Learning from the best: National innovation systems

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Learning from the best: National innovation systems

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CONTENTS

CONTENTS ... 3
1.INTRODUCTION ... 4
2. WHAT CHARACTERISES A STRONG NIS? ... 5
2.1 System-ness ... 5
2.2 Benchmarking system performance ... 6
2.3 R&D Inputs – a quantitative challenge ... 11
2.4 R&D inputs – qualitative comparisons, a European model ... 14
2.5 Complementary inputs to R&D investment ... 17
2.6 Inputs – overview ... 18
3. PATHWAY COMPARISONS ... 19
3.1 Talent pathways ... 20
3.2 Finance pathway ... 24
3.3 Policy support pathway ... 26
3.4 International and global pathways ... 29
3.5 Technological pathways ... 31
3.6 Pathways to diffusion ... 34
3.7 Pathways overview ... 35
4. LOOKING TO THE FUTURE – INCREASING INVESTMENT, STRENGTHENING PATHWAYS ... 37
5. DATA LIMITATIONS ... 39
REFERENCES ... 40

1.INTRODUCTION

The UK government has set challenging targets for R&D investment and improving the UK's record on innovation and commercialisation. Key to achieving these targets and maximising the social and economic benefits from future R&D and related investments will be the effectiveness of the UK's national innovation system (NIS). In this paper we briefly examine the capabilities of the UK NIS relative to that of our main international competitors and identify relative strengths and development opportunities.

The concept of the national innovation system was initially introduced by Freeman (1982, 1987) and summarised by Metcalfe (1995, p. 38) as the:

> 'Set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provides the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artefacts which define new technologies'.

This emphasises that innovation and technological progress results from a complex set of interactions between system participants, including businesses, universities and government research institutes (Freeman, 1995; Lundvall, 1992; Lundvall, 2007; Nelson and Winter, 1993; Godin, 2009). This suggests that 'individual institutions' contributions are not considered in isolation, but with how they communicate with each other as components of a collective structure of information formation and use and how they interact with social institutions (e.g. principles, standards, legal frameworks)' (OECD, 1999 p. 24). Through its role in shaping policy, regulations and incentives government can play a key role in ensuring the effectiveness of national innovation systems.

Section 2 of the review provides a data based view of the UK NIS using a series of international comparisons. This emphasises the consistently low level of investment in R&D in the UK relative to our international competitors and the growing investment gap. It also emphasises the market and curiosity-driven orientation of the UK's national innovation system. Section 3 of the document focuses on the strength of the various 'pathways' through the innovation system, drawing on analogies with natural eco-systems. Section 4 looks forward to some emerging challenges.

2. WHAT CHARACTERISES A STRONG NIS?

National innovation systems vary markedly in terms of their structure, governance and capabilities, raising questions about how the strength and effectiveness of different systems can be compared. Direct benchmark comparisons are made more difficult due to nations' very different levels of investment in R&D and innovation. Is a 'strong' national innovation system one which generates high levels of innovation outputs regardless of the level of inputs? Or, is a 'strong' national innovation system one which is more efficient at translating a given level of inputs – R&D, intangibles investment etc. – into innovation outputs?

2.1 System-ness

We consider the comparative position of the UK in terms of inputs and outputs to the NIS in subsequent sections but it is also important to note the emphasis in the innovation systems literature on 'system-ness', i.e. the extent to which the different organisations within an area or nation actually do comprise a 'system'. Charles Edquist (2004) has suggested three criteria which must be met if an innovation 'system' is to be said to exist in an area:

- ***Coherence*** - an innovation system will exist when the array of organisations and their relationships in a region or nation form a coherent whole, which has properties different from the properties of the constituents. In other words, we would expect to identify feedback systems or loops, common developmental trajectories and complementary competencies between agents.
- ***Unified function*** - an innovation system has a function, i.e. it has identifiable objectives or aims to which all elements of the system contribute. This might be evident in social partnerships (either formal or informal), agreed objectives and vision.
- ***Bounded*** - it must be possible to discriminate between the system and the rest of the world; i.e. it must be possible to identify the boundaries of the system. This could be geographic but may also be sectoral or technologically based.

Discussion of the effectiveness of innovation systems has adopted three main approaches focused on organisational capabilities, system functions and, more recently, pathways. Capabilities approaches focus on the capabilities of individual organisations within the system, e.g. the absorptive capacity of firms, research capacity within universities. A functional approach emphasises system governance and operational capabilities, identifying key actors and their interactions (Roper et al. 2006). A more recent approach focuses on pathways through the system suggesting, as Shaw and Allen (2015, p. 88) suggest, 'pathways convey material and informational resources, as well as value. Like the nutrient and energy pathways in natural ecosystems. Pathways help to recycle scarce resources such as customer attention and customer-derived information'.

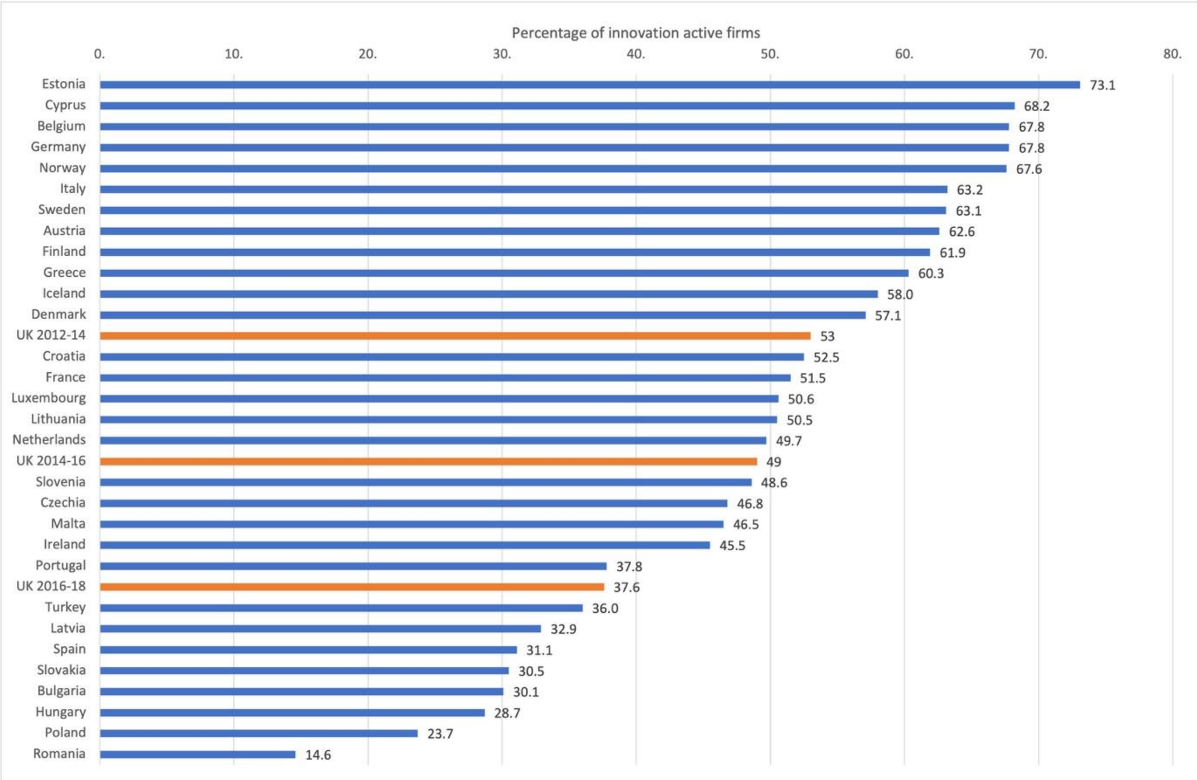
The remainder of this section focuses on calibrating the overall performance of the UK and other innovation systems before focussing on R&D and other complementary inputs to innovation.

2.2 Benchmarking system performance

Innovation – the introduction of new products, processes or ways of doing business – has a number of dimensions, not easily captured in a small number of indicators. One key multi-dimensional metric reflecting both investment in and the outputs of firms' innovation activity is the proportion of firms which are 'innovation active'. In 2016-18, 37.6 per cent of UK firms were classified as innovation active, a significantly lower level than in previous periods and also below that of many of our international competitors (Figure 1). The proportion of innovation active firms in the UK has fallen sharply in recent years. For example, in 2012-14, 53 per cent of UK firms (with 10 or more employees) were innovation active and this had fallen to 49.0 per cent in 2014-16 and 37.6 per cent in 2016-18[1]. Both positions are represented in Figure 1 which illustrates how on this metric the UK has lost ground on our international competitors over this period.

[1] Source: UK Innovation Survey 2019, Statistical Annex, Table 1a.

Figure 1: Percentage of innovation active firms in European countries 2016-18 and UK comparisons for 2016-18 and earlier periods



Sources: Eurostat CIS 11 and UK Innovation Survey Statistical Annex, Table 1a.

A rather similar story is suggested by different innovation metrics – the proportion of firms introducing innovations in goods or services and new production or service delivery processes over the last three years. In terms of new good and services, 19.1 per cent of UK firms responded positively in 2016-18 which again puts the UK in the bottom third of EU countries (Figure 2a). Here too, the proportion of product innovators in the UK has fallen over recent years (21.9 per cent in 2012-14, 24.7 per cent in 2014-16), again suggesting we have lost ground relative to some of our international competitors. In terms of process innovation, an essentially similar pattern is evident with 12.7 per cent of UK firms reporting this type of innovation in 2016-18 (Figure 2b).

Figure 2a: Percentage of firms introducing product (goods or services) innovations: 2016-2018

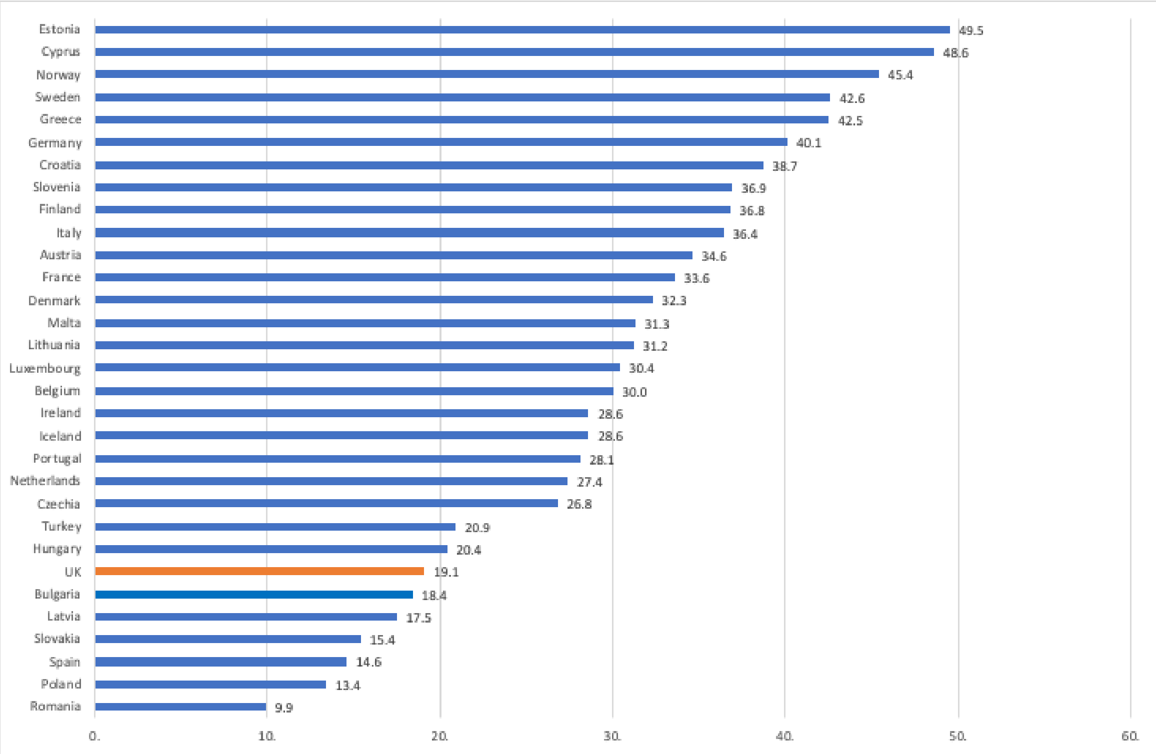
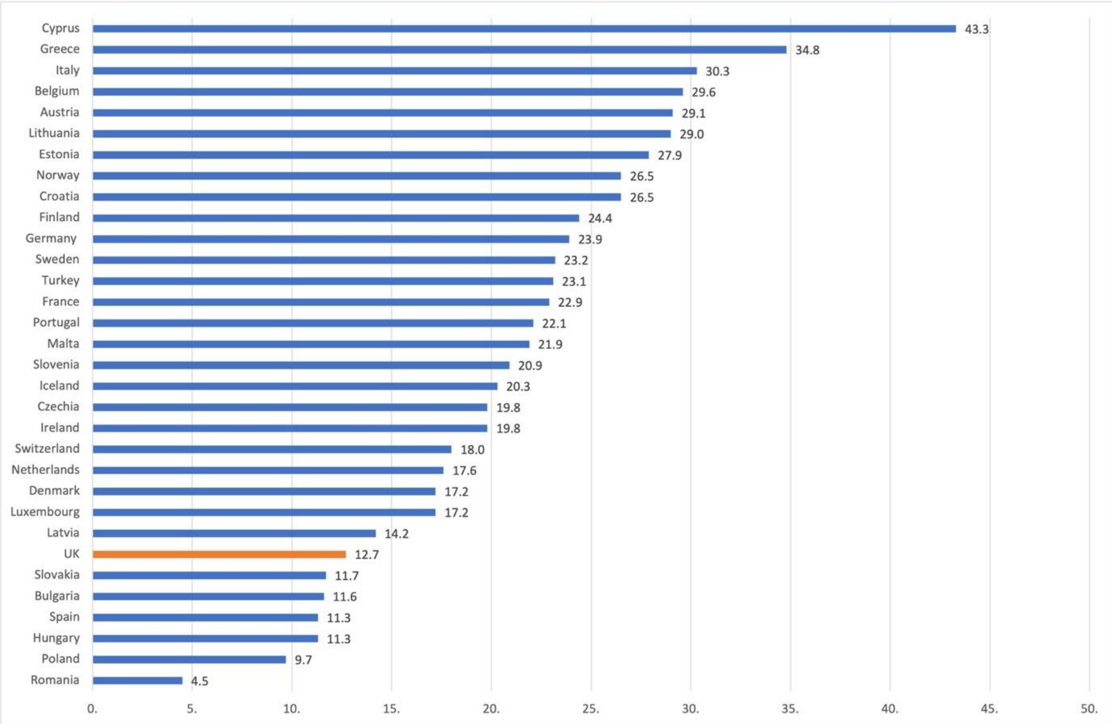


Figure 2b: Percentage of firms introducing new or improved processes or service delivery innovations: 2016-2018



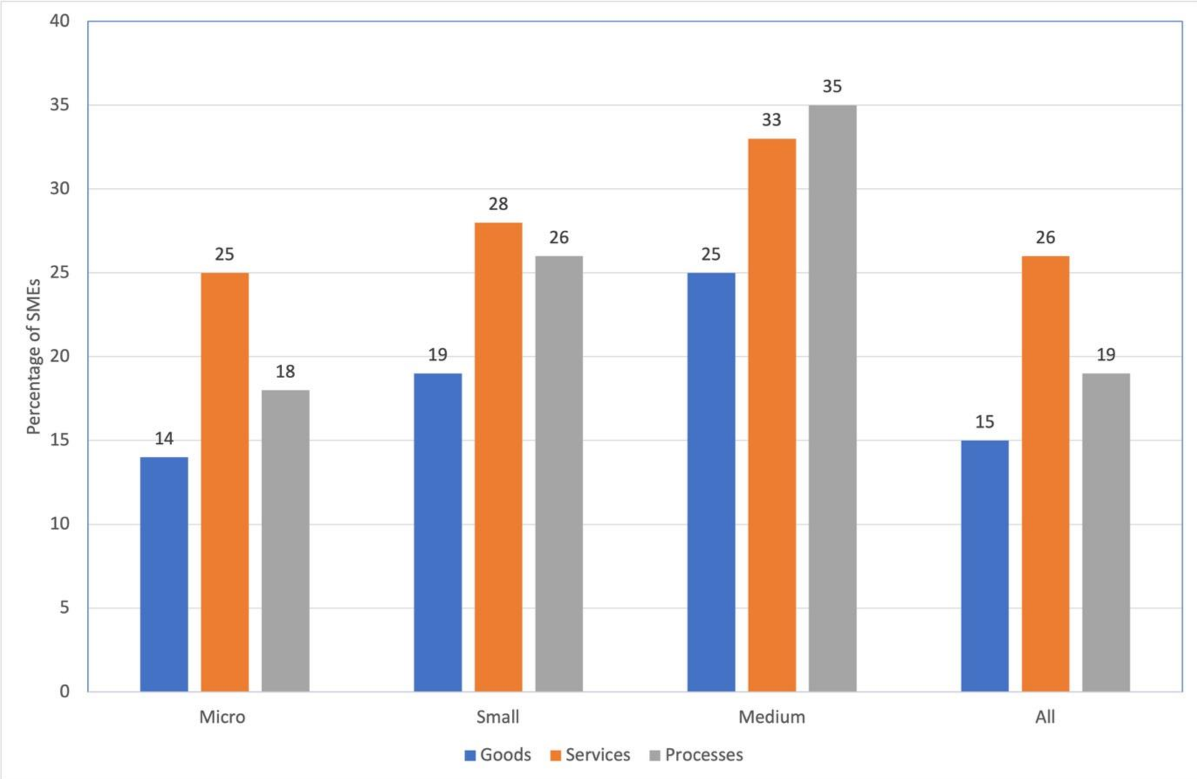
Sources: Eurostat CIS 11 and UK Innovation Survey Data Annex, Table 14.

One significant limitation of these metrics and the UK Innovation Survey itself is that this only covers firms with 10 or more employees. Micro-businesses with 1-9 employees are excluded from the Innovation Survey and we therefore have relatively little information on innovation in this critical group of firms. In particular, most university spin-outs and start-up companies begin in the micro-business category and their exclusion means we have very little information on their innovation activity. Similar issues apply to firms in creative industries the vast majority of which are in the 1-9 employee category.

Our only regular source of data on innovation in these micro firms is the Longitudinal Small Business Survey which allows us to conduct top-level comparisons of innovation in micro-businesses (both with and without employees) with larger firms in the small and medium size bands but provides little detail on the nature of innovation activity in these smaller firms. These top level comparisons suggest that levels of innovation in micro-businesses are actually slightly lower than those in the larger firms included in the UK Innovation Survey (Figure 3). This suggests that the percentage of innovating firms indicated in

Figures 1 and 2 therefore slightly over-states the level of innovation in the whole population of UK firms.

Figure 3: Innovation in micro-businesses and other SMEs: 2019



Source: LSBS employer survey 2019.

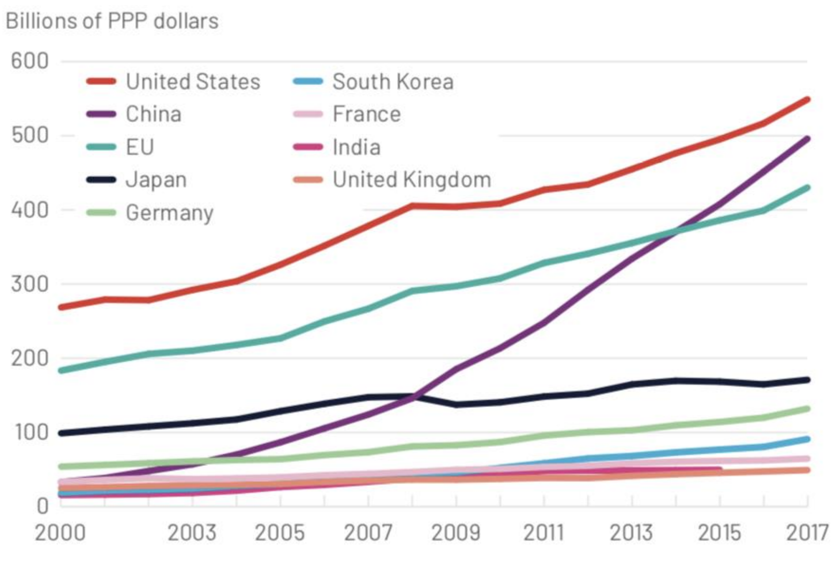
These innovation comparisons suggest that the UK innovation system produces levels of innovation output below those of many of our international competitors and that we have steadily lost ground relative to other countries. This is significant because numerous studies have linked innovation to international competitiveness and firms' future growth and productivity: lower innovation now implies lower growth and productivity in the future.

What factors are shaping the UK's innovation performance? In what follows we consider two potential – and non-exclusive – explanations. First, we consider UK's firms' and policy commitment to investing in innovation relative to that of our international counterparts. As levels of international R&D and intangible investments have increased this suggests the UK has lagged international best practice by some way. Second, in Section 3 we consider the effectiveness of a number of pathways within the UK innovation system relating to factors which may impact system efficiency. These suggest some areas of strength but also highlight some key issues which may be constraining UK innovation outputs relative to best practice internationally.

2.3 R&D Inputs – a quantitative challenge

R&D spending is perhaps the key driver of national innovation success with recent studies suggesting that a 1 per cent increase in R&D intensity – R&D spending relative to GDP – is linked to a 2.2-2.8 per cent increase in GDP growth (Sokolov-Mladenović et al. 2016; Moustapha and Yu (2020). Globally, R&D spending rose three-fold over the period 2000 to 2017 with marked increases in the US, EU and especially China (Figure 4). Differential growth rates over this period mean that the EUs share of global R&D spend has fallen from 25% to 20% while the US share has fallen from 37% to 25%. South East Asian economies (China, Japan, Malaysia, Singapore, South Korea, Taiwan and India) increased their spending share from 25% to 42% of global R&D. The UK accounts for less than 3 per cent of global R&D spending.

Figure 4: Gross Domestic expenditures on R&D, by selected region, country or economy: 2000 to 2017



Source: National Science Board (2020), Figure 11. Based on OECD indicators data.

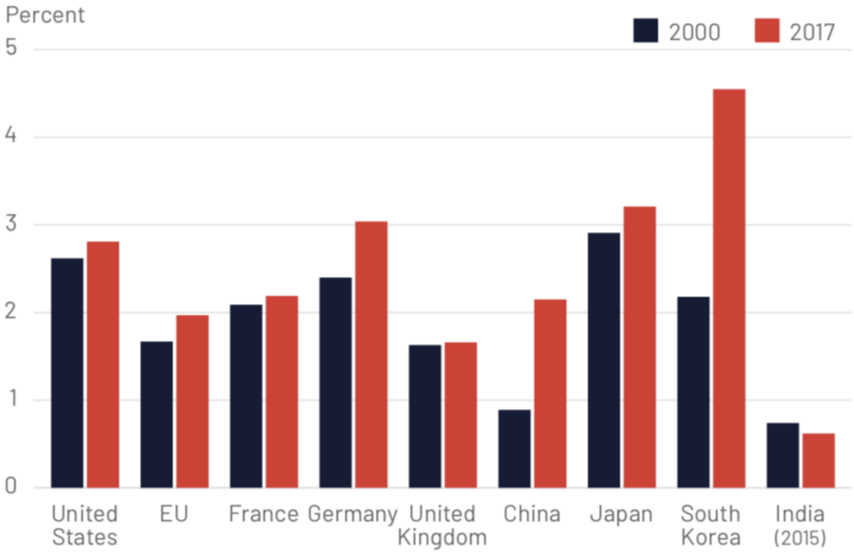
Starting from a relatively low base by international standards, R&D intensity in the UK has remained broadly static over the 2000 to 2017 period in contrast to that in most other nations (Figure 4). In other words, the gap between R&D intensity in the UK and its competitors has grown significantly over the last two decades. It is notable that this applies not just to the growing gap in R&D intensity between the UK and the economies of South East Asia but also to the gap between the UK and other major European economies (Figure 5).

While R&D intensity in most countries has risen, each country still identifies strengths and weaknesses in their R&D systems. For example:

- Korea has a particularly strong concentration of R&D activity in larger technology- based manufacturing conglomerates. Smaller firms, cultural industries and regions outside the capital are notably weaker in terms of R&D activity as are sectors such as bio-technology and life sciences[2];
- Japan maintains a strong concentration of R&D activity in automotive technologies and related supply chains including materials and digital activities. Around three-quarters of all R&D spending continues to come from manufacturing[3]. Service sector R&D activity is limited.
- Germany too has a strong business focus on R&D with a balance of investment between larger and smaller firms. This is supported by a strong university sector and well-funded non-university research organisations – the Max Planck Society, Fraunhofer-Gesellschaft, Helmholtz Association and Leibniz Association- which focus on collaborative basic and applied research.
- China has prioritised 'innovation' as the key goal of the current Five Year Plan suggesting a focus on near-market R&D activities (see below). Development has focused strongly around priority sectors and National Science Parks[4].

[2] See https://k-erc.eu/for-european-researchers/korea-rd-policy-and-programmes/
[3] See https://www.icis.com/explore/resources/news/2020/08/18/10542063/japan-r-amp-d-investments-to-stay-resilient-despite-recession-amid-pandemic
[4] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/898110/China_Snapshot_2020.pdf

Figure 5: R&D intensity by selected region, country or economy: 2000 and 2017

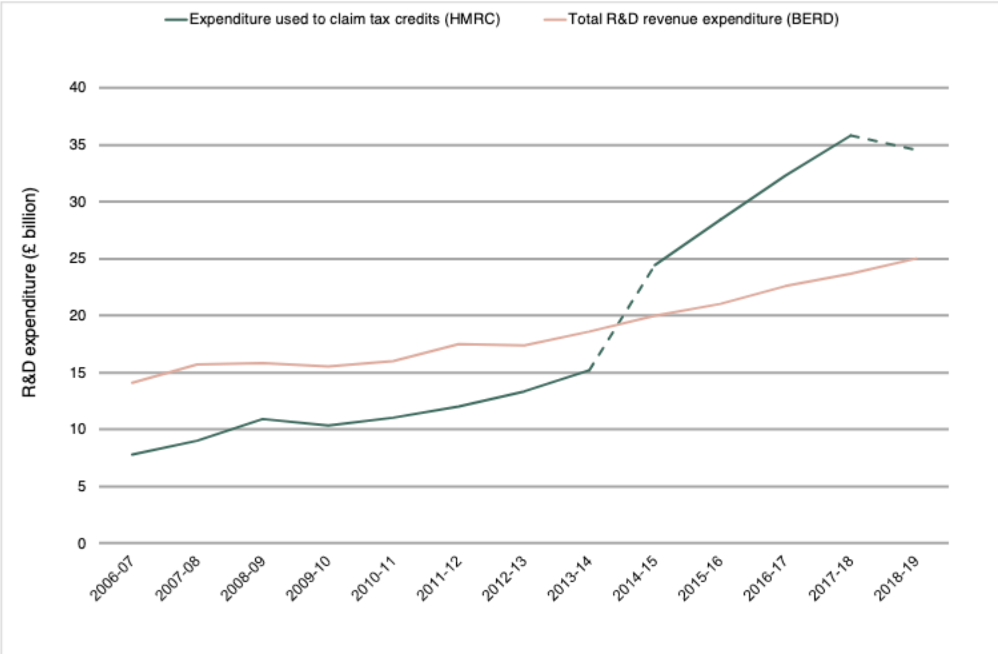


Source: National Science Board (2020), Figure 15. Based on OECD indicators data.

As R&D spending is strongly linked to future innovation outputs, and hence to growth and productivity, the persistent and growing gap between R&D intensity in the UK and its international competitors is concerning. Moreover, this increasing deficit is cumulative as current knowledge investments benefit from past knowledge investments and the learning, infrastructure and expertise they created.

One other point is worth making here regarding measures of R&D spend in the UK. As we shall see later, recent years have seen a sharp increase in the value of R&D supported by R&D tax credits. HMRC data on the value of R&D activity supported by these tax credits shows a very different trend to that suggested by the ONS data (Figure 6). This raises some important questions about the true level of R&D activity in the UK and the true underlying trend.

Figure 6: HMRC and ONS estimates of business R&D spend in the UK



Source: Figure 9, Research and Development Tax Credits Statistics, September 2020.

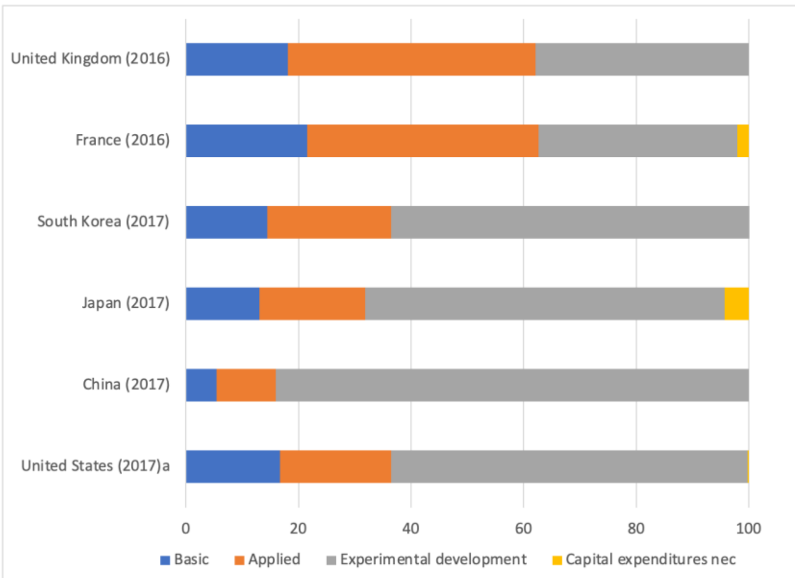
2.4 R&D inputs – qualitative comparisons, a European model

R&D spending varies significantly in its intent from near-market – experimental development – to longer-term 'basic' research. R&D intensity also varies significantly between sectors, an issue which needs to be borne in mind in making international comparisons. Within each sector, different types of R&D are complementary – part of the commercialisation pathway – and each has a potentially different profile of economic and social benefits.

Basic R&D is scientific research undertaken without any specific commercial intent. Basic R&D activity – often concentrated in universities internationally and in Germany also in public research institutes – focuses on technological discovery. Publication or patenting may then provide the basis for subsequent commercial development. Evidence suggests that the social returns to basic R&D may be greater than that of other near-market types of R&D activity, although these benefits may only be realised in the longer-term (Akcigit et al. 2020). Another key issue is around appropriation – whether a nation can 'capture' the benefits of the basic R&D in which it invests – or whether this R&D benefits firms and other national economies elsewhere. An intermediate category – 'applied' R&D – focuses on commercially relevant research but is not directly linked to any specific product or service. Applied research may relate to the identification of market opportunities or platform technologies. Near-market experimental development then focuses more specifically on the development and testing of new products or services.

There is little robust evidence on the comparative effectiveness of commercialisation processes in different countries but it is clear from the R&D figures that the emphasis on different types of R&D is very different internationally[5]. The composition of R&D spending in the UK is similar to that in other EU countries but places more emphasis on 'applied' research than either the US or Asian economies (Figure 7). China, notably, has a particularly strong focus on near-market experimental development emphasising the capability to develop technologies for the market and scaling up manufacturing processes. Note, also, that because of the higher R&D intensity, spending on basic R&D relative to GDP is still higher in Korea than in the UK (Figure 7).

Figure 7: Composition of R&D spending – various countries



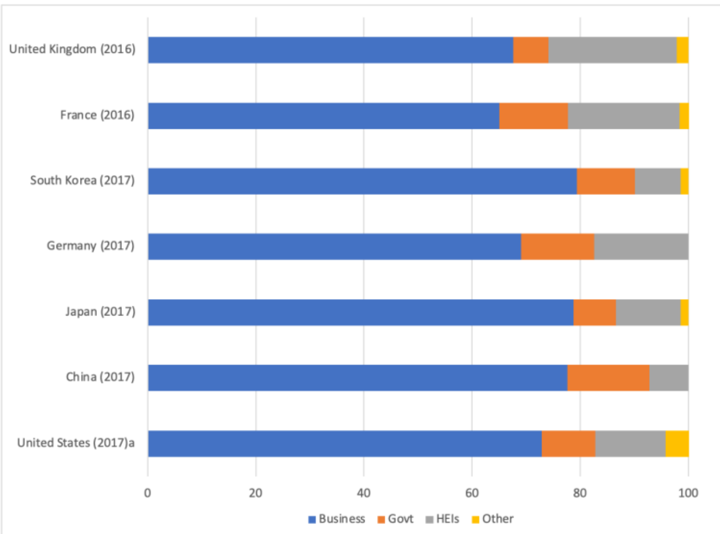
Source: Boroush (2020), Table 4-8.

[5] For a detailed discussion see: http://www.unesco.org/new/en/media-services/single-view/news/what_is_the_optimal_balance_between_basic_and_applied_resear/.

The composition of R&D by performing organisations also varies significantly between countries (Figure 8). The UK is comparable to other EU countries in the proportion of R&D undertaken by business, but again levels of business R&D are higher in the US and Asian economies. As the earlier comparisons suggest, however, the focus of much of this business investment is experimental development rather than the more 'applied' focus of much business R&D in UK firms. One possibility is that this may reflect the position of UK firms in global value chains, with design and development work being undertaken in the UK (and other European economies) and more specific product and process development concentrated in China and other Asian economies.

It is notable too that the UK has a particularly low level of government R&D and greater dependence on the higher education sector than other countries. The comparison with Germany, France, China and Korea is particularly marked. In Germany this is likely to reflect government support for Federal research organisations which sit outside the university system - the Max Planck Society, Fraunhofer-Gesellschaft, Helmholtz Association and Leibniz Association- as well as Lander research centres. The balance between university-based and government R&D has implications for the ability of government to direct research resources at specific mission-driven or technological priorities: university research is more strongly curiosity driven than mission driven making it harder for government to influence the focus of R&D activity. This lack of strategic control and focus is exacerbated by the lower overall level of R&D activity in the UK.

Figure 8: Composition of R&D by performing organisation – various countries

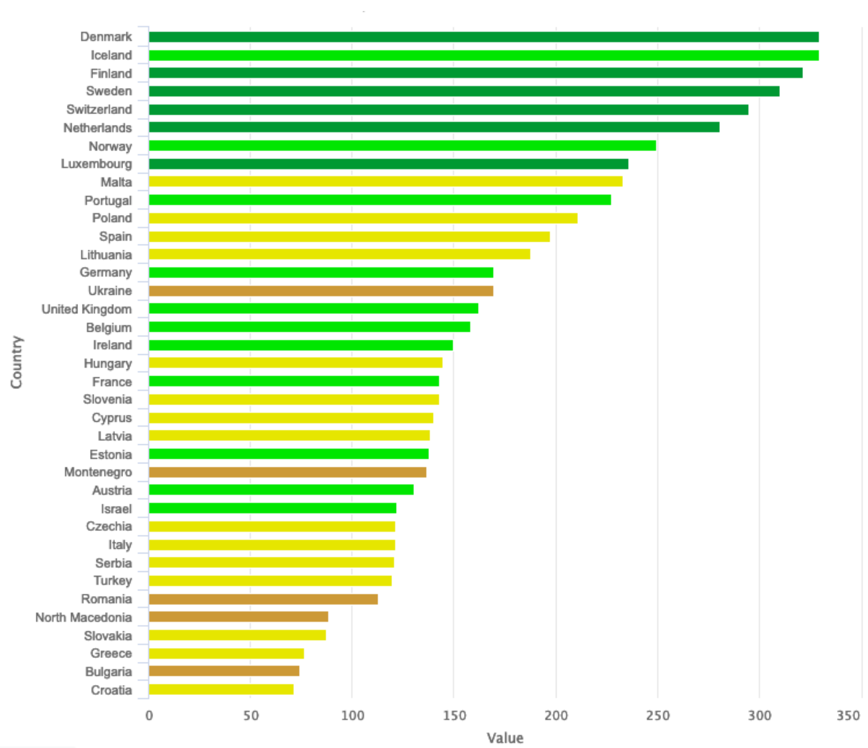


Source: Boroush (2020), Table 4-7.

2.5 Complementary inputs to R&D investment

As the previous discussion of national innovation systems (NIS) makes clear, innovation is the result of a complex and dynamic process which requires a range of complementary inputs beyond R&D. The nature of these inputs – skills, finance – will determine the strength of system pathways and the ability of the NIS to effectively translate inputs into innovation outputs. An indication of where the UK stands in this respect is suggested by the European Innovation Scoreboard 2020 and the indicator on whether the UK provides an 'innovation-friendly environment' (Figure 9). Here the UK lags other 'innovation leader' countries in Europe (dark green) and a number of other 'strong' innovators (light green). The UK itself is categorised here as a 'strong' but not 'leading' innovator. On other aspects of the 'Framework conditions' dimension of the Innovation Scoreboard 2020 covering 'human resources' and 'attractive research systems' the ranking of the UK is very similar.

Figure 9: Benchmarking the innovation environment in the UK: 2020



Source: EU Innovation Scoreboard 2020.

Other international comparisons of innovation performance paint a slightly different picture and emphasise some of the relative strengths and weaknesses of the UK's innovation system. The 2020 Global Innovation Index places the UK 6th overall globally in terms of innovation inputs and 3rd globally in terms of outputs. These rankings depend strongly on the quality of infrastructure (ICT, physical infrastructure, 6th), creative outputs and intangibles (rank 5th) finance and competition (rank 5th). The UK performs more poorly on aspects of human capital and 'business sophistication'. In terms of human capital and R&D the rankings are: Education, 35th; Higher education 15th and R&D 9th.

Other complementary investments can also play an important role with R&D in shaping innovation outputs. Based on evidence from the UK Innovation Survey Turner and Roper (2020) find that investments in design, innovation related training, and the acquisition of advanced machinery all play a significant role in shaping firms' product and process innovation success. Other studies have also emphasised the mutually-reinforcing benefits of design investment and R&D as part of firms' innovation activity (Roper et al. 2016). Similar evidence relates to digital adoption and implementation and its role as an enabler and enhancer of firms' innovation capabilities (Bourke and Roper, 2017). Aspects of management and leadership quality in the organisation of work and innovation also play a critical role in helping firms to maximise the innovation benefits of R&D and other intangible investments (Kurzhals et al. 2020).

2.6 Inputs – overview

Levels of R&D spending in the UK lag significantly, and increasingly, behind that of our leading international competitors. These gaps in investment are large and cumulatively over the years will create an increasing divide between the knowledge base available in the UK and elsewhere. The gaps are evident both in total R&D spending and business R&D spending. Recent OECD figures, for example, emphasise that busines R&D as a proportion of GDP in the UK is around 0.95%, less than half of that in Sweden (2.0%), Germany (2.0%), Switzerland (2.2%), Japan (2.6%) and Korea (3.5%). Business R&D spending in China (1.6%) and Israel (1.8%) are also significantly above that in the UK[6]. Two other features of UK R&D spending stand out. First, it is notable that the UK is disproportionately reliant on R&D conducted in HEIs with limited direct spend within the

[6] Source: OECD Science and Technology Statistics, Data for 2017.

public sector. This creates challenges in developing strategic approaches to targeting national R&D investments at specific grand challenges or missions. Second, and reflecting the position in other European economies, there is a focus in the UK on applied research rather than more near-market experimental development. This may reflect the position of UK firms in global value chains with more near-market R&D being undertaken elsewhere closer to manufacturing processes.

Turning to complementary inputs, the EU Innovation Scoreboard suggests that among the EU countries, that Luxembourg, Denmark, the Netherlands and Sweden offer the most attractive innovation environments. These countries are open for cooperation with partners from abroad, researchers are well networked at international level, and the quality of research output is high. Each has a level of R&D investment significantly higher than that in the UK. In terms of linkages and collaboration – also key aspects of the NIS – Austria, Belgium, Finland and the Netherlands perform best among the European economies. The EU Innovation Scoreboard 2020 comments: 'Companies in these countries have more versatile innovation capabilities, as they engage in innovation partnerships with other companies or public-sector organisations. The research systems in these countries are also geared towards meeting the demand from companies, as highlighted by private co-funding of public research' (EU Commission, 2020). Other dimensions of the EU Innovation Scoreboard suggest other national strengths: Sweden for human resources; Denmark for finance and innovation-friendly environment; Germany for firm investment; and Luxembourg for intellectual assets.

3. PATHWAY COMPARISONS

Recent studies have suggested the notion of 'pathways' through innovation systems as a useful diagnostic and comparative framework (Shaw and Allen, 2015). For example, the commercialisation of university research through licensing provides a clear pathway from knowledge investments, through innovation to the creation of value for producers and consumers. Effective pathways of this type define an effective NIS, while blocked or weak pathways can cause systemic problems and weaknesses and poor system functioning. Unblocking pathways or strengthening weak pathways can improve system effectiveness with the potential for substantial gains if otherwise unexploited resources can be brought into play and potentially release (De Oliveira et al. 2020). In this section we compare the strength of system pathways in the UK using a range of international comparators depending on data availability.

3.1 Talent pathways

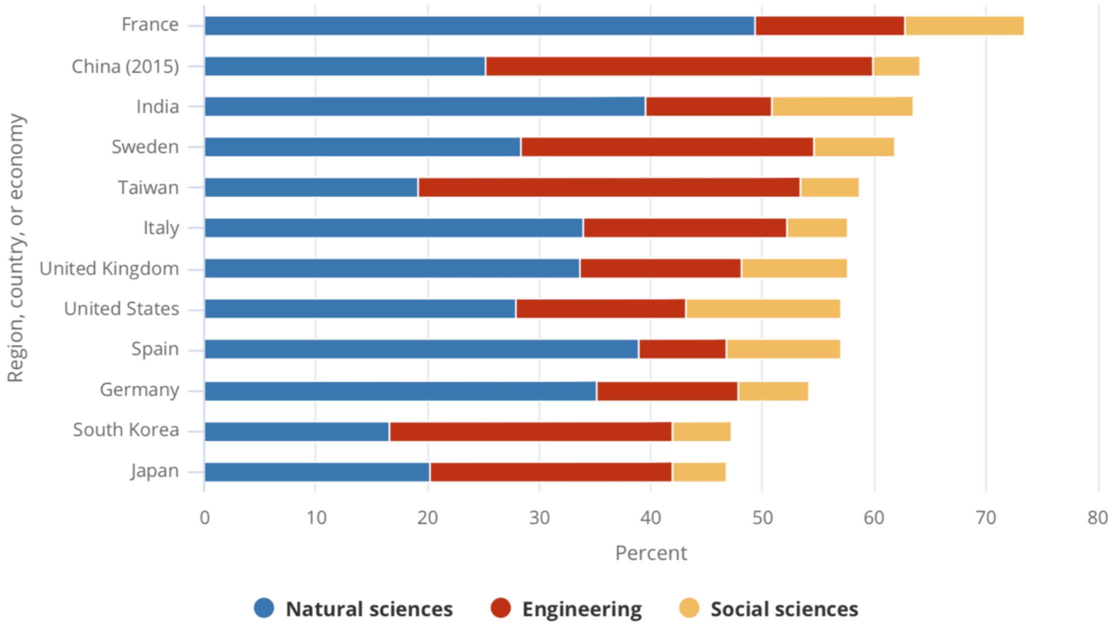
Skills or talent influence nations' innovation potential in a number of ways but here we focus on three main pathways:

- The direct contribution of science, technology, engineering and mathematics (STEM) researchers to the creation of new knowledge through R&D and innovation. A key indicator here is the number of STEM PhD students a country is producing.
- The role which STEM qualified staff play in the shaping the absorptive capacity of businesses, i.e. firms' ability to take on board new technologies and implement them within the firm.
- The broader contribution of skills to innovation which may involve both STEM and non-STEM skills. Here a key indicator is the proportion of firms reporting skills barriers to their innovation which provides a (negative) indication of whether skills are a barrier to effective pathways to innovation[7].

In terms of the spread of doctoral students across disciplines the UK profile has an emphasis on the natural sciences – the sciences and mathematics - and a slightly lower proportion of engineering PhDs than some other countries – particularly Japan, China and South Korea. The UK's profile is more closely aligned to that of Germany or the US (Figure 10). The Global Innovation Index 2020 ranks the UK in 6th place overall on innovation inputs but 20th on its specific metric related to R&D researchers per million population[8].

[7] Another useful approach here would be to compare vocational educational systems and outcomes. Nations' very different systems and qualification levels make such comparisons difficult (Kis, 2020)
[8] https://www.globalinnovationindex.org/userfiles/file/reportpdf/GII_2020_Full_body_R_58.pdf, p. 337.

Figure 10: Proportion of doctoral degrees in natural sciences, engineering and social sciences: 2016



Source: NSB Science and Engineering Indicators (NSB-2019-7), Figure 2-22. Original data from OECD.

Absorptive capacity in firms – their ability to access external knowledge for innovation and use this for their own commercial benefit – has been linked to the wider qualifications of the workforce beyond STEM skills. The Global Innovation Index 2020 (GII) ranks the UK 27th on knowledge absorption, well below its overall ranking of 6th on innovation inputs. This relatively low ranking is related to a weakness in research talent working in businesses (ranking 33)[9]. Other factors which feed into the relatively low GII ranking on knowledge absorption for the UK include: intellectual property payments (i.e. licensing), ranking 21st; high-tech imports, ranking 21st; ICT services imports, ranking 31st; and, FDI inflows, ranking 20th.

Figure 11 provides an indication of degree level qualifications among the population (bars) and among younger adults (25-34) (dots) in a range of countries. The UK compares

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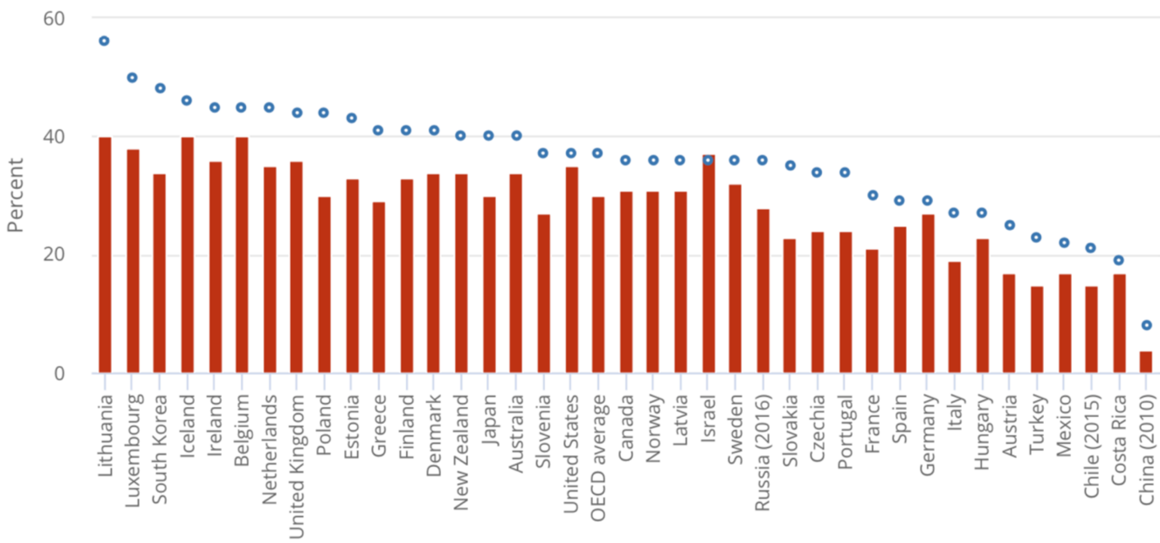
[9] https://www.globalinnovationindex.org/userfiles/file/reportpdf/GII_2020_Full_body_R_58.pdf, p. 337.

relatively well to many other countries in terms of both the proportion of younger adults with a degree and the overall proportion of the population with a similar qualification level. It is notable, however, that a number of countries with high levels of R&D investment – particularly South Korea – have a significantly higher proportion of graduates among younger population cohorts than older population groups.

Figure 11: Percentage of adults with degree or higher qualification: 2017



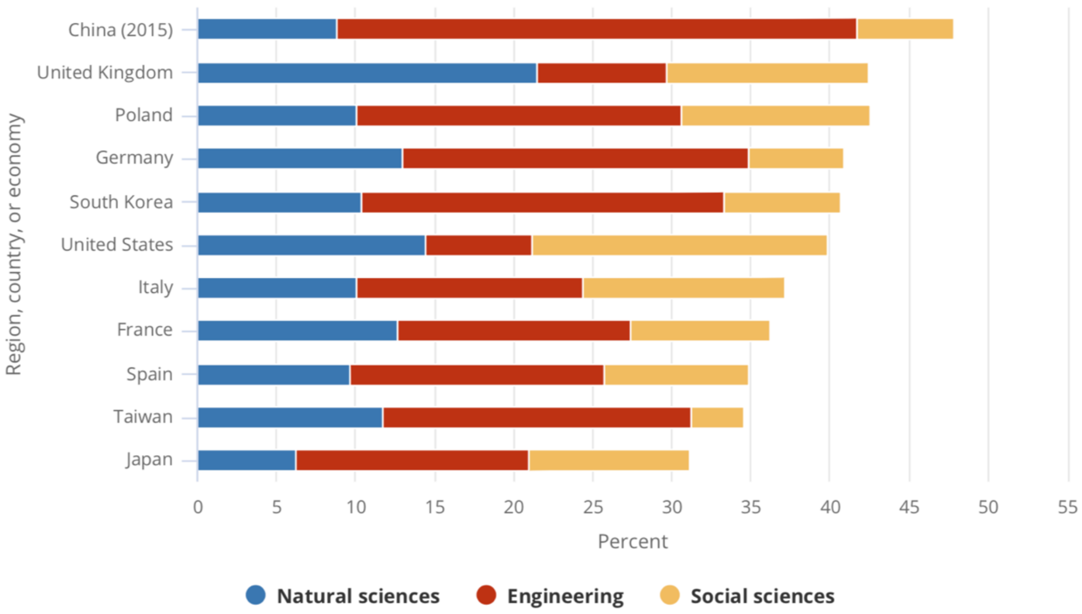
Source: NSB Science and Engineering Indicators (NSB-2019-7), Figure 2-18. Original data from OECD.

Looking in more detail at the composition of first degrees suggests that while the UK has a relatively high proportion of degrees in natural sciences the proportion of first degrees in engineering is relatively low by international standards (Figure 12). Many international competitors – notably Germany and South Korea – have significantly higher proportions of engineering first degrees than that in the UK. As a result, the Global Innovation Index 2020 gives the UK a relatively low ranking of 31 in terms of the proportion of graduates in science and engineering, compared to the UK's overall ranking of 6[10]. The lower proportion of

[10] https://www.globalinnovationindex.org/userfiles/file/reportpdf/GII_2020_Full_body_R_58.pdf, p. 337.

engineering graduates in the UK may also have implications for firms' absorptive capacity and their ability to translate externally acquired knowledge into innovation.

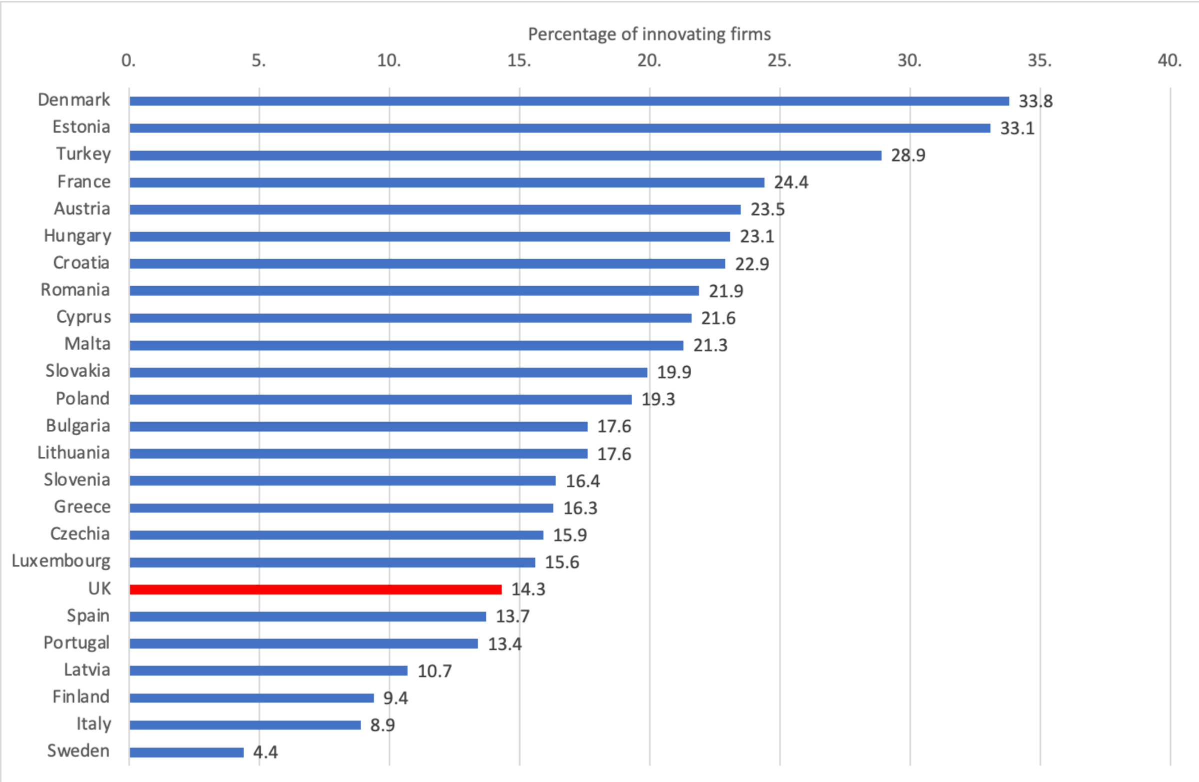
Figure 12: Composition of first university degrees: 2016



Source: NSB Science and Engineering Indicators (NSB-2019-7), Figure 2-20. Original data from OECD.

The role of skills in innovation is also reflected in the UK Innovation Survey which reports the proportion of innovating firms which identified skills as a barrier to innovation (Figure 13). The proportion of innovating UK firms identifying skill shortages as a 'high' barrier to innovation (14.3 per cent) was significantly lower than that in a number of competitor countries although information is unavailable for key comparator countries such as Germany and South Korea. It is important to remember, however, that the proportion of firms undertaking innovation in the UK is lower than that in many other countries (Figures 1 and 2) and that this UK Innovation Survey data (and the comparable EU figures) relate to firms with 10 or more employees. The implication is that where larger firms are innovating in the UK only around 1:6 see skills as a significant barrier to innovation. Skill gaps in the UK may be reducing overall levels of innovation, however, and we know very little about how skills and innovation are related in micro-businesses with less than 10 employees.

Figure 13: Percentage of innovating firms experiencing skill shortages



Sources: UK Innovation Survey 2019, Eurostat.

3.2 Finance pathway

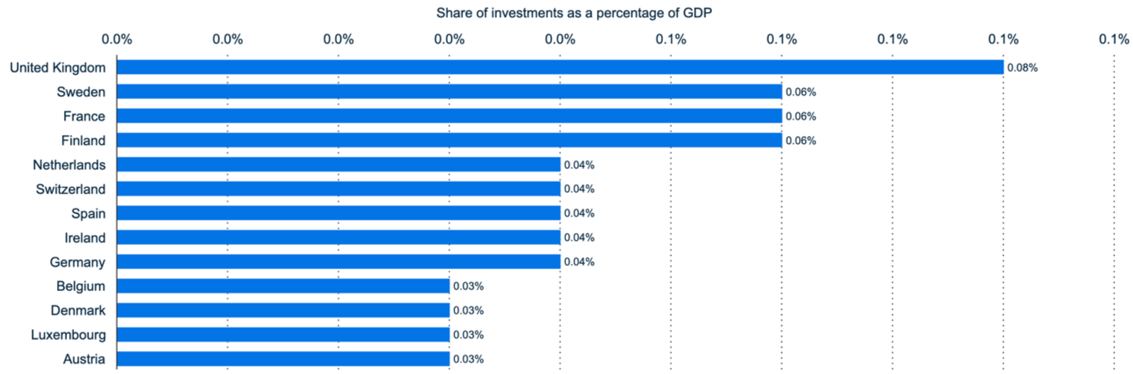
Finance plays a key role in facilitation business development of any sense and innovation is no exception. In this pathway the UK performs relatively well on a number of international metrics ranking 8th for credit availability and 5th on investment in the Global Innovation Index 2020[11]. In particular, the GII regards 'investment' as a UK 'strength' based on regulation around minority investors and the volume of venture capital deals. Here, we consider two pathways through which different types of finance can influence innovation. First, to facilitate commercialisation and spin-out activity in high-risk sectors the availability of early stage risk-capital is critical. In this respect how does the UK compare to reference countries? Second, as a broader indicator of the ease of accessing innovation finance for

[11] https://www.globalinnovationindex.org/userfiles/file/reportpdf/GII_2020_Full_body_R_58.pdf, p. 337.

existing firms we consider data from the UK innovation survey which captures the extent to which firms cite the cost and availability of finance as a barrier to their innovation activity.

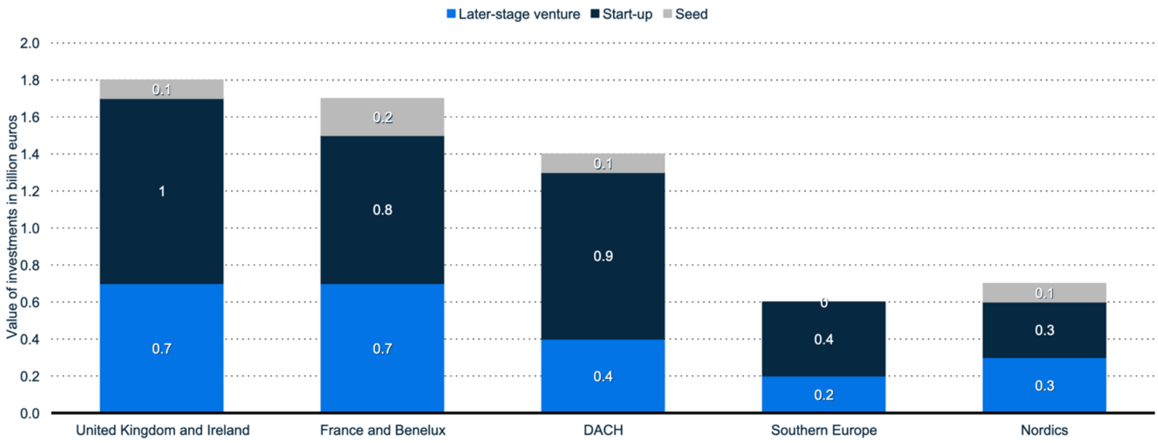
In terms of venture capital investments as a proportion of GDP the UK performs well relative to most other European economies (Figure 14): levels of venture capital investment in the UK in 2017 were around twice those in Germany, for example. In value terms, however, the bulk of the difference between the UK and other European economies comes in mid to late-stage investment rather than in early-stage risk capital (Figure 15). BCVA (2019, p. 33) provides detailed data on UK VC investments, suggesting both the diversity of sectors in which firms were investing and the rapid growth in investment in both construction and bio-technology and life-sciences between 2017 and 2019.

Figure 14: Venture capital investments as a percentage of GDP 2017 (selected countries)



Source: Statista 'Venture Capital Europe' based on data from Invest Europe, IMF. Note rounding of small figures mean that some countries are given equal proportions.

Figure 15: Value of venture capital investments by investment stage: 2017 (billion euros)



Source: Statista 'Venture Capital Europe' based on data from Invest Europe, IMF.

More generally, as in most innovation surveys the cost and availability of finance for innovation are the most commonly cited barriers to innovation activity. In the 2019 UK Innovation Survey 18.1-18.4 per cent of innovators cited finance as a 'high' barrier to innovation compared to 14.3 per cent citing skills limitations. Shortages of innovation finance were notably more common among smaller firms and among more capital-intensive manufacturing sectors. (Conversely skill barriers were more commonly cited by innovating firms in knowledge intensive services). (Source: UK Innovation Survey, Data Tables, 10a). This reflects both the nature of innovation activity in these sectors as well as the capital and human resource requirements involved.

3.3 Policy support pathway

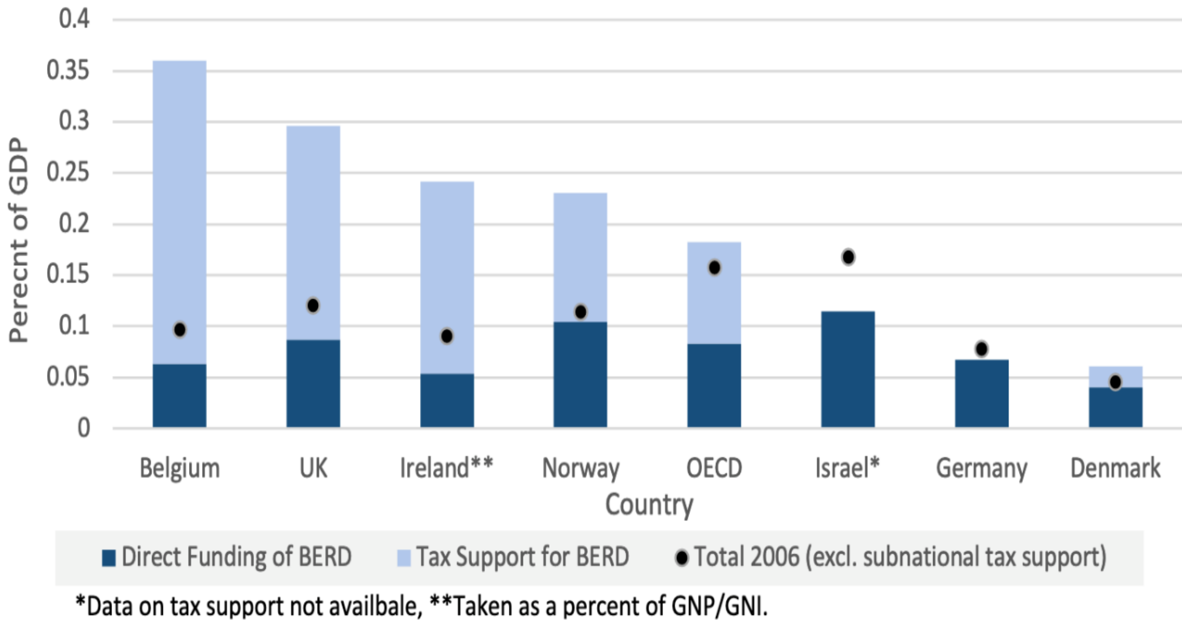
There is widespread evidence that direct policy support measures – e.g. grants, loans - to support firms' innovation can be positive and the UK has a generally well-developed set of such policy support measures (Lenihan et al. 2021). Evidence suggests that direct policy support through UKRI has a strong, significant and positive effect on firms' R&D investments and business growth (Scandura 2016; Vanino et al. 2019). In terms of direct policy support the UK has a comparable level of support to a number of reference countries as well as providing a significantly higher level of tax reliefs for R&D than some countries (Figure 16). This indirect support has grown in value significantly in recent years (Figure

17). Among comparator countries, Germany and Israel provided little or no support for R&D through the tax system in 2017, had broadly comparable levels of direct public support to the UK (as a percentage of GDP), but both have significantly higher levels of business R&D spend (Figure 5). While we lack firm specific evidence the high-level implication is that the degree of leverage or crowding-in achieved by UK support measures (both direct and indirect) for R&D is markedly lower than in both Germany and Israel. In other words, for each £1 of public investment in business R&D in Germany and Israel levels of matching private sector funding are more limited.

Some recent international evidence provides a potential (and partial) explanation. Recent evidence from a cross-country OECD study suggests that the effects of tax credits vary significantly by company size and sector. OECD (2020) drawing on the microberd project suggests the extent to which R&D tax credits either encourage or discourage private sector investments in R&D. Their analysis across OECD countries suggests that the additionality effects of R&D tax subsidies on R&D spending are strongly *negative* among large firms but strongly *positive* among smaller firms (10-49 employees). In other words, R&D tax credits are crowding-out (substituting) for private sector R&D spending among larger firms but strongly crowding-in (leveraging) R&D spending among smaller firms. The implication is that to the extent that they are supporting R&D in larger firms, increasing levels of R&D tax credits in the UK (and other countries such as Belgium) may actually be reducing levels of private sector R&D spend among larger firms rather than having the desired positive effect. In this respect it is notable that of estimated total cost of R&D tax credit of £5.1bn in 2017-18 around 46 per cent was claimed by larger firms and 54 per cent by SMEs[12].

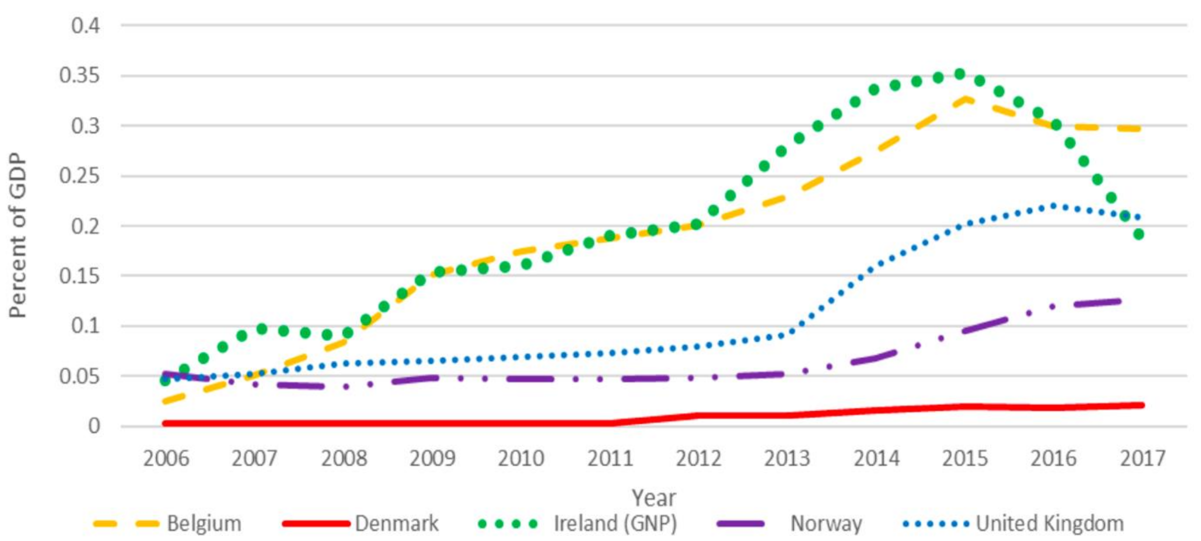
[12] Table RD2 R&D tax credits combined tables. Available at: https://www.gov.uk/government/statistics/corporate-tax-research-and-development-tax-credit.

Figure 16: Government support for R&D, 2006 and 2017



Source: Lenihan et al. (2021), Figure 2. Original analysis based on OECD data.

Figure 17: Indirect government support through R&D tax incentives for R&D as a percentage of GDP



Source: Lenihan et al. (2021), Figure 4b. Original analysis based on OECD data.

As Lenihan et al. (2021) detail, countries continue to differ significantly in the profile of direct and indirect support they offer to support firms' R&D and innovation. And, even within similar instruments such as R&D tax credits, eligibility and rates of support can vary considerably. There remains little consensus on the most effective policy-mix for supporting R&D and innovation although most economies now combine direct and indirect support measures. Firm differences and sectoral factors may also mean that similar policy initiatives 'land' differently with different types of firms and those in different localities (OECD 2020). Where complementarities between policy measures are observed, however, the effects are usually driven by smaller firms (Huergo and Moreno, 2017; Pless, 2019)[13].

Two other aspects of the policy-mix of direct and indirect innovation supports are worth noting. Indirect measures such as R&D-tax credits provide demand-led support for R&D and innovation with allocation depending purely on the eligibility criteria for firms and R&D costs. This type of measure has the potential advantage of not distorting market driven capital allocation mechanisms but has the disadvantage of not being targetable. On the other hand, direct policy supports such as grants or loans to support firms' R&D and innovation may be distort market prices but do provide a means of targeting support on specific national priorities.

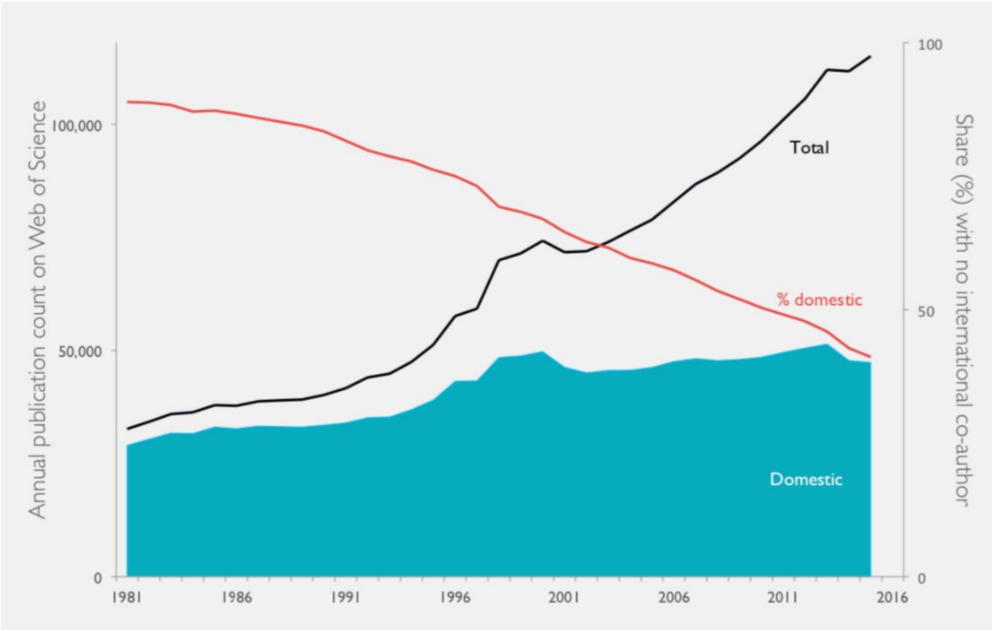
3.4 International and global pathways

International collaboration plays a key role in R&D and innovation, particularly where the focus is on more radical innovation. International collaboration also plays a significant role in firms' innovation activities and can – subject to some limitations - contribute to innovation success (Santamaria et al. 2021). Here, a number of indicators suggest the UK is in a strong position. The GII 2020 positions the UK in first place in terms of the presence of high spending, global R&D active companies and also intellectual property receipts as a percentage of total trade receipts. In terms of international collaboration in university research the UK also performs strongly with levels of international collaboration increasing sharply over the last two decades. Bibliographic analysis suggests the percentage of all research papers published solely by domestic (UK) authors has declined sharply over the

[13] See OECD (2020), pp 46-48 for a review of recent evidence on the policy mix.

last decade as the total volume of published output has increased (Figure 18). The red line in Figure 18 is the proportion of papers published purely by domestic authors.

Figure 18: Collaboration in UK research output



Source: Adams and Gurney (2016), Figure 1, page 2, based on analysis of Web of Science data.

The suggestion is that in terms of academic research at least the UK is well placed to take advantage of opportunities for international cooperation, a theme strongly supported by UKRI. The extent and scope of the UK's international research and innovation collaborations have been reshaped by Brexit and its impact on UK participation in research networks has, however, caused considerable concern[14]. Recent announcements on UK access and participation to future EU collaborative programmes will be welcomed by many in the research community and may help to sustain long-standing collaborative relationships.

[14] https://www.gov.uk/government/publications/international-research-and-innovation-collaboration.

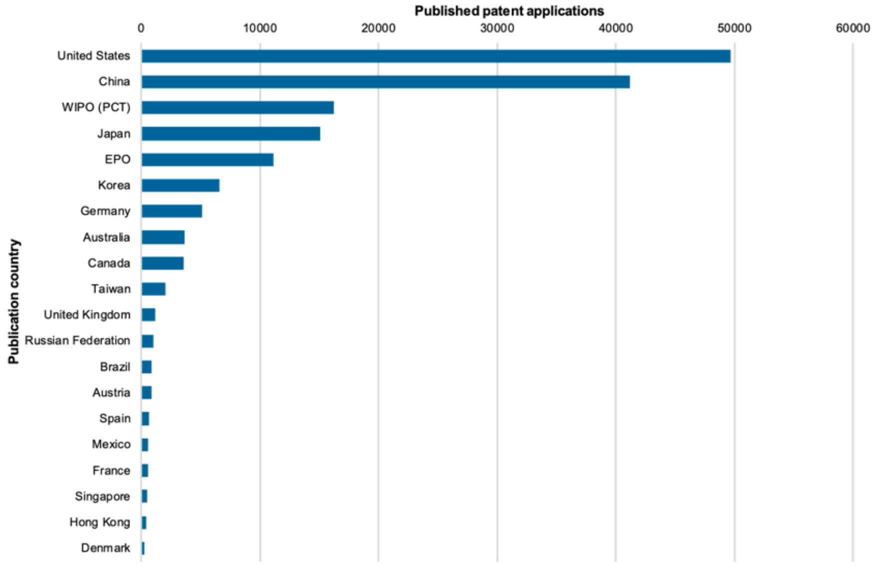
3.5 Technological pathways

Technological pathways are often complex but can be seen as how effectively an economy can take new technologies, commercialise them and maximise their value through widespread diffusion. Material and life-sciences technologies are critical here but perhaps the most significant technological advances reshaping markets and business models in our generation are those linked to digitalisation and Industry 4.0. In this section we therefore focus on how the UK has fared in developing, commercialising and diffusing digital technologies with a particular focus on artificial intelligence (AI) due to its potential impact on employment and productivity across almost all sectors of the economy.

Digital discovery in the form of patent applications by country are summarised in Figure 19. This covers the period from 1998-2017 and suggests that in terms of AI the number of patent applications in the UK is lower than that in Germany, Australia and Canada, with China and the US having a significant lead[15]. This pattern is largely replicated in terms of applicants and inventor locations. It is notable too that none of the top 20 AI patenting organisations internationally are based in the UK (Figure 20) with the list dominated by firms and other organisations in the US, China, Japan, Germany and Korea.

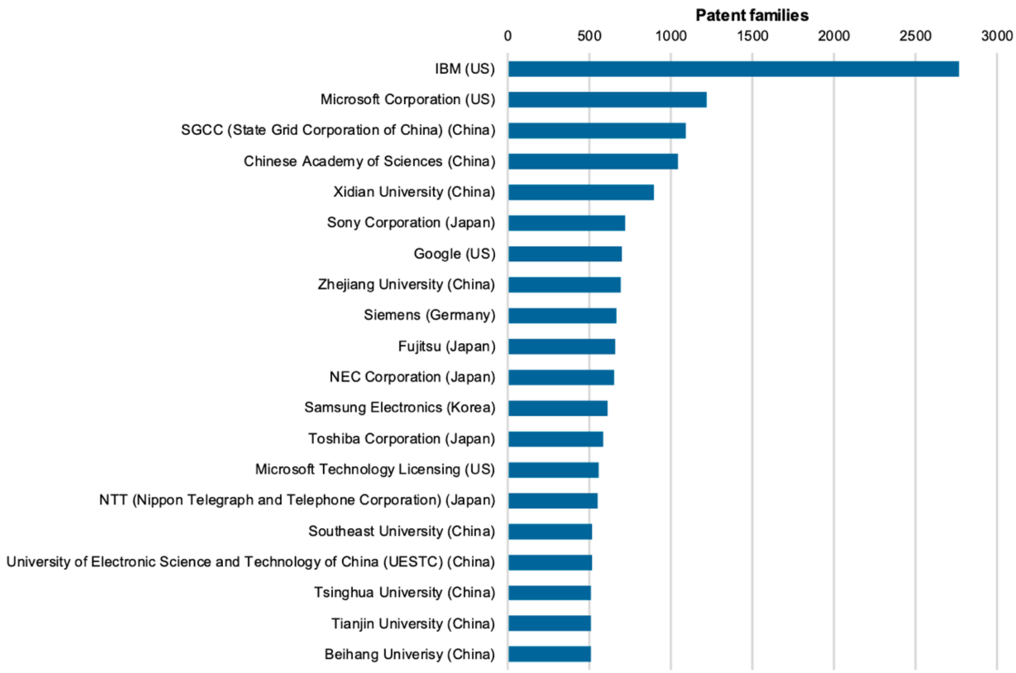
[15] Note however that these figures cover the period from 1998-2017 and do not reflect the rapid development of the AI sector in China in more recent years.

Figure 19: AI patent applications by country: 1998-2017



Source: IPO (2019), Figure 2.

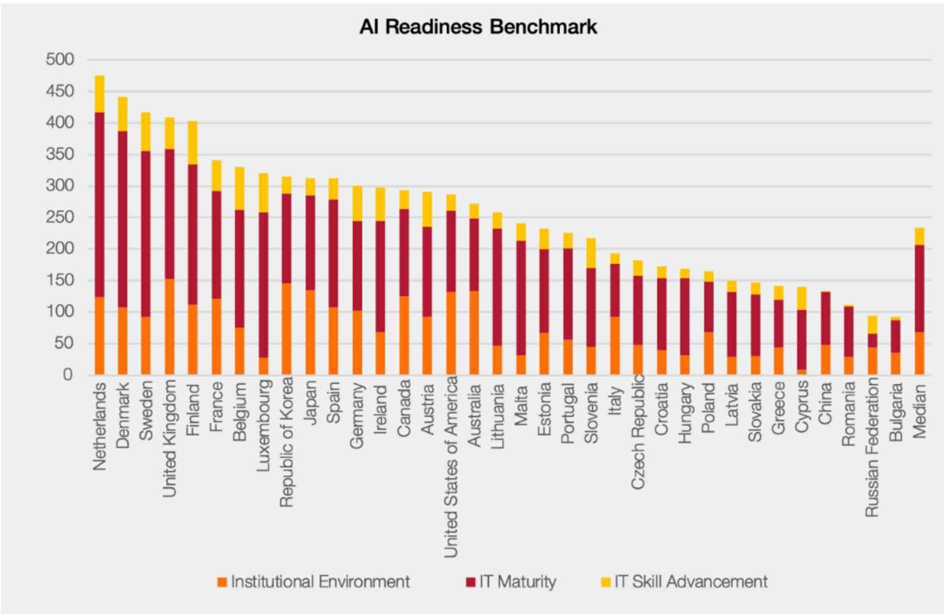
Figure 20: Top applicants for AI patents: 1998-2017



Source: IPO (2019), Figure 6.

The benefits of technologies such as AI and Machine Learning only become evidence once these technologies diffuse among the population of firms. Here, the issues involved are multi-dimensional involving aspects of skills, IT use by firms and aspects of market supply. Cap-Gemini have developed a composite measure – their AI Readiness Benchmark – which endeavours to capture each of these dimensions. Based on a range of statistical and other international comparisons, this places the UK strongly relative to other comparator economies, although the degree of IT maturity is compensated by a relatively high level of institutional capability (Figure 21).

Figure 21: Cap Gemini AI Readiness Benchmark



Source: Cap Gemini (2020), Figure 1.

In terms of technology pathways this data on AI illustrates the challenges facing the UK in establishing a position of global leadership. The scale of AI investments in other countries – particularly larger economies such as the US and China – are challenging as are the lack of UK organisations among the top patentees.

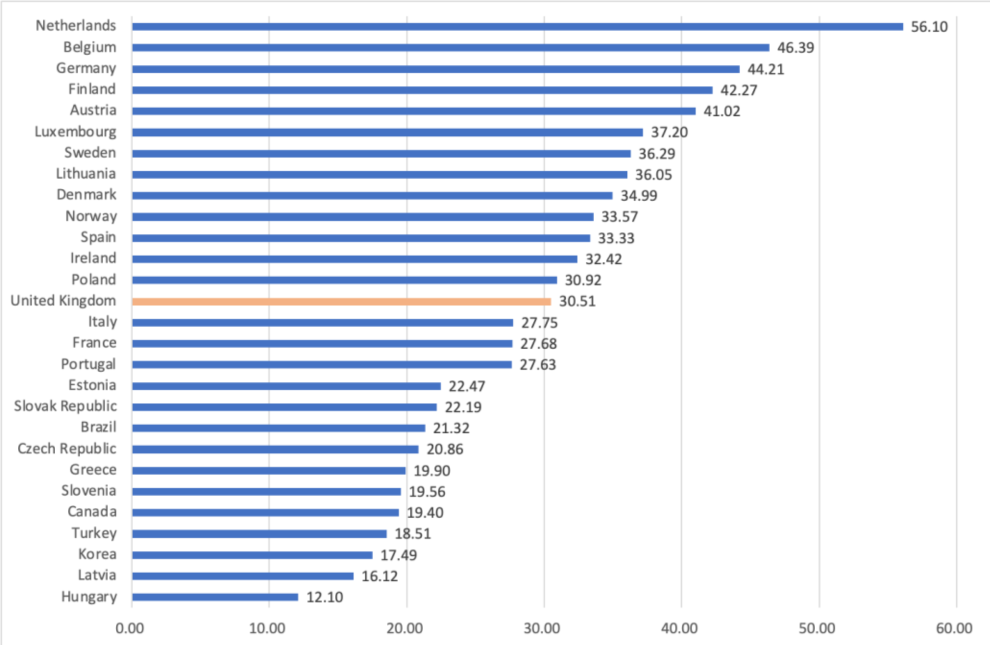
3.6 Pathways to diffusion

Maximising the social benefits of innovation requires their widespread adoption by users whether firms or households. In academic studies firms' absorptive capacity is typically related to skill levels – particularly graduate skills – and firms' in-house R&D capacity but definitions and measures vary widely (Song et al. 2018). Both are thought to be important in helping firms to identify, understand and usefully implement new technologies or ideas. In the Global Innovation Index (GII) the UK firms' knowledge absorption capacity is one of the lowest ranked elements of the UK's profile – ranked 27th overall compared to the overall rank of 6th for the whole UK innovation system[16]. Arguably this limited absorptive capacity may be one explanation for the long-tail of less productive firms identified in the UK. Higher levels of technical and organisational innovation – reflected in the adoption of management practices - and digital adoption in these firms would positively impact their productivity.

OECD data provides an indication of UK adoption of a range of digital and production technologies. Figure 21 provides an illustration of the UK's position in adoption of CRM software – a type of generic application applicable to firms across a wide range of industries. Levels of adoption of other types of digital application captured in the OECD data (e.g. robotics, EDI) would suggest a rather similar picture. As the GII knowledge adoption would suggest, UK firms lag those in a number of leading economies many of which are also those with strong R&D investment and innovation profiles. A notable exception here is Korea where adoption of CRM software is significantly lower than that in the UK perhaps reflecting the lack of innovation in many smaller Korean firms noted earlier (Figure 22).

[16] https://www.globalinnovationindex.org/userfiles/file/reportpdf/GII_2020_Full_body_R_58.pdf, p. 337.

Figure 22: Adoption of Customer Relationship Management (CRM) software: 2019



Source: OECD Statbase

While policies to promote leading-edge innovation are well established in the UK, policies to promote the diffusion of management practices and digital diffusion in the UK are largely recent introductions - e.g. Made Smarter, Be the Business – and remain either localised or small scale interventions. Help2Grow Digital announced in the 2021 budget is a more recent addition to this limited suite of policy interventions. Data on the diffusion and implementation of new technologies is also lacking, particularly for micro-businesses. Arguably the UK's relatively poor performance in the GII 'knowledge absorption' dimension and evidence from the OECD ICT adoption studies provides a strong argument for developing both data resources and policy in this area.

3.7 Pathways overview

In international terms the UK performs well in terms of natural sciences PhDs but has a significantly smaller number of engineering PhDs than that in some other leading competitor economies (Japan, South Korea). The proportion of the workforce with degree level qualifications in the UK is also high by international standards, contributing to firms' absorptive capacity. As with PhDs, however, the proportion of UK undergraduates with engineering qualifications is low by international standards. Data from the UK Innovation

Survey suggests that only around 1:6 UK innovating firms report experiencing skill challenges, however, a significantly lower proportion than in many other EU economies. Skills represent an on-going challenge for all economies, and are key to both knowledge creation through R&D and firms' ability to adopt new technologies. Compared to our international competitors, engineering pathways in the UK at both undergraduate and PhD level seem narrow and the Global Innovation Index data exposes particular issues relating to low levels of in-firm research skills in the UK.

Finance is another critical aspect of the innovation eco-system and the UK again performs well in terms of the venture capital availability although any international advantage is less clear in terms of early-stage finance. EU innovation scoreboard comparisons point to the enterprise finance system in Germany as providing more plentiful and patient capital for mainstream lending. Finance barriers are regarded by UK innovators as marginally more important than skills barriers.

UK policy supports for R&D and leading edge innovation are generally well developed providing a range of direct and indirect (tax) supports. These are generally effective in supporting enhanced growth among recipient firms (Vanino et al. 2019). Internationally, overall levels of support as a percentage of GDP are relatively high in the UK despite relatively low levels of business and overall R&D spend. One implication is that the degree of leverage or crowding-in achieved by UK support measures (direct and indirect) for R&D is markedly lower than in both Germany and Israel. Recent OECD evidence suggests this may be a consequence of crowding-out of private funding in larger firms by R&D tax credits, UK spending on which has increased sharply in recent years (OECD 2020).

Evidence from the Global Innovation Index suggests that the capability of UK companies in technology adoption may be weaker than the ability of leading-edge innovators. OECD data on ICT adoption confirms this picture and positions the UK someway behind leading competitors internationally in terms of ICT adoption. Leading adopting nations also tend to be leading innovators. Policy development to promote the diffusion of innovation seems a key priority to maximise the social benefits of innovation to all parts of the UK.

In terms of international and global knowledge pathways UK researchers seem open to collaboration and the share of research undertaken with international partners has increased sharply. The suggestion is that in terms of academic research the UK is well placed to take advantage of opportunities for international cooperation, a theme strongly supported by UKRI. Less evidence is available on firms' international collaboration as part of their innovation activity and how this influences subsequent innovation success.

Turning to technology pathways, and focusing on digital technologies, it becomes obvious that the share of global patenting undertaken in the UK is relatively limited. In terms of AI patents, global activity is dominated by China and the US with a number of other smaller economies also out-pacing the UK. Levels of ICT adoption in the UK also lag other international competitors.

4. LOOKING TO THE FUTURE – INCREASING INVESTMENT, STRENGTHENING PATHWAYS

Globally, levels of R&D investment have increased sharply over the last decade with a number of new countries particularly in South-East Asia rapidly developing their domestic capabilities. In some democracies – Korea, Israel, Austria – increases in R&D spend have been a central and sustained element of national policy agendas. In Germany, the Pact for Research and Innovation provides a strong example of the type of long-term and sustained policy commitment which is necessary to build sustained R&D and innovation capability. Originally launched in 2005, the Pact guarantees basic funding for the German Federal and Lander research institutes and the Deutsche Forschungsgemeinschaft (DFG), the main public funder for research in higher education. Now extended to 2030 the Pact provides a regular budget increase of 3 per cent pa for research organisations along with budget certainty subject to organisations meeting agreed quality criteria.

Other economies – most notably China – have structured national resources towards particular R&D missions around aspects of digital and low-carbon technologies. These changes are leading to significant shifts in the R&D landscape: 'The US continues to lead globally in R&D expenditures, S&E doctoral-level degree awards, and production of highly cited research publications … As more countries around the world develop R&D and human capital infrastructure … the US is playing a less dominant role in many areas of S&E activity' National Science Board (2020), p. 16). Static levels of investment in R&D in the UK over the last decade mean that there is now a large and increasing gap in R&D investment between the UK and its international competitors. Significant qualitative differences also exist between the UK and its competitors with R&D in the UK concentrated disproportionately in higher education and in 'applied' R&D.

As with R&D, almost all OECD economies have sharply increased the proportion of the workforce which have both graduate and postgraduate qualifications in recent years. Here, in quantitative terms the UK has a stronger profile but significant compositional differences again exist with a focus among South East Asian economies and other countries such as Germany on engineering, something which is comparatively under-represented in UK PhDs and undergraduates. Other supporting elements of the innovation system vary in strength between different countries. In a European context this identifies Sweden for human resources; Denmark for finance and innovation-friendly environment; Germany for firm investment; and Luxembourg for intellectual assets. The UK has strengths in the international orientation of its R&D activity and, compared to other European economies, the availability of risk capital.

Innovation systems thinking also emphasises the role of policy making for innovation both in shaping the environment – complementary inputs – in the innovation system and directly supporting firms' innovation activities. In policy terms, the UK provides relatively high levels of support for innovation among OECD economies despite relatively low levels of overall R&D spend. The implication is that levels of additionality or crowding in from UK policy support for R&D may be lower than competitor economies such as Germany or Israel. This may reflect the emphasis in the UK on R&D tax credits which, recent evidence suggests, may crowd-out rather than crowd-in private funding in larger firms (OECD 2020).

In terms of international and global knowledge pathways UK researchers seem open to collaboration and the share of research undertaken with international partners has increased sharply. The suggestion is that the UK is well placed to take advantage of opportunities for global cooperation although uncertainties related to Brexit remain an issue. Turning to technology pathways, and focusing on digital technologies, global activity is dominated by China and the US with a number of other smaller economies also out-pacing the UK. OECD evidence also suggests that the adoption of digital technologies and innovation in UK firms lags other international competitors and policy to support diffusion may therefore be a future priority.

5. DATA LIMITATIONS

Compiling this review has highlighted a number of limitations in the existing set of UK data resources related to R&D and innovation. First, there is some uncertainty about the true level of R&D investment in the UK illustrated by the growing gap between the HMRC and ONS estimates. Both measures are compiled in very different ways and measure slightly different concepts so differences in levels might be anticipated. The growing gap between the indicators is perhaps surprising, however.

Second, the lack of data on innovation activity in micro-businesses (with less than 10 employees) is also disappointing and means we have little consistent view on how innovation in this group of firms is changing or responding to market conditions. This is relatively easily addressed. In Germany, for example, the Community Innovation Survey covers firms with 5 or more employees rather than the lower limit of 10 employees in the UK.

Third, while the ONS E-commerce and ICT survey provides useful information on the purchase of a range of digital technologies we have little consistent data on the implementation of digital technologies and their impact on businesses. A better understanding of how digital technologies are becoming embedded in management and work practices seems important as these technologies become increasingly influential.

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