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Innovation for a strong and sustainable recovery

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Innovation for a strong and sustainable recovery

CEP COVID-19 ANALYSIS

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Summary and recommendations

- In the recovery from Covid-19, innovation and diffusion will be key to addressing several structural challenges facing the UK economy. These include improving the UK's longstanding poor productivity performance, addressing largescale disparities across and within regions, and re-orientating the economy to reach net zero emissions of greenhouse gases by 2050.

- There is a strong economic rationale for policy to increase the amount of innovation and influence its direction to help address key societal challenges including Covid-19 and climate change.

- The UK's innovation system can play a key role in addressing these global challenges, and investment in these areas can also help the UK economy pivot towards a sustainable growth pathway with opportunities spread across the country.

- Despite its high-quality research base, the UK tends to underinvest in innovation and its diffusion relative to its international peers. This has prompted several recent policy initiatives, including the commitment to achieve 2.4% of GDP being spent on R&D by 2027.

- Private sector investment in innovation tends to suffer in downturns and public budgets are under pressure due to the pandemic. This makes achieving the R&D target, via a combination of public and private investment, all the more challenging. In response, government will need to make informed decisions on where support should be channelled.

- We analyse patent data to identify areas where the UK has comparative advantage in innovation, highlighting technologies that are relevant for two key societal challenges: net zero and dealing with the pandemic. Within these the UK has a comparative advantage in ocean and wind energy; and in technologies relevant for tackling Covid-19, such as vaccine development.

- Using a new methodology which estimates the expected 'national' returns from innovation – including private returns as well as direct and indirect knowledge spillovers – we find that Covid-related technologies generate among the highest returns of any technology area. We also find that returns are high for both wind and ocean renewable energy technologies. Given patterns of regional specialisation, investment in clean technologies in particular could help deliver 'levelling up'.

Further economic and societal benefits are expected to flow from building resilience to climate change and future pandemics, and these are not captured in our estimates.

- Despite the potential economic advantages in 'clean' technologies, strong inertia in behaviours and processes and high switching costs make it difficult to shift the innovation system from incumbent dirty to clean technologies without direct policy intervention. This highlights the importance of policy credibility to guide investor expectations. Boosting innovation and steering its direction requires a combination of a coherent long-term vision and complementary short-term delivery mechanisms to create new markets.

- The government's 'Ten Point Plan for a Green Industrial Revolution' provides a clear signal for future investment and growth. This needs accelerating and complementing with consistent and long-term innovation and industrial policy to facilitate transition to sustainable business models, investments and related innovation. To help achieve a step change in the scale of R&D investment and to direct innovation towards decarbonisation and other key societal challenges policymakers should:
  - Enhance incentives for investment in innovation, in particular in areas aligned with key societal missions such as net zero
  - Develop locally appropriate innovation policy informed by analysis of innovative strength and the likely spatial impacts of support for R&D and diffusion
  - Re-emphasise and strengthen the UK's Industrial Strategy, bringing innovation policy together with the broader, complementary policies required for a sustainable and inclusive recovery and providing clear and long-term direction to the private sector
  - Maintain international openness and competitiveness of the UK's innovation system through close alignment and continued collaboration with the EU's innovation system

Introduction

Innovation and its diffusion have already played an important role in the global response to the pandemic; with rapid progress on the development of Covid-19 vaccines and treatment, and more generally via the increased adoption of digital technologies that have allowed businesses and individuals to adapt to social distancing requirements.

In the economic recovery, innovation and diffusion will be key to addressing a number of structural challenges facing the UK economy which were already present before the pandemic struck. These include the need to improve the UK's longstanding poor productivity performance, to address largescale disparities in economic performance across and within regions, and the need to re-orient the economy towards reaching net zero emissions of greenhouse gases by 2050. Among advanced economies, the UK is not alone in facing the challenges of poor aggregate productivity growth since the financial crisis and largescale regional inequalities, but these challenges are particularly pronounced here (for recent discussion, see Valero and Van Reenen, 2019).

The broad principles around strategy, investment and policy for a sustainable and inclusive recovery are set out in Stern et al., (2020) which explains how support for innovation must be accompanied by complementary investments in infrastructure, skills, natural and social capital. In a subsequent paper, Unsworth et al., (2020b) set out evidence on how a series of proactive, coordinated net-zero-aligned investments can generate new jobs in the short term, and broader economic opportunities into the medium to longer term. This paper builds on these previous analyses with an explicit focus on innovation.

There is a strong rationale for policy to both increase the amount of innovation in the economy, and influence its direction towards helping to solve key societal challenges. The market failures that are often targeted by government support for research and development (R&D) and innovation activities are well documented (see, for example, Bloom et al., 2019). In particular, the existence of spillovers is a key justification for public support for R&D. The evidence suggests that directing innovation towards clean technologies is likely to generate high economic benefits in terms of productivity growth and future competitiveness. Previous analysis of patents in the energy production and transport sectors has shown that knowledge spillovers for clean innovations are over 40 per cent greater than in conventional technologies (Dechezleprêtre et al., 2013). Productivity augmenting clean innovations are particularly effective at generating economies of scale in production and discovery, as witnessed in the falling costs of renewable energy, battery storage and electric vehicles in recent years. A body of literature on endogenous directed technical change (stemming from Acemoglu et al., 2012) highlights the need for policies to redirect innovation from 'dirty' to the 'clean' sectors in order to encourage the reduction of emissions (Aghion et al., 2019). Without intervention, inertia in behaviours and processes and high switching costs make it initially hard to shift innovation from incumbent dirty to clean technologies. There are therefore strong arguments supporting a 'mission-driven' innovation policy (Mazzucato, 2018) that can create and shape demand for innovative solutions to urgent societal challenges.

In the case of innovative zero-carbon goods and services, the UK can continue to build on its strengths via consistent policies and incentives on both the demand and supply side, and benefit from growing global demand into the future (Rydge et al, 2018). In a previous paper, we provide more details on specific areas of opportunity and how policy can maximise these with respect to goods and services relating to zero-carbon passenger vehicles (Unsworth et al., 2020a). Faced with technological uncertainty, and difficulties determining the specific areas where government support (via direct investment or incentives) will generate the highest payoffs, there is merit in granular analyses of

innovation data to help shed light on economic potential. This can inform a 'portfolio approach' which targets support towards areas where there is evidence of potential for UK innovative activity to successfully contribute to solving particular problems. In some areas, the UK might be more likely to benefit from the adoption of innovation which takes place elsewhere. Similar arguments apply across other technology areas (e.g. pharmaceuticals or biotech) where the UK has comparative advantage, where the social benefits can be large, and where global demand is likely to grow.

Strong and timely action is required given the scale of the economic shock caused by Covid-19, and the urgent need to build resilience to climate change and future pandemics The evidence from previous crises suggests that innovation in firms is likely to suffer (Roper and Turner, 2020), suggesting an even more important role for government support and incentives for innovation in the short to medium term. Nonetheless, the economic shock wrought by the pandemic is likely to prove a turning point in the allocation of investment towards key assets necessary to secure a productive, resilient and sustainable recovery (Hepburn et al., 2020). Covid-19 creates new risks, but also opportunities as behaviours change and new technologies are adopted. With a clear credible vison, and supportive policies to guide investor expectations, there is now amplified scope to invest in a more efficient, innovative and prosperous future (Zenghelis and Rydge, 2020).

This paper is structured as follows. In Section 1 we provide an overview of the UK's innovation landscape, with a summary of the UK's relative performance in terms of generating new innovations, and the diffusion of these across the economy. In Section 2, we present some new evidence on the UK's relative innovative strengths based on patenting across broad technology categories. Here we highlight innovation in categories that are relevant for addressing two key societal challenges faced today: 'clean' technologies which will be key to meeting net-zero commitments and which previous research has shown generate particularly high spillovers; and some technologies which are relevant for tackling both Covid-19 and potential future pandemics. In this category we consider innovations that can address the health impacts of Covid-19, such as vaccines; and innovations which help the economy to cope with the pandemic, such as remote working technologies. We show that the UK has a comparative advantage and generates strong spillovers in a number of relevant clean and Covid-related technologies (and broader technology classes) and that innovation in these areas is occurring across the country. We conclude with implications for innovation policy and industrial strategy going forwards.

1. The UK's innovation landscape

The UK has a strong research base, but tends to underinvest in innovation

The UK has consistently performed well relative to other comparator countries with respect to its research quality and impact (BEIS, 2019): and it is well-known that the UK punches above its weight in this regard, being home to less than 1% of the world's population but accounting for 14% of the most highly cited academic publications.[1] The UK's universities are a key asset in the UK's innovation system – a higher share of research takes place in UK universities relative to its international peers.[2] However, despite their strengths, UK research universities face a number of risks.

There are signs that UK universities have been losing comparative advantage in recent years (Hall, 2020), which may relate to rising international competition and the impact of Brexit-related uncertainty. These challenges have been exacerbated by Covid-19. Falling enrolments from international students

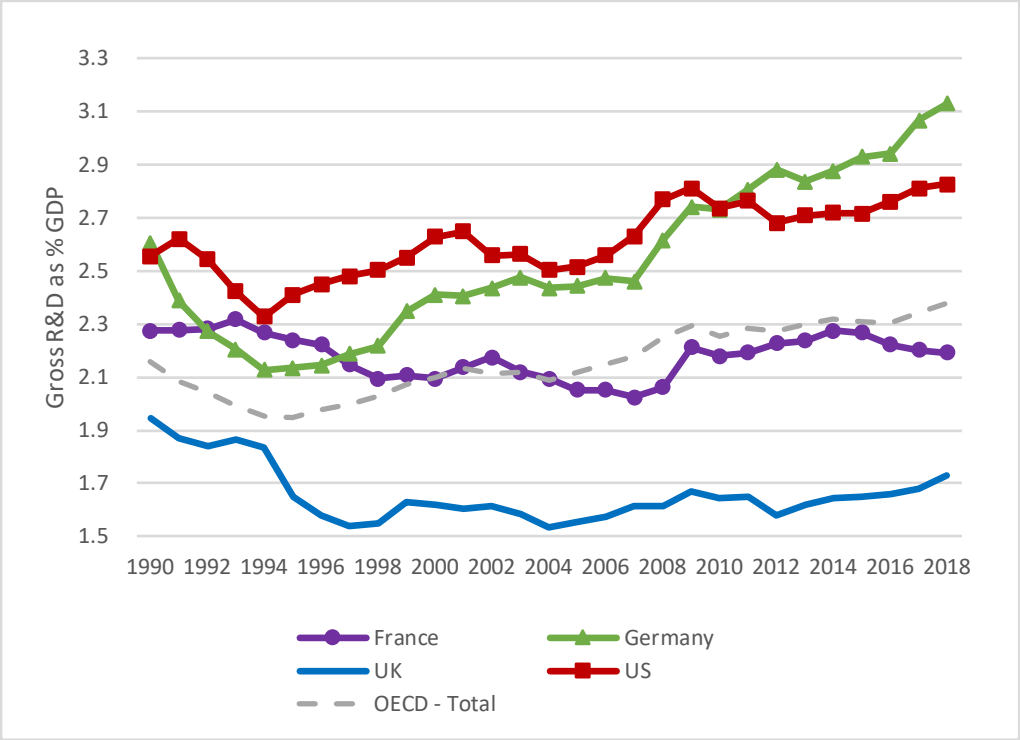
[1] On this measure China has recently overtaken the UK in second place to the United States (BEIS, 2019).

[2] According to the OECD MSTI database, in 2018 nearly 24% of UK gross expenditure on R&D was performed in the HE sectors, compared with 18% in Germany, 21% in France and 13% in the United States.

have disrupted university income streams (IFS, 2020) at a time when the institutions have had to invest additional time and resources restructuring courses in response to the pandemic.

Despite the UK's strong research performance, investment in innovation had been consistently lower than its peers, and there are well-documented issues with respect to commercialisation (see for example, LSE Growth Commission, 2013 and Dowling Review, 2015). In terms of R&D spending, a standard measure of innovation input, the UK's gross investment (both public and private) has been lower than its main peers as a share of GDP (Figure 1).

Figure 1: Gross R&D as a percentage of R&D



Note: Gross Domestic Expenditure on R&D (GERD) as a percentage of GDP, OECD MSTI, data extracted 19 November 2020

It is important to note however that the UK does better when comparing intangible investments, largely reflecting the UK's strengths in services. Over the period 2000-13 the UK had one of the highest rates of investment in intangible assets as share of GDP in the EU-14, at 9% of GDP, second only to Sweden (Corrado et al., 2018).

With respect to patenting, a standard measure of innovation output, while the UK displays international comparative advantage across a number of technologies (see Section 3), it is ranked 15th globally in terms of total patents normalised by population.[3]

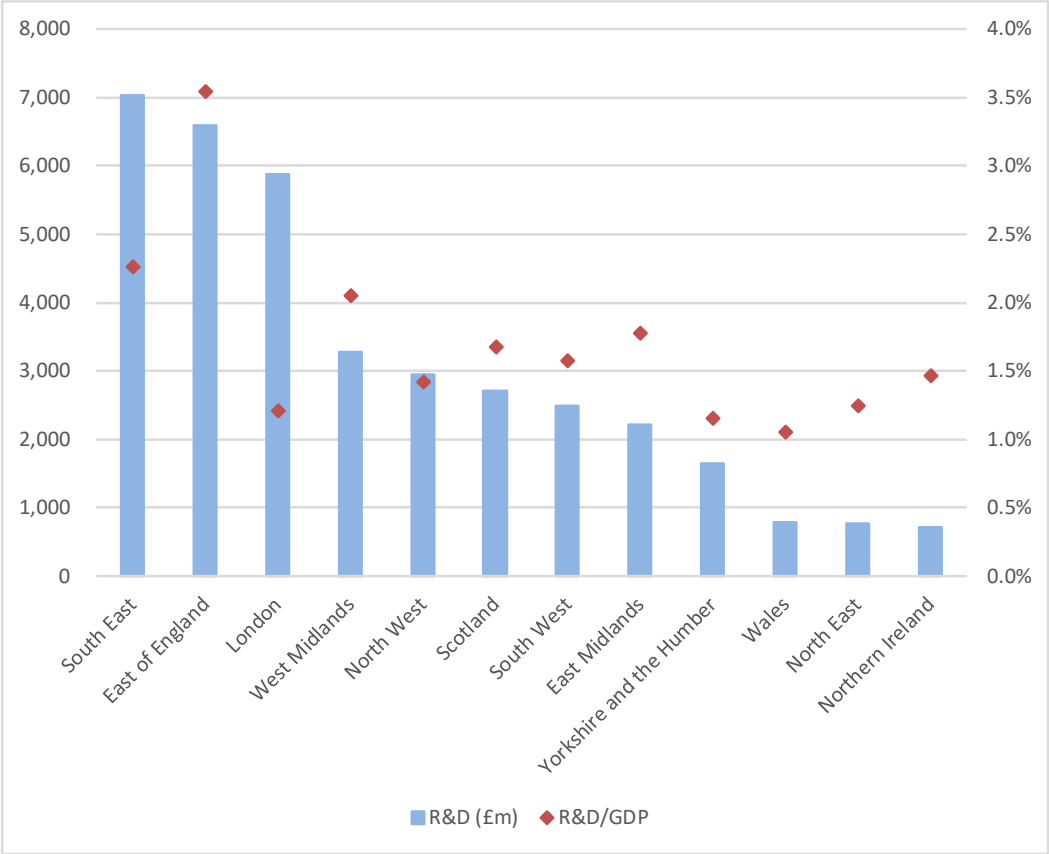
Business-university collaborations remain challenging to facilitate, with a need to better understand the complex barriers to collaboration and the policies which can encourage it (OECD, 2019). And on the

[3] See analysis by the World Intellectual Property Organization at https://www.wipo.int/edocs/pubdocs/en/wipo_pub_941_2019-chapter1.pdf

demand side, innovative firms have long faced challenges accessing finance for R&D activities (LSE Growth Commission, 2013, 2017).

In addition, the UK's research and innovation activity is regionally concentrated- in particular within the 'Golden Triangle' between Oxford, Cambridge and London. Figure 2 shows that, in absolute terms, over half of UK R&D expenditure takes place in London, the South East and East of England, and R&D represents the highest share of GDP in the East (for more discussion and maps at a more granular level, see Bernick et al., 2020). A map showing the spread of patenting across Great Britain is provided in Figure 5 (panel A). Again, on this measure of innovation 'output' there is a clear concentration of activity in the South East, East of England and London.

Figure 2: R&D Expenditure in the UK's regions (2018)



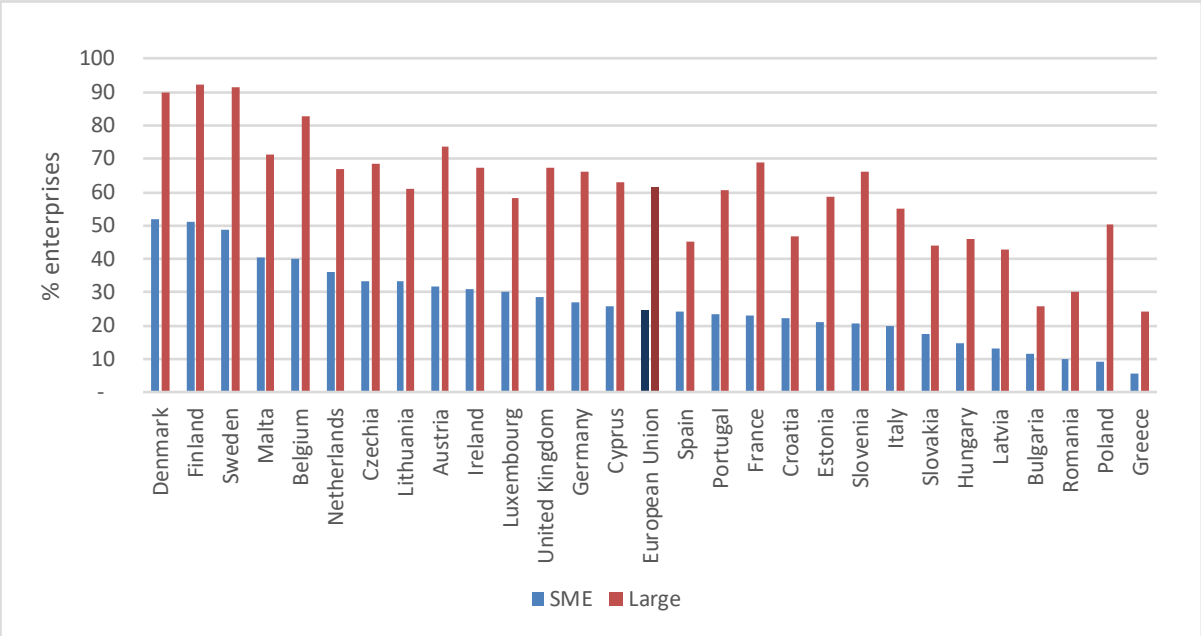
Note: Authors' analysis based on aggregates sourced from the Office for National Statistics. R&D data: 'Country and Regional breakdown of expenditure on R&D in the UK by sector of performance', published 2 April 2020. Regional GDP data sourced from 'Regional economic activity by gross domestic product, UK: 1998 to 2018'.

Recognising the need for greater support for innovation activity, in 2017, the government made a commitment to achieving 2.4% R&D as a share of GDP by 2027. The recent UK R&D roadmap sets a long-term vision for the UK to become a 'science superpower', and a new UK R&D Place Strategy linking research and innovation to broader governmental objectives such as the 'levelling up' agenda and the context of recovery from Covid-19 is forthcoming.

The UK lags behind many of its comparators on technology adoption

A key factor holding back productivity growth in the UK has been the limited diffusion of existing productivity-enhancing technologies and practices, in particular amongst the 'long tail' of UK SMEs. According to the World Economic Form World Competitiveness report, WEF (2019), in the UK 'ICT adoption, while increasing, remains low by OECD standards: the country ranks 31st globally and only 16th in Europe, with a score of 73.0, which is 20 and 15 points lower than the scores of Korea and Sweden, respectively'. Consistent with this, statistics compiled by the European Commission's Digital Scoreboard show that digital intensity amongst UK enterprises is middling relative to EU countries, though larger firms do relatively better than their smaller counterparts (Figure 3).

Figure 3: Enterprises with High Levels of Digital Intensity, by Size (2019)



Note: Data extracted from European Commission, Digital Scoreboard; and based on Eurostat - Community survey on ICT usage and eCommerce in Enterprises. Digital Intensity score is based on counting how many out of 12 key digital technologies are used by each enterprise. High levels are attributed to those enterprises using at least 7 of the listed digital technologies. More information can be found here.

There are similar issues with respect to productivity-enhancing organisational practices in UK firms. The World Management Survey (Bloom and Van Reenen, 2007) has shown that UK firms are on average worse managed than those in the US and Germany[4]; and the UK has a thicker tail of badly managed firms.

A number of policy initiatives in recent years seek to improve the adoption of technology and management practices in UK firms – addressing key barriers that prevent adoption (particularly in smaller firms).[5] There are also diffusion challenges in the public sector, with evidence highlighting that the NHS needs to improve diffusion by implementing programmes to support healthcare services

[4] Bloom et al., 2017 estimate that management practices account for over half of the gap in total factor productivity between the UK and the United States.

[5] These include the establishment of Be the Business in 2017 with funding and support from the UK government and industry; and the BEIS Business Basics Programme which tests ways to encourage SMEs to adopt productivity-enhancing technologies and management practices.

adopting ideas developed elsewhere (Horton et al., 2018). The case for providing this support for diffusion in healthcare provision has only grown stronger given the Covid-19 pandemic.

The Covid-19 crisis creates new risks but also opportunities for innovation

The Covid-19 crisis creates new risks for innovation in firms (Roper and Turner, 2020). The literature on previous crises suggests that, going forwards, financially constrained firms will find it harder to resume R&D activities,[6] and continued uncertainty due to Covid-19 and the UK's future trading relationship with the EU is likely to harm investment further.[7]

In surveys conducted since the start of the pandemic, Roper and Vorley (2020) found that in June/July nearly 80% of Innovate UK grant holders had either stopped or reduced R&D activity due to immediate disruptions; and in June, McKinsey (2020) found that commitment to innovation-led initiatives had decreased as companies focus on short-term issues. Financing challenges also risk threatening some of the UK's most promising innovative businesses. Beauhurst - an organisation that tracks 'high-growth' firms in the UK – estimated that while the outlook for these businesses has improved since April, as at September 2020, 27% of companies in this category faced moderate risk of closure, with a further 4% facing severe of critical risk (Beauhurst, 2020). Of course, over and above medical research into vaccines and treatments, a number of sectors and technologies have seen increased demand and investment during the crisis. Evidence from patenting in the United States shows that the Covid-19 has affected the direction of innovation towards new technologies that support video conferencing, telecommuting, remote interactivity, and working from home (Bloom et al., 2020).

On the diffusion side, there is emerging evidence that Covid-19 has accelerated the adoption of new technologies and practices amongst UK businesses in the initial months since lockdowns began (Riom and Valero, 2020; Be the Business-McKinsey, 2020). In a survey of UK businesses conducted in collaboration with the Confederation of British Industry, Riom and Valero (2020) found that between March and July 2020, more than 60 per cent of firms had adopted new digital technologies or management practices since the start of the pandemic, and nearly 40% had invested in new digital capabilities. Moreover, the majority (over 90%) of adopting firms intended to keep such changes in place once the immediate crisis is over. At the same time however, businesses cited continued uncertainty and financing constraints as key barriers to adoption (consistent with other surveys on innovation[8]) and there are therefore risks of negative impacts on adoption as the economic effects of the crisis continue to unfold. For further discussion on the impact of Covid-19 on technology adoption in firms, see Valero and Van Reenen (2020).[9]

2. Areas of opportunity: evidence from patent data

While there is significant uncertainty over future competitiveness, tracking innovation activity can give an indication of the areas in which the UK might enjoy future advantage and help to inform the design of targeted innovation support. In this section, we set out an analysis of patent data which sheds light on the UK's international comparative advantage in innovation across key technology areas. We include all broad categories of technology, but highlight specific categories that are relevant for addressing two

[6] A number of studies have shown that R&D activity tends to suffer in downturns. Aghion et al. (2012) finds that this is particularly the case for credit constrained firms following the financial crisis. See OECD (2012) for a summary of evidence.

[7] See Bloom et al., 2018 for analysis of Brexit-related uncertainty and discussion on why uncertainty harms investment, and Altig et al., (2020) on Covid-19 induced uncertainty.

[8] See, for example, Figure 7 in the UK Innovation Survey, 2019.

[9] Forthcoming piece for the Economics Observatory.

major societal challenges faced today: tackling Covid-19 and decarbonising the economy. We also highlight where in the country these types of innovation are taking place.

Similar analyses could be conducted in relation to other societal goals, for example the Industrial Strategy grand challenge of 'healthy ageing', or at different disaggregations (for example, Unsworth et al., 2020a consider in detail a number of technologies relevant for zero-carbon passenger vehicles).

We also carry out analysis to understand the 'value for money' of innovation support across types of technology, from a UK perspective. We seek to identify technological areas that are attractive for government support because they generate relatively high total economic value to society. To gauge the total economic value of an innovation, we consider both the private value to the innovator, and the value of spillovers the innovation generates by inspiring other innovators. As the latter type of value is not internalised by the organisation that invests in R&D, it constitutes an externality that justifies government support for R&D. We complement our measures of total economic value with estimates on the cost of generating a marginal innovation to arrive at a measure for the 'return to government support for R&D'. As such, this measure allows us to identify areas of interest from the perspective of UK industrial policy for innovation.

It is important to note that the estimated total value does not include the value of other important – but hard to quantify – externalities associated with favouring some technological fields over others. For instance, the methodology does not capture the widespread benefits of reducing global warming, or better managing future pandemics. Instead, our analyses can be informative on the question of whether opting for an ambitious package of R&D support in socially relevant sectors may cost us in terms of innovation (and hence, productivity growth), or is more likely to also address market failures for innovation. In other words, our analyses help us identify an industrial strategy that may result in a 'win-win' scenario of benefitting future growth as well as addressing societal challenges.

We caveat this analysis by noting that this type of evidence forms one part of a holistic understanding of the UK's innovative competitiveness. Not all innovation is patented – particularly in service sectors - indeed, the measurement and analysis of innovation is in itself an innovative area of research in the social sciences as data taken from company websites and communications are increasingly being used to measure innovative activity (see, for example, innovation mapping analysis carried out by NESTA on the creative economy, NESTA, 2018).[10] A complementary analysis is set out in Unsworth et al., (2020b) that demonstrates another method to highlight areas of potential innovation opportunity. This analysis combines data on international comparative advantage, based on trade data, with measures of economic complexity and relatedness to the UK's specialisms.

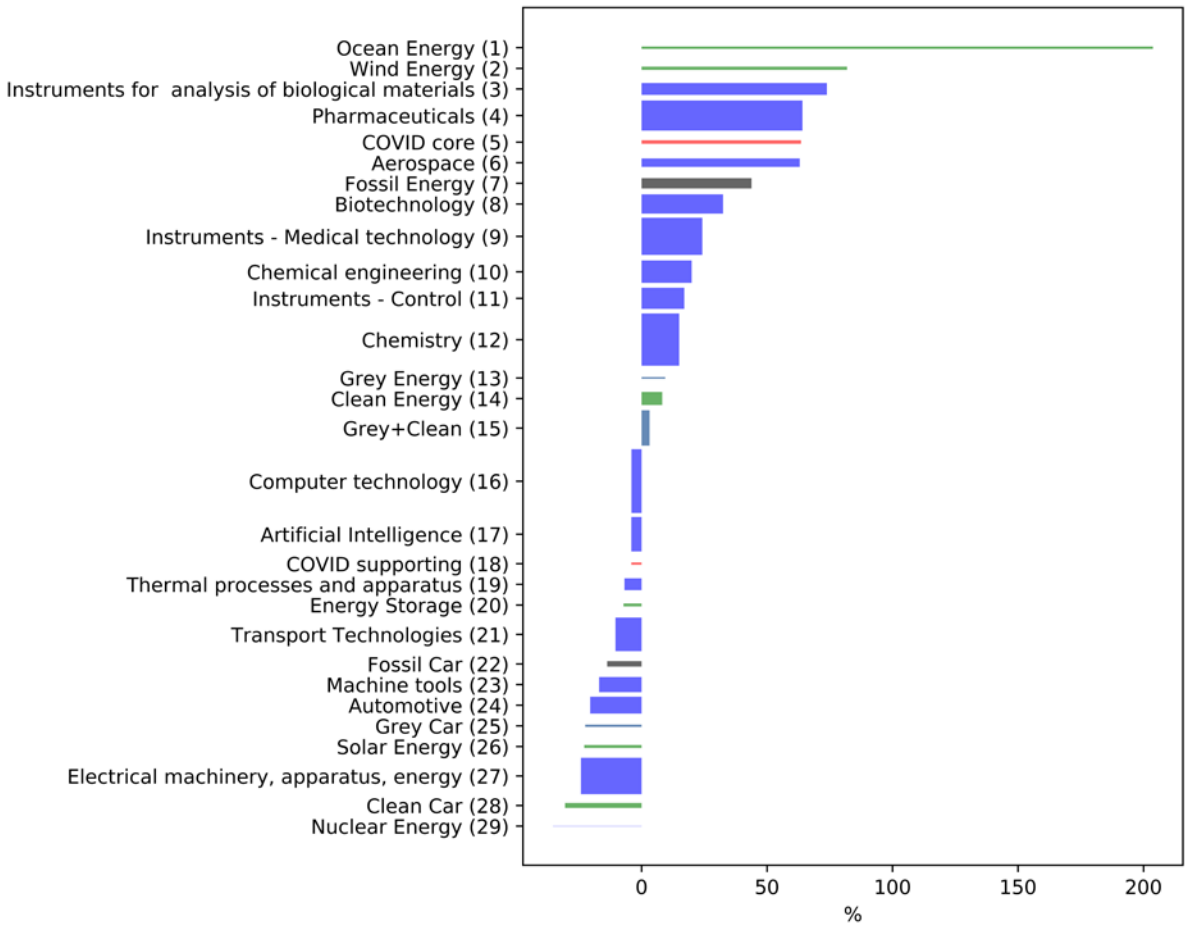
Areas where the UK has comparative advantage in innovation

Revealed technological advantage (RTA) is defined as the share of an economy's patents in a particular technology field relative to the global share of patents in that field. This gives an indication of the relative specialisation of a given country in different categories of technology: an RTA of 0 per cent would indicate that the UK's share of innovations in the category is aligned with the global average. An RTA above 1 suggests that the UK specialises in that particular area.

[10] This is an area of current CEP research funded by the ESRC (grant # ES/T002506/1).

The UK's RTA compared to the rest of the world in key areas of innovation over the period 2005 to 2014[11] is set out in Figure 4. We include commonly recognised aggregate categories of technology, for example pharmaceuticals and aerospace. Alongside this, we include technology classes that are relevant in tackling two key challenges faced by society today: Covid-19 and climate change.

Figure 4: UK RTA in key areas of innovation compared with the rest of world (2005–14)



Note: The length of each bar on the horizontal axis shows the RTA; the width of each bar on the vertical axis reflects the number of patents in each category. *Source:* Authors' estimates based on PATSTAT.

In the 'Covid core' category we include technologies of the type that are relevant for directly limiting the health impact of Covid-19 (e.g. vaccines, medical equipment).[12] 'Covid supporting' refers to innovations which can help the economy to cope with the pandemic in terms of working practices, which more recent analysis have seen increased patenting activity (see Bloom et al., 2020 on 'working from home' related technologies). While a wide range of innovations fall into this category, we focus

[11] Although we rely on patent applications and application dates, these are only recorded in the public patent databases once the patent application has been fully processed which can take several years. Hence there is a time lag of three to four years. Since we are using the 2018 version of PATSTAT this leaves us with 2014 as the last usable year.

[12] Given that the data relate to the period 2005-2014, this classification does not include patents directly related to tackling Covid-19, but rather patenting in areas that are relevant for tackling Covid-19, such as the development of vaccinations.

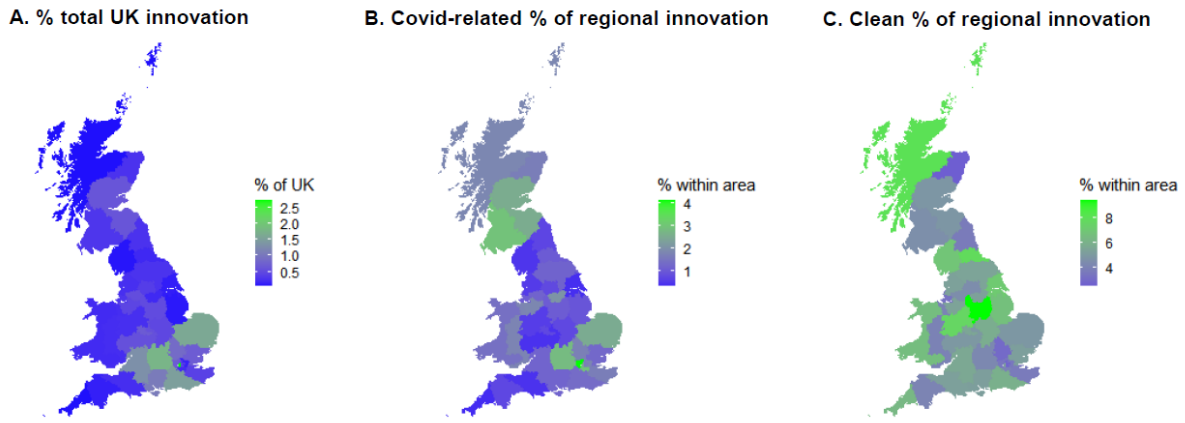
here on innovations which relate to automating office processes.[13] We highlight a number of 'clean' categories here too across energy and automotive, showing both the RTAs for the categories as a whole (e.g. clean energy) and specific technologies within those categories (e.g. ocean energy).[14]

This analysis demonstrates that the UK has comparative advantage in a number of the key areas we highlight, in particular with clean energy: in ocean and wind; and in 'Covid core' technologies. The UK does not exhibit RTA in 'Covid supporting' technologies, or 'Clean cars' as an aggregate category.

Mapping patenting activity across the UK

Analysing innovation activity, as measured in patents, at the regional level can help inform the place-based R&D strategy which is currently under development, by revealing parts of the UK that appear to be performing well in terms of particular types of innovation. Using the same groupings as before, we show areas that already appear to have relative specialisms in Covid-19-related and clean technologies based on the inventor addresses in patent applications. Figure 5 shows how innovation activity is distributed across NUTS2 level regions of Great Britain. Panel A maps total patents across regions, and presents a picture consistent with Figure 2 on R&D; that much of Great Britain's innovation activity is occurring in London, the South East and East of England.

Figure 5: Distribution of patenting across Great Britain



Note: Panel A gives the share of total patents by NUTS2 region. Panels B and C show the share of each region's innovation that is 'Covid-related' and clean respectively. Covid-relevant includes Covid core and Covid supporting as previously defined. The analysis covers the period 2004–14. *Source:* Authors' estimates based on PATSTAT

Panels B and C then show, as a share of the innovation that is occurring in particular regions, the amount that is related to Covid or Clean technologies. This analysis allows us to compare the extent to which regions might be specialised in these technology areas relative to other regions. The Covid-related shares mirror the overall distribution of innovation across the country, reflecting the R&D strengths in London, Oxford and Cambridge Universities and the surrounding areas in biomedical sciences. However, Scottish regions are also responsible for a relatively high share of Covid-relevant innovation.

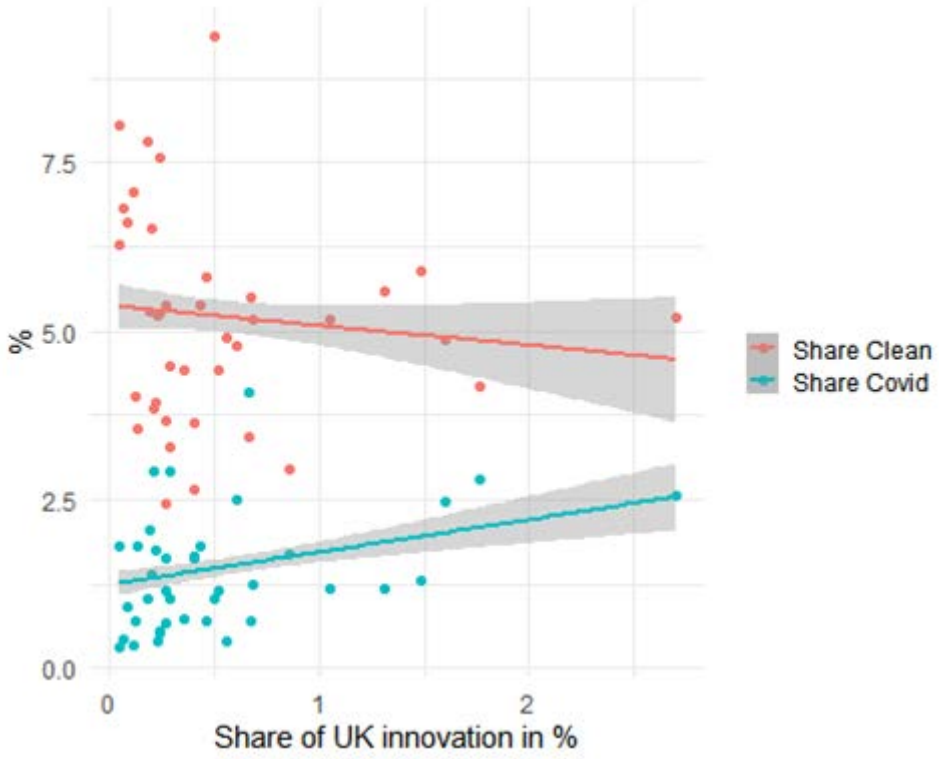
[13] For 'Covid Supporting', patent technology classification G06Q10/10 is included: 'Office automation, e.g. computer aided management of electronic mail or groupware; Time management, e.g. calendars, reminders, meetings or time accounting'.

[14] Note that in this context 'grey' relates to technologies that improve energy efficiency, as opposed to creating new zero-carbon innovation.

Furthermore, in comparison to the pattern for total innovation, there are relatively lower shares of innovation in the West Midlands and Gloucestershire, Wiltshire and Bristol/Bath areas.

A different picture emerges when focusing on clean innovation. Here, we find that there is disproportionately more innovation taking place in Yorkshire, the East Midlands and the West Midlands. This evidence implies maintaining support for R&D in these crucial areas is likely to benefit a range of regions across the UK, which could help support the government's ambitions to 'level up' the UK. These relationships can be summarised in Figure 6. The negative slope for clean technologies shows that some of the areas that account for a relatively small share of total innovation in the country are relatively specialised in clean technologies. This suggests that support for clean innovation could have an important role to play in levelling up, and this might apply in particular in areas where the UK also has international comparative advantage (including Ocean and Wind energy), and where there is evidence that there are positive national economic returns in these types of technology (as we show in the next section).

Figure 6: Regional specialisation in Covid / Clean technologies versus share of total innovation



Note: The x-axis plots the data from panel A (Figure 5) the share of total patents (across all technology classes) by NUTS2 region. The y-axis plots the share of each region's innovation that is 'Covid-related' and clean respectively (equivalent to panels B and C in Figure 5). *Source:* Authors' estimates based on PATSTAT

This type of spatial analysis can complement the analysis of potential job creation and wider economic benefits from net-zero-aligned investments across key areas of a net-zero- aligned economy (energy efficiency in buildings, natural capital projects, active travel equipment and infrastructure, renewable power generation and distribution, electric vehicle production and charging infrastructure, and carbon capture utilisation and storage and hydrogen production) set out in Unsworth et al., (2020a).

Estimating the national economic returns of different areas of innovation

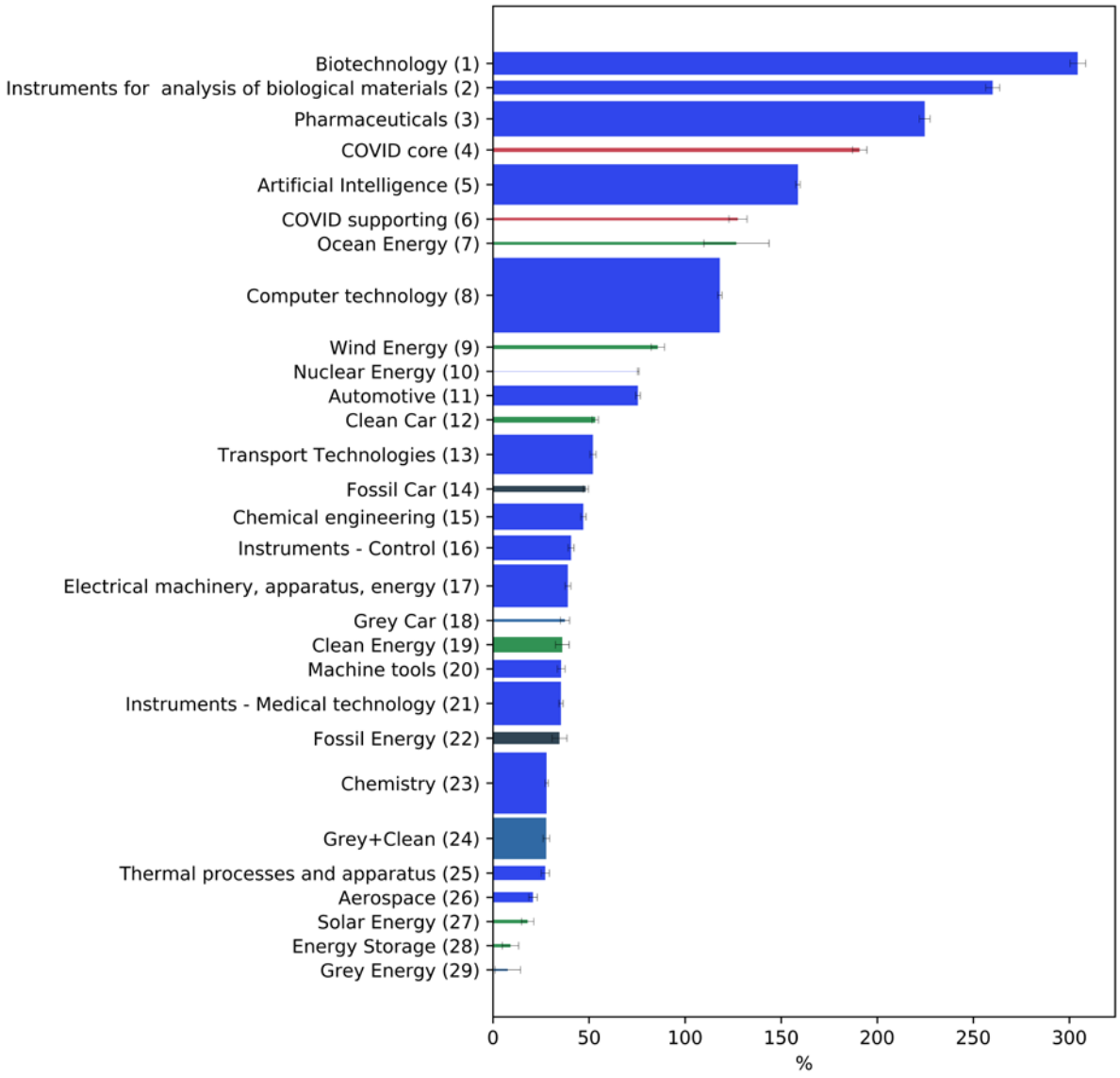
While the RTA gives an indication of the areas in which the UK has specialised, it does not give an indication of the economic value that can be generated by a particular type of innovation. Nor does it take into account the variation in knowledge spillovers that different technologies generate. Moreover, it ignores variation in the ability of governments to promote further innovation in specific areas. The 'IStra-X' industrial strategy index methodology, developed by Guillard et al. (2020), provides a framework to take these issues into account. It allows for the computation of the national economic return on potential government R&D subsidies to different technology areas. This is based on a model of the innovation process which we fit to global data on patenting and valuations of companies undertaking innovation.[15] This also takes into account the possibility that innovators in different areas might vary in their responsiveness to government R&D support.

Figure 7 shows the UK's national returns from UK innovations across the same groupings of technology classes as the previous figure. It demonstrates that public R&D investments in technologies that we consider in 'Covid core' can be expected to deliver amongst the highest returns of any technology area in the UK. Similarly, even though the UK does not have a RTA in 'Covid supporting', on average the UK innovations that do occur in this area do generate relatively high levels of social return in the UK although they are somewhat lower than for Covid core technologies. The clean technology areas we found to have high levels of RTA – i.e. in particular ocean and wind – are also found to have relatively high returns. Overall, this analysis suggests that investment in innovation related both to tackling Covid-19 and reaching net zero carbon emissions can deliver strong returns in the UK.

This is an emerging methodology, and there are other benefits and costs that may not be captured, for example innovations that are not patented (particularly relevant in the service sector), or patents that are not perceived by the stock market to deliver value at the point of filing. Moreover, it may be that market valuations underlying our methodology are clearer in more distinct areas of innovation (e.g. pharmaceuticals) than in incremental advances in inter-related technologies where the full market potential is not yet understood. Nonetheless, the methodology provides new insights into the possible UK returns across different types of innovation, including those that are relevant in the context of the pandemic and for reaching net zero emissions of greenhouse gases which would also generate broader socio-economic gains.

[15] We assume that the private value of an innovation can be captured by shocks to the shares of listed innovating firms. We infer the value of innovations of non-stock listed firms by comparing them to stock listed firms in the same narrow technology area. The value of spillovers created by an innovation is a portion of the private value of all innovations that build upon it. Therefore, we only capture value of innovation to the extent it translates into some firm's profit.

Figure 7: UK returns to public R&D investments across technologies, 2005–14



Note: The Figure reports average returns to public R&D subsidies by technology area. The calculations account for direct and indirect knowledge spillovers occurring within the UK, variations in private R&D returns, variation in R&D costs and differences in the responsiveness to subsidies between different technology areas. This is based on the 'IStra-X' indicator as developed by Guillard et al. 2020. The length of each bar on the horizontal -axis shows the IStra-X value; the depth of each bar on the vertical -axis shows reflects the number of patents in each category. *Source:* Authors' estimates based on PATSTAT.

Assessing opportunities for innovation and diffusion

Analysis of patents highlights areas which provide particular opportunities due to the UK's relative technological advantage and/or spillover benefits which are felt in the UK. This type of analysis can therefore help to target innovation support to areas that are relevant in terms of addressing societal goals, and where there are growth opportunities that can be realised in the UK, and where (given existing or emerging specialisation in different areas) such innovation might also play a role in levelling up. In areas where the UK does not exhibit RTA, and where spillovers generated in the UK appear lower, a focus on the diffusion of innovation invented elsewhere might be more cost effective.

Unsworth et al., (2020a) discuss these issues in the context of the car industry, with calculations for relevant technologies at a more disaggregated level. As shown in their Figure 1, the UK lacks RTA for clean cars as an aggregate category, though it does possess strengths (and spillovers are relatively large) in specific sub-categories including connected and autonomous vehicles and vehicle-to-everything technologies. Despite the varying strengths within clean cars, this broad category of technology will be critical to the UK decarbonising road transport and improving air quality, making diffusion of zero-emission vehicles a strategic priority for government. Furthermore, increased/accelerated demand for these products in the UK relative to the rest of the world may in turn create new opportunities for UK-based innovation and potentially production. This would be welcome news for the UK's automotive industry which plays an important role in local identities in regions such as the West Midlands. However, to realise these opportunities, the UK needs to have the appropriate supply-side policies and incentives in place (Unsworth et al., 2020a). Bringing forward the phase-out of new sales of internal combustion engine vehicles to 2030 is a positive step in this regard.

Within clean energy, it is worth highlighting that the analysis we have presented suggests that ocean energy is an area where the UK has comparative advantage and where national economic returns to UK innovation are high. While this is a relatively small area of innovation to date, these results suggest that perhaps there should be greater policy focus on tidal power. The government's new 'Ten point plan for a green industrial revolution', for example, emphasises wind but not ocean energy.

3. The policy opportunity

The unprecedented economic shock and ongoing challenges induced by the pandemic will require an investment-led recovery at a time when confidence in the economy is weak (Stern et al., 2020; Besley and Stern, 2020).

Our analysis in Section 2 highlights the UK strengths and economic returns associated with clean technologies in a number of areas. New polices and incentives are needed, since under business as usual, there is a path dependence towards investment and innovation in the areas which companies know best. In many situations, these remain high carbon incumbent technologies (Aghion et al., 2019).

Government support packages and the incentives they create can be designed to facilitate transitions towards new sustainable business models and related innovation focused on zero-carbon goods and services. As set out in the Ten Point Plan, there has already been progress in terms of committing resources towards a sustainable recovery in the UK across energy, carbon capture and storage, transport, energy efficiency in buildings and natural capital. Such policy commitments and new investments provide clear direction of travel in certain areas to the private sector which should incentivise increased investment and innovation in the relevant technologies. In fact, the tenth point is explicitly focused on the development of the technologies needed 'to reach new energy ambitions and make the City of London the global centre of green finance'.

However, comparative analysis suggests that overall packages of support for clean activity announced so far in key comparator countries France and Germany appear larger in magnitude.[16] There is therefore now the need and opportunity for the UK to build on its announcements to date by initiating a tranche of additional investments and incentives into recovery. This can mark the establishment of a coordinated,

[16] For comparisons of resources committed in Covid-19 recovery packages, specifically related to 'clean unconditional' (support for production or consumption of energy that is both low-carbon and has negligible impacts on the environment if implemented with appropriate safeguard), or 'clean conditional' (support the transition away from fossil fuels, but unspecific about the implementation of appropriate environmental safeguards), see https://www.energypolicytracker.org/.

long-term approach to government spending that will provide incentives for innovation to achieve net zero, as well as create jobs as highlighted in Unsworth et al., (2020b).

In the context of recovery from Covid-19, the commitment to net-zero and the UK's departure from the EU (and hence loss of access to the European Investment Bank), the case for establishing a new National Investment Bank (LSE Growth Commission, 2017) to accelerate investments in sustainable projects and related innovation is even stronger today (Besley and Stern, 2020). The government's announcement of a new National Infrastructure Bank, to be operational in Spring 2021, is an important recent development. This will allow government to work alongside and foster the private sector to reduce, manage and share risks, thereby lowering the cost of capital and 'crowding-in' (rather than squeezing out) private investment (Besley and Stern, 2020; LSE Growth Commission, 2017).

Policy frameworks such as the UK's industrial strategy at the national and local levels can have renewed relevance by setting the long-term direction for investments in sustainable innovation (and hence reducing policy uncertainty), and linking this to complementary investments in skills and infrastructure. These should be joined up with the UK's innovation strategy, including the forthcoming place-based R&D strategy in which the role of social science, arts and humanities research (as well as STEM) should all be emphasised via their contribution to innovation directly (e.g. in the creative sectors, or via the development or understanding of new business practices) and indirectly via building understanding of barriers and policy levers for improving innovation and its diffusion.

At a more granular level, there is extensive evidence on the types of policy lever that are effective for generating innovation (as set out by Bloom et al., 2019). In particular, R&D tax credits are effective for stimulating innovation and spillovers, and public investments in R&D generate strong spillovers into industry – such effects tend to be localised and are stronger for more research-intensive institutions and areas with higher absorptive capacity. Building human capital is also crucial for both invention and diffusion. But the need for more evidence on the complementarities between different policy levers to encourage university-business collaboration has been highlighted (OECD, 2019).

It is worth noting that the past is not an adequate guide to the future, in the context of facilitating and inducing a structural transformation and where the aim is to generate dynamic returns through economies of scale in production and discovery. Dynamic market failures occur where a technology or network will clearly be superior in the future, once on a path of endogenous innovation, but are not cost effective to begin with. A fruitful approach to addressing dynamic market failures might be for market shaping policies and mission innovation to focus on creating new opportunities for the future (Kattel et al., 2018). State-led innovation can take the form of deployment support to create new markets, basic R&D support to stimulate innovation and also targeted 'research missions' to achieve important economic and societal objectives, such as zero-carbon or public health.

Policy recommendations

The following policy actions in recovery can help to achieve a step change in the scale of R&D investment and to direct innovation towards decarbonisation and other key societal challenges:

Accelerate the drive to 2.4% R&D as share of GDP with enhanced incentives for innovation, in particular in areas aligned with key societal missions including reaching net zero emissions

Investment in R&D can be scaled up and more effectively directed in order to generate the innovation required for sustainable growth. Continued business disruption and uncertainty due to the pandemic and

the UK's future trading relationship with the EU create additional challenges in achieving this. The drive to increase the quantity and quality of investments in innovation can be accelerated via:

- Increased and targeted public support for R&D in areas with strong potential to contribute to the global frontier and/or generate large economic benefits in the UK
- Strengthened incentives in the tax system, including effective carbon pricing and R&D tax credits – the latter could be enhanced for clean technologies or research and innovation activities in areas relevant for other key 'missions' (e.g. resilience to pandemics or improving productivity)
- Appropriate regulation and demand side mechanisms that create growing UK markets for new technologies
- Conditionality mechanisms in Covid-19 related support packages for polluting sectors which drive businesses towards clean innovation and more sustainable business models
- Building and evaluating policies to encourage more university-industry collaboration
- Enhanced support for innovative SMEs that are particularly likely to face heightened financial constraints during the crisis

Develop locally appropriate innovation policy informed by analysis of innovative strength and the likely spatial impacts of support for R&D and / or diffusion in different places

Increased focus on place in the UK's innovation system has the potential to reduce regional disparities, but this requires a nuanced approach. Increasing R&D spending in areas without absorptive capacity may not deliver economic benefits in those places and is therefore unlikely to help achieve levelling up. Such areas are likely to benefit more from policies to aid diffusion, at least in the short term. In turn, this could raise demand for R&D activities and support amongst businesses over time as they become more technologically advanced. Innovation can be built in less R&D intensive areas by:

- Investments in complementary assets, in particular skills. Both the Higher Education and Further Education sectors play an important role, as both scientists (inventors) and technicians are required to facilitate innovation and its diffusion
- Business support policies to aid diffusion, including access to finance and information. More evidence on the effectiveness of different types of policy in different contexts can be built with robust monitoring and evaluation
- Ensuring that funding decisions consider the extent to which the geographic impact of R&D may not be limited to the place in which the R&D activities actually take place. For instance, in certain cases R&D in one area could benefit other areas due to the application of technologies, connectedness in supply chains or other spillovers

Re-emphasise and relaunch the UK's Industrial Strategy, bringing innovation policy together with the broader, complementary policies required for a sustainable and inclusive recovery and providing a clear and long-term direction to the private sector

The extent of government support for industry due to Covid-19, and the scale of investment needed (in the public and private sector) to meet net-zero commitments, presents an opportunity to develop a strong partnership between the public and private sectors with incentives aligned towards innovation-led sustainable and inclusive growth across the country. This can be achieved with:

- A re-emphasised and long-term industrial strategy (at the national and local levels), with clean growth at its core – tying in the policies for a Green Industrial Revolution which have been announced to date

- A further strengthening of the institutions governing industrial policy, putting it on a par with other areas of economic policy (LSE Growth Commission, 2017), with better data, evaluation and information sharing between areas
- A programme of net-zero aligned investments in productive assets across the economy that can create jobs in the short term, and broader economic benefits into the medium to longer run

Maintain international openness and competitiveness of the UK's innovation system

The UK's departure from the European Union damages the attractiveness of the UK for top international talent (particularly from the EU), international research collaborations, and as a location for international businesses engaged in global value chains to conduct their R&D- all of which have benefitted the UK economy to date (Azmat et al., 2018; LSE Growth Commission, 2017). The UK can futureproof and ensure the long-term openness and attractiveness of its innovation system by:

- Seeking to minimise frictions in trade across both goods and services in the future UK-EU trading relationship
- Maintaining access to EU innovation funding and research partnerships, making up any shortfalls in funding

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