1 regions of West Midlands, East Midlands and South West.
156 Excludes Innovate UK funding to HEIs. https://www.ukri.org/about-us/what-we-do/funding-data/regional-distribution-of-funding/

Figure 7.2 shows that the GSE and the Midlands have attracted increased business R&D investment at a faster rate – supporting the evidence on virtuous circles of private R&D investment.

Figure 7.2: Business R&D expenditure by region[157], 2013-2018

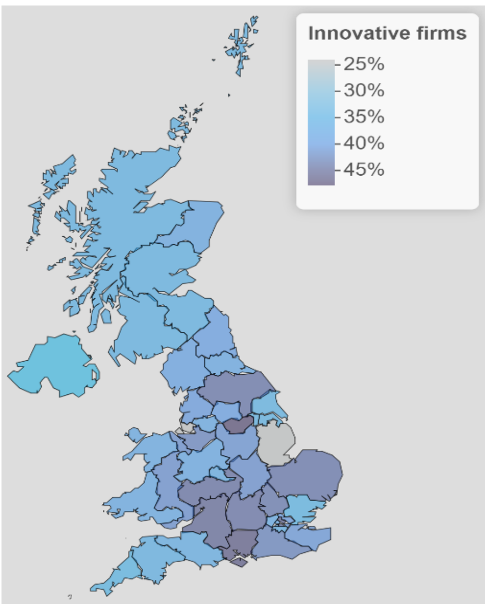


Source: ONS

Innovation outcomes from business R&D

We have also examined the UK Innovation Survey[158] to better understand the concentration of innovation outcomes from R&D, findings suggest that while total innovation activity (Figure 7.3)

Figure 7.3: Proportion of firms that were innovators, 2016-2018, UKIS



[157] Some regions have been combined due to a lack of available data.
[158] A biennial survey that asks businesses about various aspects of their innovation-related activities. Using these data, we can measure the level, types and trends in innovation to inform government policy.

in the UK is most concentrated in the GSE and major UK cities, this concentration varies by innovation type.

Important measures of innovation, which often but do not always stem from R&D, are product innovations[159] and process innovations[160]. Process and product innovation levels in each region point to higher levels of innovation in and around major UK cities. However, Figure 7.4 shows that process innovation is slightly less concentrated than product innovation (Figure 7.5). One hypothesis is that this is because process innovation can be cheaper and more accessible for firms, especially if the process relates more to ways of working and therefore does not require the same level of investment as product innovation.

Additionally, new-to-market goods and services as a proportion of turnover (Figure 7.6) are partially concentrated in the West of England but can be found across the UK. Overall, fewer regions do well on this measure, perhaps because new-to-market innovation is more difficult to achieve than process or product innovation. Again, we see central regions innovating more than coastal regions.

Figure 7.4: Proportion of firms engaging in process innovation, 2016-2018

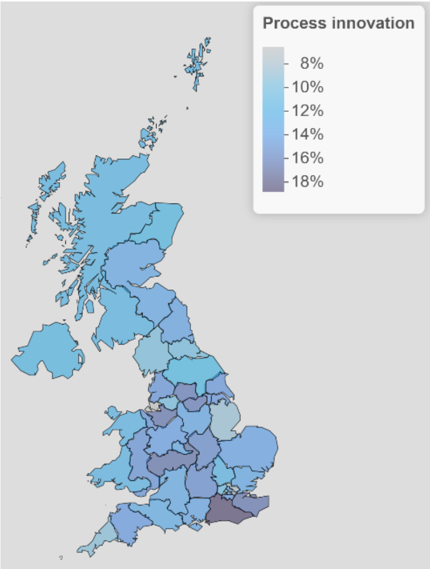


Figure 7.5: Proportion of firms engaging in product innovation, 2016-2018

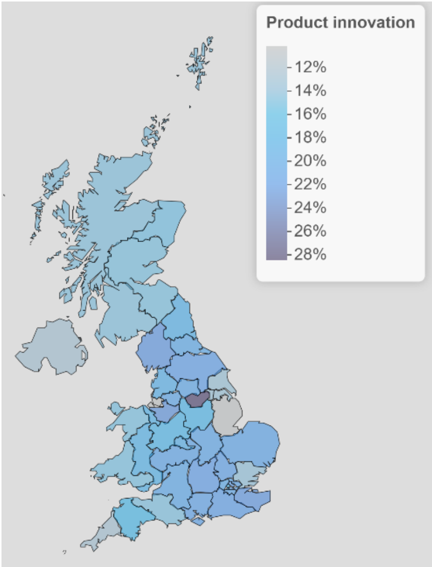
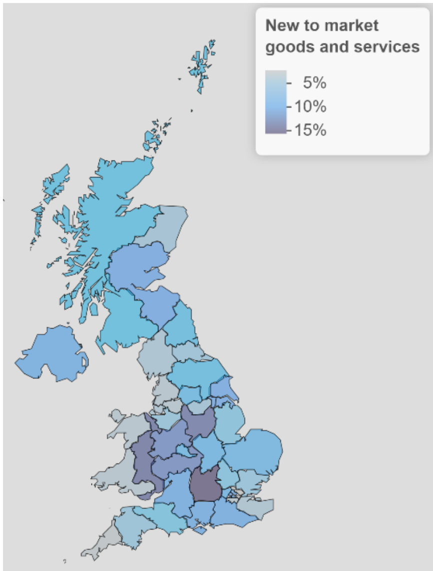


Figure 7.6: New to market goods and services as a proportion of turnover, 2016-2018



Furthermore, the innovation and productivity benefits to places from RD&I investment depend on the capabilities and strengths of the local ecosystem. This includes differing absorptive capacity strengths across local firms to recognise and use the type of R&D being produced;

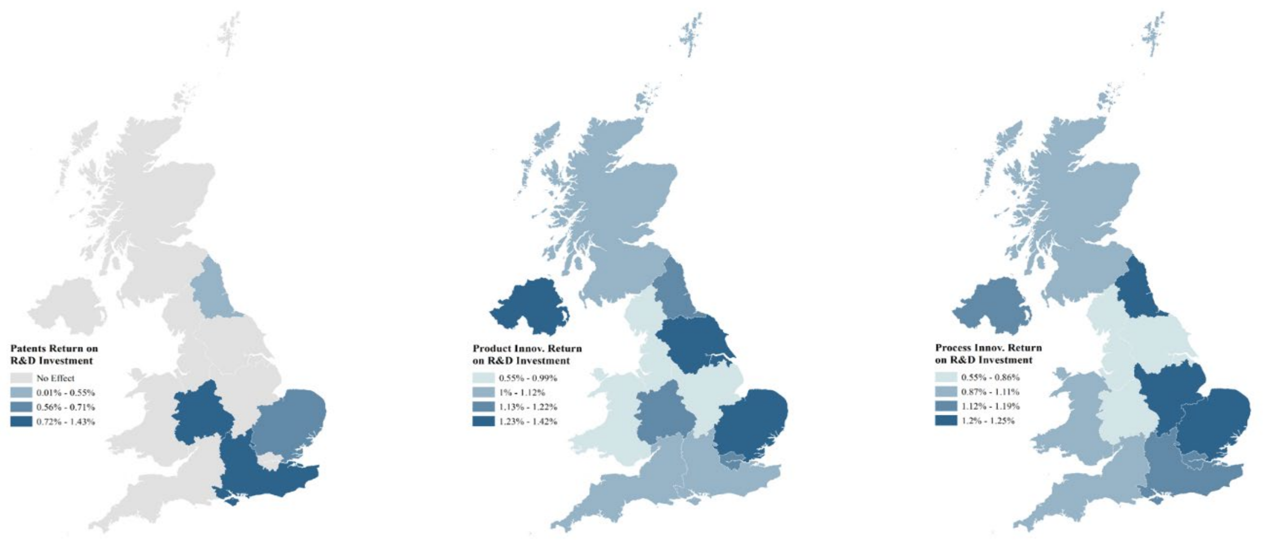
[159] Product innovation can either create new goods and services (that differ significantly in their characteristics or intended uses from previous products in a given market or firm), or it can significantly improve technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics.
[160] Process innovations are the implementation of a new or significantly improved production or delivery method. For example, significant changes in techniques, equipment and/or software intended to decrease unit costs of production or delivery, to increase quality or to produce or deliver new or significantly improved products.

the supply and demand for the skills needed to innovate, including leadership and commercialisation skills; the type of innovation that comes from the R&D being produced; and the industry sector composition of the local area.

Recent research for BEIS[161] analysed the relationship between R&D investment and the introduction of innovations within each region (Figure 7.7). This report highlighted the large differences in innovation returns from R&D across the UK[162] but also found evidence of innovations spilling-over from R&D produced in neighbouring regions illustrating that the benefits to different places are difficult to trace with precision.

The research shows, firstly, that the relationship between R&D investment and process innovation has been stronger in the East of England, the East Midlands and the North East (Figure 7.7), which follows the distribution of manufacturing industries across UK regions. Secondly, the relationship between R&D investment and product innovation has been stronger in Yorkshire and the Humber, North East and the West Midlands. Thirdly, R&D investment was associated with firm patenting activity in only a few regions, namely the South East and the West Midlands. The higher levels of patents in these regions could be related to the clustering of major research-intensive companies and research institutes in these regions, especially in Cambridgeshire, Oxfordshire and Warwickshire – although it should be recognised that patents are an incomplete measure of innovation as they do not capture the many ideas that do not seek patent protections, including trade secrecy or gaining lead time advantage over competitors to protect the innovations of value.

Figure 7.7: Effect of R&D investment on patents, product and process innovations across UK regions[163]



[161] NIESR, (2021). Drivers of innovation and productivity in the UK. Access here
[162] They show the percentage increase in the likelihood of different innovations (patents, product- and process innovations) for each percentage increase in R&D expenditure. For example, a figure of 1.5% would mean that a 1% increase in R&D expenditure would lead to a 1.5% increase in the propensity to introduce innovations.
[163] Notes: NIESR estimations based on Innovation Survey and ONS Business Structure Database datasets between 2011 and 2017. The maps report the percentage change in terms of the likelihood of firms introducing one of the innovation outputs as a consequence of a 1% increase in total R&D investment.

This analysis also found evidence of regional benefits to firms of locating near research producing universities[164] – specifically process innovations and of new-to-market products introduced by firms. An approximate estimate shows that these positive effects of university research spillovers for private firms were stronger at a closer distance and not significant beyond a 15 miles distance from universities (consistent with studies outside of the UK[165]).

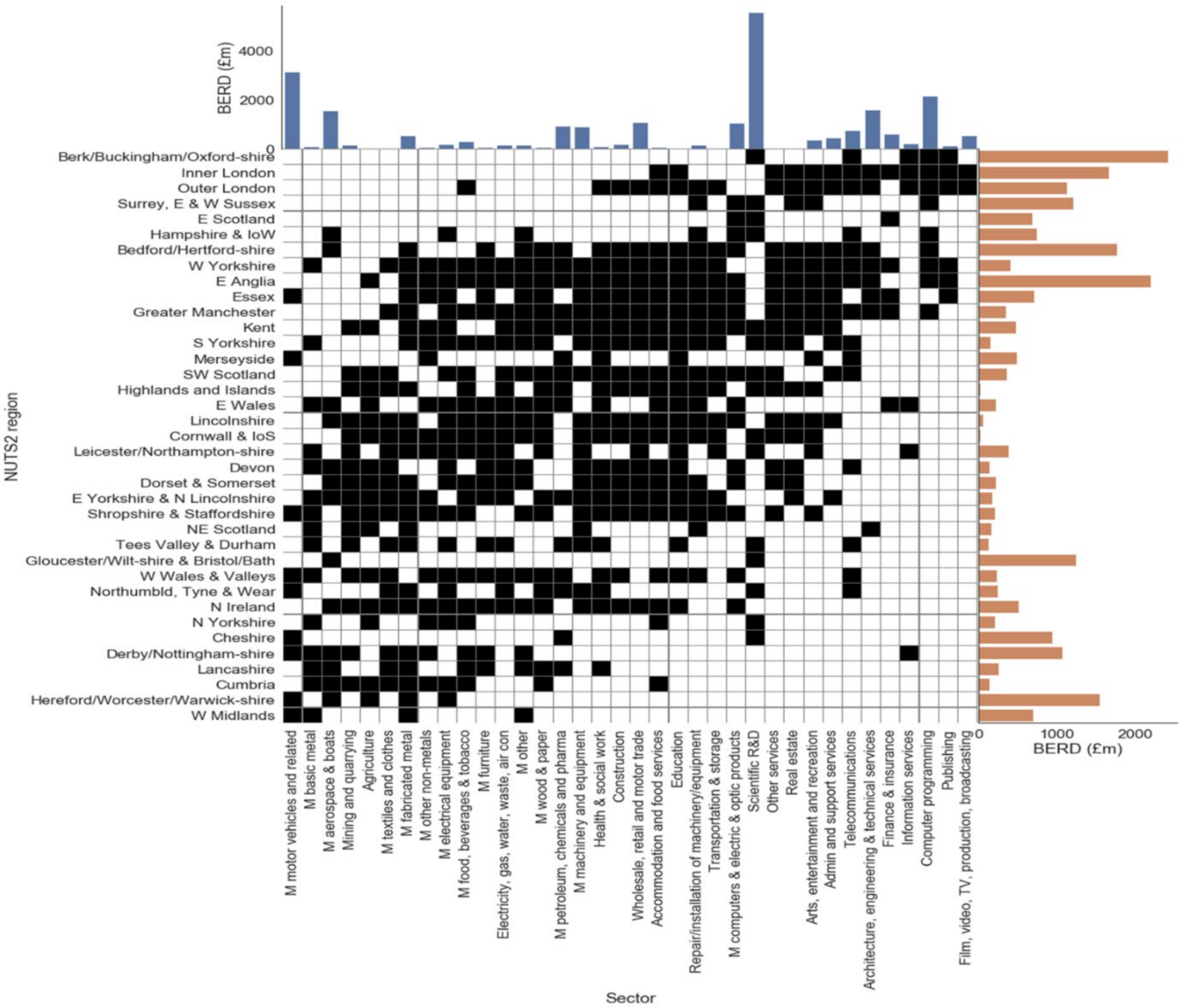
The importance of distance also depends on the type of firm and the social networks that innovators can access. For example, a study[166] of interactions between university and businesses (Knowledge Exchange) spillovers found that direct collaboration between businesses and universities (as opposed to indirect research spillovers), increases the probability of new-to-market innovations by 5.2% with regional universities (defined as within 100 miles) and 8.4% with national universities (defined as over 100 miles away), perhaps due to it being less likely that the closest university is the best matched to firms conducting this frontier innovation.

However, when the results were broken down by firm size, collaboration with regional universities increased the probability of new-to-market innovations by 7.1% for small firms, and 6.8% for medium firms; while large firms do not see a statistically significant result for collaboration with regional universities. These findings show a greater importance to small and medium firms for local universities, compared with large firms that can connect to partners further afield. This suggests that some local economies have a greater relative need for Knowledge Exchange between local firms and local research organisations, depending on their prevalence of smaller firms.

Differences in regional innovation returns from R&D are also likely to be driven by specific strengths places have in business sectors or important or emerging technologies. An important question for places, where we are limited by the availability of timely data, is "What are the comparative advantages of UK places in producing business R&D?". R&D expenditure by sector gives us an initial view of the high-level picture that subregions have diverse comparative advantages in producing business R&D, as shown in Figure 7.8[167]. For example,[168] Eastern Scotland (row 5) has a comparative advantage in three sectors (manufacturing computers, electric and optical products; scientific R&D; and finance and insurance). Some subregions have a comparative advantage in many sectors, but these regions and sectors tend to have lower levels of business expenditure on R&D.

[164] Measured using the average research income of universities in the same NUTS 1 region weighted by the geographical proximity of the firm to each university.
[165] Andersson, R., et al. (2009). Urbanization, Productivity, and Innovation: Evidence from Investment in Higher Education. Journal of Urban Economics, 66, 2-15. 10.1016/j.jue.2009.02.004
[166] Enterprise Research Centre, (2017). Accessibility, utility and learning effects in university business collaboration
[167] https://institute.global/policy/levelling-innovation-boosting-rd-underperforming-regions
[168] Black squares indicate sectoral strengths for each region, while the horizontal bars indicate total business expenditure on R&D (BERD) for each region, and the vertical bars indicate BERD for each sector. Sectors starting with 'M' are manufacturing sectors.

Figure 7.8: Regional R&D strengths in industry sectors and UK subregions[169]



Source: Institute for Global Change, 2020

Investing in the regional capabilities needed for R&D

All the above variations in regional R&D inputs and outcomes highlight that policy interventions need to vary accordingly, and that more precise and accessible spatial data would help to evaluate policy decisions.

As well as analysis of how R&D can maximise innovation for firms now, evidence shows that building the regional capabilities necessary to do R&D in the future is important to sustain and grow UK R&D activity. International evidence warns against the value of implementing R&D interventions without first having or building supporting capabilities[170]. This has been described as a "capability escalator"[171], where a firm, region or country needs to build management

[169] Note: A black square shows the subregion has business R&D intensity greater than the UK average.
[170] Coad, Mathew and Pugliese (2020). What's good for the goose ain't good for the gander: heterogeneous innovation capabilities and the performance effects of R&D.
[171] Cirera and Maloney (2017). The Innovation Paradox.

capabilities, STEM skills, access to R&D infrastructure and links between universities and businesses to maximise the benefits from their R&D investment.

To illustrate the point that a critical mass of R&D capability is important to optimal investment returns at a regional level, one study approximates[172] that commercial innovation returns to R&D are maximised when total regional R&D activity reaches 2% of the regional economy, but if and only if regional skill levels are also sufficient.

A New Spatial R&D Data Tool

As a first step to more precise and accessible data on subregional RD&I, BEIS is publishing a new spatial R&D data tool. Co-developed by BEIS and NESTA, the tool provides indicators to compare the scale of subregional R&D systems in the UK, by measuring the factors needed for public R&D; private R&D; and business innovation from R&D collaborations. Anyone will be able to access the website, visualise and explore trends in data, and use this as a foundation for further analysis.

The tool will support local and national policymaking on R&D, as well as the Government's wider objectives. For example, it can show which subregions have been most effective in attracting private R&D investment and talent, and it can be used as part of the wider analysis on 'levelling up' regional productivity in the UK. The trend data from this tool can also be extracted and used when monitoring and evaluating the impact of interventions, to strengthen our understanding of what works in place-based research and innovation.

However, a final important note is that the benefits from regional R&D investment are wider than commercial innovation returns. As well as the direct economic benefits of increasing firm productivity and the non-economic benefits to health, the environment and communities, R&D investment also has a role in attracting, training, retaining talented and innovative people to a place; enabling absorptive capacity for knowledge and technology that aids firms to adopt innovations created elsewhere; and enhancing/sustaining the capacity to produce and use R&D in future.

Conclusion

Both R&D and wider innovation activity in the UK are concentrated in clusters, partly due to agglomeration benefits of a skilled workforce, developed infrastructure, amenities and collaboration networks attracting innovative firms and people. This has contributed to a virtuous circle for clusters of RD&I activity where a high concentration of research-intensive organisations attracts talent and investment, and is a preferred destination for people and firms, including from outside of the UK.

[172] Charlot, S., et al. (2015). Econometric modelling of the regional knowledge production function in Europe. Journal of Economic Geography, 15(6), 1227–1259

Meanwhile, other places in the UK have experienced a low innovation, low productivity, low investment circle that is unlikely to be broken without intervention tailored to each region's different strengths and needs. The UK has a smaller number of subregions that perform above European regional averages in overall levels of R&D[173].

The evidence we have reviewed (and the spatial R&D data tool we are launching) indicates that investing in regional R&D would benefit regional, and UK-wide, productivity, because a) the UK has places holding many of the factors needed to produce R&D and innovation such as infrastructure, university and business collaborations and the ability to attract skilled labour forces and b) because all UK regions host innovative firms that have seen productivity gains from R&D and innovation output.

[173] According to Gini-coefficient analysis using 2016 Eurostat data, the UK has higher R&D intensity inequality (0.34) than European countries including Germany (0.31), France (0.29) and Sweden (0.25).

Government Taking the Lead: Missions and Technology Advancement

Government plays a role in supporting businesses and other innovators to direct their innovation efforts towards embracing the opportunities that come from addressing the world's biggest challenges for the UK economy and society; sending clear signals enable businesses to plan their own activities and co-invest alongside government. The following two sections set out how mission-based policy and identifying technological advantages can achieve outcomes that support UK economic growth and prosperity, and tackle major societal challenges.

Innovation Missions

Mission-oriented policies set defined goals and work to achieve them in a set time. Traditionally these goals were technological (such as in the case of US ARPA or NASA), but more recently they have been broadened out to include societal challenges such as focusing on addressing climate change.

Government's role in innovation policy has been approached from three different theoretical perspectives. Neoclassical theory sees innovation policy to fix market failure; the systems of innovation approach argues innovation policy tackles system failure in addition to market failure; and most recently the mission-oriented approach argues innovation policy needs to provide clear direction and coordination.

The mission-oriented approach lays stress on 'directionality' through policy. Thus, government policy does not merely fix existing failures, it creates new markets with clear direction. This stance has been described as "big science deployed to meet big problems"[174], where rather than just facilitating innovation through horizontal policies that level the playing field, government initiatives also feature explicit technological and sectoral directions. This has been a fundamental tenet of public programmes in fields such as defence, agriculture and space exploration.

More recent mission-oriented policies have focused on broader societal challenges, often aligned to global megatrends that pose significant risks but also offer real opportunities. Socio-economic and technological goals are set to tackle societal challenges like climate change and our ageing society. These challenges also have complex coordination problems with many interacting causes and solutions that go beyond technologies and require social and behavioural transformation to affect change. For example, it is widely accepted that tackling climate change is not only about new technologies but also changes in consumption and production behaviours.

[174] Ergas, H. (1987). Does technology policy matter. Technology and global industry: Companies and nations in the world economy, pp.191-245

Key criteria for a successful mission innovation programme

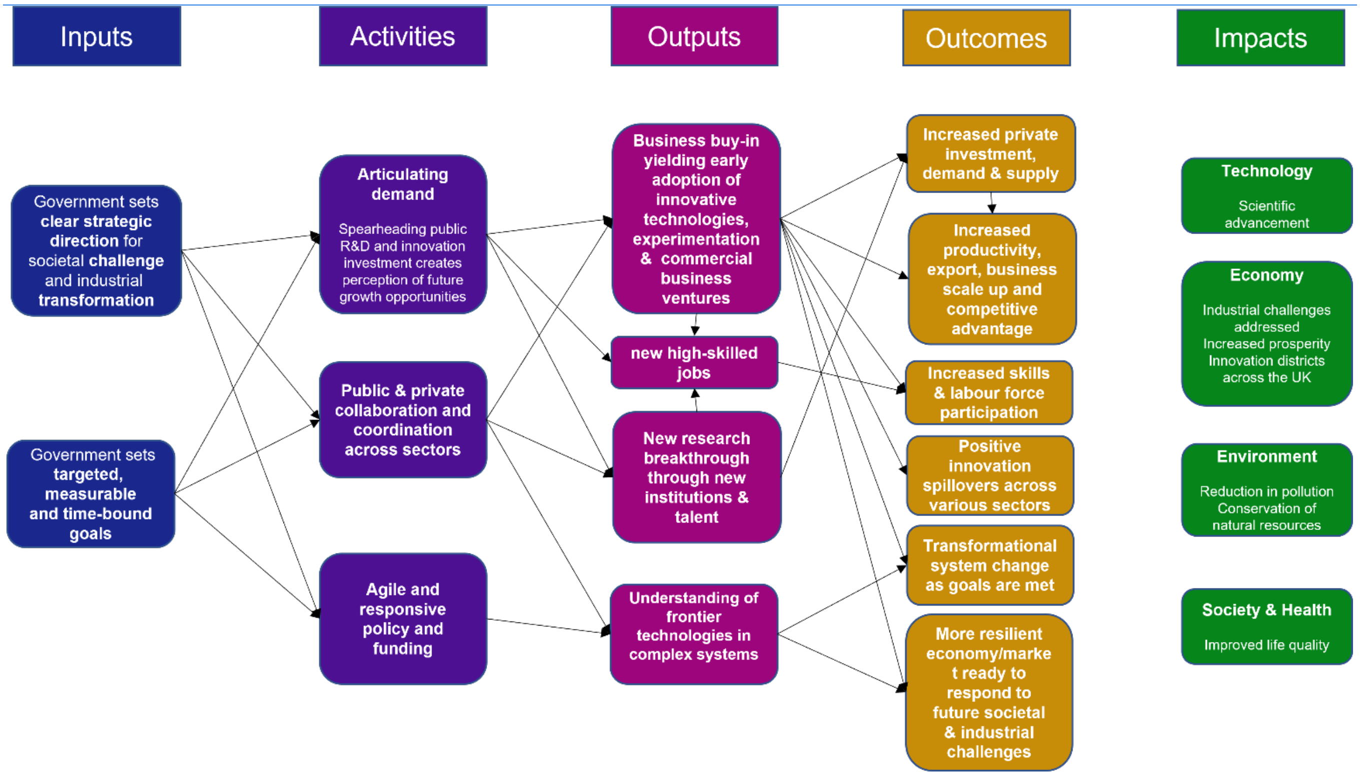
Selecting missions is a highly complex process. Successful missions should fulfil the following key criteria:

- Directionality - the state explicitly sets the direction in line with a country's core strengths.
- Portfolio approach to innovation - experimentation is considered one of the key features of innovation, therefore a missions-oriented approach tries to manage risks, rather than avoid them at all costs.
- Policy coordination - the need to move away from a 'siloed' approach to policy to ensure cooperation between different parts of government.
- Decentralised governance, multiple bottom-up solutions - involvement of a wide group of key actors and stakeholders to avoid the pitfalls of top-down planning.
- Cross-discipline, building a system of innovation - the need to foster collaboration between different elements of the national innovation system in order to build a strong innovation ecosystem.
- Focus on structural change, dynamic efficiency and spillovers - targeting technological solutions which could bring about change and economic benefits to a wide variety of sectors and create new markets and products. This also requires government project appraisal methodology to capture the full range of benefits from structural changes and spillovers, as opposed to more traditional 'static' cost-benefit analysis.
- Long-term horizon and patient finance - mission-oriented policies often target long-term challenges and, therefore, require long-term financing arrangements.
- Targeting well-defined issues - missions target specific and well-defined societal issues. They aim to foster innovation as a 'by-product' of solving a specific problem.

Mechanism of impact

The logic model below demonstrates how missions, through providing a clear strategic direction for a societal challenge, and through setting time-bound and measurable goals, can stimulate public and private cross-sectoral collaboration and create future growth opportunities. Such activities encourage market experimentation leading to increased demand and further innovation spillovers across sectors.

It is worth noting that the innovation process of mission-oriented policy is non-linear because we are dealing with complex systems, which include feedback loops within the system that are not captured here. As such, a systems-thinking approach is required once specific missions are defined.



Conclusion

Our Innovation Missions programme will help boost the standing of the UK and UK businesses on the world stage. It sends a clear signal that the UK is committed to making meaningful contributions to global challenges as identified in the Sustainable Development Goals and EU Horizon missions. This will position the UK as the best place in the world to trial global solutions.

Missions will draw on policy areas set out across the breadth of the UK Innovation Strategy, including talent and skills, regulation, and international commercial and scientific diplomacy to provide a whole-system approach to achieving missions. We will work with our partner organisations to identify and announce a set of ambitious and inspiring missions that cover the breath of the themes outlined in this paper.

Unlocking Technological Innovation

Technological innovation is a cornerstone of economic competitiveness, growth and productivity in every sector. Furthermore, some technologies have the potential to provide fundamentally new ways to advance knowledge, drive efficiency, support new-to-market products or services, or assist with environmental protection. Identifying the UK's strengths in new and emerging transformational technologies across digital, medical and manufacturing sectors, will help underpin the competitiveness of a wide range of existing sectors in the future, and are therefore strategically as well as socially important.

The late twentieth-century saw a rapid uptake of consumer electronics and digitalisation, alongside new technologies solving problems more effectively, cheaply and quickly. The modern digital economy, a critical enabler of the UK's world-leading services sector, contributed £149 billion to the UK in 2018[175]. The wider, general purpose application of digital technologies across sectors increases their development speed and sustains their acceleration over time as they find new areas of application.

The UK is the second-best performer in the G7 in terms of unicorns (a privately held start-up company valued at over $1 billion) created in 2020[176]. As the leader in Europe, the UK attracted a record $15 billion private VC investment for emerging technologies in 2020. This is minor when compared with the US ($144 bn) and China ($44.5 bn), but it displays relative UK advantage given the size of these comparator economies. This shows that global investment in emerging technology areas is high, and also concentrated: the top 10 countries worldwide raised 91% of all emerging tech investment in the 5 years to 2019[177]. This evidence highlights the international competition amongst top performing economies to invest in emerging technologies. Instead of competing on scale of investment with these leading economies such the US and China, the UK must identify which strategic investments in deep and transformative technologies are crucial for future prosperity and national security to carve out a relative specialism.

Supporting transformational Deep Tech in the UK

Government's role in supporting these technologies involves coordinating other elements of the system such as standard setting, infrastructure, co-investment, and skills development. Ensuring sufficient firm and market capability will allow the UK to exploit the opportunities offered by new and emerging technologies, and the supporting market structures to facilitate pull-through into the market. Having the finance backing technologies and the appropriate skills base to translate and diffuse these changes is crucial for the UK to carve out a global leadership position in deep and transformative technologies. A leading example for the UK is

[175] Department for Culture, Media, and Sport (DCMS), Sectors Economic Estimates 2018: GVA
[176] Tech Nation 2020 report
[177] Tech Nation 2020 report. 91% of all VC funding (£) in emerging technologies since 2015 was collectively raised (in order of volume) by the United States, China, UK, Israel, Cayman Islands, Canada, France, Switzerland, Singapore and Japan.

artificial intelligence (AI): investments in AI as a share of private VC investments for all digital technologies has increased[178], and the UK is building the skills base to compliment funding, as shown by having the highest share of AI talent in Europe[179].

The mission and technologies sections of the UK Innovation Strategy outline the levers through which government will support the ecosystem to de-risk participation and innovation in technological development. BEIS, UKRI and IPO joint analysis[180] identified main technologies listed in the UK Innovation Strategy which we believe have potential to unlock future gains in the UK and tackle societal challenges, with further work needed to prioritise these and identify the role for government in each case.

Identifying the UK's technological strengths

The UK has a long tradition of excellence in research and technological innovation, tending to excel at the early stages of basic research, ranking first in the G7 every year since 2007 for field-weighted citation index[181]. The journey to bring tech-based innovations to market is often long, complex and non-linear, and some phases of this process stronger than others in the UK. Examples of UK technological success – cultivating the environment for these technologies – and potential include:

- Artificial Intelligence: AI has the potential to transform across multiple industries. By 2030, UK GDP is predicted to be £2,252 billion, of which AI could account for 10.3% (£232 bn) of growth from 2017[182]. Regarding levels of private investment in AI, the total amount of capital raised by UK AI companies reached a record level of $1.3bn, and VC fundraising activity for AI in UK continues to rise[183].
- Robotics and Automated Systems (RAS): Beyond industrial applications, RAS has the potential to impact a wide range of sectors, with use-cases and opportunities across the economy such as automated guided vehicles, mobile retail robots, and humanoid customer service robots. Based on current adoption trends, the total economic impact of RAS uptake is estimated at around £6.4 bn by 2035, and if we could grow our current adoption rate this potential impact could be increased[184]. However, the UK lagged other nations in the adoption of industrial robots[185].

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[178] BEIS analysis of Beauhurst January 2021 data download
[179] AI Talent insights from the European Market, 2019.
[180] Methodology to Identify Emerging Technologies with UK Commercialisation Potential, BEIS (2021). Access here https://www.gov.uk/government/publications/methodology-to-identify-emerging-technologies-with-uk-commercialisation-potential
[181] International comparison of the UK research base, 2019 (p.5). https://www.gov.uk/government/publications/international-comparison-of-the-uk-research-base-2019
[182] McKinsey Global Institute 2019. Artificial Intelligence in the United Kingdom; Made Smarter Review 2017;
[183] Tech Nation, Tech Nation report 2019
[184] Robotics and Autonomous Systems Market Study, BEIS (2021). Research undertaken by London Economics. Access here
[185] PalPack: A recent IFR report has shown the UK is falling behind in the use of robots in manufacturing. https://www.palpack.co.uk/news/uk-fails-to-make-list-of-innovators/

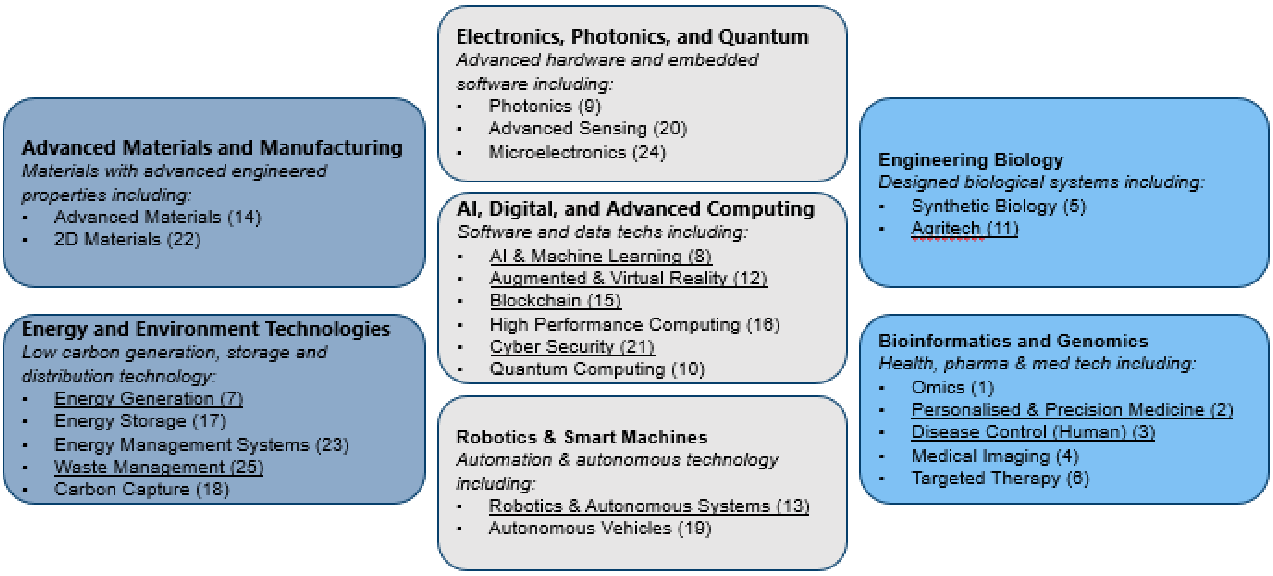
Two independent analytical ranking and prioritisation exercises were undertaken in support of the UK Innovation Strategy and are published alongside this paper.

- Identifying leading UK technology families: Horizon scanning insights, building on more than a decade of prior emerging technology identification activities by Innovate UK, identified specific technological advances from over 400 monitored technologies and mapped across to seven technology families. Within this grouping are specific near term (enabling) and longer term (emerging) technologies that present opportunities for the UK[186]. These seven families meet broad criteria for innovation interventions: they show large global market opportunities over the next decade, strong UK academic and industrial interest, and capability relative to other nations, delivery of societal benefits, and clear added value from public investment in the technology[187].
- Identifying potential UK comparative advantage in technologies: Starting from a range of horizon scanning exercises, an initial longlist of technologies was filtered down from around 300 to 25, using a ranking exercise developed by BEIS and UKRI to identify and compare the commercialisation potential of specific technologies. This exercise employed a two-stage process: Firstly, identifying and ranking the leading technologies by UK R&D funding and R&D outputs (publications, citations, patent activity); secondly assessing UK market capability and activity to commercialise these technologies, using UK business activity and venture capital trends[188].

The outcomes of these two analytical exercises were mutually supportive: the shortlisted technologies with the most potential can be mapped back to the seven groups, to reinforce the choice of those groups – demonstrating that they have significant strategic and economic potential, as shown in Figure 9.1 below. This analysis will be an input into policy choices about which technologies to prioritise and is published for the purpose of transparency.

[186] Enabling technology meant as commercialisation underway or expected within the next five years. Emerging tech are those for which commercialisation expected in the longer term, generally 10+ years.
[187] Innovate UK blog, LINK TBC
[188] Methodology to Identify Emerging Technologies with UK Commercialisation Potential, BEIS (2021)

Figure 9.1: How specific areas of potential comparative advantage/commercialisation strength nest into the seven broad technology families[189]



Source: A combination of BEIS, UKRI, IPO and Innovate UK analysis. Further details of these two projects are in the accompanying publications.

Mechanism of impact

To pull through technology at the cutting edge, government strategic focus will be on a sub-set of technology groups, with a particular interest in 'deep' or 'transformative / general purpose' technologies. The nature of support required for 'Deep Tech'[190] propositions, which exhibit longer development pathways needing patient capital or government funding, will differ to some other technologies which instead may look to have material commercial impact in five years, then cross-sectoral spillover in the medium 10 to 15-year time horizon.

The case for government to support Deep Tech innovation process is strong, given private finance incentives can lead to a lack of patient capital to bring technologies to market and scale. Access to specific skills, knowledge and infrastructure are needed to ensure sufficient firm capability. Technology development often requires bespoke, expensive infrastructure that is infrequently used by a single company – but is a valuable resource when able to be utilised by many firms. Government support in this area includes investment in key national scientific infrastructure such as National Laboratories, as well as via Catapults and Innovation and Knowledge Centres.

[189] Note: UK R&D strength ranking in brackets. Those in top-10 incorporating commercialisation strength are underlined.
[190] Following Imperial College's definition: deep techs are those based on significant scientific advances or engineering innovations, but which require a long period of development and/or considerable capital investment before commercial applications are successfully made.

Government support differs for each technology type at different points of their development lifecycle. Thus, the particular role for government needs to be considered and barriers in each case, reviewing and adapting its activities.

The Integrated Review[191] highlights an 'own-collaborate-access' framework that will guide future government activities on building and exploiting capability in priority technology areas. This will enable the UK to establish a leading position, establish partnerships and acquire knowledge in areas of national strategic importance.

The development of high-tech advances involves high costs, beyond the financial and technical capability of private firms, justifying the need for government facilitative intervention to address these market failures[192]. The supporting environment – provision of public goods (infrastructure, knowledge creation), creating innovation incentives (signposting and reducing frictions to access finance), and reducing information asymmetry (facilitating knowledge sharing and network creation) – is instrumental in supporting and strengthening the UK's ability to bring technological advances to market and scale.

In realising the route to impact for each technology family, monitoring of R&D investment, matching talent and skills, and ensuring the supporting business ecosystem is in place is crucial. Other elements such as overcoming information failures, developing global standards and export opportunities ensure the UK is strategically placed to benefit from supporting cutting-edge technologies.

Conclusion

Complementary horizon-scanning analysis highlight UK research strengths lie in health and life science related technologies (genomics, precision medicine, drug discovery) as well as in the fields of AI, quantum technologies and computing, photonics and advanced materials, and energy generation. These technologies have leading measures of research and innovation, strong underpinning sectors and national programmes to support their breakthrough into mainstream markets. Even greater gains are to be made in the cross-translation of ideas into a range of sectors. This is corroborated by evidence showing the UK ranked joint third for quantum research[193] and exporting our expertise in vaccine development and genomic sequencing deliver these gains. The UK cannot out-compete international leaders such as the US and China on spend (shown through AI equity investments) or volume of research outputs (patents and bibliometrics) but should target activities in technologies with UK market potential to unlock their full benefits.

The success of the technology families identified lies in the future prioritisation and targeting of government and business activity to respond to market opportunities. Technology families

[191] https://www.gov.uk/government/collections/the-integrated-review-2021
[192] Link and Siegel 2007. Referenced in Jue Wang 2018. Innovation and government intervention: A comparison of Singapore and Hong Kong, Research Policy, Volume 47, Issue 2. Access here
[193] Government Office for Science, 2016. The Quantum Age: technological opportunities. Access here

provide a starting point for prioritisation where the UK should display leadership. This will be driven by the new Prime Minister-chaired National Science and Technology Council.

Proposals in the UK Innovation Strategy draw on a range of levers to address barriers in the innovation ecosystem. These range from implementing programmes such as Help to Grow: Digital to increase technology uptake and promote investment, adoption and industrialisation of deep and transformative tech, to using government convening power to bring major UK industry players and supply chains together to drive deployment and fostering ongoing skills development.

Conclusions

To become a global hub for innovation by 2035, the UK needs to cement its current strengths and make ambitious and sustained improvements in many areas. This ranges from finance to skills, from technologies to missions, from increased investment in R&D to innovation adoption, and from place specific policy to ecosystem wide changes.

Evidence shows strong UK position on innovation outputs as reflected in the 4th ranking in Global Innovation Index and its unrivalled status in research publications. Comparison with other countries also shows that many countries are outpacing the UK in R&D investment, proportion of innovative businesses and adoption and diffusion of innovation across the economy. The global competition in these areas will only intensify as new technologies become central to future economic growth, jobs, security and competitive advantage.

Unleashing Business: While the UK has a vibrant financial sector and capital markets, evidence points to gaps in access to finance for innovative businesses that arise due to market failures as well as regional disparities. These gaps constrain highly innovative start-ups, scale-ups and other innovative businesses to raise finance to innovate.

Modifications to regulatory frameworks can have significant influence on how innovation occurs in a country, and the relationship varies by sector, time scale, or market. Government or industry need to be forward-looking and consider the wider innovation impacts when developing and setting regulatory frameworks and the interplay between them.

The UK has the potential to improve the adoption and diffusion of innovations across sectors and the economy. Government plays a role in signposting and facilitating commercialisation activity, networking opportunities and seeing innovation as core to business activity.

The UK is a global innovation leader as shown in global indexes and other international standards. There are large benefits to be gained from further exploiting global R&I collaboration opportunities and continued support to our collaborative innovators.

People and Talent: To meet the skill gaps – identified in digital, leadership and specific STEM skills – expected by 2030, it is critical to upskill the existing workforce to meet the UK's innovation potential, as well as increasing the skills of new entrants. Various literature can be pointed to showing the positive contribution of diversity to innovation performance, with particular value on gender and ethnic diversity within organisations.

Institutions and Places: Regional evidence reviewed (and the spatial R&D data tool we are launching) indicates that investing in regional R&D would benefit regional, and UK-wide, productivity, since the UK has places holding many of the factors needed to produce R&D and innovation and also because all UK regions host innovative firms that have seen productivity gains from R&D and innovation output.

Missions and Technologies: Working with key partners, ambitious and inspiring missions will be identified which draw on policy areas set out across the breadth of the UK Innovation Strategy, including talent and skills, regulation, and international commercial and scientific diplomacy to provide a whole-system approach to achieving missions.

The success of the technology families (identified through analysis published with this paper) lies in the future prioritisation and targeting of government and business activity to respond to market opportunities. Technology families provide a starting point for prioritisation where the UK should display leadership to unlock their full potential and benefits.

With the actions laid out in the UK Innovation Strategy, the UK can enable a step change in innovation performance and harness its benefits in the shape of economic growth, productivity improvements, new sectors and new jobs. Investment in innovation, both public and private, will also be crucial to address challenges from climate change and the ageing society to global pandemics.

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