Rocket science

How can the UK become a science superpower?

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Edited by Will Tanner

ONWARD

About Onward

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Our goal is to address the needs of the whole country: young as well as old; urban as well as rural; in all parts of the UK – particularly places that feel neglected or ignored in Westminster – by working with ordinary people directly and developing practical policies that work.

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About the programme

Onward's Science Superpower Programme is a two year research programme exploring how ministers can realise their ambitions for the UK to be a "science superpower".

It fills a major gap in the current policy debate by bringing together some of the finest scientific minds with leading policymakers to explore the strategic challenges, opportunities and trade-offs that the government and scientific community face. Building on Onward's successful work on levelling up and net zero, it is not only generating new analysis, but will put forward bold ideas to rapidly scale, accelerate and commercialise science and technology – and diffuse innovation throughout the economy.

The programme will run from early 2022 to late 2023, publishing five major policy papers and convening regular events between policymakers, scientists, investors and industry to inject purpose and energy into one of the most exciting, but historically underserved, areas of policy.

Rocket Science is the first paper produced by the programme, investigating the current state of UK science in technology in relation to its peers. The four papers to follow will propose policy solutions in more detail.

About the authors

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Summary of the argument

If the UK is to be a "science superpower", we need to rethink our strategy for science.

Since the 1980s, UK science policy has adhered to a model of science that is mostly organised at arm's length, driven by curiosity, and disproportionately funded by taxpayers. It is a model that has generated a broader and deeper science base than any comparably sized nation, as evidenced by the weight of Nobel Prizes, Fields Medals, highly-cited papers and world-leading universities. The UK's science system is without doubt one of the UK's greatest national strengths.

It is also an asset that we could exploit more effectively. Within the term "science superpower" lies not only a desire to *create* knowledge but an intent to *mobilise* it in the UK's interest. This might mean "hard" or "soft" power. It might be directed towards economic, technological or military ends. It might be in response to biological, environmental or security threats. But it necessarily requires policymakers to treat scientific knowledge, networks and institutions not just as public goods but as national capabilities in an increasingly competitive and threatening world.

The question is how the UK can adopt such a posture without undermining excellence elsewhere. The Government has already set a bold ambition for R&D and matched it with a generous funding settlement. By 2027, the UK should be spending the 2018 OECD average – 2.4% of GDP – on R&D (the 2020 OECD average increased to 2.68% of GDP). But rhetoric and fiscal commitments need to be framed by a clear idea of what it means to be a science superpower, and a long-term strategy for becoming (or remaining) one. That is the task of this paper.

It is clear that there is no single model for being a science superpower. But we do identify four characteristics of science superpowers that should guide the UK's ambitions. These are as follows:

First, science superpowers prioritise *academic foundations*. That is to say, competitive R&D investment, well-regarded research institutions and strong intellectual property assets.

This is arguably the focus the UK has chosen to date. We have an excellent research base, as defined by publications and citations, but this is despite relatively low levels of spending, not because of it. The UK suffers from chronically weak R&D intensity: of eight comparable science economies, the UK is one of only two countries, along with France, that spent a lower average share of national income on R&D in the 2010s than in the 1990s. If R&D spending had kept up with the OECD average since 1990, the UK would have spent an additional £212 billion on R&D over the last two decades.

Second, science superpowers have deep *knowledge networks*, in that they host the best research, attract the most promising scientists, and lead global regulation of technologies.

The UK's knowledge networks are mature. As a share of total publications, UK papers are more likely to be highly cited than any of our peer group, and more than half (55%) of UK papers are a result of international collaboration, up from 26% in 1998. Among our peer group, the UK has the second highest share of patents with at least one foreign co-inventor (23.7%) and before the pandemic was ranked in the top five science collaborator countries in every single EU state. In the MHRA and NICE, the UK also has some of the world's leading regulators. But there is more we could do to exploit international networks, especially as the UK's geopolitical focus changes post-Brexit.

The third trait of science superpowers is *absorptive capacity*: the ability to absorb ideas within the real economy for economic benefit.

The UK economy has weak absorptive capacity. UK universities are geared towards academic influence rather than industrial output: 18 UK universities are in the top 100 rankings for academia but just five feature in the top 100 most innovative universities. UK businesses report an average level of productivity lower than businesses in the US, Germany or France, likely caused by lack of innovation and capital investment. Meanwhile, the UK trains far more postgraduate students per capita in science and technology-related fields than many of our key competitors, but far fewer of them go on to apply their skills within the UK labour market. While the UK has average levels of mobility of academic researchers to industry, it performs relatively poorly compared to peers on the movement of industry researchers into academia. Perhaps as a result, the UK files fewer patents as a share of GDP than most of our competitors, and has seen the ratio of patents to R&D spend decline consistently for the last two decades.

Fourth, science superpowers typically exert their scientific influence overseas through *technology exports* – the sale of high-tech products and services, including intangibles, overseas.

The UK underperforms on most scientific export measures. The UK exports fewer high-tech manufactured goods by value than France, Japan and Korea, let alone the export superpowers of Germany, the US and China. Even in areas of perceived strength, such as pharmaceuticals, the UK's share of exports has been declining for decades. And even if we did export more, the UK would benefit comparatively less than other countries because one in three UK-invented patents are owned by foreign residents, compared to one in four in France and Israel, one in five in Germany and one in ten in China. This may be attributed to the very high foreign ownership of businesses that carry out R&D in the UK, with foreign-owned entities accounting for 53% of business R&D expenditure.[1]

So the UK has strong academic foundations and knowledge networks from which to supercharge its scientific ambitions. But if ministers are to be successful they will need to address other strategic weaknesses. The first step is obviously closing the UK's long-term R&D funding gap. But we should also be taking steps to strengthen absorptive capacity in the economy, boost specific high-tech exports and ensure that the UK benefits from postgraduate science training and UK-origin patents.

In practice, this means reforming the UK science ecosystem to meet five key tests, which we explore in further detail later in this paper:

1. **Strategic direction.** The Government should be more assertive in deploying R&D funding in areas of UK comparative advantage or to address a strategic weakness.

2. **Applying ourselves.** The UK's higher education system should do much more to encourage application of research, and businesses should respond by increasing their own R&D intensity, increasing demand for scientists within the domestic economy.

3. **Policy certainty.** Private investment in R&D should be encouraged by giving businesses simpler, long-term incentives providing a stable policy environment that allows companies to plan investments with certainty.

4. **Relentless adoption.** The UK should do more to support businesses and individuals to adopt cutting edge technologies so we can fully realise the benefits of technology.

5. **Exporting influence.** UK firms could do much more to export their products overseas, particularly intangibles, and to set standards for future technologies to get ahead of these emerging markets.

Now is the right time for policymakers to lift their eyes and raise their ambitions for British science. In the wake of the coronavirus pandemic and invasion of Ukraine, when science policy is more salient than any time since the Cold War and national security is front of mind for voters, policymakers have a unique opportunity to assure the UK's position as a science superpower for decades to come. We must take it.

Chapter 1

What does it mean to be a “science superpower”?

This chapter first explores what it means to be a "science superpower", a term that barely registered in the public consciousness before a few years ago but which now encapsulates the UK's entire science policy.

It goes on to explain the four dimensions by which ministers might seek to achieve or maintain the UK's "superpower" status in science. The next chapter compares the UK to other countries across each of these dimensions.

Superpowers control great power plus great mobility of power

The first recorded use of the term "superpower" was in William Fox's 1944 book, *The Super-Powers*, whose subtitle listed the United States, Great Britain and the Soviet Union as the preeminent forces on the international landscape, on whom the prospects of peace rested.[2] Fox distinguishes these three nations from their competitors on the basis not only of their inherent advantages – particularly their military, economic, or technological superiority – but also their ability to use it through diplomatic, cultural and other means. Britain, the US and the Soviet Union are characterised, in his words, by "great power plus great mobility of power".[3]

In this definition, scientific advancement becomes less of an end, or "good", in itself and more a means to defend or compete for limited resources. In the final months of the Second World War these resources were mostly tangible – land, food and energy – but today they are also intangible – knowledge, intellectual capital and digital assets – which the modern economy has made both mobile and increasingly valuable. A modern scientific superpower is therefore a nation that not only possesses great scientific power but has the ability and willingness to mobilise them to accumulate knowledge and influence as well as money and natural resources.

Although the original definition of a superpower was not tailored to the specific context of science, subsequent uses of this term have shown the ways in which different countries may be considered superpowers in different fields. There are several specific traits which could reasonably form a modern definition of a science superpower:

1. **International reach.** It is axiomatic that a superpower must have the ability to influence others on the world stage. There is clearly no such thing as an insular superpower. North Korea, for example, has total power over its own population but very limited power over other nations: it is not a superpower, however much Kim Jong-Un wants it to be. By contrast, South Korea not only has world-leading high-tech manufacturing capacity, its exports help to shape international standards and supply chains: in this sense, it might be termed a manufacturing superpower. This is the "mobility of power" that Fox writes about: the ability to exert power over other nations.

2. **Hard and soft power.** A superpower can wield power in different ways. Traditional definitions of power differentiate between "hard power", focused on military intervention, coercive diplomacy, or economic sanctions,[4] and "soft power", which relies on persuasion or attraction as a means to get others to do what one wants. The United States is a military superpower through its hard power – sustained high levels of military investment and a willingness to act militarily to protect their interests abroad, and through diplomatic leadership through NATO and, more recently, AUKUS. The UK might be considered a diplomatic superpower, combining "soft" influence through the Commonwealth, international development and the cultural role of the English language and the BBC, and "hard" power through membership of the UN Security Council and the nuclear deterrent.

3. **Rank exclusivity.** Not every country can be a science superpower. The competitive context in which superpowers operate necessitates at least some form of exclusivity. While the original wartime narratives focused on the Big Three, the same thinkers later questioned whether the natural classification of superpowers can form a triadic, dyadic or a multipolar phenomenon.[3] For the purposes of this paper, we suggest that a science superpower must rank in the top three in a particular competitive domain. It seems non-controversial to state that beyond third place a country is no longer world-leading.

4. **Source of comparative advantage.** A country is considered a superpower in a certain field when its power originates from a particular comparative advantage. For example, the United States and China are viewed by some as economic superpowers because they have the highest GDP. The US, China and (until February) Russia were deemed the world's three military superpowers because they have the largest or most advanced armies. Brazil and Germany might be called football superpowers because they have the best performing national teams. If the UK is to become a science superpower, the assumption should be it does so because of an underlying comparative strength in science.

So for the UK to be a science superpower it must have (a) significant influence over the rest of the world, (b) either through soft or hard power, (c) be amongst the top three nations in its field, and (d) have its power emanating from a specific advantage in science.
But 'science' is too nebulous a term. What do we mean by science? What kind of scientific power would be most useful for the UK to wield? How has the UK tried to wield scientific power in the past?

Science superpowers lead in strategically important arenas to support domestic growth and influence abroad

The term science has many meanings. In his 2014 review of the UK's Research Councils,[5] Sir Paul Nurse defined it broadly: "in the context of the entire academic landscape, reflecting the Latin root, 'scientia', meaning knowledge. All academic disciplines contribute to the vigour of the research endeavour, including the natural sciences, technologies, medicine, the social sciences, the arts and the humanities".

Clearly this is too broad a definition to be useful for the UK's ambitions to be a science superpower: the UK cannot be world-leading across the entire edifice of academic knowledge. But the review's *narrower* definition of scientific *leadership* is apposite, defining this as a combination of funding (for scientific research), capacity building (in terms of the skills, processes and resources needed to conduct or utilise science) and securing the UK's status as a world leader across the breadth of disciplines, while promoting the application of its research for societal benefit.

This definition is reflected in the letter from the Council for Science and Technology to the Prime Minister in June 2021, which set out a vision for the UK to "keep its place" as a Science Superpower through a combination of broader industrial strategy, innovation policy, action to raise economic productivity and international thought leadership, as well as scientific discovery in a narrower sense.[6] In essence, the Council views superpower status as being driven by more than just money and citations: it is also about how investment and basic research are applied in the real world.

The Government's own thinking is reflected in the *Integrated Review*, published in March 2021 – the closest that policymakers have come to developing a "superpower" strategy in recent years. The Review's "first goal is to grow the UK's science and technology power in pursuit of strategic advantage". It goes on: "in the years ahead, countries which establish a leading role in critical and emerging technologies will be at the forefront of global leadership" and "anticipating, assessing and taking action on our [science and technology] priorities… will become increasingly important to our domestic prosperity and our international relationships in the coming decade."[7] Following the report, the National Science and Technology Council, chaired by the Prime Minister, was established with the mission of setting "strategy on how science and technology will tackle great societal challenges and transform lives."[8] This is science treated as a national asset, not just a public good.

It follows from these definitions that we need a different framework for thinking about science to that of the past if we want to be a science superpower today. There are two dimensions worth focusing on in particular. First, the choice between domestic goals – such as local capacity and societal benefit – and international status, including reputation, trade and scientific-military alliances. Second, the spectrum between discovery (or "basic") science, that seeks to obtain new knowledge about the natural world and how it operates, and the "application" of sciences, i.e. the use of knowledge and methods to solve specific problems, improve productivity, or capture commercial benefit. A good example of the latter is the system of Technology Readiness Levels (or TRLs) originally developed by NASA to measure the maturity of different technologies for space exploration.[9]

Exploring the combination of these different characteristics – basic or applied; domestic or international – we can quickly identify different *types* of scientific superpower to which the UK could aspire. Of course this analysis is neither exclusive nor exhaustive. But breaking down scientific power into these segments is useful in categorising four distinct postures for countries wishing to be, or become, science superpowers.

The four combinations are as follows:

1. **Academic foundations**
   Nations primarily focused on domestic goals and basic research specialise in "academic foundations". They typically prioritise building strong foundations in basic science, for example by funding universities, as well as the acquisition of technological knowledge by domestic firms through a combination of direct R&D incentives and indirect regimes to support licensing, contract R&D or company acquisition.[10] In this case, scientific influence is exercised primarily by using economic power to buy up emerging science and technology companies and intellectual property, allowing the nation to reap the benefits from innovation both at home and abroad. An example might be France, which has a high share of basic R&D and a clear strategy of public investment in technologies where it has actual or perceived commercial advantage, such as nuclear energy.[11]

2. **Knowledge networks**
   Nations that focus on basic science within an international context exercise power through networks of human knowledge – by leading the regulation of nascent technologies, hosting the world's most cutting edge research and attracting the world's most promising scientists. An example might be the United States: authors from the USA publish the highest number of highly-cited scientific publications, and universities in the USA attract scientific talent from across the world. This gives the USA

enormous influence on which areas of science and technology are explored, what kind of training the best scientists receive, and how new technologies are adopted.

3. **Absorptive capacity**

   Nations that combine a focus on the domestic economy but with applied science derive power by taking the best the rest of the world has to offer – the best inventions, processes, software and engineers – and using them to maximise labour productivity and quality of life. They are defined by their absorptive capacity, or their "ability to identify, assimilate, transform, and use external knowledge, research and practice"[12] for economic benefit. An example is Ireland, which has used low corporate tax rates and a muscular inward attraction regime to attract foreign technology companies, driving up its productivity (GDP/hour worked) to among the best in the world.[13]

4. **Technology export**

   Nations that focus on international power driven by applied science tend to be exporters of technology. Their power derives from the creation and export of high-tech goods, cutting edge software or pharmaceutical products which other countries struggle to match and which sets the standards for whole industries. In the past, these exports would have been largely hardware, but in the future exports will be increasingly intangible, in the form of software, intellectual property or creative output. Examples of scientific exporters might include Germany or Japan, whose automobile exports from companies including Volkswagen Group, Daimler, BMW (Germany), and Toyota, Honda, Nissan, Subaru and Suzuki (Japan) have dominated global markets in terms of both volume and quality standards for much of the last half century.

The boundaries between these four concepts are necessarily blurred. It is possible for a country to be good at both basic and applied science, or to be powerful both in terms of domestic investment and international exports. It is also true that different strengths reinforce others: science investment is likely to boost absorptive capacity, which in turn can support greater import and export of ideas and goods.

The point, however, is that any strategy to attain or maintain science superpower status requires both a clear-eyed understanding of a country's strategic strengths and weaknesses, and for policymakers to make choices about where to direct their resources and political capital.

The UK has at different times shifted between all four of these policy postures

Apply this framework to the recent history of science policy in the UK and we can quickly see how unstrategic science policy has been.

The most straightforward case for the UK being a science superpower lies in its academic foundations. Historically the UK spent a comparatively high share of GDP on science and innovation. As recently as 1981, the UK committed 2.24% of GDP on R&D, higher than Japan (2.00%) and only marginally lower than the US (2.27%). Since the 1980s, the balance of government funded research has shifted from research in public labs to research carried out at universities.[14] Research councils direct the vast majority of funding with extraordinary autonomy on the principle of excellence determined by academic peer review. This has directed the vast majority of research funding towards universities, and elevated many of them to among the best in the world when ranked by citations or publications.

More recently, there has been a political shift towards domestic technology adoption, underpinned by a growing interest in industrial strategy and innovation policy. In 2013, Lord Willetts argued that strong basic science and flexible markets are not enough to be a leading scientific nation, and that the Government needed to do more to back "key technologies on their journey from the lab to the marketplace". This "missing third pillar to any successful high tech strategy",[15] as he termed it, became a central pillar of UK science policy in the 2017 Industrial Strategy and Life Sciences Industrial Strategy, and to a lesser extent the 2021 Innovation Strategy.[16] It was also a key driver behind the 2018 establishment of UKRI and a strong theme in Sir Patrick Vallance's 2019 Science Capabilities Review, which criticised the lack of scientific expertise in Whitehall and highlighted the value of public research institutions (government labs).[17] In all cases, it is possible to see a strategy of building absorptive capacity, driven by a focus on applied science within a domestic context.

At the same time, the UK has increasingly sought to influence global standards and regulations around new technologies and ideas. In 2010, the Coalition Government published a Blueprint for Technology, which included plans for regulation reform and improvements to infrastructure and skills.[18] More recently, the Government has introduced plans to develop global regulatory standards for artificial intelligence and machine learning,[19] cryptocurrency and blockchain,[20] and data ethics.[21] And the 2021 Integrated Review explicitly referenced the soft power derived from tech regulations describing "regulatory diplomacy: bringing together governments, standards bodies and industry to influence rules, norms and standards – particularly in rapidly evolving areas such as space, cyberspace, emerging technologies and data."[7] In the last decade this has been accompanied by multiple visa innovations to attract the best scientists, including the Tech Visa and Global Talent Visa,[22] as well as funding for cutting edge science institutions such as the Crick Institute,[23] Jenner Institute[24] and Graphene Institute.[25]

And while the UK is not a scientific exporter on the scale of Germany or Japan, policy has nevertheless at times prioritised international markets and influence. For example, the recent Integrated Review spoke explicitly of the UK's ambition to be a global services, digital and tech hub, as well as science as a source of soft power.[7] Similar rhetoric is discernible in announcements about net zero, where the UK has a perceived comparative advantage in some technologies, for example nuclear fusion and small modular reactors, where export opportunities are routinely cited.

As a result the UK has fallen between stools and failed to capture the gains from innovation

While the UK has simultaneously attempted each of the above strategies, they have all been incomplete. The result is a scientific power that is a "jack of all trades, but arguably a superpower of none".

For example, the idea that ministers have deployed an "academic foundations" approach – prioritising domestic investment in basic science – is fatally undermined by the repeated failure to match this model with the resources required. Despite R&D spending exceeding that of Japan in the early 1980s, the UK failed to keep up spending as the economy grew, falling to 1.5% of GDP in 1997 and continuing to hover around that value for about 15 years before resuming a slow upward trend since 2012. As early as 2004, Gordon Brown set a target for UK R&D spending to reach 2.5% by 2014.[26] By 2017, it had been reduced: to Theresa May's target of 2.4% of GDP by 2027 and 3% in the longer term.[27] While that ambition nominally remains, the current Government has already downgraded its R&D investment forecast from £22 billion by 2024/5 to 2026/27 in the 2021 Budget.[28] In the same period – since 2004 – countries such as Korea have almost doubled their share of R&D spending, reaching an impressive 4.8% of GDP in 2020. If UK R&D spending had kept up with average spending across the OECD, we would have spent an additional £212 billion on R&D over the last two decades. Given the multiplicative impact of R&D funding, this significant underinvestment in the past few decades goes a long way to explain the UK's sluggish growth and low productivity figures.

Meanwhile, there are some that would argue that the UK's ability to shape the international context of ideas has been undermined by the failure to maintain participation in EU regulatory and knowledge sharing bodies, from the EMA to Horizon, or replace membership with alternative international agreements. This is clearly contested – and there are signs that the UK is starting to embrace a different international apparatus through AUKUS and life science partnerships during the pandemic, although these are much more focused on exports than basic science.

Similarly, there is a strong argument that the UK's recent shift towards technology adoption and exports are both seriously hampered by political uncertainty and endemic policy churn. As both Diane Coyle and the Government's own Industrial Strategy Council have argued, the constant chopping and changing of policy runs counter to the need for coordination across government and to offer certainty to investors and entrepreneurs.[29] While the UK was busy announcing (but not implementing) four entirely different growth strategies between 2015 and 2021 (the 2015 Long Term Economic Plan; 2017 Industrial Strategy; 2021 Build Back Better: Our Plan for Growth; and 2021 Innovation Strategy), China has implemented one five year plan and started to deliver another.

This may be one reason why these repeated efforts to increase productivity have so far failed to boost the UK's sluggish rate of growth. As the Chancellor noted in his recent Mais Lecture, innovation broadly defined as multifactor productivity drove around half of the UK's productivity growth in the last half century. But the rate of increase has slowed since 2008, and to a greater degree than many of our competitors, with the difference explaining almost all our productivity gap with the USA.[30]

We are entering an era in which security is likely to shape science policy more than any time since the Cold War…

The original understanding of a superpower was focused on military and diplomatic might in order to secure national security. But, as recent crises have reminded us, other forms of national security such as health security and energy security matter too. This broader notion of security is rightly recognised by the Government's Integrated Review, which argues for the strategic deployment of scientific investment and expertise to meet these national threats.

These threats are clearly growing. The emergence of COVID-19 serves as a terrible reminder of the risks posed by zoonotic diseases and other health risks, such as antimicrobial resistance. The 2016 O'Neill Review on Antimicrobial Resistance estimated that by 2050, ten million lives a year and a cumulative 100 trillion US dollars of economic output are at risk due to the rise of drug resistant infections.[31] The invasion of Ukraine has reignited great power conflict, and exposed the unreliability of trade flows as a guarantor of global cooperation and peace.

Meanwhile the consequences of both the pandemic and the invasion on supply chains and energy prices has revealed the fragility of the UK economy to external shocks and the lack of domestic resilience in both energy security and strategic industries such as high value manufacturing. The UK currently imports 28% of its total primary energy from abroad, and relies on fossil fuels for 77% of its energy[32] – placing it behind 18 other countries in terms of energy security through domestic production, energy storage and diversity of supply.[33] In recent months, UK dependence on overseas supply chains in goods as diverse as carbon dioxide, electronic components and steel have ground domestic industries ranging from slaughterhouses and food production to aircraft manufacture to a halt.

… in the wake of a decade and a half in which our failure to exploit scientific innovation slowed national productivity

The importance of innovation for the UK's long term economic prosperity cannot be overstated. As Professor Richard Jones has remarked: "Not all innovation arises from formal research and development, but it is striking that the UK's decline in productivity growth follows a period in which the overall R&D intensity of the UK economy declined substantially, and that the UK's weak performance in productivity growth compared to international comparator countries is correlated with comparatively low R&D intensity."[34] In other words, the key to returning to higher growth lies in the R&D statistics.

Scientific discovery and application is the only proven way to drive long-term economic growth at a national level. Ever since the Nobel laureate Robert Solow showed that 90 per cent of the variation in economic output was not explained by available capital and labour, innovation has been known to be a key variable in nations' long-term productivity rates.[35] And as Solow's model has been built upon over time, including by Paul Romer's work[36] on technological endogeneity and Douglass North's work[37] on the role of institutions and trust as the lubricant of exchange, the conclusion that technological innovation is the ultimate source of growth has only become stronger.

In the United States, for example, research shows that most of the additional employment created between 1980 and 2005 came from firms less than five years old.[38] As Stanford's Enrico Moretti has shown, high tech firms are engines of job creation: for every innovation job created in a city, around five jobs in the wider local economy are created too. This multiplier effect drives up prosperity outside immediate knowledge rich industries and generates wider prosperity.[39]

Figure 1: UK Labour productivity since 1971

Source: Adapted from Jones, R., 2019. *Resurgence of the Regions*

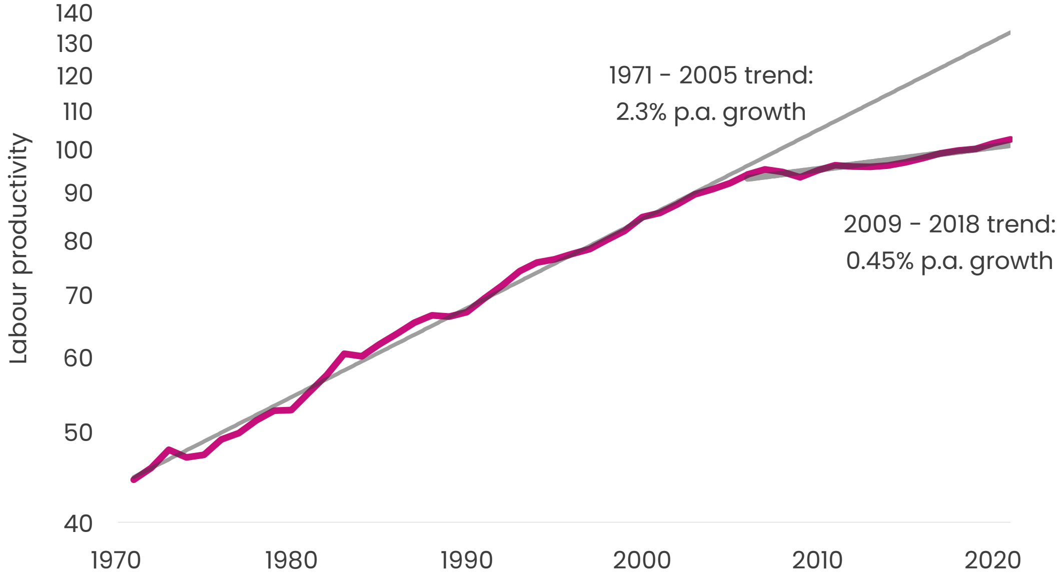
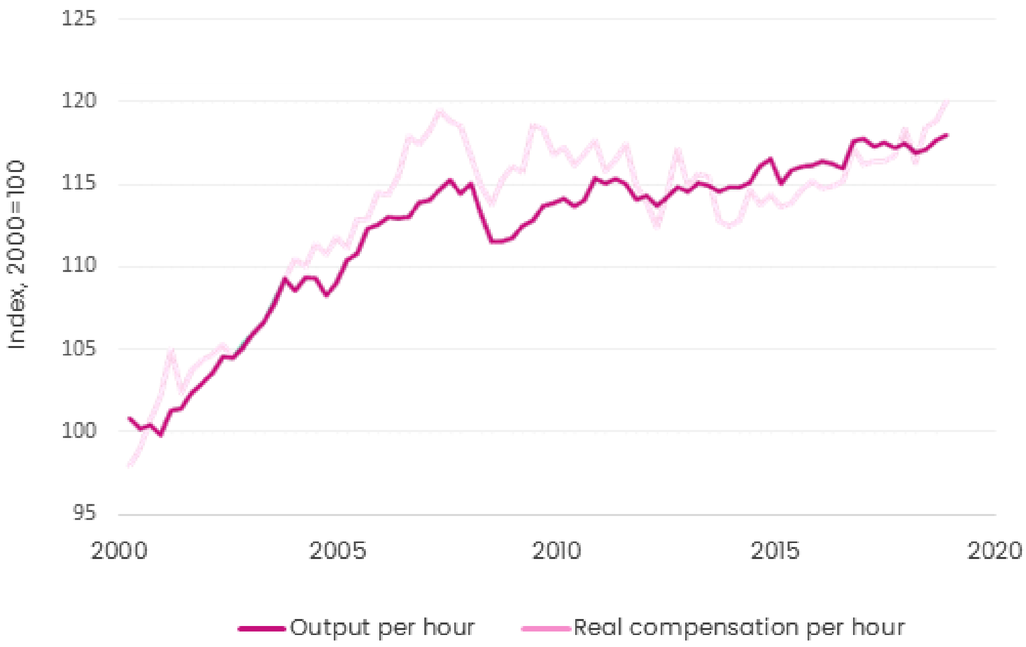


Figure 2: UK productivity and total labour compensation, 2000-2019

Source: Adapted from HMT, 2021. *Build Back Better*



In the UK, a recent government analysis showed that “both R&D investment and innovation significantly boost productivity growth”, with an increase of R&D investment yielding, on average, an economic return of 20 pence on the pound.[40]

This is not a new finding. As David Sainsbury, the former UK science minister, argues in his recent book *Windows of Opportunity*: “very few countries have ever developed by means other than innovation, learning and the growth of industrial production. The only exceptions to this rule have been unusual cases such as the Gulf states, where the natural-resource endowment has been so huge relative to the population that it is doubtful any policy lessons can be learned.”

For the UK, therefore, scientific innovation is a critical way to kickstart the economy from its post-2008 hangover. For several decades in the post-war period, UK productivity growth rose steadily by 2% a year. But following the 2008 financial crisis, this growth has fallen, with productivity almost flatlining. This has a direct impact on living standards given the close relationship with wages, with compensation per hour worked tracking labour productivity rates closely since 2000 (see Figure 2 above).

The conditions are ripe to supercharge the UK’s science ambitions

This is not the first time a Prime Minister has pledged to transform Britain’s scientific ambitions or output. Nearly sixty years ago, Harold Wilson warned that if Britain were to prosper, a "new Britain” would need to be forged in the "white heat" of a scientific revolution.[41] In 1988, Margaret Thatcher told the Royal Society that “a nation which does not value trained intelligence is doomed”.[42] Thirty years later, in 2018, Theresa May stood in the shadow of Jodrell Bank Observatory and proclaimed that Britain was “in pole position” to take advantage of “a new technological age”.[43]

But results have not always followed rhetoric. In the last sixty years, the UK’s scientific position has fallen rather than risen on several key metrics. So why should it be any different today? What conditions are in place today that did not exist in previous decades to give us confidence that the UK might realise the ambitions it has had since the Cold War? Why might the UK be able to become a “science superpower” now if it has been unable to before? There are four reasons to be optimistic:

- First, the pandemic has increased the salience of science, and particularly the social and economic value of research and development, in the public’s mind. The Chief Scientific Adviser and Chief Medical Officer appeared daily on national broadcasts; the Scientific Advisory Group for

Emergencies (SAGE) advised on regulations that affected every person and business in the UK; and UK scientists received national credit and gratitude for their development of the Oxford-AstraZeneca vaccine.

- Second, even before the pandemic, the Government had committed to a level of fiscal support for science that has evaded previous administrations. In 2019, the Chancellor announced an increase in funding for research and development up to £22 billion, almost doubling the Government's science spending by 2024 (this has since been pushed back to 2026/27). This included the establishment of new institutions, such as the Advanced Research & Invention Agency (ARIA) to fund high-risk, high-reward scientific research.[44]

- Third, the UK's departure from the European Union gives the UK both the flexibility and the "burning platform" to develop a more ambitious national plan at a time when the EU is embracing a more interventionist regulatory posture. As the Chancellor noted in his recent Mais Lecture, "outside the EU, we now have greater freedoms and flexibility than we've had in forty years. And we're going to use those freedoms to ensure our regulatory systems in technology, life sciences, financial services and beyond support innovation."

- Fourth, the UK has intellectual heritage and commercial assets that mean we are well-positioned to exploit some of the biggest scientific challenges of our time, including the global shift towards net zero carbon emissions by 2050; the growth of machine learning; the explosion of interest in bioengineering and synthetic biology to prevent disease and increase crop yields; and the rising importance of gene therapy and precision medicine.

The question is not whether the opportunity exists. It is how the UK can capitalise on it, to deliver a more R&D intensive, commercially innovative and scientifically influential economy today. The Government has rightly set the ambition. But how should it go about doing it? Where are the UK's strengths, and what weaknesses should we address if we want to assure our position as a science superpower? That is the subject of this paper.

The next chapter explores how the UK compares to a number of our competitors across the four dimensions set out above. The subsequent chapter then sets out some of the strategic choices facing the UK to secure superpower status and the steps that ministers should take now.

Chapter 2

How does the UK compare to our peers?

The previous chapter explored what it means to be a superpower, the characteristics of different kinds of science power, and the history of UK policy in that context. This chapter applies that framework in practice, examining the UK across a wide variety of metrics relating to both basic and applied science, and domestic and international focus, against a number of peer comparator countries.

The countries included for comparison have been chosen because they are leaders in net research spending (USA, China), research spending as a percentage of GDP (South Korea, Israel) or are similar to the UK in terms of GDP per capita (Germany, France, Canada, Japan).

The UK economy suffers from chronically low R&D intensity

The UK will always struggle to compete with the world's largest economies, particularly the USA and China, in terms of its absolute investment in science.[45] As Margaret Thatcher made clear in her speech to the Royal Society in 1988, most countries can never hope to make anything other than a small contribution to the overall quantum of the world's fundamental research.[42] For a country like the UK, the question is how much R&D is allocated relative to the size of the wider economy, how that spending is allocated, and the value generated from it for both scientific knowledge and the real economy.

Nevertheless, science investment is one of the clearest signals of a country's commitment to science and it would follow that a government pledging to become a science superpower should consider raising science spending, both in absolute terms and as a share of GDP.

Spending is low in relative as well as absolute terms, and falling further behind

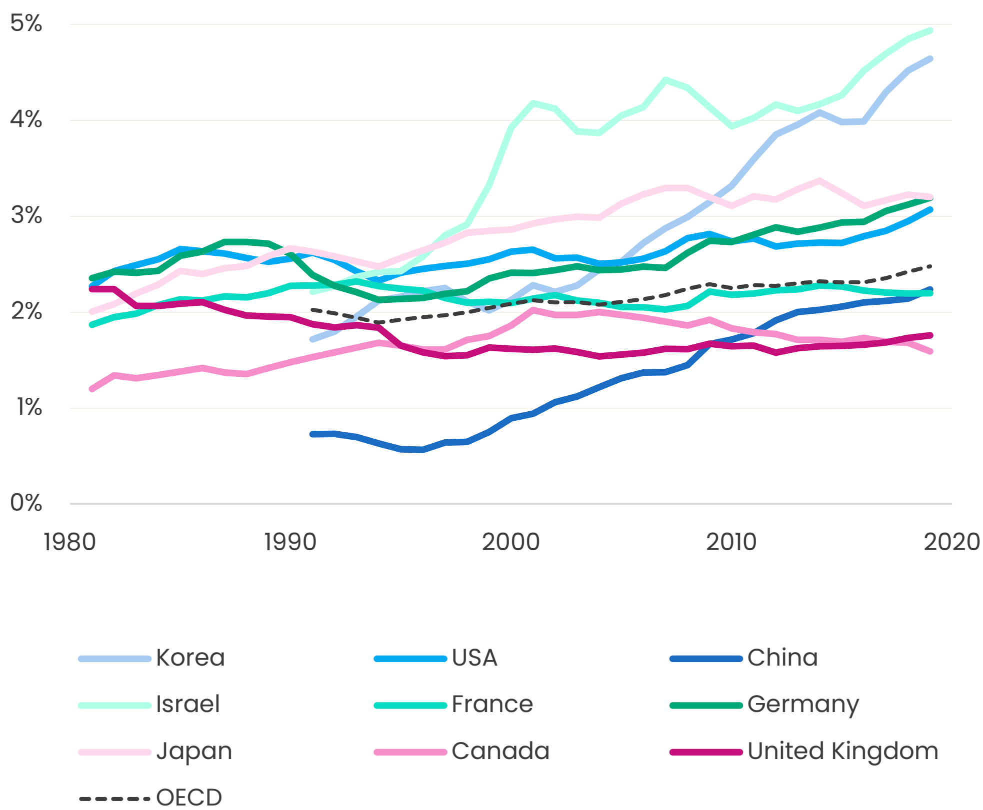
If we consider total expenditure on research and development – which captures spending from businesses (both foreign and domestic), governments, private non-profits and higher education institutions – the UK pales behind many of our competitors. In 2018, on purchasing power parity terms, the US spent over $587 billion on R&D. This compares to $465 billion in China and $173 billion in Japan. The UK spent just $51 billion in 2018, one eleventh of the raw capital investment in science in the USA.

But it is as a share of the economy that the UK's low research intensity becomes clear. As recently as the 1980s, the UK was one of the most-research intensive economies in the world, spending 2.24% of GDP on R&D in 1981. At the time, this placed the UK among the biggest investors in domestic science, with spending higher than Japan (2.00% of GDP) and only marginally lower than the US (2.27%).[46]

Yet in the decade that followed, UK R&D spending fell to 1.8% of GDP on R&D and has barely moved since.

Between 1991 and 2019, UK R&D spending marginally fell from 1.9% to 1.8% in 2019. During the same period, most of our competitors did the opposite, dramatically increasing investment. South Korea and Israel more than doubled R&D spending as a share of GDP, from 1.7% and 2.2% of GDP respectively in 1991 to 4.6% and 4.9% of GDP in 2019. Nor is this an artefact of year-on-year variation: as a share of GDP, the UK is the only country in the comparator group for this paper that spent less on R&D, on average, during the 2010s than it did during the 1990s. If UK R&D spending had kept up with average growth across the OECD between 1999 to 2019, we would have spent an additional £212 billion on R&D over the last two decades.

Figure 3: Total expenditure on R&D as a share of GDP, select countries
Source: Gross domestic spending on R&D, OECD



The UK's profile of R&D is markedly different from most of our competitors

As well as a lower quantum of spending, the UK has a different profile of R&D, both in terms of how R&D is funded and the setting in which R&D is performed. This in turn influences the type of research the UK invests in.

UK R&D is more reliant on government funding, and less reliant on business, than most of our competitors. More than £1 in every £4 of R&D in the UK (26%) is funded by government. This is higher than the United States (22%), China (21%), Japan (15%), and Israel (11%). Within our comparator group, only countries with higher tax-to-GDP ratios overall have a higher share of state-funded R&D: taxpayers in Germany (28%), France (32%) and Canada (32%) all spend more.

In turn, a lower proportion of R&D is funded by businesses. Just 55% of UK R&D is funded by businesses, compared to 64% in the United States, 79% in China and Japan, and 77% in Korea. Only Canada (43%) and Israel (37%) have a lower share of R&D supported by domestic business than the UK, although the latter may be skewed by the fact that most (52%) of Israel's R&D investment comes from foreign sources, which includes foreign businesses. Aside from Israel, the UK has a higher level of foreign funded R&D than any comparator country. Nearly £1 in every £7 (14%) of UK R&D is funded from overseas, more than twice the share in Germany (6%) or the United States (7%).

However, while the UK is more reliant on taxpayers for *funding* R&D than most other countries, it is much less reliant on national research institutes, such as government labs, for *performing* R&D, with research funding much more likely to be spent within universities than any other country within the peer group except Canada. Universities spend almost a quarter (24%) of total R&D expenditure, more than twice the level of university-led R&D in Japan (12%) and around three times as much as Korea (8%) and Israel (9%).

At the same time, UK businesses perform relatively little of the R&D that is funded. In the UK, less than £7 in every £10 of spending is by businesses, equal with Germany (69%) and marginally higher than France (66%). In Korea, Israel and Japan, at least £8 in every £10 of R&D funding is spent by businesses.

This feeds through into the type of research conducted in the UK compared to elsewhere – what might be termed the composition of the UK's "R&D portfolio".

Figure 4: Share of R&D expenditure by funder, 2018

Source: Gross domestic expenditure on R&D by sector of performance and source of funds, OECD

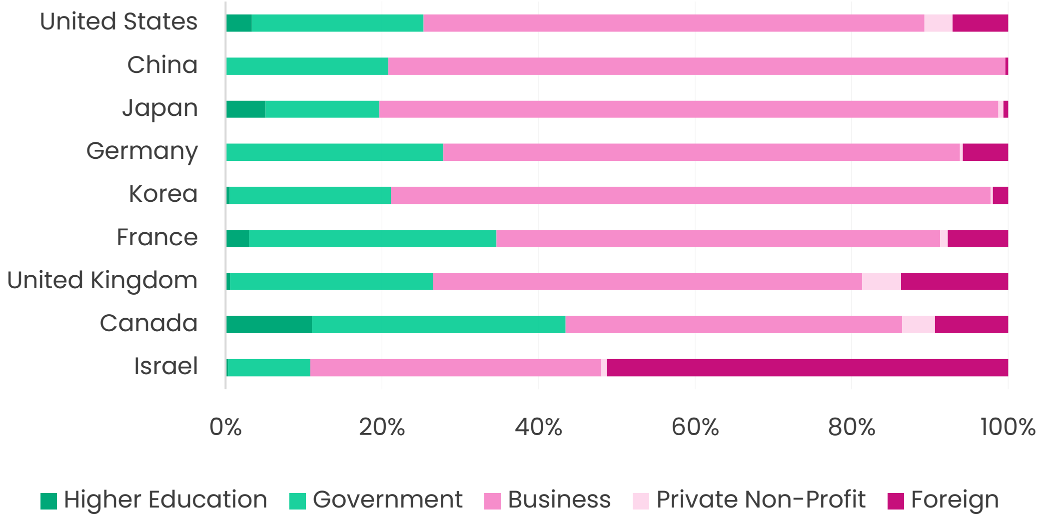
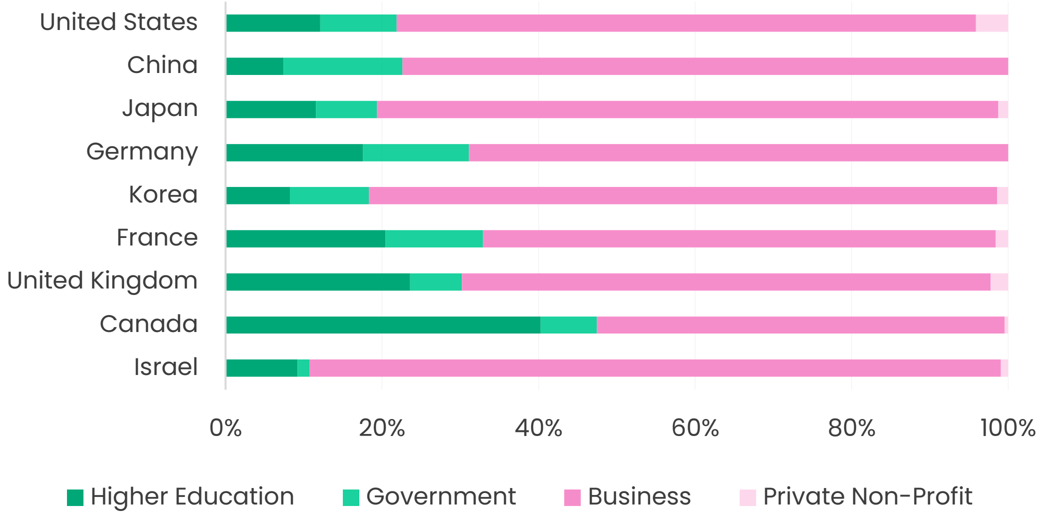


Figure 5: Share of R&D expenditure by sector performing research, 2018

Source: Gross domestic expenditure on R&D by sector of performance and source of funds, OECD



Overall, the UK's balance of research skews towards basic research under the OECD Frascati definitions. In 2019, 18% of UK R&D was defined as basic research, second only to France within the peer group (23%). This is nearly twice the level of Israel (10%). Meanwhile, only 38.5% of UK research is defined as experimental development, compared to nearly 80%, for example, in Israel.

Breaking this down by sector, we can see that a greater share of university R&D goes towards applied research than in other jurisdictions, with more than half (52%) of university research defined as applied research, compared to between 25% and 49% in the remainder of the peer group. This is consistent with the fact that the UK is an outlier in terms of how much state supported R&D is done in universities as opposed to free-standing government research institutes.

Business and Government R&D in the UK also tends to be more applied in nature. On both counts, only Germany and France conduct a higher share of applied science by businesses and government than the UK, with the UK dedicating a far greater share to this category than Korea, Israel and Japan. These countries, by contrast, spend far more on experimental development within business and government-led R&D, where the UK under-invests compared to its peers.

This is partly a function of who performs the research. Nations with higher levels of business- or government-led research tend to have higher levels of experimental development performed by businesses, with Israel (87%), the United States (78%) and Japan (76%) focusing most on this type of research. Meanwhile, systems with a greater reliance on government funding – the UK, France and Germany, in particular – tend to have the greatest emphasis on applied science.

Figure 6: Total expenditure on R&D broken down by type of research, 2019
Source: R&D expenditure by sector of performance and type of R&D, OECD

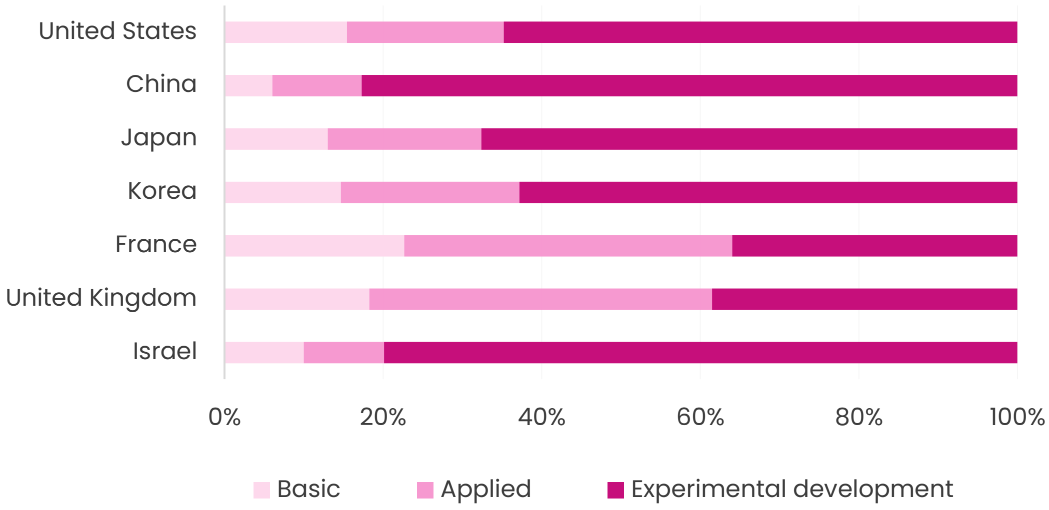


Figure 7: R&D performed by business by type, 2019
Source: R&D expenditure by sector of performance and type of R&D, OECD

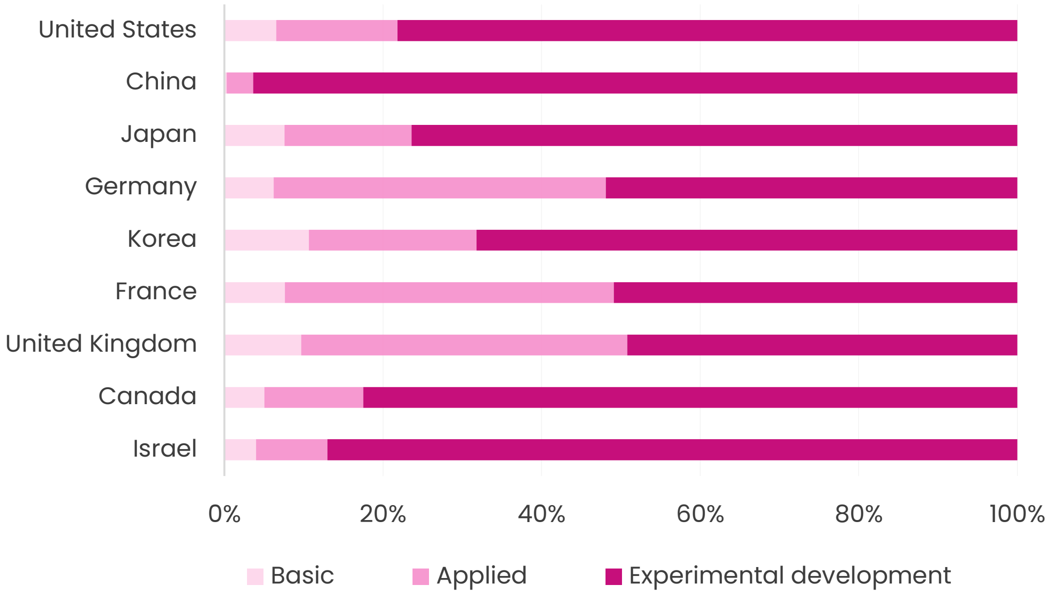


Figure 8: R&D performed by government by type, 2019

Source: R&D expenditure by sector of performance and type of R&D, OECD

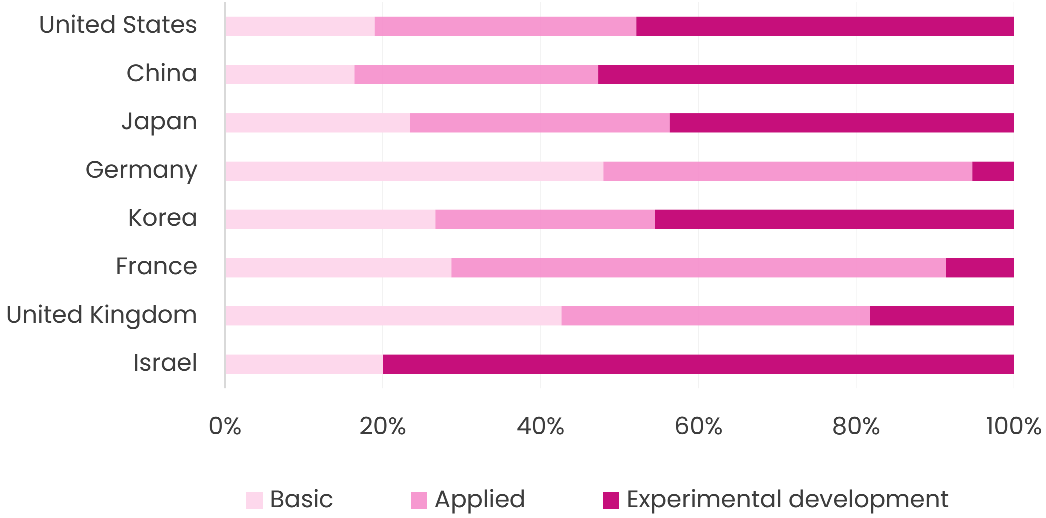
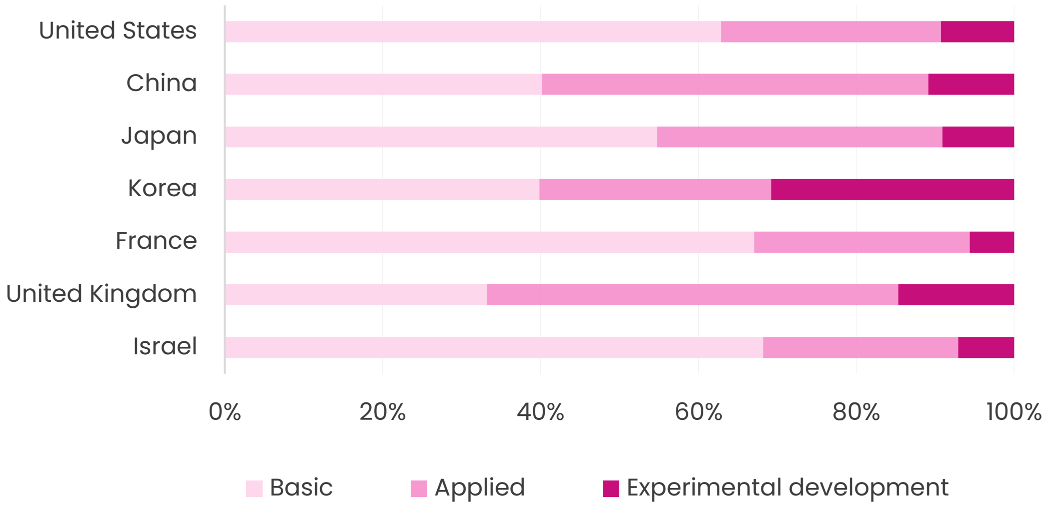


Figure 9: R&D performed by higher education by type, 2019

Source: R&D expenditure by sector of performance and type of R&D, OECD



The UK's "academic foundations" mean we are world-leading in citations and publications

The quantum and composition of funding, however, are inputs. As argued earlier, the UK will never be able to compete in terms of the overall levels of funding for R&D but with the right funding *mix* and R&D *strategy*, there is no reason why the UK cannot punch above its weight. So, to what extent does the UK's approach currently deliver outsized returns? Do the UK's academic foundations make it a "science superpower"?

The UK is highly effective on at least one measure of research effectiveness: citations. This is a direct result of the incentives built into the science system, in which citations are one of the key metrics by which academics are valued and by which funding applications are evaluated. It is one of the most important drivers of behaviour within the UK science system – and it shows.

Looking at the number of highly-cited publications (those that are in the most-cited 1% of global publications) as a proxy for scientific influence, the UK has maintained a steady share of highly-cited publications since 2000, with the UK's share rising from 12.3% in 2000 to 13.6% in 2018. Over the same period, the USA's share of highly-cited publications fell by a third, from 54.1% to 36.6%, while China's share rose more than fifteen-fold, from 1.2% to 19.6%, overtaking the UK in 2017 for the first time.

Figure 10: Highly-cited publications (top 1%) by location of institution that the researcher was affiliated to, as a share of world's highly-cited papers
Source: International comparison of the UK research base, BEIS

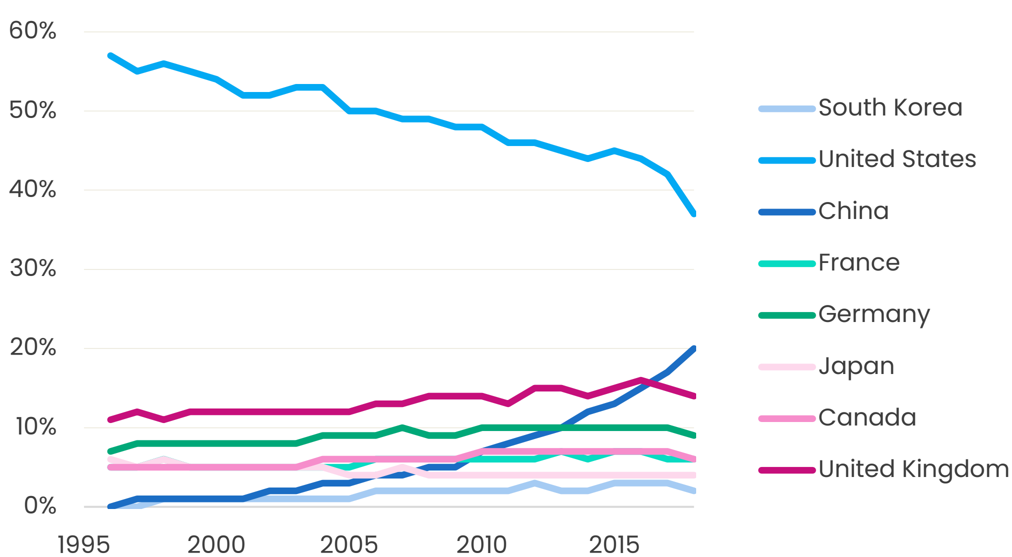


Figure 11: Highly-cited publications as a share of domestic publications
Source: International comparison of the UK research base, BEIS

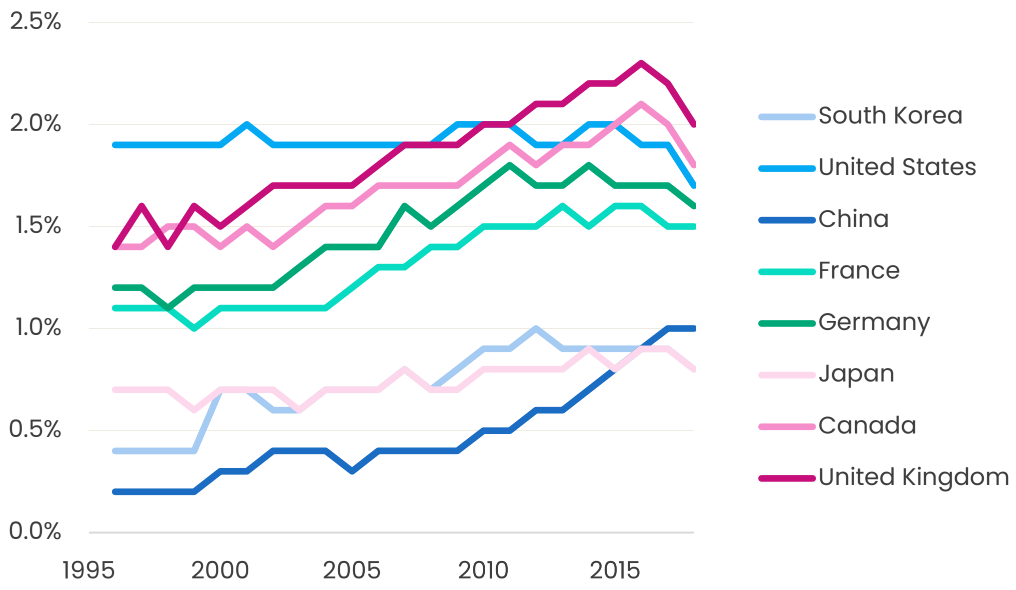
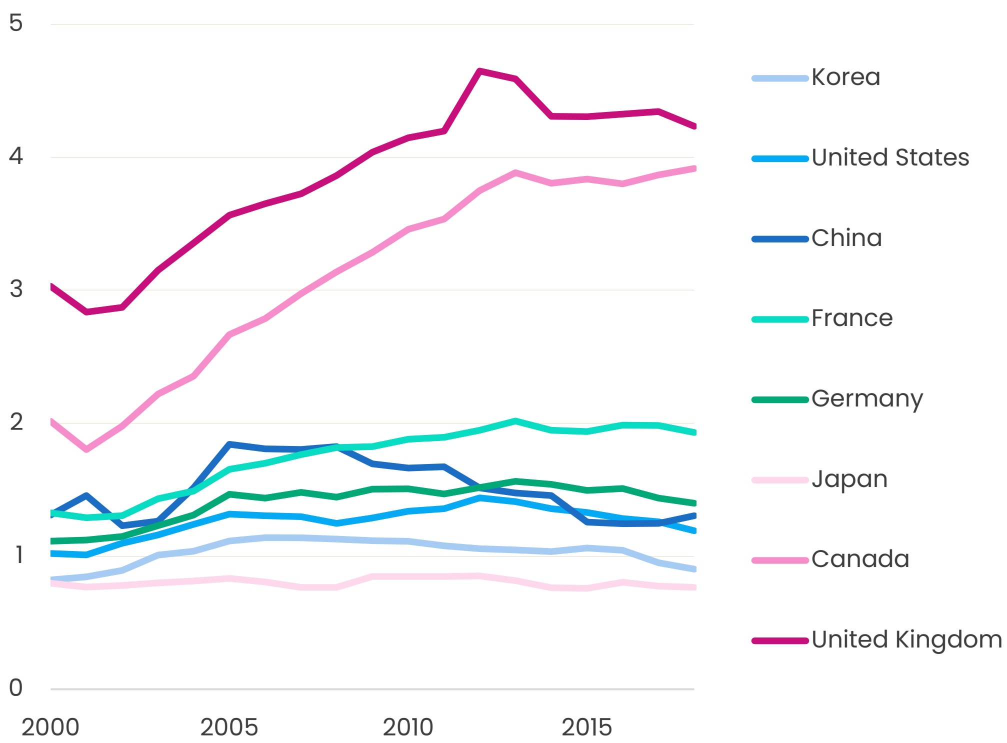


Figure 12: Number of publications per 1 million USD invested in R&D
Source: International comparison of the UK research base, BEIS



Moreover, as a share of total publications, UK papers are more likely to be highly cited than any of our peer group (see Figure 11). One in every fifty (2%) UK papers is within the top 1% of cited publications, higher than Canada (1.8%), the United States (1.7%) and double the share of China (1%). This has grown over time, from 1.5% of papers being highly-cited in 2000, allowing the UK to overtake the United States on this measure in 2012.

This is also true when publications are weighted against the national R&D spend. The UK generates more than four publications per million purchasing power parity (PPP) dollars of spending, rivalled only by Canada and more than twice the ratio of the US and China. In essence, the UK may not spend as much but the money it does direct towards research is used highly *efficiently* to generate influential discoveries, as measured by highly-cited academic publications. Given that the UK also leads the world when it comes to highly-cited publications as a share of total publications, it is clear that this is not a result of quantity over quality.

Table 1: UK H-index rank in each field of STEM from 1996-2020
Source: SCOPUS Data, Scimago Journal & Country Rank

Subject	UK global ranking	Subject	UK global ranking
Overall	2	Materials Science	4
Chemical Engineering	4	Medicine	2
Chemistry	4	Neuroscience	2
Computer Science	2	Pharmacology	2
Dentistry	2	Physics	3
Earth Science	2	Psychology	2
Energy	3	Social Science	2
Environmental Science	2	Veterinary	2
Immunology	2	Multidisciplinary	2

This influence persists across disciplines. Looking at the UK's global H-index* ranking for different disciplines, we can see that the UK is a leader across the board, ranking in the top four countries in terms of H-index in every field between 1996-2020. The US is ranked first in every one of the fields, and the UK ranks second in the majority of fields. In the fields where the UK is third or fourth, only China or Germany rank higher.

* The H-index score is a standard scholarly metric in which the number of published papers, and the number of times publications are cited, are balanced. It is therefore a measure of both quality and quantity of research.

The fields where the UK is comparatively weaker are chemical engineering, chemistry, materials science, energy and physics. If policymakers were hoping to double down on specific research strengths, the H-index would suggest computer science, environmental science, pharmacology, psychology, medicine, multidisciplinary research, neuroscience, social science and veterinary science. In each of these fields the UK has an H-index at least 10% higher than the third ranked country.

These academic foundations are enhanced by deep "knowledge networks"

One reason UK research is highly cited is the deep scientific networks that exist between researchers and institutions here and elsewhere in the world. This is partly a function of history: London hosts the one of the world's oldest scientific institutions, the Royal Society, and is the birthplace of *Philosophical Transactions*, the first peer-reviewed scholarly journal. But it is also a function of an increasing culture of collaboration across boundaries in recent decades.

The UK has consistently generated a higher proportion of publications as a result of international co-authorship in the last few decades than most of our competitors, and has been increasing levels of collaboration faster than other countries (see Figure 13). In 1998, just 26% of UK papers were a result of international collaboration. By 2018, this had risen to 55%, second only to France and considerably above the OECD average.[47]

While the US remains the largest single source of co-authorship, collaboration with European countries considerably increased during the UK's membership of the EU. In 1981, 43% of the UK's international output comprised UK-Europe collaborative papers; in 2012 it was 60%.[48] Today, the UK is ranked in the top five science collaborator countries in every single EU state.[49] This is one reason why the UK's putative associated membership of Horizon, the EU's research & innovation framework, on which the EU Commission has not yet made a decision, is such a contested issue.

Figure 13: Share of publications that resulted from international collaboration

Source: International Comparison of the UK Research Base, BEIS

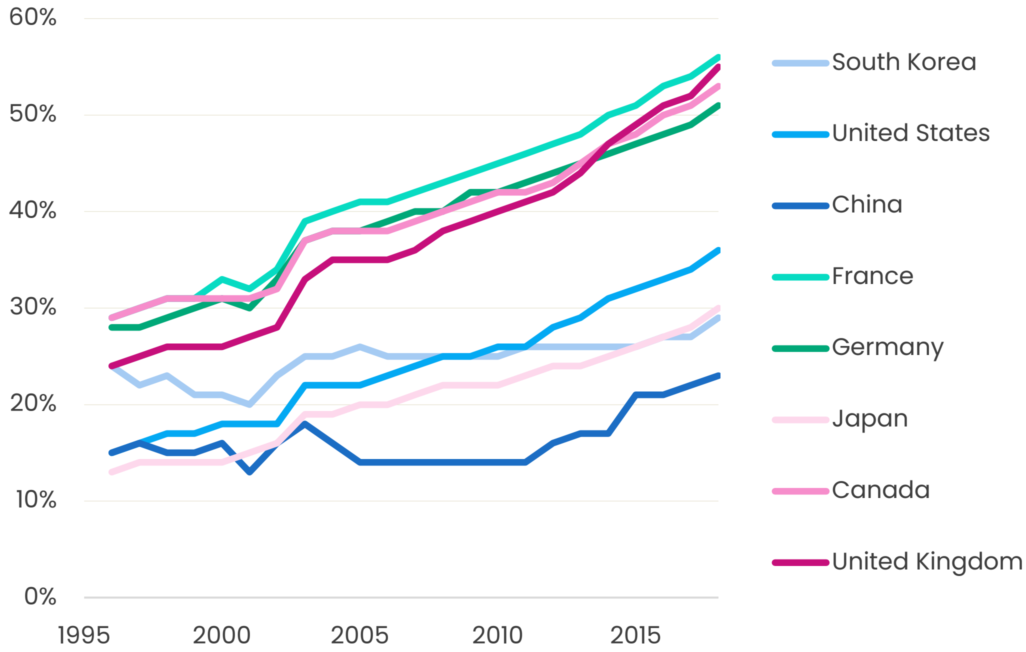
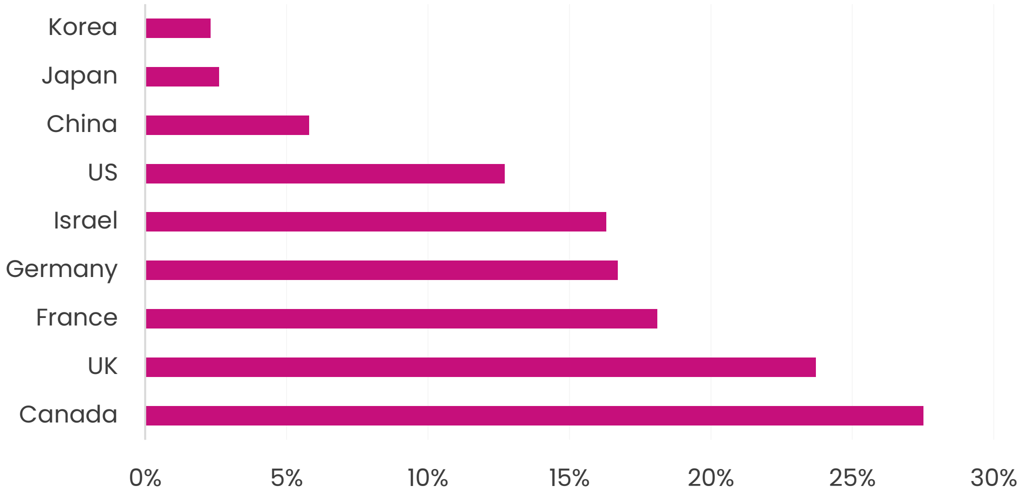


Figure 14: Percentage share of patents invented domestically that have at least one foreign co-inventor

Source: Indicators of international cooperation, OECD, 2019



These international networks extend from publications to patent filings. According to the OECD, the UK has the second highest proportion of patents with at least one foreign co-inventor, with 23.7% of patents co-invented with a researcher overseas. This comes second only to Canada which cooperates on 27.5% of its patents, and exceeds the international collaboration levels of France (18.1%), Germany (16.7%), and Israel (16.3%). By contrast, just 2.3% of patents filed in South Korea are invented with an overseas co-inventor.

This is supported by the UK's large proportion of highly qualified academic researchers, many of whom are from overseas themselves. As Figure 15 below shows, the number of students graduating in 2019 at the doctoral and masters levels in fields relevant to science and technology* were higher than in any of our comparator countries. Research training is usually delivered at the postgraduate level, which is why bachelor's degrees and their equivalent were not represented, although the UK also leads by this measure.

At the doctoral level, more students were awarded a PhD in the UK than in any other country, as a proportion of each country's population (Figure 15). In 2019, the UK produced 294 doctoral graduates in STEM subjects for every million people, closely followed by 263 graduates per million in Germany, 182 in Korea, and 120 in the USA (OECD). With regard to disciplines, the UK leads on the proportion of doctoral graduates in ICT technology, natural sciences, mathematics and statistics, but it produces relatively fewer graduates in the disciplines of health and welfare, agriculture, and engineering in relation to other countries, coming second to Germany, Japan and South Korea respectively. And at masters level, the UK produced the second highest proportion of graduates, with 1370 STEM students graduating in 2019 per million of the total population, after France, which produced 2002 masters graduates for every million of its population.

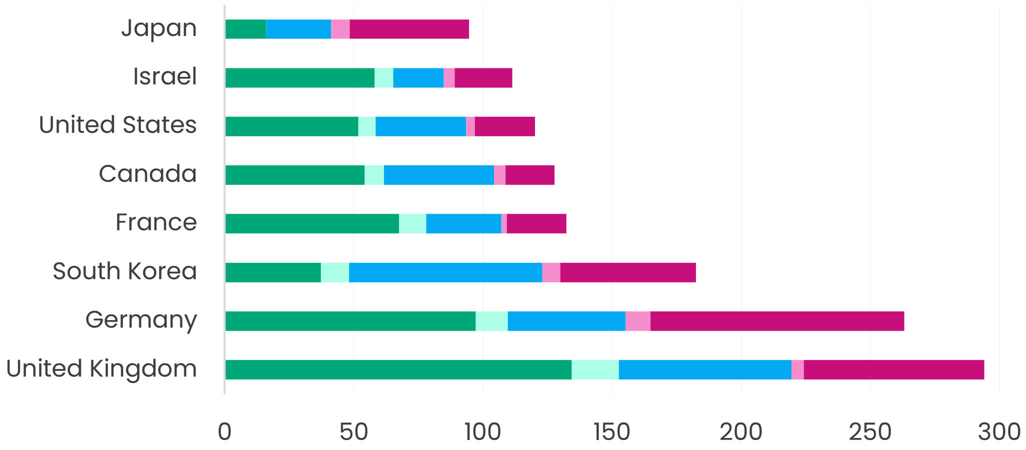
Compared to other countries, a disproportionate number of doctoral students in the UK come from overseas, reflecting UK higher education's business model of training researchers from around the world as an export industry that cross-subsidises domestic enrolment. In 2019, international students accounted for 41% of the UK's doctoral enrolment, ahead of our peer countries[50]. France and Canada had the next highest portions of international doctoral students, at 38% and 34% respectively. By contrast, Germany had a share of 12% and Korea 14% doctoral students who were international. However, most non-EU foreign students leave the UK after their studies – for example among non-EU migrants issued a study visa in 2015 only 15% had permission to stay in the UK at the end of 2020.[51]

* The subject areas included in the statistics are health and welfare; agriculture, forestry, fisheries and veterinary; engineering, manufacturing and construction; information and communication technologies; natural science, mathematics and statistics.

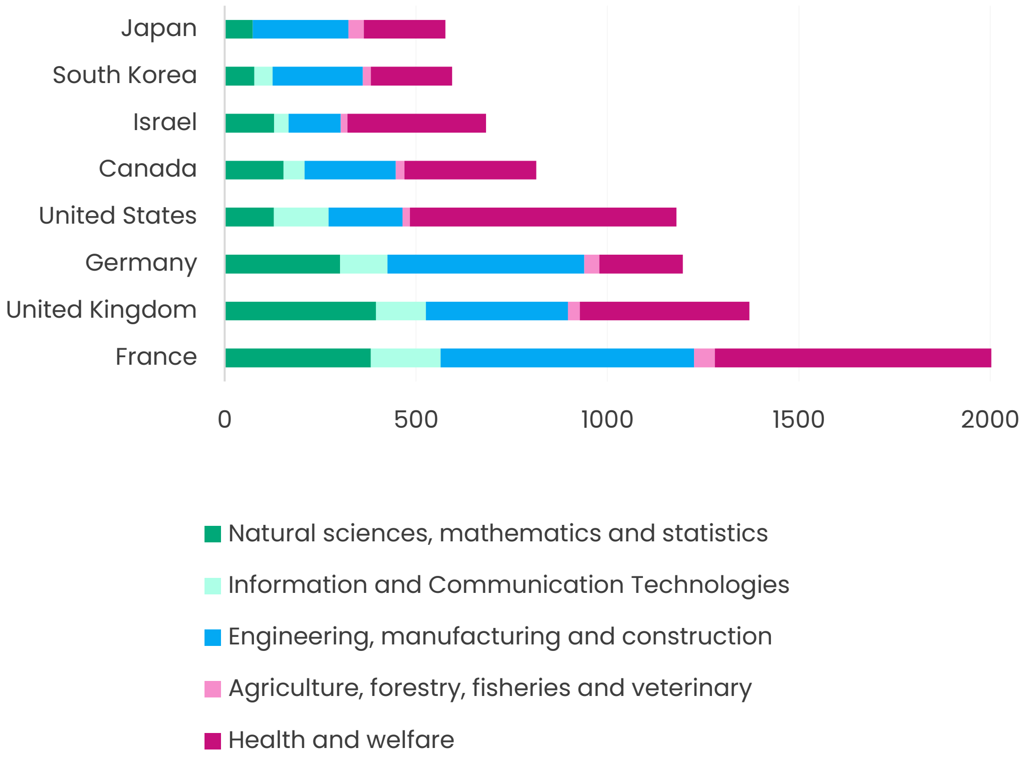
Figure 15: Number of STEM students graduating at the masters and doctoral level in 2019, per million of the population, by country and area of study

Sources: Graduates by field; Population, OECD. Onward analysis

Doctoral graduates



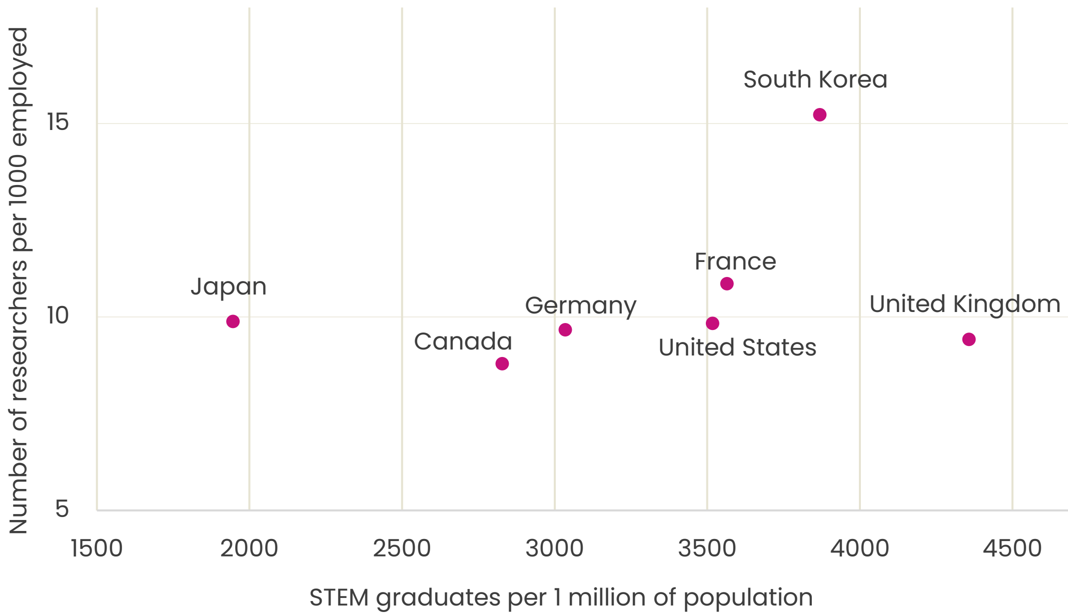
Master's graduates



This model therefore means that the UK leads our competitors in teaching STEM students at university but trails them in the number of researchers that are actually in the workforce. Only Canada has fewer researchers per share of the labour force among our comparator countries.

Figure 16: Number of STEM students graduating in 2019 vs the proportion of the workforce that are researchers

Sources: Researchers; Graduates by field, OECD. Onward analysis



But despite strong foundations and networks, the UK lacks "absorptive capacity"

So the UK performs world-leading basic science and holds deep international networks to disseminate knowledge. But, as discussed in the previous chapter, the UK's ability to act as a "science superpower" hinges on our ability to leverage that research into national gain, either by absorbing those ideas within the real economy or exploiting them through hard or soft power overseas. If we cannot, the UK risks being merely a "laboratory assistant to the world", capable of genius but incapable of reaping the rewards.

An economy's readiness to assimilate new scientific knowledge and technology depends on a number of factors, including having a highly skilled workforce, basic technical infrastructure, technology awareness in the consumer population, and the transfer of knowledge between universities and businesses to create marketable products. Across many of these measures, the UK scores relatively highly. But as explored below, we often fail to exploit these inherent advantages.

UK universities are geared towards citations rather than innovation

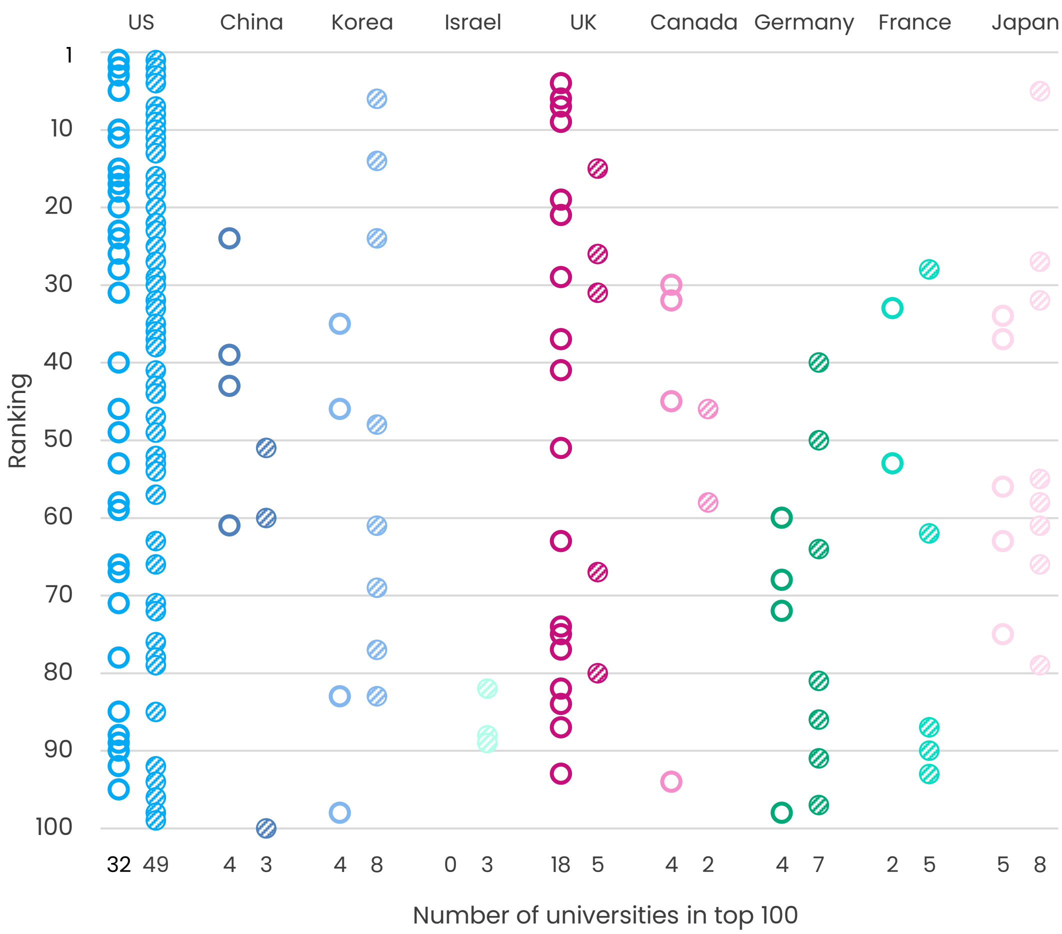
UK universities are frequently referred to as "world-leading", and in many respects they are. The UK has 17 universities in the global top 100 of this year's QS World University Rankings (2022), which combines metrics related to academic and employer reputation, research impact, and international collaboration. These include four universities in the top ten, including Oxford (2), Cambridge (3=), Imperial (7) and UCL (9). This is further evidence of the UK's strong "academic foundations" and represents a pool of institutional capital from which the UK's scientific power could be drawn.

But at the moment this institutional capital is not being leveraged for economic benefit. When measured by innovation, UK universities fare poorly. Just five UK universities are listed in the Reuters rankings of the 100 World's Most Innovative Universities (2017), which examines patent filings, patent grant rates, and patent citations by institution. These include Imperial (10), Cambridge (18), UCL (31), Oxford (32), Manchester (49) and King's College London (99). Both Korea and Germany have more of the world's most innovative universities than the UK, at eight and seven universities in the top 100 respectively. The USA leads in both types of rankings, with 49 universities in the 100 most innovative universities and 32 universities in the top 100 in the QS rankings.

Figure 17: Comparison of UK universities in research and innovation rankings

Sources: QS World University Rankings, 2017; Reuters Top 100: The World's Most Innovative Universities, 2017. Onward analysis

Key: Transparent dots = QS rankings; Filled dots = Reuters innovation rankings

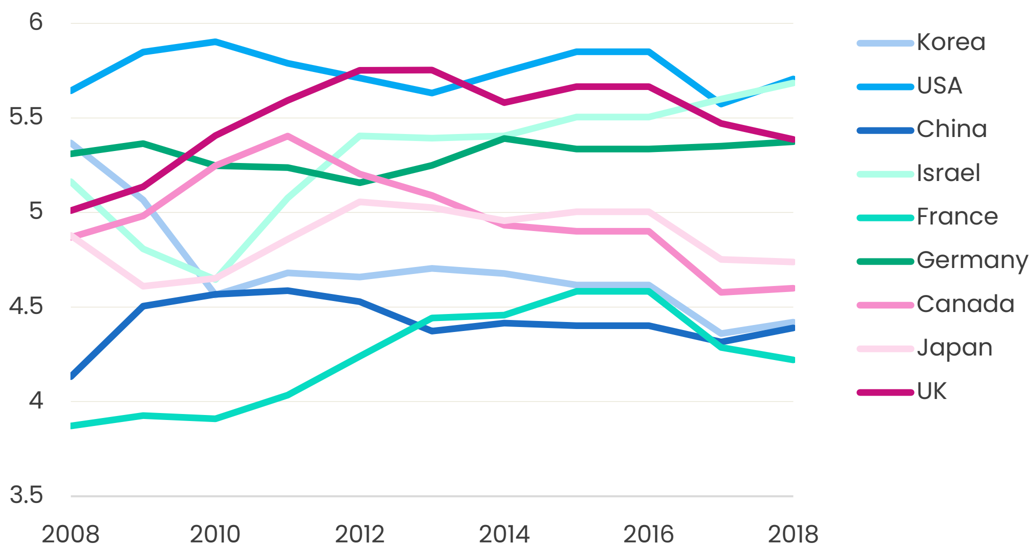


The UK has the greatest imbalance between the number of institutions that rank highly on research versus those that rank highly on innovation. Innovation-intensive universities in the UK account for less than a quarter (22%) of our total places in the top 100s, with the remaining majority occupied by institutions that rank highly on research and teaching rather than innovation. As a comparison, the US has over half (60%) of its top ranked places occupied by innovation-intensive universities.

The UK's weakness on innovative universities seems surprising in view of the relatively high levels of perceived collaboration between businesses and universities. The Executive Opinion Survey[52] developed by the World Economic Forum (WEF) surveys nationally representative samples of companies (in terms of size, industry and region) with the following question: “In your country, to what extent do business and universities collaborate on research and development (R&D)?", where 1 is “do not collaborate at all” and 7 is “collaborate extensively”.

As Figure 18 shows, between 2010 and 2016 the UK ranked in the top two of our comparator group alongside the US, although both were recently overtaken by Israel. Germany follows closely behind. Although the data reflect the views of only around 83 respondents per country, this nevertheless suggests that UK universities enjoy a relatively strong reputation among business leaders.

Figure 18: Perceived strength of university-industry collaboration in R&D
Source: Executive Opinion Survey, World Economic Forum, 2020
Key: 1 = not at all; 7 = to a great extent



Partly as a result, the UK underperforms on measures of applied innovation, such as patents

While the UK excels on academic measures, it fares much worse against measures of applied innovation, or the translation of innovations “from laboratories and scientific publications into novel inventions and commercial products”.[53] According to the best measure of globally significant inventions, “triadic patents” – those filed in the European Patent Office, the United States Patent and Trademark Office and the Japan Patent Office for the same invention – the UK files fewer patents as a share of GDP than most of our competitors, and has seen the ratio of patents to R&D spend decline consistently for the last two decades.[54]

As shown in Figure 19 below, the country that fares best on this measure is Japan, which has consistently filed the highest level of triadic patents as a share of GDP since the early 1990s and maintained a high level of inventiveness since. While all other countries within the comparator group have seen triadic patent rates decline aside from China, other countries with high proportional rates of patenting include South Korea, Israel and Germany. The UK has been in the bottom three countries, alongside Canada and China, for the past 20 years with a gradually declining trend of globally significant patents as a share of GDP.

One explanation for this is the UK's low overall (and particularly business) R&D spend as a share of GDP. If we spend less than other countries as a share of national income, is it any wonder we generate fewer patents as a share of national income? If this were true, it would support simply spending more on R&D to boost inventiveness. But that is not the whole story. The UK not only generates fewer patents than other countries relative to income, it does so relative to R&D spend as well.

As shown in Figure 20 below, the UK generated the third highest rate of patents relative to R&D spending in 2000, at 67 triadic patents per $1 billion of investment, behind only Japan (137 per $1 billion) and Germany (97 per $1 billion). However, in the last two decades, the UK's innovation returns have declined faster than other countries, meaning the UK not only generates around a third of the number of patents (25 per $1 billion), it also now falls behind Israel and South Korea as well as Germany and Japan.

The UK's relative weakness in patent measures is not surprising given the UK's stronger reliance on universities to perform a higher share of government-funded R&D and relative shortfall in business-led R&D, which will tend more towards patents and commercial application. But it is instructive. It shows that the UK's science output is in large part a function of the incentives and institutions that policymakers put in place. Reforms could help move the UK towards a science model based less on basic research and more around commercialisation and application.

High levels of postgraduate training do not translate into a strong technical workforce

The UK's failure to leverage its institutional capital is matched by its failure to exploit its human capital reserves. As discussed earlier, the UK trains among the most postgraduate researchers per capita. This should be an enormous comparative advantage, providing a stream of technical researchers to support innovation within the real economy.

Figure 19: Number of triadic patents per 1 billion GDP, by inventor's country of residence

Sources: Patents by technology; Gross Domestic Product, OECD.

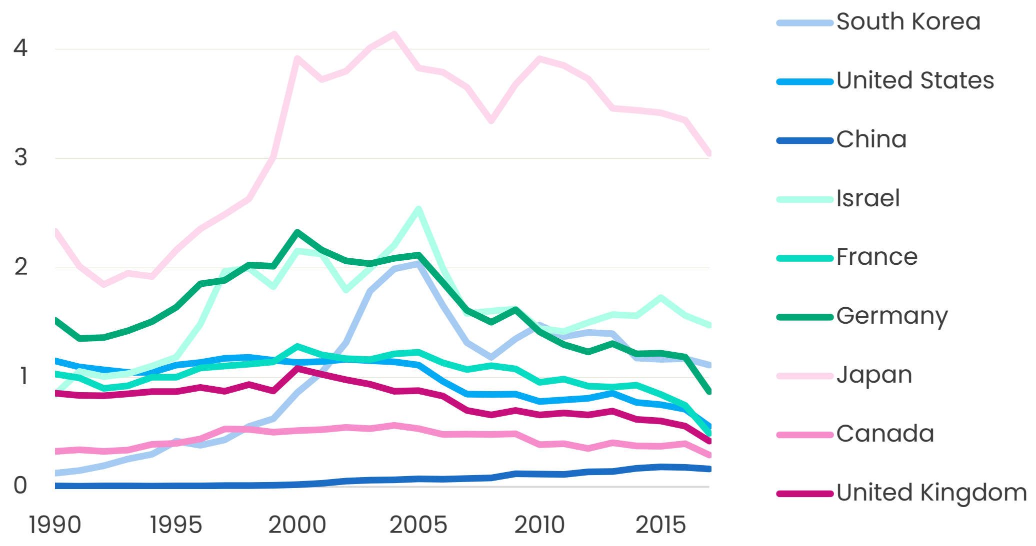


Figure 20: Number of triadic patents per 1 billion USD spent on R&D

Sources: Patents by technology; Gross domestic expenditure on R&D, OECD

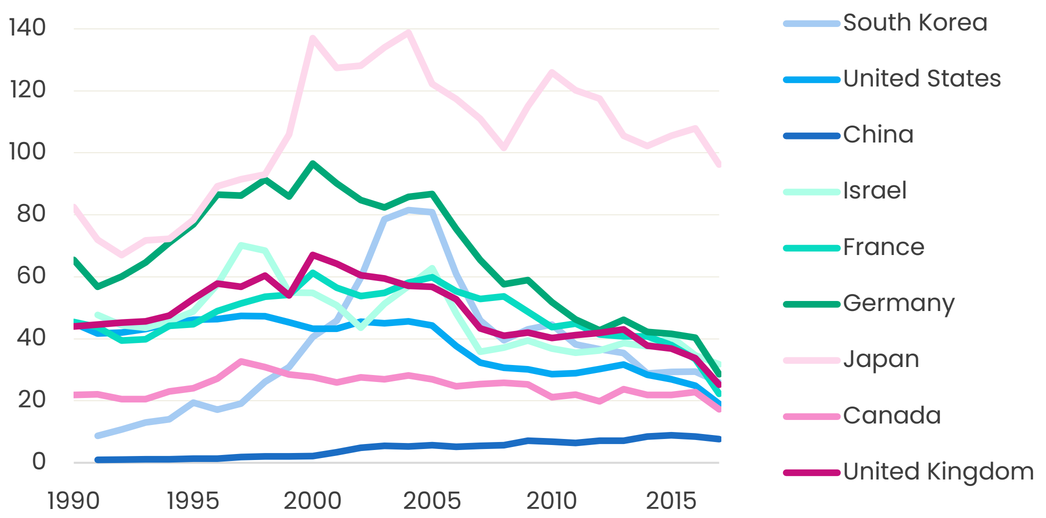


Figure 21: Number of researchers per 1000 employed

Source: Researchers, OECD

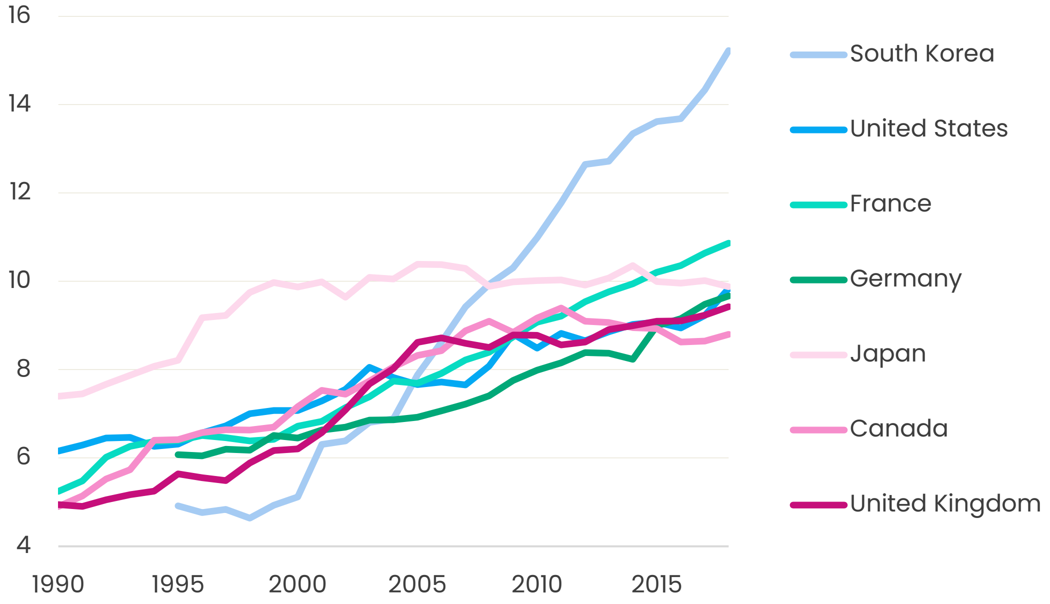
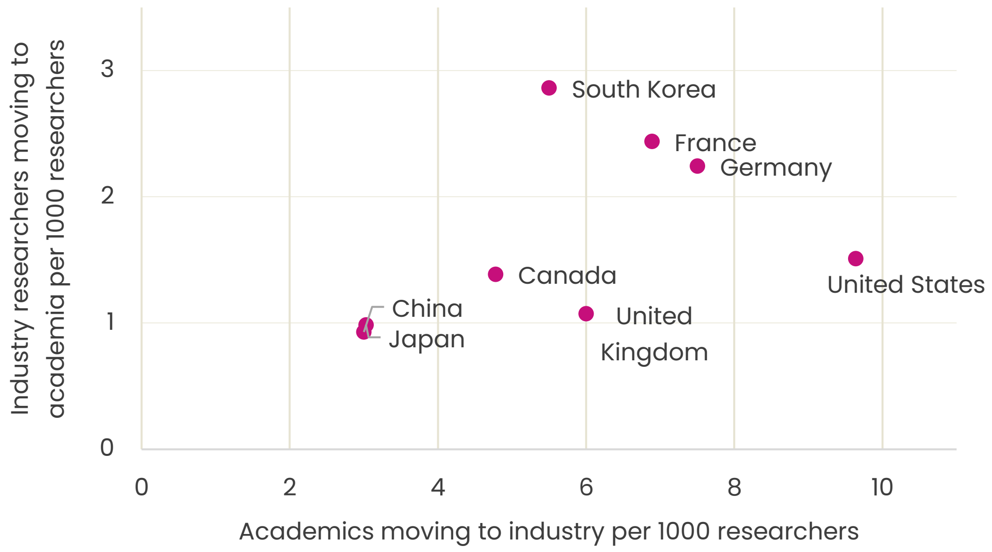


Figure 22: Movement of researchers between industry and academia

Source: Adapted from "Talent Swap" figure, Nature Index, 2017-19



But the UK also, paradoxically, has among the fewest researchers within the labour force of any of the nations in our comparator group (see Figure 21). Just over 0.9% of the UK labour force is defined as a researcher, compared to 1.5% in Korea and lower than Japan, Germany, France, and the USA. Only Canada has a lower proportion of researchers relative to the wider labour market.

More importantly, the UK's share of researchers within the labour force is growing at a slower rate than our competitors, with the exception of Japan. In the period since 1990, the share of researchers within the labour force more than tripled in Korea, mirroring the rapid increase in R&D spending. Over the same period, with proportional UK R&D spending largely flat, the UK's share of researchers has approximately doubled, but this still lags behind our peers. Japan has maintained a consistently higher proportion of researchers, reflecting its relatively high levels of R&D spend over the period, but has recently been overtaken by France and Germany.

The UK also suffers from perennial skill shortages in STEM subjects. The Department for Business, Energy and Industrial Strategy has highlighted the 'particular skills shortages in sectors that depend on STEM subjects.' According to a recent Government survey, there were around 200,000 roles requiring hard data skills but 46% of businesses had struggled to recruit for these roles over a two-year time frame.[55]

One possible explanation is the high share of graduate researchers leaving the country after their studies, as mentioned earlier. Another is that qualified researchers choose not to use their skills within scientific disciplines, limiting the spillovers from their training, and instead opt for more lucrative careers. In 2018/19, around 42% of maths graduates and 18% of physical and geographical sciences graduates were employed in business, HR or finance six months after graduating. Meanwhile, around 16% of chemistry and 21% of physics graduates were working in business, HR and finance, compared to around 17% and 6% of graduates from those subjects respectively working in science.[56]

Another reason may be the relatively weak mobility between business and academia in the UK. Between 2017-19, just one industry researcher in every 1,000 moved into academia in the UK and six academics moved the other way. This compares to nearly three industry researchers joining academic institutions in Korea and nearly ten academics joining businesses in the United States, as shown in Figure 22 above. This is likely to be a direct result of the value that UK universities place on publications and citations, which makes it difficult for industry researchers to re-enter academia after having spent time away and places a lower premium on industry experience and innovation metrics such as patents.

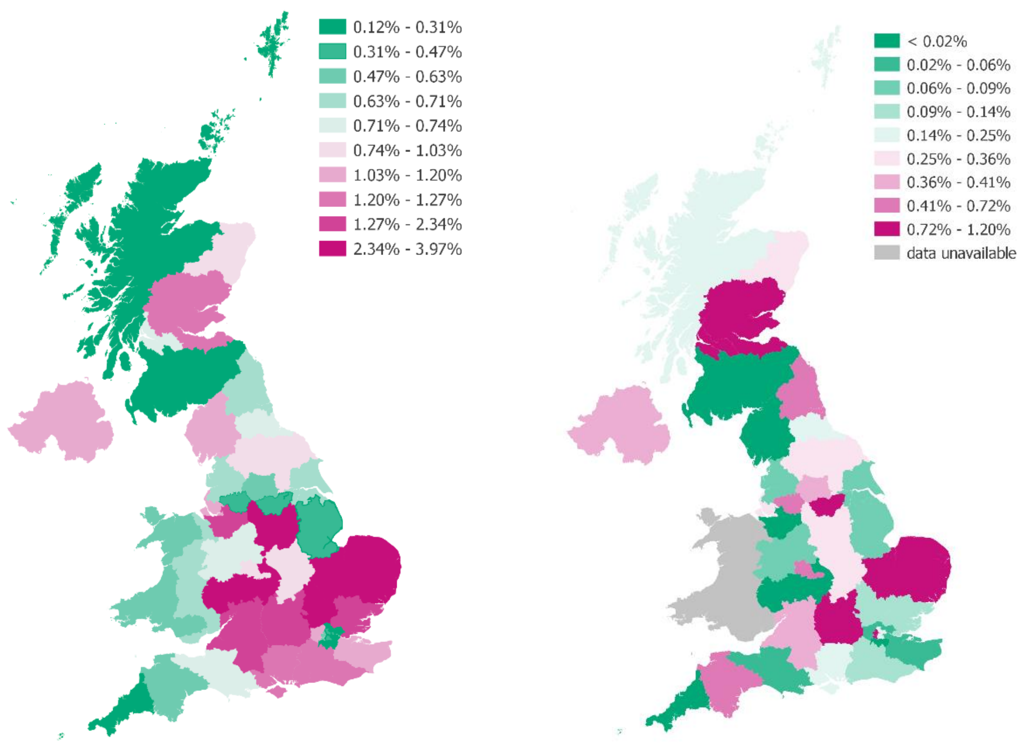
Absorptive capacity, and R&D activity, varies significantly between regions of the UK

On average UK businesses contribute less to national R&D expenditure than businesses in peer countries. But the UK has significant geographic imbalances in this regard, with regions such as East Anglia, and Herefordshire, Worcestershire and Warwickshire benefiting from higher business investment in R&D.[57]

This is broadly mirrored by the investment into R&D performed by universities, suggesting research intensity in both sectors is linked. This imbalance of R&D funding allocation highlights an opportunity for R&D investment to contribute to the levelling-up agenda, directing additional funds to places other than the south-east of England.

Figure 23: Business R&D (left) and Higher Education R&D (right) as a percentage of GDP, 2018.

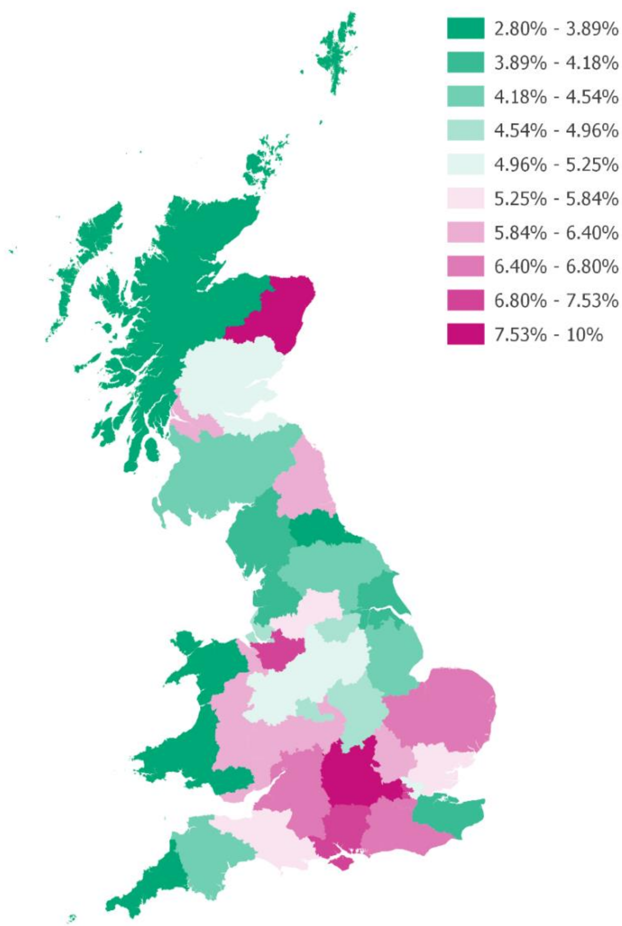
Source: Intramural R&D expenditure by sectors of performance and NUTS 2 regions; GERD by sector of performance and NUTS 2 regions, Eurostat



Although business spending on R&D is focused on a small number of regions, this does not necessarily mean that the UK's capacity for scientific research and development is limited to those areas. Some of the UK's scientific capacity comes in the form of human capital, as gleaned from the density of STEM professionals in the working population.[58] The highest share of employees working in STEM is expectedly found in Berkshire, Buckinghamshire and Oxfordshire at 10%, but the second highest is located in North Eastern Scotland at 9.9%. These areas are closely followed by London, Cheshire and Hampshire, with the latter two regions having 7.5% and 7.1% respectively. These figures suggest that the UK's scientific workforce extends beyond the areas where business R&D expenditure is currently focused, and so there is scope for other regions to engage more intensely in R&D if businesses choose to increase their expenditure in those areas.

Figure 24: Percentage of the population employed in science, research, engineering and technology professions, 2019

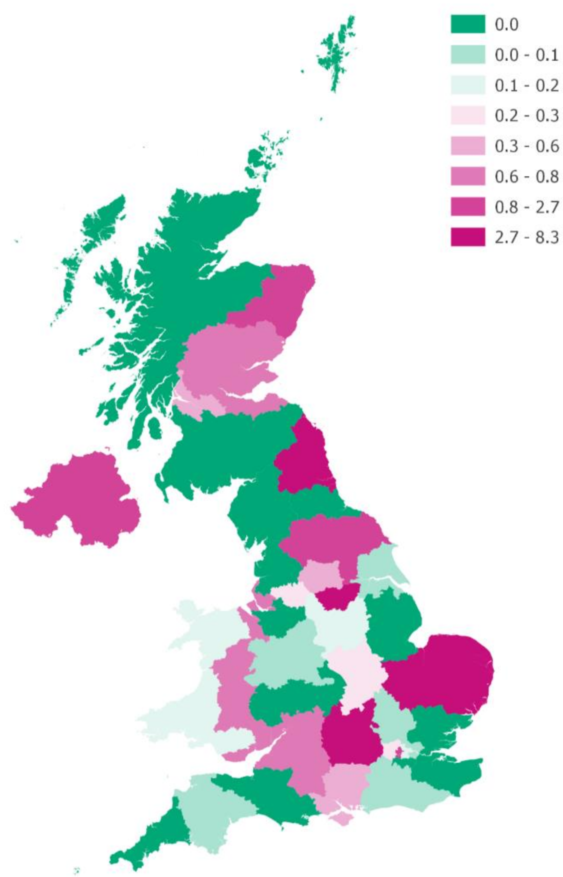
Source: Research & Development spatial data, BEIS/Nesta



Absorptive capacity can also be considered in terms of the ability to translate basic scientific knowledge into inventions that are commercially valuable and useful to consumers. As we observed earlier, UK universities generally perform well on global rankings of research quality, but lag behind on the appropriation of those inventions through intellectual property (IP) rights. Regional analyses reveal that universities in Berkshire, Buckinghamshire and Oxfordshire generate the most revenue from their IP, producing a 0.083% share of their regional GDP. They are closely followed by universities located in Northumberland, Tyne and Wear, who contribute a 0.072% share of their region's GDP. Next comes South Yorkshire at 0.055% and East Anglia with 0.039%. While it is intuitive to see Oxfordshire and East Anglia on this list, given that they house the UK's two best universities, the strong performance of universities in Northumberland and South Yorkshire in appropriating the value of their IP indicates their ability to generate value from research, and the potential for commercial returns from further investment in universities outside the Golden Triangle.

Figure 25: Amount of income from IP generated by universities as a share of regional GDP (x100), 2018

Source: Research & Development spatial data, BEIS/Nesta



The UK's lack of absorptive capacity is exacerbated by a weakness in exporting innovation

As well as failing to exploit its academic foundations and knowledge networks domestically, the UK also struggles to leverage innovations overseas, in the form of high-tech exports and intellectual property.

The UK underperforms its potential on tangible high-tech exports

One measure of technology exports is the share of trade occupied by high-skill and technology-intensive manufacturing.

In absolute terms, the UK exported $125 billion of high-tech manufactured goods in 2020, less than France ($169 billion), Japan ($185 billion) and Korea ($239 billion), and well behind Germany ($409 billion), the US ($457 billion) and China ($960 billion), only higher than the much smaller economies of Israel ($29 billion) and Canada ($63 billion). In ICT services the UK is more competitive, exporting just under $30 billion a year, behind only Germany ($35 billion), China ($59 billion) and the United States ($57 billion) and more than double its imports of ICT services.

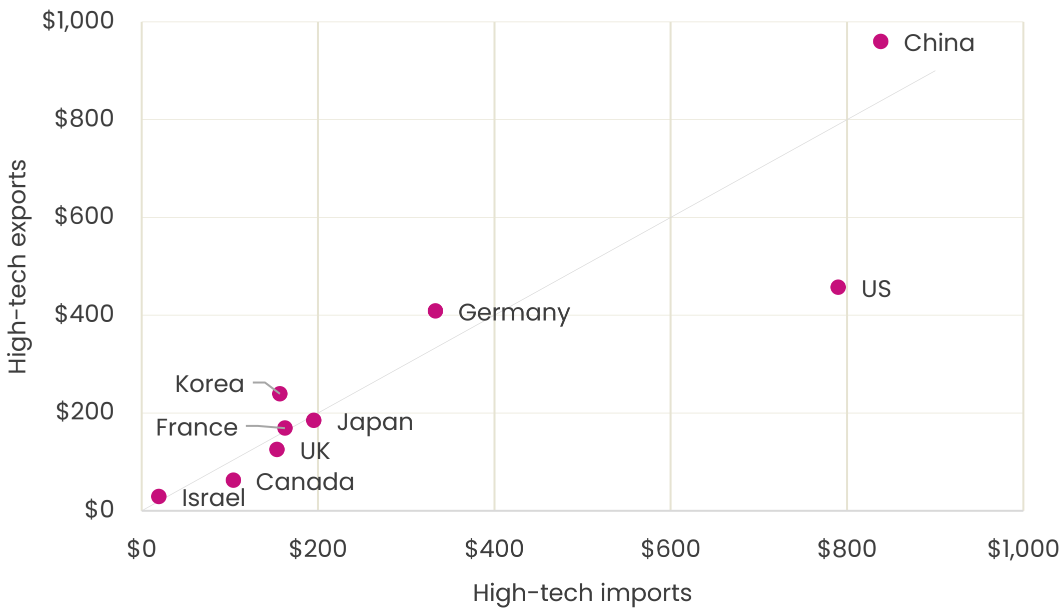
As a share of total world exports, the UK exports 2.3% of high-skill technology-intensive goods, and 3.3% of ICT services.[59] Lower on both measures than China's 17.6% and 8.3%, the USA's 8.4% and 8.0%, Germany's 7.5% and 4.9% respectively and lower than Korea (4.4%), Japan (3.4%) and France (3.1%) in high tech exports, but higher in ICT service exports. Korea and Israel's exports are more one-sided with Korea reporting 4.4% of the world's high-tech goods but only 0.9% of ICT services, and Israel representing the opposite position with 0.5% and 2.6% respectively.

Even in areas of perceived strength, such as pharmaceuticals, the UK fares much worse than we might expect. In absolute value terms, the UK was only the world's 9th largest exporter of pharmaceutical goods in 2020, exporting $25.4 billion in pharmaceutical exports. This means that Germany exports nearly four times the value of UK pharmaceutical exports and places the UK behind a number of much smaller economies, including Ireland ($67.0 billion), Switzerland ($77.9 billion), Belgium ($44.4 billion) and the Netherlands ($30.6 billion). Notably, China ($12.3 billion) remains a weak exporter of pharmaceuticals, behind Singapore ($14.0 billion) and Denmark ($16.7 billion), suggesting that this is an area where Western comparative advantage still matters considerably.[60]

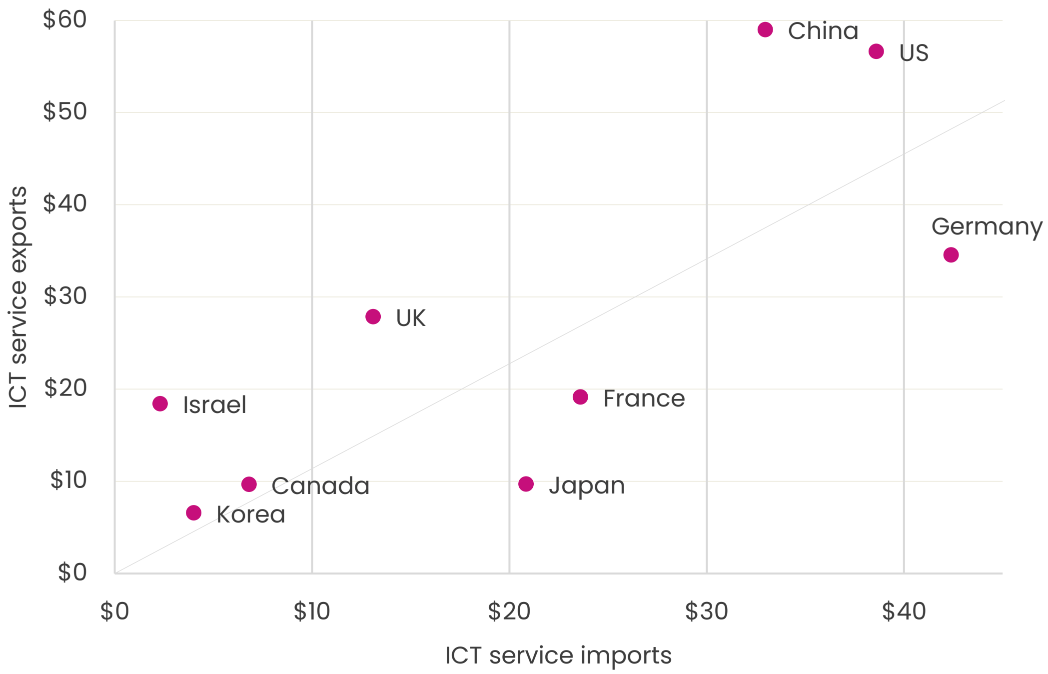
Figure 26: Exports and imports of high skill and technology intensive manufactures and ICT services, 2020

Source: Merchandise trade matrix; Exports and imports by service-category and by trade-partner, UNCTADStat

High-tech exports and imports (in billion USD)



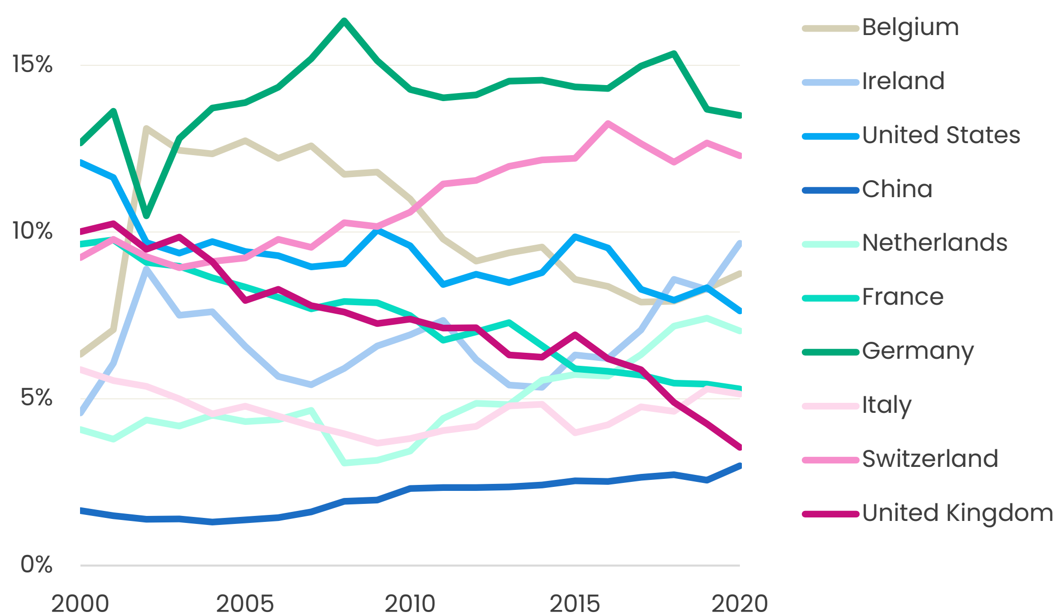
ICT service exports and imports (in billion USD)



And as a share of world exports of pharmaceuticals, the UK's position is being eroded over time. As shown in Figure 27, in 2000 the UK made up more than a tenth of the world's pharmaceutical exports. However, in the two decades since, that figure has fallen to less than 4%, a far steeper decline than any other country in our sample. This is not an inevitable effect of globalisation or China's growing market share (which remains less than 3%): Switzerland has seen its share grow from 9.2% in 1990 to 12.3% in 2020 and even in the six years since 2014 Ireland has grown its share of global pharmaceutical exports from 5.3% in 2014 to 9.7% in 2020.

Figure 27: Share of global pharmaceutical exports

Source: Merchandise exports by product group, WTO



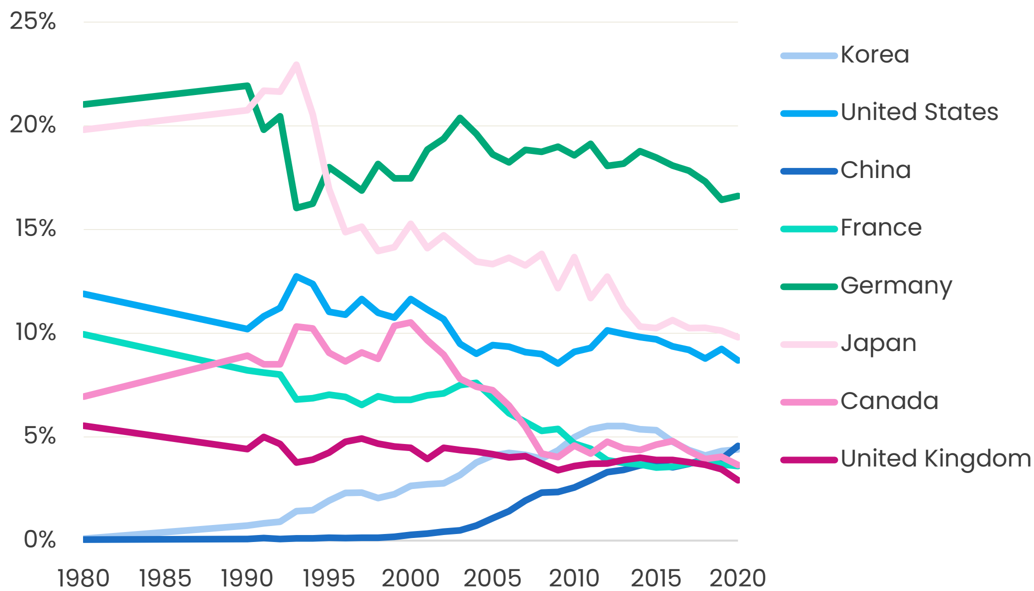
Looking at pharmaceutical exports in terms of trade balance paints an even bleaker picture. In 2010 the UK was 4th in the overall global trade balance in pharmaceuticals reporting a $9.7 billion trade surplus. Just ten years later, the UK is 98th in the global trade balance of pharmaceuticals, with a greater than $1 billion trade *deficit*.[61]

Another good example is automotive manufacturing. In the 1950s we were the largest exporter of cars in the world.[62] But the second half of the 20th Century saw the precipitous decline in the automotive industry: almost all UK car brands were bought by foreign companies, and manufacturing output was overtaken by our competitor countries. By the 1990s UK automotive exports accounted for less than 5% of the global market, and our market share has declined since then to less than 3% in 2020. This compares poorly to smaller economies including Canada (3.6%), France (3.6%) and Korea (4.4%) and doesn't come close to major car exporting nations such as Japan (9.8%) and Germany (16.6%).

Despite low market shares compared to our comparator countries, the latest UK trade figures show that cars and pharmaceuticals are the second and third highest value export categories for the UK worth £21.8 billion and £21.7 billion respectively in the 12 months preceding March 2022.[63] Automotive and pharmaceuticals are two of the UK's strongest export sectors, but by these measures the UK still ranks poorly compared to our competitors.

Figure 28: Share of global automotive product exports

Source: Merchandise exports by product group, WTO



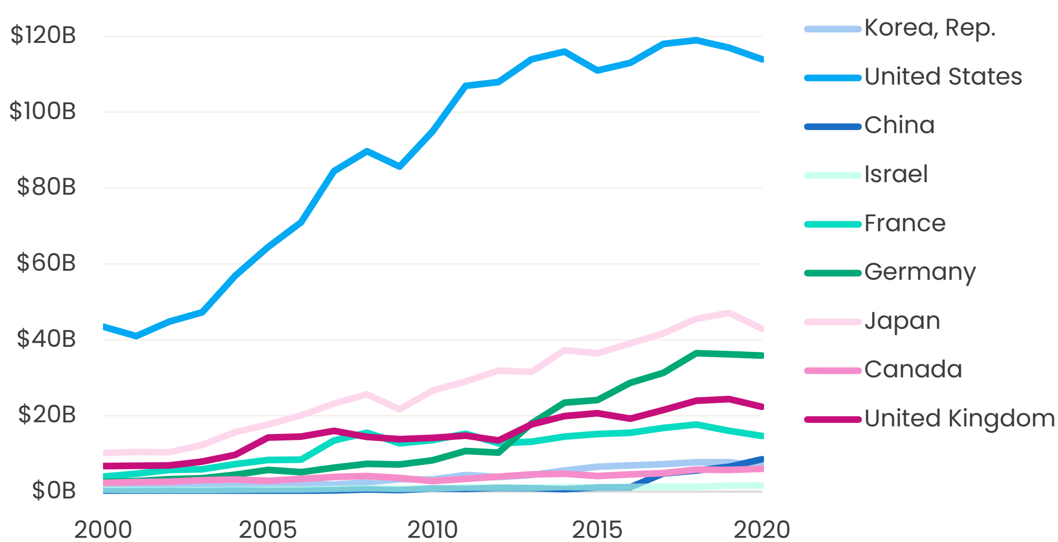
The UK appears to be well-placed to exploit the rise in "intangible" exports

Alongside exports in terms of products and services, it is also useful to think about where the value is generated or 'harvested' throughout the lifecycle of an invention. The economic benefit of the invention may be felt differently by different countries depending on the stage which they occupy in the value chain. For example, if an invention happens in the UK but is manufactured in India, one can ask how much of the profit generated remains in the UK and how much remains in India. This is particularly pertinent to China, given, as Brooks and Wohlforth have observed, "half of all Chinese exports consist of what economists call 'processing trade', meaning that parts are imported into China for assembly and then exported afterward."[64]

A better way to trace the national origins of expertise is to consider the revenues generated by each country's intellectual property (IP), what might be termed "intangible exports" – drawing on the recent work on the intangible economy by Stian Westlake and Jonathan Haskel. We can see this clearly if we consider the proceeds from IP charges, which covers transactions between resident and non-residents for the use of proprietary rights (such as patents, trademarks, copyrights and franchises) and for the use of original works (such as books, software, cinematography, and music).

Figure 29: Charges for the use of intellectual property, receipts (exports only)

Source: IMF Balance of Payments Statistics Yearbook, World Bank



As shown above, over the last two decades the USA has consolidated its position as the world's leading intellectual property exporter, generating $114 billion in intellectual property receipts in 2020 — more than double the country in second place, Japan. China, by contrast, remains one of the weakest IP exporters in our peer group, generating just $9 billion in overseas IP charges in 2020.

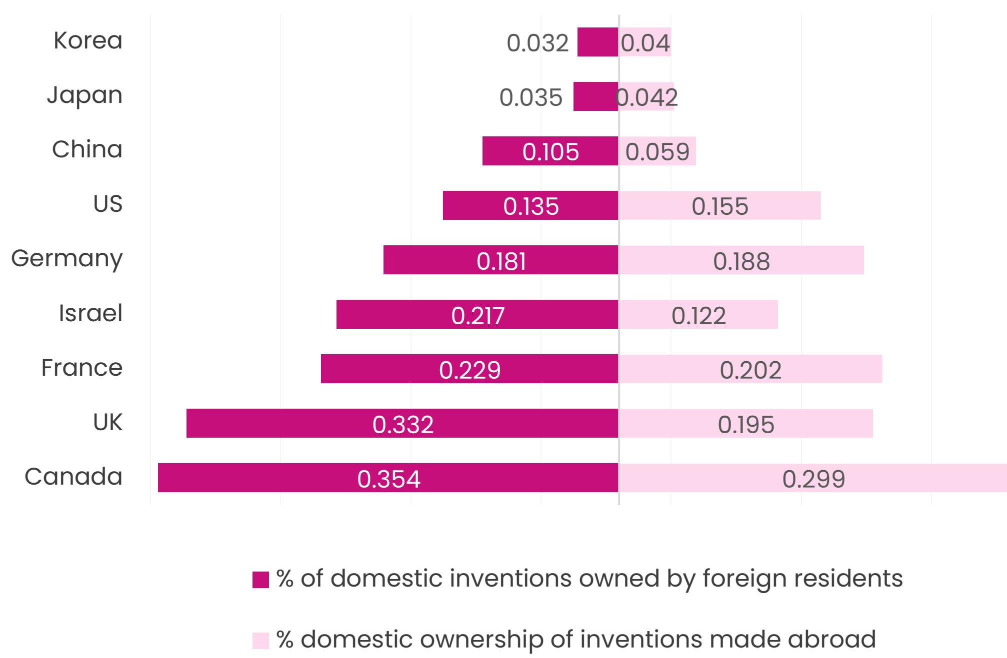
In a sign of the strength of the UK's intangible economy, the UK generates more than $22 billion in overseas IP charges, less than the US, Japan and Germany in absolute terms but over 50% more than France ($15 billion) and over three times that of South Korea ($7 billion) and Canada ($6 billion). Israel, despite its high levels of R&D investment, generates only $2 billion of IP exports.

The implication is clearly that the UK is well placed to exploit its research base into intellectual property exports. But it also poses the question: are we scoring highly in IP exports because we have so little value being generated by domestic companies using UK intellectual property? And, if so, are Germany and Japan even further ahead in terms of generating valuable IP – or are other countries such as China or South Korea so far behind because they generate significant value from domestic use of IP?

It is not necessarily the case that the UK will fully benefit from these exports. A closer look into cross-country ownership of patents reveals that the UK has a similar share in inventions made abroad as a percentage of total patents owned as Germany and France, but a much larger share of patents invented in the UK that are foreign owned. One in three UK-invented patents are owned by foreign residents, compared to fewer than one in four in France and Israel, fewer than one in five in Germany and just one in ten in China.

Figure 30: Cross country ownership of patents filed under the PCT, 2019

Source: Indicators of international cooperation, OECD. Onward analysis



In combination with the earlier findings around patent receipts and academic citations, this implies the UK science system generates inventions and innovations that are valuable, but that they are often exploited more effectively overseas than in the UK.

Chapter 3

What must we do to secure science superpower status?

The UK's ability to remain scientifically competitive in an increasingly multipolar and complex world depends on capitalising on our strengths and shoring up our weaknesses.

As this paper has demonstrated, the UK has many inherent strengths: the intellectual capital of globally influential research; institutional strength in the form of highly competitive universities and agile regulators; the human capital embedded in postgraduate research. These are all enormously powerful assets which exude both hard and soft power and contribute heavily towards UK productivity, wages and living standards. But it is also clear that the UK underperforms its potential, and not just because the UK has invested far less than our competitors on R&D since the 1980s.

Using the analytical framework set out in the first chapter, the UK has strong *academic foundations* and *knowledge networks*. But the UK is much weaker when it comes to the *absorptive capacity* of the domestic economy and the record of *exporting technology* to international markets. The UK's excellence in basic research is not exploited in the real economy, or directed towards strategic national priorities, as much as it could be. UK-originated intellectual property is simultaneously more likely to be owned overseas, and less likely to generate exports. A high density of postgraduate researchers has not translated into a high density of industrial innovators.

These outcomes are not inevitable. Just as the UK's strengths are the result of policy choices, so too are our weaknesses the result of cumulative decisions over time. The UK can – and should – take deliberate steps to build on its strengths and address areas where it is falling behind. The Government has already started this process – through the integrated threat assessment at the heart of the Integrated Review and the 2021 uplift in R&D spending. But there is more to do.

This chapter sets out a number of key shifts that policymakers should be considering to ensure the UK can credibly call itself a "science superpower" for decades to come.

Science policy should become more strategic, while protecting scientific independence

Research funding in the UK rightly operates according to the Haldane Principle, the concept developed in 1918 that decisions on individual research proposals are best taken by researchers themselves, decided through a process of peer review. The principle was restated by Lord Willetts in 2010 and enshrined in legislation in the 2017 Higher Education and Research Act.[65] In theory, it ensures that quality and impact, rather than political considerations, determine which research gets funded.

While individual funding decisions should clearly not be dictated by politics, there is a good case that the UK could be more strategic in where its research spending is focused – both in terms of the stage of research (in terms of Frascati terminology); the type of institution in which it takes place; and the problems it is seeking to address. In practice this means using the uplift in public R&D funding to increase funding for downstream research, while maintaining a high level of investment in basic research, which remains one of the UK's great strengths.

Historically, such an approach was not understood to cut across the Haldane Principle. As noted earlier in this paper, the UK is known for having a university-driven, basic-research-led science system. But it was not always the case. As the historian Jon Agar has noted, before the decisions of the Thatcher-led Conservative Government in the mid-1980s, the UK funded a large amount of "near-market" research, such as the Microelectronics Industry Support Programme, worth £70m over five years and the Alvey programme, worth £350m between 1982 and 1987, to support next generation computing. Many of the patents from these programmes were held publicly, in the National Research Development Corporation, which dated to the 1940s. However, in 1987, science policy switched to funding what is now called "curiosity-driven research", ending a more directive stance.[66] There remains a debate about how successful such "near-market" research was in practice, with some arguing that the Alvey programme failed to drive up UK competitiveness in ICT, but it still serves to underline that governments until relatively recently played a much more directive role in scientific funding.

In recent years, the UK has started to be more explicit about the strategic focus of research. After 2010, the then Science Minister, David Willetts, developed a number of initiatives to target the next great technologies that could spur growth and innovation. The Strength in Places Fund, while small in size, set out to specifically fund research outside the Golden Triangle of Oxford, Cambridge and London; the Industrial Strategy Challenge Fund was organised around four "missions" – clean growth, ageing society, future of mobility, and AI and the data economy. Meanwhile, the Ministry of Defence's recent Science and Technology Portfolio is organised around a number of "enduring science and technology challenges", including "pervasive, full spectrum, multi domain intelligence, surveillance and reconnaissance (ISR)" and "asymmetric hard power".[67]

But the UK remains much less strategic than many of our competitors. The United States, Germany and South Korea all operate well-established networks of national laboratories. And in the time it has taken the UK to publish an industrial strategy, growth strategy and innovation strategy, China has not only implemented a five year plan but moved onto the next. There is a strong case for the UK Government being more directive with its research and development funding to tackle technological challenges where we have a comparative advantage or a strategic weakness. In some areas, such as cyber security or high value green manufacturing, we might have both.

Research funding and institutions should be reformed to better exploit the UK's latent strengths

It is fair to say that the UK has many of the world's best universities. The UK is highly competitive on one aspect of higher education and scientific research – publications and citations. We generate the most academic papers as a proportion of research spending, and rank third in publishing highly-cited papers. These measures are important in the context of the "science superpower" agenda: they are a useful proxy for both soft power – in the form of global scientific influence – and hard power – in the form of a country's ability to attract the best scientists and host leading edge research.

But to say that the UK has many of the world's best universities is also a selective truth. Because against standardised measures of applied innovation and commercialisation, UK universities fare poorly when compared overseas. If ministers want that to change, the UK's unique funding and institutional set-up – with the vast majority of funding research decided by independent research councils and flowing through universities, rather than being directed to a greater degree by government and allocated towards national laboratories, private sector research institutes and business-led innovation – will require reform.

This need not mean moving away from a university-led model, which has proven an enduring and successful way to both discover and teach new ideas for centuries. Many universities have demonstrated their adaptability and their power as clusters of innovation in specific fields, such as the Sheffield Advanced Manufacturing Research Centre in the UK, Oxford Science Innovation in Oxford, and Stanford University's School of Engineering. But those examples also demonstrate that such a model does require universities to change their operating model, by working more directly with private investors and companies, fostering a culture of entrepreneurship and innovation, and shepherding research into application more deliberately.

This is partly due to the wider incentives of the higher education system. Since the introduction of higher student loans in 2012, the university funding model has been predicated on research being co-funded by a cross-subsidy from overseas student fees, who each pay an average of £5,100 more than it costs to educate them. University research is underfunded against its true costs – UKRI grants aim to provide 80% of the costs of a project, with the rest being made up by other funding sources within the university – but the actual average cost recovery has been in decline over the last decade and now sits at approximately 72%. The gross funding gap is estimated to amount to £4.3 billion across the UK higher education system. The cost recovery for home-fee PhD studentships is even lower: around 50% of the cost of training a British PhD student is recovered by the university.[68]

This dependence on foreign students to subsidise research might hinder the UK's ability to become a science superpower in two ways. Firstly, it encourages universities to prioritise training foregin students that are less likely to become part of the UK workforce than domestic students, exacerbating the drought of industry researchers we currently face. The numbers back this up – in 2019 46% of UK PhD students were from overseas compared with 38% in France, 23% in Japan and 20% in Germany.[69] Second, it makes universities – a valuable national asset – vulnerable to foreign influence, whether that is through knowledge transfer of valuable technologies or influence over the universities' behaviour in order to placate a major source of foreign students (China has shown its willingness to use university students to exert pressure on Australia for example[70]).

As ministers implement wider changes to higher education funding for teaching, and invest much more in UK R&D over the next few years, now is the right time for policymakers to consider reforming these structures to both drive greater application of research and to retain a greater share of scientists emerging from universities. However, if these reforms reduce the amount of funding derived from home students, universities' reliance on foreign student fees will only grow. This doesn't leave many attractive policy options on the table – increasing the price cap on home student fees is likely to be unpopular with the public, and particularly younger voters, while increasing government funding for university teaching will put more pressure on an already-straining government budget which is trying to mitigate a cost of living crisis while interest-rates also increase the cost of borrowing.

Businesses need simplicity and long-term certainty to drive up private R&D spending

The UK suffers from lower business R&D than many of our competitors. If, for example, UK businesses spent as much on R&D per capita as Germany, then UK R&D spending would have been $40 billion higher in 2018 alone. The long run effect on productivity and scientific power is considerable.

There are a number of theories as to why businesses invest less in R&D in the UK than elsewhere, ranging from the tendency of public R&D funding to support early stage and university-led research, rather than experimental or applied research in more varied settings; the bias of the UK economy towards services rather than more R&D-intensive manufacturing activity; and the mobility of capital in the UK market.

A more prosaic reason may simply be policy complexity. In absolute terms, the UK has tax reliefs on R&D that are both more numerous and more generous than many of our competitors (see Table 2).

The UK has seven different types of R&D relief available, ranging from loans, depreciation on assets, tax credits, cash grants, tax deductions and patent protections. The only other country in our peer group with more is France, with eight. In contrast, some of the countries with the highest level of business investment, Japan and South Korea, only offer one form of government support for R&D – tax credits, while the USA offers only tax credits and tax deductions.

Moreover, many of the UK's reliefs have been added incrementally over the past few decades – such as the R&D tax credits in 2001; the Patent Box in 2013; RDEC claims for large companies in 2013; the enhanced SME deduction in 2015; the Industrial Strategy Challenge Fund in 2017 – and some, including the super-deduction introduced in 2021, are time-limited. Compare this to Japan, which has maintained the same R&D tax credit since the 1980s, and the problem becomes clear.

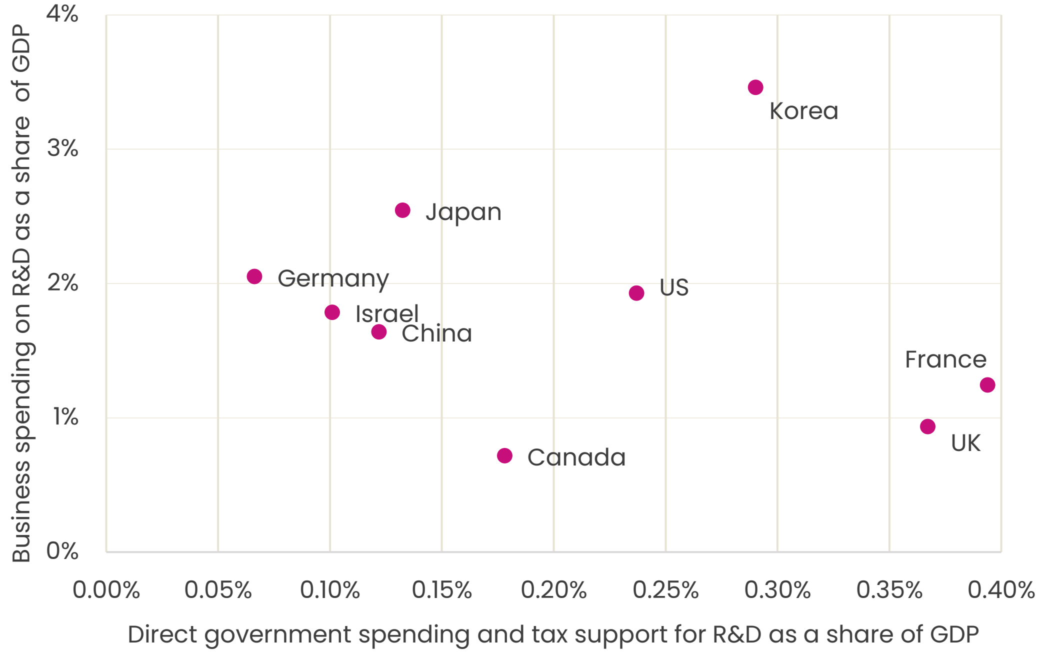
The churn and complexity within the UK's R&D incentives regime means it fails to achieve its purpose of encouraging greater investment in R&D by firms. Small companies find it so difficult to determine which incentives they qualify for that they often hire a third party to work it out for them – taking a cut of the incentive and in the process lowering the efficiency of the tax relief. Larger companies can't plan long-term R&D investment programmes when there is significant uncertainty over what incentives they will be able to claim in future years.

Frustratingly, the incentives are costing the Government dearly, for very little payoff. The UK is one of the most generous funders of business R&D in the OECD, spending more in tax support for business R&D than almost any other country. For example, in 2018, UK tax reliefs on R&D were worth 0.25% of GDP, considerably more than the OECD average of 0.1% of GDP. Yet UK business investment in R&D was significantly lower than the OECD average, and far less than our competitors discussed in this report. In fact, since tax credits were introduced in the UK, business R&D investment, as a share of GDP, is estimated to have *decreased* between 10-15%.[71]

Table 2: Types of financial incentive offered for business R&D by country
Sources in superscript

	Implied value of tax subsidy rates on R&D spending[72]		Direct support for business R&D (% of GDP)[73]	Number of national financial incentives[74]	Business spending on R&D (% of GDP)[75]
	SME	Large firm			
Canada	0.31	0.13	0.16	6	0.72
UK	0.27	0.11	0.41	7	0.93
France	0.43	0.43	0.39	8	1.24
China	0.08	0.23	0.13	4	1.64
Israel	0	0	0.09	6	1.78
USA	0.07	0.07	0.22	2	1.93
Germany	-0.02	-0.02	0.07	3	2.05
Japan	0.2	0.17	0.12	1	2.55
Korea	0.26	0.02	0.29	1	3.46

Figure 31: Business spending on R&D vs Direct government support for business R&D, grant funding and tax reliefs
Source: R&D tax expenditure and direct government funding of BERD; Gross domestic expenditure on R&D by sector of performance and source of funds, OECD, 2018



At the same time, the taxpayer also supports, through tax relief, a large amount of R&D that is either performed overseas (estimated at £4-7 billion/year), limiting UK spillover effects, or work that does not qualify technically as R&D: in 2019/20, UK companies claimed tax relief on £47.5 billion of R&D expenditure, but ONS estimates suggest that businesses only carried out £26.9 billion of privately financed R&D in the UK.[76] This suggests that UK businesses are both claiming more on R&D than they should, and claiming for activities which are not, in fact, R&D. Analysis of UK tax credits by Dr David Connell at Cambridge University claims that all four categories of credit deliver an expected additionality ratio of 1.0 or less.[73]

It is difficult not to draw the conclusion that UK R&D reliefs require far-reaching reform to make them considerably simpler and to introduce much greater long-term certainty into the process. This is an example of where less is more: the countries with the fewest tax breaks (and the lowest levels of complexity) receive the highest levels of business R&D investment.

Government should actively focus on building absorptive capacity in the wider economy

The UK could be better at absorbing new ideas and technologies emanating from both domestic research and international innovation. While the UK has strong technology adoption at a consumer level – with some of the highest smartphone market penetration in the world, strong levels of internet access even in older age groups, and a higher level of technology literacy than in many of our competitors – we underperform on many industrial measures of application, such as patenting, spin-outs and business technology adoption.

This is partly a function of skills. In maths and science teaching, the UK still lags significantly behind our competitors in East Asia, even if we do compare favourably to some Western competitors. Digital literacy is also lower than in other countries, despite the transformative effect of the pandemic on remote and hybrid working and digital adoption. These new models of working open up specific possibilities for the UK's strong services sector.

We should also improve synergy between universities and businesses, developing mechanisms for university and research institute expertise to be accessible to businesses. The introduction of the Catapult Network following Herman Hauser's 2010 review has started to create a stronger institutional network for the dissemination of innovation within specific industries, and the Made Smarter initiative, part-funded by Government, is a good example of how targeted investment can drive technological adoption within industries. But this is an exception, not the rule.

There has been, for example, no similar attempt to support the adoption of machine learning tools to support SMEs to improve their efficiency, or to improve adoption of renewable technologies to reduce commercial energy bills, despite the UK having strong domestic expertise in both sectors and government policy strongly supporting expansion. A good example of what is possible is the UK Government's work on cybersecurity, where both the National Cyber Security Centre at GCHQ protects both government and commercial assets from cyber threats and the National Cyber Security Programme uses pull-through procurement and partnership with industry to support innovation.

Sustaining scientific growth over the long term also requires a greater focus on demand "pull factors" rather than technology "push factors". For example, digital skills and inclusion are likely to drive a large amount of technology development in the coming decades: the UK ranks among the leaders for digital governance and internet access,[77] but 23% of people from low-income households still lack confidence in using a search engine to access government services.[78] Fixing this will be a prerequisite to generating productivity gains from the technical infrastructure available in the UK.

It will be critical to take into account the regional disparities in absorptive capacity when designing measures to boost uptake of science and technology. Currently many of the programmes, such as tax credits and excellence-based funding, pour more investment into the areas which are performing best, rather than try to improve the performance of areas lagging behind. This not only concentrates spending at the expense of others, but also overheats the most prosperous areas of the country. If future investments were more dispersed, Professor Richard Jones explains that it "would address two of the UK's biggest structural problems: its profound disparities in regional economic performance, and a research and development intensity". This is evidenced by the fact that East Midlands, West Midlands, Southwest and Northwest England have relatively low public spending on R&D, but disproportionately high private sector R&D investment,[79] suggesting that Government investment could support and grow existing private sector innovation capacity and productivity – and deliver significant spillover effects. For example, for each job in high technology, knowledge intensive industries at least one additional job is generated in support or retail sectors in that city.[80]

We need a targeted approach to boosting science exports and international investment

The UK is not a world leader in high-tech exports or science or technology investment. In high-tech exports we fall behind our peers and even in pharmaceuticals, an area of perceived strength, the UK comes 9th in the value of exported goods.[81] While the UK has a growing number of unicorn firms, there are relatively few large science and technology firms. For example, the Thomson Reuters Top 100 Tech Leaders list only features one UK company.[82]

The UK's strengths in basic science mean that focusing on exports may involve trade-offs. And given the current levels of exports and international investment, the UK faces a steep uphill struggle to compete in this area overall. However that does not mean that there is not more the UK could be doing to open up new export markets for UK innovation, increase the attractiveness of the UK as a place to invest in science, and set international standards, especially in intangibles.

This will require the UK targeting its approach in two ways. First, in areas of true comparative advantage, the UK should actively seek to build export pipelines and support firms to sell their technologies overseas. Where government does not have the data to identify areas of comparative advantage, it should develop it. But on currently available data, this might include specific industries such as gene editing, AI, advanced materials, and advanced energy technologies.

With academic expertise, an effective regulatory environment, an appropriately skilled workforce, the necessary infrastructure and adequate funding, we could be globally competitive in these emerging fields without trying to take on established industries such as semiconductor and automotive manufacturing. This may not make us a science superpower in exports and investment, but it would deliver many of the benefits of superpower status, and could set us up to become a future superpower if – as is likely – these emerging technologies become a major part of the future world economy.

Second, we need to make sure the government sets clear, long-term priorities so that businesses can have confidence to invest in the R&D and manufacturing capability that we will need if we are to be globally competitive. This is likely to include some more hands-on government intervention than has been usual in the UK, working with companies to make sure that we offer the right balance of skilled labour, infrastructure and investment capital for the UK to compete with the current world leaders in high-tech manufacturing. We can look to Ireland as a successful example of this strategy.

Conclusion

We have a golden opportunity to lift our ambitions for UK science and technology. For forty years the UK has focused its attention on funding the supply-side of science, generating world-beating academic research and training a great number of STEM graduates, hoping that private industry would build on these with their own investment into R&D. That business investment has in large part failed to materialise, and our technology exports have declined significantly. It is time for a new approach.

It is the ideal time to strategically refocus science and technology funding and policy to drive growth in vital emerging sectors such as quantum computing, gene editing, zero-emission energy and artificial intelligence. And to make sure we have the domestic capacity to ensure health, energy and military security, all while driving productivity and prosperity in the left-behind regions of the UK. Investing in these emerging technologies now will give us a chance to become the technology exporters of the future and a science superpower.

Our universities are a great asset – we must not neglect them – but we cannot expect them to do everything necessary to make us a science superpower. We need to ensure there are other institutions in place to help with the commercialisation of research and technology transfer to existing industries. This could be through further investment in the cluster and catapult network, or rebuilding the UK's national laboratories, but these functions need to be provided from somewhere if the UK is to claim it is a science superpower.

This investment can be funded, in part, by reforming R&D tax incentives which have been costly to the Treasury while arguably generating limited additional business R&D. There is a strong argument that it is time the UK invested money in mid-to-late stage R&D through a suite of more targeted mechanisms, rather than broad, ineffective tax incentives.

If these reforms are to be effective, they must be long-term. The UK has suffered from significant science policy churn, particularly in the years since the Gordon Brown-led Labour party. Constant changes to UK science priorities and funding mechanisms have made it difficult for companies to make long-term investments in R&D infrastructure. Brexit has only made this policy and regulatory turmoil worse. The Government will need to signal to businesses that their priorities, and the support behind them, will be long-lasting to give them confidence to invest. We won't be able to attract the business investment in science and technology we so desperately need without it.

The UK has often made the biggest policy strides during times of turmoil; this is such a time. In the wake of the COVID-19 pandemic, Brexit and a war in Europe, it's time we drove through reforms that will set up the UK as a science superpower for decades to come.

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