Independent Review of the UK's Research, Development and Innovation Organisational Landscape

Final Report and Recommendations

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

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Foreword

This Review of the research, development and innovation (RDI) organisational landscape of the UK was requested in 2021 by the UK Government's Secretary of State for Business, Energy and Industrial Strategy (BEIS). The objectives of the Review are to explore the existing ecosystem of research, development and innovation within the UK, to identify improvements to the organisational research landscape that are required to deliver the Government's ambition to be a science superpower, driving economic growth and societal benefit, and to ensure that RDI organisations — ranging across the whole landscape, from those carrying out discovery research to those supporting innovation — are effective, sustainable and responsive to future priorities and developments. The full Terms of Reference for the Review are to be found in Appendix 1.

The content of this Review is my responsibility alone, but I have been aided in this work by a Scoping and Advisory Group with further support from a Sounding and Challenge Group. In addition, discussions have taken place with a wide range of individuals covering the RDI landscape. I am grateful to all of them for their advice and critiques, which have been invaluable. I also thank the individuals and organisations who responded to a call for information and comment and completed a survey of publicly funded RDI institutions for their time and contributions. The names of all these people and organisations can be found in Appendix 2. All information presented in this document is accurate to the best of my knowledge at the time of publication. Finally, I thank Holly Yates, Lucy Absolom and the Secretariat provided by BEIS (and latterly by the new Department for Science, Innovation and Technology), and Kathleen Weston of the Francis Crick Institute, for their tireless efforts and never-ending patience in assisting me with this Review.

Sir Paul Nurse OM CH FRS

Executive Summary

Research, development and innovation (RDI) is an essential driver of productivity and sustainable growth, and has a critical role in securing economic, societal and strategic benefits. Delivering a significant increase in investment and ensuring a high-performing RDI landscape is crucial for the future success of the UK. Today's discoveries are the foundations for tomorrow's prosperity, and effective mechanisms to support development and commercialisation drive near-term sustainable growth and productivity. However, stability and clarity in the Government's strategy for RDI are essential for securing both long-term sustainable economic growth and increased inward investment to the UK.

This Landscape Review was commissioned as part of the 2021 UK Innovation Strategy, to describe the diversity of UK RDI organisations, to identify strengths and weaknesses, and to make recommendations for improvement of the RDI landscape, with a primary focus on researchers and RDI funded by the public purse. The Review covers these areas and also comments on how the various RDI organisations interact with and support industry, commerce, and society more generally. The various terms used within the Review are defined in the main body of the Review and the Glossary.

The patchwork of Research Performing Organisations (RPOs) and research funders that comprise the UK's RDI landscape is the product of decisions taken over many years and reflects changing, sometimes short-term, public policy priorities and initiatives, and varied approaches to public funding of research. The Review has gathered extensive evidence about the UK's RDI endeavour and has identified significant problems, some of which are long-standing and serious. These problems mean that if the UK is to achieve its ambition of becoming the science superpower that it needs to be to drive future commercial and societal benefits, further piecemeal changes of the type attempted in recent decades will not be enough. Therefore, rather than a prioritised menu of possible alternative initiatives, the Review has produced an integrated set of recommendations, the implementation of which need to be considered as a whole to deliver a powerful overall outcome. These recommendations form a blueprint which will catalyse evolutionary changes across the entire landscape that in total will generate a revolution in how RDI takes place in the UK. Government has a very important long-term role to play in bringing this about. It will require increased investment, reduced policy volatility, a clear focus on optimising and implementing change, good data collection, and a long-lasting, consistent, systematic approach to policy development and safeguarding of the RDI landscape.

UK RDI is in danger due to underinvestment in the sector by successive Governments, which has undermined the resilience of the RDI endeavour as a whole. Total UK investment in Research and Development (R&D) is thought to be around the 2019 OECD average of 2.5%[1], but lags behind commercially successful research-intensive nations such as South Korea, the United States and Germany, whose research spend was 3.2-4.6% of GDP in 2019. The UK value for the percentage of GDP spent on R&D was thought for many years to be 1.7%, but this is now known to be a mistake, due to longstanding Office for National Statistics (ONS) errors in data sampling, which underestimated the contributions made by UK industry and higher education. The ONS has not yet released revised figures for R&D expenditure as a percentage of GDP, but DSIT estimates suggest that in 2019, using ONS and OECD data, it was between 2.6% and 2.7%, close to the OECD average of 2.5%.

Confirmation of the new figure for overall R&D spend is not due until late 2023, but what is not in doubt is that funding of R&D directly performed by UK government entities is very low, at only 0.12% (DSIT estimate 0.1%) of GDP, putting the UK below the estimated OECD average of 0.24% for 2019 and 0.26% for 2020, and far behind most other research-intensive nations. Expenditure on all domestic R&D funded by the UK Government[2] is 0.46% (DSIT estimate 0.5%) of GDP, in 27th place in the 36 OECD nations, considerably less than the OECD average of 0.6%, and substantially lower than South Korea, Germany and the United States, which spend 0.66-0.96% of GDP on R&D. This underinvestment by the Government must be rectified if the present problems of the UK RDI endeavour are to be corrected, so recent commitments made by the Government to increase their investment in R&D are to be welcomed. It should be emphasised that in an uncertain economic climate, sustained growth through RDI investment is even more essential. The long-term RDI investments made now by the Government will go on to support sustainable economic growth, improved productivity and the creation of the jobs and industries of the future, and will drive inward investment and secure the UK's international reputation. They are also required to bring about societal benefits such as delivering net zero and improving health care, as well as coping with national and global emergencies.

This Review identifies ten important attributes for a successful RDI landscape, including values that ensure the pursuit of research is the pursuit of truth. These

[1] OECD average figures do not take into account the UK's new figures after the introduction of the ONS's revised methodology in November 2022. This applies to all OECD figures quoted in the Review. Based on the ONS's revised figures, DSIT has independently made estimates for some of the figures quoted in the Review, which are rounded up or down by DSIT to the nearest decimal point.
[2] 'Government-financed GERD' is the domestic R&D which is funded directly by Government. This is different to UK Government expenditure on R&D as it does not include R&D tax credits or expenditure overseas such as ODA, and uses what businesses report they receive from Government rather than Government-reported spend on supporting businesses.

attributes are: high research quality; agility and flexibility in approach; permeability between sectors, disciplines and organisations; transparency and navigability for those seeking to engage with R&D; a skilled workforce; inspirational leadership; a good research culture embracing ethical behaviour; strong international collaboration; and financial sustainability. The recommendations of the Review aim to strengthen these areas with the ultimate objective of empowering researchers so they deliver a research endeavour that drives the economic, societal and strategic benefits necessary for the future success of the UK. They are written to guide the newly established and very much welcomed Department for Science, Innovation and Technology (DSIT), which can act as a driving force to improve the UK's RDI organisational landscape, so the country can truly become a scientific superpower.

The Review's conclusions and the 29 recommendations it makes appear below, organised according to the different parts of the RDI landscape. These recommendations address the following five general issues relevant across all the UK's RDI endeavour:

- RDI is needed to secure increased productivity and sustainable growth. The role of public policy and investment in creating the conditions for RDI to thrive has been recognised by Government. However, this political interest can have the unintended consequence of driving policy volatility and short-term policy-making, and recent years have seen an increasing turnover of new initiatives, schemes and programmes which are not always properly integrated with one another. This undermines development of RDI, particularly within the application part of the research spectrum, which can have a negative effect on private investment. Stable and predictable policy environments build investor confidence and have the potential to increase access to both short and longer-term financing for UK RDI. In the future, after taking into account the reforms recommended by this Review, Government needs to reduce policy volatility across the landscape.
- The UK RDI landscape is hard to navigate. There is insufficient permeability of ideas, people and technologies between different RPO sectors, and a lack of transparency, inclusivity, and shared understanding of what these various sectors can offer and provide. Interactions between academia and industry are sub-optimal. Sustainable growth of the UK economy relies on effective support from RDI, and these defects in permeability and inter-sectoral collaboration may be contributing to the UK's present weak productivity.
- Attention must be paid to the financial sustainability of public research funding, and action taken across the landscape to understand the challenges this presents. The future success of UK RDI is explicitly contingent upon the Government's commitment to grow investment in RDI. There is a pressing need for more complete 'end-to-end' funding of research activities beyond

direct research costs, including adequate support for administrative services, sophisticated technical cores and facilities, and for ‘well-found’ laboratories.

- While university research has been broadly sustained, partly through increasing reliance on cross-subsidy from commercial sources, the UK’s RDI landscape has had a long period of flat and in some sectors declining budgets. This means that other non-university RPOs, such as Government funded institutes and research establishments, which can have prominent roles in international collaboration and competition, have seen a long trajectory of decline. The excellent UK universities should receive increased support for the outstanding research they can deliver, to ensure that they are competitive with universities in other countries. In addition, the Government's clear commitment to a sustained uplift in RDI budgets now creates an opportunity to rebalance the UK RDI landscape by consciously investing in a greater diversity of organisational types and approaches. This approach has been shown to enhance focused research as well as innovative translation activities.
- Checks and balances on organisations using public research funding are important, but the operations of research funders and RPOs are hindered by excessive bureaucracy, with too much emphasis on audit-oriented reviewing and reporting rather than the quality of the research being produced. Restrictions on issues such as pay also severely constrain public bodies operating in the RDI landscape. Much of this bureaucracy has its origin in Government controls and rules, particularly from the Treasury, although bureaucracy can also be excessive in non-Government funded research activities. These ways of working, combined with deficiencies in ‘end-to-end’ research funding have led to long-standing inefficiencies, wasting both money and researchers’ time. The problem of excessive bureaucracy has also been independently verified by the 2021 Review of Research Bureaucracy, led by Professor Adam Tickell, and the 2022 Review of UK Research and Innovation (UKRI), led by Sir David Grant.

Key findings

Universities

UK universities have a broad and deep multidisciplinary research base from discovery through to application, with demonstrable excellence in many research areas. They are a major strength of the UK RDI landscape, and their diversity and quality are positive characteristics of the UK RDI ecosystem. Universities receive the largest proportion of public RDI funding and that has increased in recent years. This has supported the ongoing development of an impressive university sector in the UK, something recognised across the world. However, the Review draws attention to key

longstanding issues around the financial sustainability of public funding for university research which have consequences for universities and other research organisations throughout the UK RDI landscape.

Conclusions

The financial sustainability of the public research funding for universities needs to be urgently addressed. ‘End-to-end’ research support has four components: direct research costs; administrative services; technical facilities; and laboratory facilities. The present funding arrangements do not provide adequate support for all these components, and need to be overhauled to ensure that they do so. Proper ‘end-to-end’ funding is required in universities to fully support research activities with mechanisms that do not have perverse incentives or outcomes, and that better consider the quality and not just the quantity of research delivered. There needs to be a detailed review of response-mode and competitive grants, full Economic Costing (fEC) and Quality-related Research Funding (QR), and where necessary, these funding mechanisms should be reformed or replaced. The present underpinning of UK university research by other commercial income sources, notably fees paid by international students, is valuable, but care is needed as such sources are not always reliable and sustainable. Many universities play an important role in supporting businesses in their local economies to engage with RDI; this is considered further in the section on ‘RDI and society’.

Recommendations

1. Government should take account of the true cost of ‘end-to-end’ research activity to generate a sustainable RDI endeavour. Government, working with UKRI and the UK higher education funding bodies, should review and when necessary reform competitive and response-mode grant funding, QR (and Devolved Administration equivalents), and fEC, and replace them with improved mechanisms. Overall objectives should be to optimise research delivery, remove perverse incentives and outcomes, and ensure the longer-term sustainability of the research system.

2. Universities should develop plans to optimise their operations in support of research, to empower researchers and reduce their administrative loads, and to improve the quality of support services, core technical facilities, and well-found laboratory buildings and infrastructures. Government, working with UKRI, the UK higher education funding bodies and the wider sector, should consider more transparent mechanisms to provide assurance and accountability on QR funding.

Public Sector Research Establishments (PSREs)

PSREs are valuable national assets which strengthen the broader UK RDI system. Their remit includes focused research activities covering discovery, translation and application, providing services important for key sectors of the economy, operating critical national RDI infrastructure and capability and carrying out monitoring and regulatory functions. The role of PSREs and other publicly funded research institutions has reduced in prominence in recent decades and they are valued and resourced less than similar networks funded by our international comparators. This may have been the unintended consequence of other policy choices. A uniform reform package is unsuitable for such a diverse mix of organisations, but Government should take a more strategic approach to better harness their expertise and maximise their effectiveness.

Conclusions

PSREs are the least visible RPOs in the landscape, and some face operational challenges that prevent them maximising their contribution to UK RDI. A siloed and restricted funding environment risks placing constraints on their functionality and limits the ability of Government departments and external RPOs to work with them. Government procurement and financial frameworks, and restrictions on issues such as pay inhibit effective activity within this part of the landscape. PSREs are sometimes unable to take longer-term strategic decisions due to a lack of sustainable funding. Much more can be done to harness the collective human and technical capabilities of PSREs on behalf of Government and the RDI sector more broadly. Government departments should work together more to identify cross-cutting priorities to improve coordination across the system.

Recommendations

3. Government departments should clarify the missions of their individual PSREs, allow them greater freedom of action, and ensure their effectiveness. Departments should improve internal awareness of PSREs' capabilities, and use PSREs to inform RDI strategy and policy making, working within and across departments. Permeability and agility would be further improved by increasing the visibility, interactions and partnerships between PSREs, and between PSREs and the rest of the RDI landscape, including commercial organisations.

4. Funding streams for PSREs need to be protected and reformed to ensure long-term sustainability. Constraints, which appear to have their origins in the Treasury, over funding, pay and other conditions of working should be reduced. The reforms of funding proposed for the universities should also be applied to PSREs.

5. PSREs should be stringently reviewed, and those that have outlived their purpose or are not working effectively should be reformed, reduced or closed, and any savings generated recycled into Government R&D budgets.

Institutes and Units

Institutes and units are focused on research ranging from discovery through translation to application, and play a specific and important role in the landscape. Their research-focused missions and ability to be flexible and agile can deliver effective research outcomes and act as a magnet for global research talent.

Conclusions

Research institutes and units play a unique, beneficial role in the UK's RDI landscape and this sector requires expansion to contribute more to the UK's RDI capability. Their mission focus is attractive to high quality researchers and can facilitate multi-disciplinary approaches to research problems. The success of institutes and units depends on clarity of mission, effective leadership, good impartial governance, sustained funding, and appropriate location. Effective strategies and operational procedures must be in place to guard against complacency, stagnation, or a drop in research quality. Units can be set up quickly and should have focused objectives, and where appropriate, defined time limits for their operations. Generally, they benefit from proximity to other RPOs, and can be merged or evolved to form new institutes.

Recommendations

6. Institutes and units need sustained financial support, including un-hypothecated funding, to ensure 'end-to-end' research support. The funding arrangements of recently established institutes and units, particularly the 'hub and spoke' models, must be reviewed to make sure that they are fit for purpose. The reforms of funding proposed for the universities should also take account of the needs of institutes and units.

7. Institutes and units need a well-defined mission and purpose, and should be given the autonomy and funding necessary to achieve their objectives, which may be time limited. There need to be clear and agreed mechanisms by which institutes and units can be adapted, reduced or closed when necessary.

8. Institutes and units must have high quality administrative as well as scientific leadership. They generally benefit from being co-located with other RPOs, but if their overall administration is the responsibility of another co-located or

funding organisation, rigorous contractual arrangements must be in place to ensure independence of operation and quality of service.

9. New research institutes and units should be considered when strategic RDI priorities best supported by focused research missions are identified by Government, UKRI and other funders. Possible examples include enhanced activities in climate change and its mitigation, antimicrobial resistance, synthetic biology, and artificial intelligence. Themes should be identified through mapping and reviewing, taking account of emerging technologies, scientific areas, and Government priorities. Pre-existing institutes and units could be merged and expanded to create new institutes, and consideration should be given to co-location and co-funding with other RPOs. Establishment of new institutes and units should follow the principles outlined in the Review.

Other Components of the RDI Landscape

Better understanding of other components of the RDI landscape and the relationships between them will bring about more awareness of the capabilities they offer to the UK RDI endeavour.

Conclusions

Charity funding is a valued additional component of research support in the UK, but the shortfall in ‘end-to-end’ support of charity research grants is damaging the RDI endeavour and must be addressed. UK academies and learned societies are internationally renowned organisations making wide-ranging and valuable contributions to all aspects of the UK RDI landscape. Arts, cultural, humanities and social sciences organisations, together with the heritage and cultural sector, contribute to the UK skills base and business-led RDI activity in related fields, and are a growing segment of the UK economy. Collections held by heritage and cultural organisations, including PSREs such as the Natural History Museum and Kew Gardens, are invaluable national assets. Generally, research based on collections is inadequately supported in the UK.

In addition to the translational activities carried out by the universities, PSREs and institutes, a variety of other translational research organisations form a valuable bridge within the RDI landscape, and promote industry needs. They can test pre-commercial ideas and address emerging challenges, but their success can be variable. The establishment of Catapults has broadened the range of translational research organisations in the UK, but no one organisational model can meet the wide variety of roles for translational research organisations. Translational research organisations have been shown in other countries to increase regional research capability. This part of their role could be better developed in the UK. Increasing their

scale and efficiency is important for promoting growth of the UK economy and increasing productivity.

Recommendations

10. Government and the charitable sector should work together to ensure that 'end-to-end' funding is provided for research supported by philanthropy.

11. Support for research undertaken by galleries, libraries, archives, museums, and the heritage and cultural sectors should be increased, and support for long-neglected collections-based research put in place.

12. Coherence between translational research organisations, including those embedded within other RPOs, and the rest of the landscape should be increased. Government is advised to optimise translational research organisations by increasing their number, widening access and promoting the benefits of translational research capability, including regionally. Government should explore routes by which RPOs across the RDI landscape, including PSREs, can contribute to translational activities.

Industry and the Private Sector

The private sector is the largest funder and performer of RDI in the UK, and growth of the private sector's investment in RDI is important if UK business is to become more productive and drive sustainable economic growth. Business spend on RDI in the UK is concentrated in certain large multinational companies and in some parts of the small and medium-sized enterprise (SME) sector, and these investments are generally geared towards later stage experimental development research, although they also include some discovery activities.

Conclusions

Incentivising further private sector RDI spending, thereby unlocking the economic value for business returns and increased productivity, will require commitment from both business and Government. Government should take a more strategic long-term approach to facilitating private investment in key sectors and technologies where the UK has a competitive advantage.

Not all businesses are aware of the benefits of investing in RDI, or of the support for innovation available from the wide range of RPOs in the landscape. Equally, parts of the academic RDI landscape are sometimes reluctant or face barriers when engaging with industry. The sectors need to work better together so that the barriers that inhibit exchange and sharing of knowledge, resources and researchers can be broken down. Different models work well in different international, national, local and

sectoral contexts. Businesses are more likely to invest in RDI when there is long-term policy stability, a set of fair regulatory structures, a robust intellectual property system, Government investment, and a skilled workforce.

Recommendations

13. Government should use its convening power to create a favourable environment for business to invest in RDI, tackling causes identified by this Review as holding back further business investment, and where expedient, providing financial support. Examples of such support are funding which leverages private investment or promotes collaboration between industry and the rest of the RDI landscape.

14. To understand the benefits of RDI for commercial activities and the economy, a culture change promoting openness, mutual respect, closer interaction, collaboration, and permeability of ideas, technologies and people has to occur in both business and academia. Government has a role in conveying the benefits of RDI investment to businesses, shareholders and academia, embracing practices from countries with high business RDI investment rates. Mechanisms to deliver this should be explored and implemented.

RDI and Society

Successful RDI can lead to advancements for society beyond economic growth. Government has a particular responsibility for RDI in this area as it cannot be driven by commercial activities alone. Better nationwide distribution of RDI knowledge and capabilities will also contribute to achieving equitable regional economic growth throughout the UK.

Conclusions

Government departments should be more active in ensuring that RDI is available to inform their policy development. Obvious examples of such policies are in health care, equitable regional economic growth across the country, and delivery of net zero, but others include education, care for the environment, transport and town planning. There are significant opportunities in the UK for improving health care through RDI, but clinical researchers are finding it increasingly difficult to combine a research career with the demands of their clinical training and NHS duties. This is damaging medical research, with negative consequences for both health care and the economy, and needs to be urgently resolved.

The RDI landscape should be permeable to knowledge, skills and expertise across the UK. Poor permeability can prevent local areas and businesses from engaging

with and benefitting from their local RPOs, and this is likely to be a limiting factor in addressing regional RDI imbalances. In particular, universities could further contribute to equitable regional economic growth by providing an enhanced gateway for their local industries to learn about RDI activities in RPOs and research activities elsewhere in the UK, including in other universities. Interventions to promote regional RDI capability require close co-operation between central government, RPOs and local universities, communities and institutions, including the development of public-private partnerships, and will need time, robust evaluation, and sustained funding.

Recommendations

15. Government should take particular responsibility for driving RDI that provides societal benefit as well as economic growth. Examples are health care delivery, equitable regional economic growth throughout the UK, and the delivery of net zero. Where appropriate, public-private partnerships should be encouraged.

16. Government and RPOs should partner with local communities to support RDI relevant to their needs, to bring about more equitable regional economic growth based on local expertise and demands and driven by community benefit as well as academic criteria. Universities and other RPOs should support their local community and economy by enhancing their role as an information nexus and by helping local industries link to research capabilities wherever they are in the UK.

17. There is an urgent problem with the current mechanisms for clinician scientists to effectively develop and undertake their research careers. The Government, taking into account devolved competencies, must rectify this to both improve the ability of the NHS to deliver more effective health care and to help the UK economy.

Actions for Government to support a thriving RDI Landscape

Government has an important role in safeguarding the success of the RDI landscape. As well as the absolute imperative of providing more funding for RDI, actions must be taken to ensure a clear fit-for-purpose strategy, a focus on outcomes, better coordination of RDI policy, and better career structures for the RDI workforce.

Funding

Conclusions

DSIT estimates using the latest ONS statistics published on 22 November 2022 suggest that in 2019, total UK R&D investment was 2.6%-2.7% of GDP, but the UK still lags behind nations such as the USA, South Korea and Germany, which invested 3.2 to 4.6% of GDP. Further, the data on publicly funded R&D reflect sustained underspending: at only 0.1% of GDP in 2019, expenditure on R&D directly performed by the UK Government was near the bottom of the OECD nations, which average 0.24%. Though higher, UK Government expenditure on all domestic R&D still comprised only 0.5% of GDP (DSIT estimates),[3] putting the UK in 27th place in the 36 OECD nations, well behind the top ten nations, who committed between 0.69–1.01% of GDP to R&D. The UK Government's present level of R&D funding will be inadequate to drive the economic and societal benefits that the Government desires.

There are significant incompatibilities and differences between different funding streams in the UK, which add to the complexities of the UK RDI landscape. Organisations compete for funding, which can be a driver for quality but can also have a negative influence on collaboration and the delivery of properly priced research programmes. The availability of un-hypothecated core funding, or access to wider resources which can be used for core funding, varies for the different organisations across the landscape. These factors are negatively affecting sustainability, operations and agility in responding to emerging priorities, and are also inhibiting permeability, interactions, and collaborations throughout the RDI landscape.

Recommendations

18. Government must work with UKRI and the wider RDI community to consider more stable and properly costed funding structures, aimed at ensuring the quality of the existing landscape and its sustainability.

19. Government must increase its long-term commitment to invest more in RDI. In addition to reviewing incentives in public funding for university research, Government should review the balance of funding across the landscape, and explore how planned increases in RDI public funding can provide more un-hypothecated core funding for RPOs to allow them to deliver their mission more effectively, to promote collaboration and interaction across RDI sectors, and to empower local RPO leadership and researchers.

[3] This is different to UK Government expenditure on R&D as it does not include R&D tax credits or expenditure overseas such as ODA, and uses what businesses report they receive from Government rather than Government-reported spend on supporting businesses.

International collaboration

Conclusions

The Government should support the UK's leading role as a convener and collaborator in globally important research, and this requires association with the highly respected Horizon Europe programme. Relationships with EU collaborators need to be protected, maintained and expanded, because the free exchange of researchers, ideas and data with our closest research-intensive neighbours is vital for UK RDI. Loss of such international collaboration due to short-term decision making will damage the long-term UK RDI landscape. Broader policy objectives such as in immigration, Overseas Development Assistance (ODA) and education need to be aligned with the Government's RDI policy.

There are research areas of global strategic importance where new multinational intergovernmentally funded institutes could be contemplated, such as an international institute of climate change and mitigation. Such institutes are powerful tools for multilateral collaboration, and bring benefit not only internationally, but for the host nation. Government should maintain its commitment to protect, celebrate and globally promote the right to academic freedom.

Recommendations

20. Government should ensure that international collaboration is protected and encouraged, and should resolve problems damaging the UK RDI landscape's international links. This is particularly relevant to our close scientific collaborators in the EU, and it is essential that the UK associates with Horizon Europe. Government should take action, including consultation with Devolved Administrations, if its broader policy objectives on areas such as immigration, ODA and education are hindering wider objectives for long-term RDI policy.

21. The UK should consider opportunities to host new intergovernmental multinationally funded institutes and international research infrastructures.

Policy stability

Conclusions

At every level of the UK's RDI endeavour, from Government Ministers in Cabinet to the operations of individual RPOs and funding organisations, there needs to be a systematic coordinated approach to RDI strategy and policy setting, with clear accountability and a focus on overall safeguarding of the RDI landscape. The newly established DSIT should set out a coherent and long-term vision for science and

research, including clear identification of national programmatic and technological research initiatives, particularly at the more applied end of the spectrum. This will give RPOs, investors, global companies and researchers, who all have concerns about short-term decision making, the confidence they need to operate, interact and invest within the UK's RDI landscape.

RDI requires sustainable local and national scientific infrastructure, and DSIT should put in place policy and financial frameworks for establishing, maintaining and upgrading such infrastructure, acting as convenor, facilitator or investor, according to need. The National Science and Technology Council (NSTC) and UKRI could provide support for this. The NSTC has the potential to improve alignment and reduce barriers on those issues over and above existing roles and responsibilities of Departments, including facilitating agreement and co-ordination across Government, for matters that are not currently examined or decided elsewhere. It should be noted that the NSTC, which was created, then cancelled, and has now been reconstituted as a Prime Minister-chaired Cabinet committee, is an example of the policy volatility discussed earlier. Stability would be further improved if as far as possible, Government, the Opposition, and the Devolved Administrations could agree on long-term policies.

Recommendations

22. DSIT should define the overall architecture and governance for cross-Government RDI policy, setting out accountabilities from Cabinet and below. This should include the National Science and Technology Council (NSTC), as well as other key RDI spending departments, UKRI and other funders, to ensure roles are complementary, and to improve alignment on policies.

23. From Cabinet level downwards, all interested parties in Government must take responsibility for the high level and effective safeguarding of the future success of the UK RDI landscape. This oversight should include an authoritative working group set up by DSIT, operating across Government, the RPOs and the funding organisations, which will take long-term responsibility for implementation of the recommendations of this Review.

24. Government should establish a research vision and strategy including long-term programmatic, infrastructure and technological initiatives, which is especially relevant at the applied end of the research spectrum. This will give RPOs, investors and global companies the confidence to invest, operate and interact with the UK RDI landscape.

Diversity in the landscape

Conclusions

Due to its diversity, the UK's RDI landscape can be challenging to navigate. Improved knowledge and better shared understanding of the landscape will improve visibility, support better planning and decision making for UK Government RDI policy, and identify new opportunities for business RDI investment and activity. This must include reliable data concerning levels of investment in and funding of the various sectors of UK RDI. The recently exposed shortcomings in such analysis, which has underestimated investment by industry and higher education, perhaps for decades, was missed by both Government and academic policy makers and commentators, and will have damaged past UK RDI policy development.

A mutual understanding between universities and other RPOs across the RDI landscape will bring wider benefits, and a greater focus on collaboration and sharing of knowledge and resources between all RPOs will improve the spread of benefits of research across the UK and within local communities. The UK RDI landscape would also benefit from greater inclusivity and the creation of more diverse RPOs. Rigorous assessment of strategic need and the conditions necessary to generate high quality research should be coupled with decisions about the nature and length of any new organisation's research mission, governance and sponsorship mechanisms. Above all, there must be a commitment to long-term funding support.

Controls and rules applied by Government and research funders have implications for the operation and agility of RPOs in the landscape. In particular, current review and reporting approaches are driven heavily by resource intensive, formal audit-style processes and do not put enough emphasis on the quality, effectiveness and outcomes of research conducted by RPOs. Assurance mechanisms grounded more in earned trust rather than detailed audit, combined with an increased focus on measuring quality, will facilitate a higher performing RDI landscape. ARIA, a new addition to the UK RDI landscape, has been set up within a more flexible framework which should also apply to other RPOs and research funding organisations. Public bodies in the RDI landscape are also particularly hampered by pay-related controls.

Recommendations

25. Government needs to develop effective mapping of UK RDI, covering the missions, financial investment in different sectors, research capabilities, and locations of RPOs, and also monitor international RDI activities to identify successful features and models. DSIT, working with UKRI and other interests across Government, could carry out this function. An agreed shared picture of the RDI landscape should be produced, together with a commitment to regularly update it.

26. Government should increase efforts to link the different elements of the UK RDI landscape together with the commercial, industrial and societal components that benefit from research. To spread the benefits of research through communities across the UK, partnerships, collaborations and interactions must be built so that all components are mutually aware, and permeable with respect to ideas, information, technologies and people.

27. Government must replace frequent, repetitive, and multi-layered reporting and audit by Government departments and UKRI with a culture of confidence and earned trust, as also referenced by the Independent Review of Research Bureaucracy. Reporting and reviewing of RPOs should focus on the quality and appropriateness of the research being carried out. The framework by which ARIA will operate should be applied to other components of the RDI landscape.

28. Public sector controls which reduce the agility and performance of RPOs need to be reformed. Salaries must be internationally competitive. Where Government-imposed pay limitations are damaging the mission of an RPO, they must be revised, and the decision-making mechanisms made more flexible.

Talent

Conclusions

Ensuring high-quality training, tackling the perceived lack of long-term job prospects, and creating a better understanding of the range of opportunities to move careers between RPOs are important to ensure the sustainability of the RDI landscape. More flexible and better designed training programmes would be a useful step towards relieving some of the pressures faced by early career researchers, who are the ‘engine room’ of UK academic research. These changes would increase research productivity, allow more time for researchers to decide whether they are suitable for a research career, and keep a greater number of talented individuals within the system. Researchers should receive wider training and be made much more aware of opportunities outside academia, because skilled researchers are required elsewhere in the RDI landscape and beyond. Better training and career progression must also be considered for technicians, engineers, and other essential facilities support staff, and Government should include these as part of any long-term sustainable research strategy. Science education should begin in primary schools, not only to help generate a pipeline for an RDI workforce, but also to ensure a future UK citizenship engaged with science.

Recommendation

29. Government should ensure that there is a well-trained RDI workforce available at all levels, and long-term educational planning to ensure a future pipeline of researchers and technicians. Career pathways for those roles that underpin effective research delivery, including technicians and project and programme managers, should be strengthened so the importance of these roles is better recognised. Training and career structures for early career researchers, including PhD students, post-doctoral researchers and starting faculty, need to be reviewed and reformed. Career path diversity and permeability between different RPOs should be encouraged.

Review implementation

If adopted as a whole, the Review's recommendations form a blueprint that can bring about the changes needed to ensure a revolution in the UK RDI endeavour. A Government response is expected to follow in due course. The arrangements within Government that are needed to tackle the problems identified and secure the delivery of longer-term change, as outlined in this Review, should be considered. These should include an authoritative working group, which should be set up as soon as possible, with the power to ensure implementation of the Review's recommendations. Use should be made of small-scale pilot projects trialling recommendations, to test how they should be implemented more widely. These include: 'rescuing' some of the institutes the Review found were in difficulties; reducing bureaucratic constraints to better support research-intensive PSREs; providing end-to-end core funding and greater autonomy to pockets of research excellence in the universities; developing a new Scottish biomedical research institute; and setting up information facilities within universities in disadvantaged areas, to connect the local communities and businesses to research, wherever it may be found in the UK. Association with Horizon Europe should also be quickly established to prevent the loss of some of the UK's most talented researchers, and to maintain collaborations set up over many years with one of the largest and most powerful research communities in the world.

The Review

Why research, development and innovation matters for the UK

This Review presents an opportunity to strengthen the foundations and operations of the research, development and innovation (RDI) organisational landscape in the UK. Securing and revitalising our RDI-performing organisations and advancing our national research and innovation capability is crucial because it is only through RDI that our country can thrive, driving sustainable economic growth through increased productivity, improving public services and the quality of our lives, protecting the environment, and meeting future global and national crises and challenges.

For the purpose of this Review, research and researchers are defined broadly across all disciplines, encompassing the natural and social sciences, mathematics and the arts and humanities, and applications arising through clinical medicine, engineering, and the creative arts. While the emphasis of the Review is on the sciences, which receive the largest proportions of public funding[4], it is important to recognise that the arts, humanities and social sciences make a vital contribution to society and culture as well as to knowledge in their own fields; they also have a significant role in supporting private enterprise in sectors such as the creative and digital industries.[5] Rather than emphasising distinctions between these disciplines, the Review usually refers more generally to 'researchers' instead of, for example, scientists, engineers, clinicians or social scientists. Researchers working in all disciplines produce reliable knowledge and insights about the natural world, ourselves, and our societies, and their work opens up new possibilities for useful applications.

Research is based on investigating and collecting information aimed at the discovery of new understanding. This generates new knowledge, theories and applications. Research activities substantially contribute to the genesis of original ideas, which are the engines of human advancement. New or improved knowledge leads to applications and inventions, followed by innovation and commercialisation driven by further investment and human enterprise. All these activities fall within the definition of Research, Development and Innovation (RDI) that is used in this Review, and all

[4] See for example: UKRI. UKRI's budget allocation explainers, 2022, 4, accessed Oct 10, 2022, https://www.ukri.org/publications/ukri-budget-allocation-explainers/

[5] Roberta Comunian, Alessandra Faggian, & Sarah Jewell, "Embedding Arts and Humanities in the Creative Economy: The Role of Graduates in the UK", *Environment and Planning C: Government and Policy,* 32, 3(2014): 426-450, accessed Oct 10, 2022, https://doi.org/10.1068/c11153r

are important: new applications and technologies generated by development and innovation feed back into research to enable new discoveries, to drive sustainable economic activity, to enhance public services, to generate more productive, skilled and satisfying jobs, and to improve living standards, leading to longer, healthier and more satisfying lives. RDI is also needed to ensure adequate environmental monitoring and regulatory frameworks, effective Government policy development, and the enhancement of education, culture and our civilisation.

A thriving RDI landscape is also central to the future of the UK, improving the country's global strategic advantage. A strong RDI system is important for the UK's international standing: operating at the scientific frontier means the UK can make important contributions to solving global challenges, such as climate change and improving resilience to pandemics. The UK economy gains by producing new technologies and products that are in demand internationally. Further, a well-functioning RDI landscape will generate significant benefits throughout the UK, by enabling distributed economic growth and benefit to the whole of society, as well as preparedness for global or national emergencies. For the UK to thrive we have to depend more on our brains and our scientific endeavours, and that requires an effective high performing RDI landscape.

The ambitions of the Review and Government

The Government's ambition is for the UK to be a science superpower, competitive with other research-intensive and successful nations around the world. Being a science superpower means carrying out world class science, tackling international challenges for the global good, supporting collaborative talent, adopting values embracing critical thinking, peer-review, openness and data sharing, and attracting global RDI funding to the UK. The aim of this Review is to identify the changes and improvements required in the RDI landscape to maximise its contribution to the UK's future success. The Government has a key role to play in nurturing the health of this landscape, and it is vital that delivery of science and research occupies a central place in Government across all Cabinet responsibilities, for both the UK Government and the Devolved Administrations. The recently established Department for Science, Innovation and Technology (DSIT), and the National Science and Technology Council (NSTC) are welcome developments which provide mechanisms that can develop and implement strategies and policies with a focus on driving and supporting science across Government, to improve the UK RDI endeavour.

The UK research base is generally considered to be internationally competitive, built as it is on a 350-year-old tradition of scientific achievement within the UK encompassing the Age of Enlightenment and the subsequent and continuing Industrial Revolution. But past achievements must not lead to complacency. New global issues present new challenges and opportunities, and technological advances are transforming how research and innovation are undertaken. The UK must be able to respond to these developments. Many other countries have recognised the power of research and its importance for their futures and are investing accordingly in RDI. The UK has to do likewise.

For the last two decades, total UK investment in research and development (R&D) had been thought to be around 1.7% of gross domestic product (GDP). However, due to long-standing errors in data collection, for some years the Office for National Statistics (ONS) has been significantly underestimating both the number of RDI-active businesses in the UK, and the levels of RDI independently funded by the higher education sector. As a result, UK RDI policy development has been based on

unsatisfactory information. It should be noted that concerns regarding data sampling were raised by the UK Statistics Authority in 2012.[6]

New estimates that more accurately reflect R&D performed in the business and higher education sectors have now been produced, but the ONS has yet to update the figure for the UK's investment in R&D as a percentage of GDP. DSIT internal estimates suggest that if this figure had been produced, it would be between 2.6% and 2.7% for 2019 (compared to 1.7% using the previous methodology), and between 2.9% and 3.0% for 2020 (likely to be artificially high as GDP shrank during the COVID-19 lockdown). These figures roughly equal the OECD average of 2.5% for 2019 and 2.7% for 2020, but the UK is still lagging behind nations such as the USA, South Korea and Germany, which invested 3.2–4.6% of GDP on R&D in 2019, and 3.1–4.8% in 2020. The UK's ambition should be to drive investment in RDI to a level that matches these and other research-intensive and commercially successful countries.

These ONS methodology changes have not affected the figures on UK Government spend on R&D, which international comparisons show is very low. Funding of R&D directly performed by Government entities (such as Public Sector Research Establishments; PSREs) is only 0.12% (DSIT estimate 0.1%) of GDP, putting the UK in 24th place in the 37 OECD nations, well below the OECD average of 0.24%, and even further behind most other research-intensive nations.[7] In addition, the overall direct UK Government spend on domestic R&D was only 0.46% (DSIT estimate 0.5%) of GDP in 2019, the most recent year analysed, again less than the OECD average of 0.6%, and much less, for example, than the Governments of South Korea, Germany and the United States, who spent 0.66-0.96% of GDP in 2019.[8]

The historically low level of UK Government investment is a danger to the UK's ability to grow the economy in a sustainable way and to improve the quality of life of its citizens. This Review makes recommendations to improve the UK's RDI landscape, but any changes will not be fully effective unless there is significantly more Government funding for RDI; it is well-documented that public funding for RDI

[6] UK Statistics Authority, Statistics on Research and Development (produced by the Office for National Statistics), 2012, accessed Oct 10, 2022, https://osr.statisticsauthority.gov.uk/wp-content/uploads/2015/12/images-assessmentreport218statisticsonresearchanddevelopmen_tcm97-41963-1.pdf

[7] "Main Science and Technology Indicators: GOVERD as a percentage of GDP", OECD, accessed Oct 10, 2022, https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUBu. Note: For some countries figures are estimations and definitions differ.

[8] "Main Science and Technology Indicators: Government-financed GERD as a percentage of GDP", OECD, accessed Oct 10, 2022, https://stats.oecd.org/Index.aspx?DataSetCode=MSTI_PUB. Note: For some countries figures are estimations and definitions differ. 'Government-financed GERD' is the domestic R&D which is funded directly by Government, UKRI, and higher education Funding Councils This is different to UK Government expenditure on R&D as it does not include R&D tax credits or expenditure overseas such as ODA, and uses what businesses report they receive from Government rather than Government-reported spend on supporting businesses.

creates the certainty needed to attract investment from the private sector. Recently, the Government has prudently committed to increasing public spending on RDI; however, in the challenging context of wider public spending restraint, if the UK is to achieve its aim of becoming a science superpower on a level with the best in the world, it is essential that this funding continues to grow over the long-term.

To achieve the Government's ambition and to support its role as a responsible and responsive custodian of the RDI landscape, it is necessary to get a clear picture of the diverse components of the current UK RDI landscape and of how these components do or do not interact with each other, to identify what works well, and to consider what changes and improvements may be required. RDI activities are complex, covering discovery, translational, and applied research. The institutions that deliver RDI are also complex and diverse. They include for example, universities, Public Sector Research Establishments (PSREs), other institutes and research units, and industrial research facilities. Funding of UK research comprises a patchwork of public and private monies, from the UK Government, Devolved Administrations, universities, charities, industry and other sources.

To protect and enhance the quality of the UK's RDI landscape it is important to understand how the organisational landscape is shaped in the UK and other countries by different funding and organisational approaches, and to assess whether the UK's current research organisational models and funding methods could be improved. The Review provides a description of key features of the UK RDI landscape and the issues affecting how it operates, with brief international comparisons. Some of the problems that will be considered are long-standing and have not proved simple to resolve, but nevertheless need to be dealt with if the RDI landscape is to be fully fit for purpose.

A number of the elements required for a successful RDI endeavour are wholly or partly in place. However, the Review identified a range of problems, some of them long-standing and serious, which are in addition to the Government underinvestment described above. There is no single, sweeping change that will address these challenges. For the future success of our country, what is required is a range of evolutionary changes, which if adopted together will substantially improve UK RDI to deliver economic and societal benefit. This will bring about a revolution in UK science and the use of that science for the public good, particularly through the empowerment of researchers to deliver high quality science and applications, and also through increasing permeability across the system, including with industry and commerce. As already emphasised, this can only be delivered by an appropriate level of Government investment as part of an economic growth strategy.

The Review's approach

The Review has considered the RDI landscape as it presently exists in the UK, with international comparisons, and has spoken to stakeholders from the breadth of the landscape, drawing out implications for the system as a whole. Input and evidence received have been extensive in terms of issues covered and areas explored. This reflects the wide range of RDI activity across the UK and is indicative of the complexity of the landscape. The Review has a primary focus on researchers and RDI funded by the public purse, and has not commented on every issue raised during the engagement process, instead focusing on those which were considered to be most important to the operation of the RDI landscape. The analyses and recommendations aim to identify improvements required in the RDI landscape to maximise its contribution to the UK's future success.

The major focus of the Review is on RDI supported by Government funding, which is where Government can have the greatest impact. The nature of RDI supported by Not For Profits tends to overlap with Government funded RDI and so the recommendations that are made are generally relevant to this sector as well. The Review found that researchers from different sectors did not always know very much about each other, and so each component of the landscape is described and analysed, to inform those working in other sectors about the full scope of the RDI landscape. This is a first step towards bringing about a more permeable and inclusive RDI culture. Industrial and commercial RDI, which is discussed more fully elsewhere in the Government's recent Innovation Strategy[9] and has been covered in earlier reviews,[10] is considered in this Review primarily in the context of enhancing interactions and permeability with the other research sectors, which will strengthen the UK RDI landscape as a whole.

Political governance of the RDI landscape across the UK is based on a mix of powers, including those that are devolved, reserved, and shared or exercisable concurrently. The Review recognises that the UK Government and the Devolved Administrations all exert influence on the landscape through spending, strategy setting and wider policy responsibilities. The Review has sought to reflect the views and experiences of those across the UK and recognises that in responding to the findings, it will be necessary for the DSIT Secretary of State and other DSIT

[9] Department for Business, Energy and Industrial Strategy, UK Innovation Strategy: leading the future by creating it,.2021, accessed Oct 10, 2022, https://www.gov.uk/government/publications/uk-innovation-strategy-leading-the-future-by-creating-it

[10] See Department for Business, Energy and Industrial Strategy, The Dowling Review, 2015, accessed Oct 10, 2022, https://www.gov.uk/government/publications/business-university-research-collaborations-dowling-review-final-report
Government Office for Science, A Review of Government Science Capability 2019, accessed Oct 10, 2022, https://www.gov.uk/government/publications/government-science-capability-review

Ministers to work with ministerial counterparts in the Devolved Administrations, enabling identification of opportunities for the UK landscape to thrive in its entirety. This will include in areas of mixed responsibility, but also more generally, to ensure that different initiatives and strategies led by different governments can complement each other as much as possible.

A number of past reviews and strategies have sought to analyse various parts of the RDI landscape and have made recommendations for how they can be nurtured and strengthened,[11] and this Review builds on these earlier recommendations. The key attributes of an effective RDI landscape and a set of strategic objectives for the UK's RDI landscape have been identified, providing the basis against which to assess both the outcomes of the UK Government's response, and the operation of the landscape in the future.

Methodology of the Review

This Review has drawn on a wide range of evidence from across the breath of the UK RDI landscape, to identify its strengths and weaknesses. The Review engaged with over 200 organisations and individuals throughout the UK, and in total received input from over 270 UK and international organisations. A Scoping and Advisory Group and a Sounding and Challenge Group made up of individuals with expertise across the RDI landscape based in the UK and internationally, provided evidence and debate. Qualitative and quantitative data were gathered primarily using interviews and surveys, and from Government and academic research publications. A survey was sent to UKRI institutes, Public Sector Research Establishments (PSREs), Catapults and independent research organisations. 110 organisations responded; around 60% of those who received a direct invitation. The survey asked questions about the type of activity performed, the workforce and location, governance, funding and finance issues, and interactions with other organisations.

Analysis of this evidence has produced 29 recommendations designed to address five general issues, listed in the Executive Summary, that are relevant across the UK's RDI endeavour.

[11] Department for Business, Energy and Industrial Strategy, UK Innovation Strategy: leading the future by creating it,.2021, accessed Oct 10, 2022, https://www.gov.uk/government/publications/uk-innovation-strategy-leading-the-future-by-creating-it; Department for Business, Energy and Industrial Strategy, The Dowling Review, 2015, accessed Oct 10, 2022, https://www.gov.uk/government/publications/business-university-research-collaborations-dowling-review-final-report;
Government Office for Science, A Review of Government Science Capability 2019, accessed Oct 10, 2022, https://www.gov.uk/government/publications/government-science-capability-review; Department for Business, Energy and Industrial Strategy, R&D People & Culture Strategy, 2021, accessed Oct 10, 2022, https://www.gov.uk/government/publications/research-and-development-rd-people-and-culture-strategy

Attributes of an effective landscape: UK and international overview

The Review begins by considering the attributes that are generally important for a high quality, effective RDI landscape, and for the operation of Research Performing Organisations (RPOs) within that landscape. What follows has a focus on science but is relevant to all research disciplines including the social sciences, humanities and the creative arts. It applies to how research is done, how RPOs should operate, and to two further flanking components required for the overall RDI landscape to be effective in its operation and delivery of benefits: the overarching role of Government, and the industrial and societal elements that are the recipients and beneficiaries of RDI outcomes.

The RDI landscape

Although there are differences in the ways RDI is carried out in the various parts of the landscape, there are common **values** throughout. These include pursuit of research built on verifiable and credible data, an objective mindset when undertaking the processes to gather those data, rational thinking, a healthy scepticism, an abhorrence of the falsification or distorted selection of data, and a commitment to academic freedom. Research in science and other disciplines is the pursuit of truth, and requires a culture and community which fully embraces that principle.

It is axiomatic that all parts of the RDI landscape should be driven by the pursuit of excellence, where **quality** and excellence are defined appropriately depending upon the context, mission and strategy of the RPO in question. Discoveries and achievements need to be based on experiments and observations that are verifiable and independently reproducible, and on arguments that are coherent and consistent. There need to be high standards applied and appropriate judgements made about what research is carried out, who is supported to undertake that research, and how research performance is reviewed. All research requires an assessment of excellence that depends on rigorous impartial scientific review by accomplished independent researchers. Such review should not be confused with ‘audit’ or be based on a culture of inappropriate metrics or criteria.

Agility and **flexibility** within the RDI landscape help to boost capability and operations and futureproof organisations by enabling fast responses to scientific progress, and changes in domestic and global RDI contexts, including the management of emergencies. RPOs and funders should be proactive in setting and agreeing strategy, and critically reviewing and challenging their own procedures and processes, so they can respond rapidly to major scientific and technological

advances and to changing higher level priorities, both nationally and in the wider world.

Permeability of ideas and people throughout the RDI ecosystem, as well as the co-ordination and connection of different RPOs, are essential factors for the success of the RDI landscape, which should also have a high degree of coherence, inclusiveness and stability to safeguard such interactions. RPOs need to be well connected with respect to ideas, information, technologies and people. Mutual awareness on the part of researchers across fields and sectors is important for collaboration, co-ordination, creative challenge, and mutual support. A virtuous circle of research activity linking discovery to application, and application to further discovery, means that all parts of the landscape will derive benefit from other parts. Good permeability across the landscape also reduces the risks of individual components becoming insular and self-referential, which can happen if there is a lack of appreciation of the capabilities and insights of other parts of the diverse landscape. Low permeability of ideas and people can even be a problem within an individual RPO, resulting in different disciplines within an organisation becoming siloed.

Promotion of increased permeability and awareness also enhances the connection of local needs with national capabilities. Maximising the success of the RDI landscape requires an understanding and **mapping** of the existing landscape, including knowledge of the RDI activities being undertaken in different places and of the economic and social activities dependent upon that research, coupled with accurate estimates of the investment that is being made, by whom it is made, and in which RDI sectors. Such information is necessary if the UK is to effectively leverage existing and emerging local, regional and national capabilities and strengths to guide decision making and future investment. Local interactions are an effective mechanism to connect research capability with the needs of the local community.[12] [13] A critical mass of firms, innovators and researchers can be brought about by clustering,[14] and gives regions the ability to specialise and develop expertise[15] in certain research areas and technologies. However, this depends on wider shared infrastructure attracting innovators to this location. Ultimately, developing such clusters, and the necessary research infrastructure, is just one part of building a

[12] Michael Kitson, 2019, “Innovation Policy and Place: A Critical Assessment, A Paper for UK Research and Innovation”, Cambridge Journal of Regions, Economy and Society, 12, 2(2019): 293-315, accessed Oct 10, 2022, https://doi.org/10.1093/cjres/rsz007
[13] Innovation Caucus, Understanding Cluster Growth Potential, 2022, accessed Oct 10, 2022, https://innovationcaucus.co.uk/2022/06/13/understanding-cluster-growth-potential/
[14] Innovation Caucus, Understanding Cluster Growth Potential, 2022, accessed Oct 10, 2022, https://innovationcaucus.co.uk/2022/06/13/understanding-cluster-growth-potential/
[15] Hart, “University of Reading: Innovation Clusters: Key Concepts”, Working Papers in Land Management & Development, (2000): 1-15, accessed Oct 10, 2022, https://www.reading.ac.uk/LM/LM/fulltxt/0600.pdf

competitive national innovation system.[16] Such geographic clustering need not be an obstacle to more equitable regional economic growth if knowledge is efficiently disseminated to where it is needed, irrespective of where the knowledge is generated. This requires a highly connected, inclusive and permeable RDI endeavour linking locations throughout the UK, and also absorptive capacity: the capability to recognise the value of new, external information, to assimilate it, and to apply it for economic and industrial strategy as well as for science policy.[17]

A **skilled** and qualified **workforce** is critical for effective RDI activity. UK universities play an essential role in education and training, but other parts of the research ecosystem, including further education colleges, research institutes, and industrial research facilities, can also make important contributions, both for training and for widening the diversity of researchers and ideas borne from different experiences, for example, by attracting talented students and researchers from around the world. It is imperative that the RDI system is able to sustain a well-trained RDI workforce with broad technical capability, and to ensure constant refreshment of that capability. Across the RDI landscape, there is also a requirement for talented and engaged leaders whose objectives should be to empower researchers to release their individual creativity and passion for discovery, and to ensure that bureaucracy is kept to a minimum. Outstanding leadership and operational management are transformative, and attention should be paid to how leaders are developed, nurtured and supported. Often the range of skills required will need a diverse leadership team bridging scientific and technological expertise and practical operational capability. Attracting the best candidates internationally is critical, because highly accomplished researchers who are also excellent leaders are rare. This is best achieved by having a high quality RDI ecosystem, and a welcoming culture for researchers from other countries. International competition to recruit both academics and international students, who can stay on and contribute to the economy, is stiff, and the UK can only be successful if potential recruits have confidence in the sustainability and effectiveness of the UK RDI landscape.

Quality RDI can only be delivered if it is based on a good scientific **culture** with a focus on integrity and ethical behaviours, which produces long-term verifiable and trustworthy knowledge and increases the general public's trust in the scientific

[16] OECD. National Innovation Systems, 1997, accessed on Oct 10, 2022, 26-28, https://www.oecd.org/science/inno/2101733.pdf
[17] Wesley Cohen, & Daniel Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation", *Administrative Science Quarterly* 35, 1 (1990) 128-152, accessed Oct 10, 2022, https://www.jstor.org/stable/2393553

endeavour. [18] [19] Trust is also enhanced by balanced and reliable communication about science in the mass media, promoted by organisations such as the Science Media Centre,[20] [21] and by adequate and appropriate science education in schools.

RDI is a global enterprise and cannot thrive without effective **international collaboration**. Over the last decades, UK researchers have both led and participated in many multilateral collaborations and interactions with researchers in Europe. These are important because Europe is one of the three major science communities in the world, the other two being North America and the Far East. Being an active leading member of the European science community means that the UK RDI endeavour is part of a powerful critical mass and concentration of talent. Promoting and maintaining the UK's close links to European science is an important attribute of an effective UK RDI landscape. Collaborations elsewhere in the world are also important, but because of distance and sometimes cultural and organisational differences, they are often more difficult to put in place and operate.

Finally, it takes time to build scientific capacity, and that capacity is fragile if funding is insufficient or unstable. Effective RDI is dependent upon long-term **financial sustainability** and confidence to establish and maintain RPOs, scientific infrastructure and high-quality scientific teams. Financial sustainability requires a proper understanding and provision of 'end-to-end' funding (that is, the total financial support required) of research endeavours (fully explained later, in the 'Universities' section and elsewhere). When a research activity is only partially funded, it leads to inefficiencies which result in money being wasted. RPOs should be properly funded to undertake research, but also need to arrange their own finances so that the research they carry out is supportable in a sustainable manner.

These factors – values, quality, agility and flexibility, permeability, mapping, a skilled workforce, leadership, culture, international collaboration and financial sustainability - should steer the evolution of the RDI landscape. They will form a guide for subsequent discussions in this Review.

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[18] The Royal Society, The Public Understanding of Science, 1985, Public Understand of Science, accessed Oct 10, 2022, https://royalsociety.org/~/media/royal_society_content/policy/publications/1985/10700.pdf

[19] House of Commons, Science and Technology Committee, Research Integrity: Six Report of Session 2017-2019, 2018, accessed Oct 10, 2022, https://publications.parliament.uk/pa/cm201719/cmselect/cmsctech/350/350.pdf

[20] Science Media Centre, Consultation Report, 2002, accessed Oct 10, 2022, https://www.sciencemediacentre.org/wp-content/uploads/2012/09/Science-Media-Centre-consultation-report.pdf

[21] Florian Wintterlin et al., "Predicting Public Trust in Science: The Role of Basic Orientations Toward Science, Perceived Trustworthiness of Scientists, and Experiences With Science", Frontiers in Communication, 2022, accessed Oct 10, 2022, https://www.frontiersin.org/articles/10.3389/fcomm.2021.822757/pdf

This delineation of the attributes of an effective RDI landscape has focused on principles and practices shared across the UK landscape. However, there is an important and specific distinction, which lies in the differing approaches for driving successful discovery and applied research. Discovery research probes the unknown, providing new knowledge and understanding about the natural world and ourselves. Because of its very nature, its results cannot be easily predicted, and it is usually best generated bottom-up, by giving scientists and scholars the independence and academic freedom to pursue curiosity-driven research into topics that interest them. By contrast, research at the applied end of the spectrum is more prescriptive, aimed at particular outcomes such as development of a specific technology or a societally relevant objective, and such activities require direction by more top-down programme-focused strategies. These opposite approaches are complementary, and both are required in a healthy and productive scientific ecosystem: what makes applied research thrive is an alertness in identifying, capturing and investing in those discoveries which have the potential to profoundly impact our culture and civilisation, or lead to applications of importance to society as a whole. In turn, translational and applied approaches not only drive these useful outcomes, but also feed back into and influence discovery research.

UK overview

The UK RDI landscape of Research Performing Organisations (RPOs) covering a range of capabilities and perspectives collectively form the UK's scientific and creative endeavour. UK organisations performing RDI share the common aims of the pursuit and application of knowledge, but vary in their scale, structure, discipline, geography, business model, and their relationships with each another. This patchwork of RPOs is the product of years of scientific initiatives, and a range of changing policy and funding objectives and choices. The features of the current landscape have been shaped by successive governments, departmental reorganisations and siloed responsibilities, global trends, and local strengths, as well as the contributions, passions and ambitions of many individuals and organisations, resulting in complexity, confusion, and sometimes incoherence.[22] The landscape can change quite rapidly, which is not easy to capture or to compare internationally because of differences across countries of history, political structures, economic systems, scale, and local R&D environments, as well as differences in terminologies, classifications and reporting criteria. Nevertheless, although challenging for these reasons, such comparisons do offer valuable examples and insights. Bearing these complexities in mind, what follows is a broad description of the UK RDI landscape in the national and international contexts, which defines the main characteristics and

[22] Kieron Flanagan et al., Lessons from the History of UK Science Policy, 2019, accessed, Oct 10, 2022, https://www.thebritishacademy.ac.uk/publications/policy-histories-lessons-history-uk-science-policy/

trends, and provides the basis for improvement of the future scientific prospects of the UK.

The current UK RDI landscape is dominated by the UK's accomplished university sector, which is complemented by a significant but often less visible array of other RPOs, a highly heterogenous group including publicly funded research institutes and Public Sector Research Establishments (PSREs), industry and other organisations that perform research. Public funds flow into hundreds of organisations in the UK: for example, in 2020-21, 3,872 organisations received funding from UKRI.[23]

The UK's international standing

The UK scores consistently highly on various measures of research, development, and innovation performance internationally,[24] reflecting the country's strength in its leading universities and research institutes, and in innovation. The UK is similar to many other European countries[25] in that discovery research makes up a substantial amount of its publicly funded R&D, but it is unusual in that greater amounts of public funding are channelled through universities rather than through institutes or national laboratories.[26] The UK receives a higher proportion of R&D investment from overseas sources than most other high-income countries. Universities attract a substantial amount of the R&D investment from overseas, second only to the private sector, and also perform most of the R&D funded by private non-profits.[27] The strength of the UK's university sector, together with the much smaller research institute sector, is reflected in the UK's high global rankings on measures of academic reputation,[28] helping to maintain the UK's historic advantage in discovery science. For example, the UK is second only to the US in producing scientific Nobel Laureates,[29] and is fourth globally in the number of Fields Medals winners.[30] League tables of prizes and citations have limitations, but as of 2019, the UK was ranked first

[23] UKRI, UKRI performance metrics 2020 to 2021, 2021, accessed Oct 10, 2022, 5, https://www.ukri.org/publications/ukri-performance-metrics-2020-to-2021/
[24] See Department for Business, Energy and Industrial Strategy, International comparison of the UK research basis, 2022, accessed Oct 10, 2022, https://www.gov.uk/government/publications/international-comparison-of-the-uk-research-base-2022 or WIPO, Global Innovation Index 2021, 2021, 3-4, accessed Oct 10, 2022, https://www.wipo.int/global_innovation_index/en/2021/ for example.
[25] For example, Germany, France and Italy.
[26] "Main Science and Technology Indicators: GERD by sector of performance", OECD, 2018, accessed Oct 10, 2022, https://www.oecd.org/sti/msti.htm
[27] "Main Science and Technology Indicators: Percentage of GERD financed by the rest of the world, Percentage of GERD by sector of performance", OECD, 2018, accessed Oct 10, 2022, https://www.oecd.org/sti/msti.htm
[28] "QS World University Rankings 2022", accessed Oct 10, 2022, https://www.topUniversities.com/University-rankings/world-University-rankings/2022
[29] From 2001 up to 2021, the number of Nobel Prize winners only in the fields of Medicine, Physics or Chemistry , born in the UK, See "Nobel Prize-Laureates", Opendatasoft, accessed Oct 10, 2022, https://public.opendatasoft.com/explore/dataset/nobel-prize-laureates/table/?disjunctive.category
[30] "Fields Medal for Mathematics By Nation", Areppim, accessed Oct 31, 2022, https://stats.areppim.com/stats/stats_fieldsxnation.htm

in the G7 for Field Weighted Citation Impact. The UK university sector is renowned both for its teaching quality and research reputation.[31]

The UK scores well on measures of innovation output against countries with comparable populations.[32] Taking into account the innovation environment and market sophistication, as well as knowledge, technical and creative outputs, the Global Innovation Index ranks the UK fourth among high-income-group economies and third among the 39 European economies measured, with the UK performing well on metrics of innovation for its GDP per capita.[33] However, despite this favourable environment, the UK has suffered low productivity growth for over a decade since 2008/09[34] and the poor growth is expected to continue.[35] The UK's poorer productivity performance relative to other leading economies is a complex issue, attributable to a number of factors and not just the UK's RDI landscape. However, improving the diffusion, permeability and translation of RDI knowledge into benefits for UK industry and society is important to address the UK's productivity challenge.[36]

The UK has been making progress by learning from international practices and has been setting up new RDI models such as Innovation Accelerators and Regional Investment Companies. The UK needs to build further on this by horizon scanning internationally to guide policy towards models of 'best practice' for RPOs to achieve national goals such as stimulating regional growth, maximising productivity, improving research output and protecting national capabilities. Given varying institutional structures, market mechanisms and knowledge cultures, no one country or regional model should be a single guide, but we can learn from the best of what is happening elsewhere to determine what can work well in the UK RDI landscape.

To better understand the current UK RDI landscape and how it may be improved, a brief description and critical analysis of the major RPO sectors is given below.

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[31] Department for Business, Energy and Industrial Strategy, International comparison of the UK research base, 2019, 2019, accessed Oct 10, 2022, https://www.gov.uk/government/publications/international-comparison-of-the-uk-research-base-2019
[32] WIPO, Global Innovation Index 2021: United Kingdom, 2021, 1, accessed Oct 10, 2022, https://www.globalinnovationindex.org/analysis-economy
[33] WIPO, Global Innovation Index 2021, 2021, accessed Oct 10, 2022, https://www.globalinnovationindex.org/analysis-economy
[34] "What is the productivity puzzle?", ONS, 2015, accessed Oct 10, 2022, https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/labourproductivity/articles/whatistheproductivitypuzzle/2015-07-07; WIPO, Global Innovation Index 2021: United Kingdom, 2021, accessed Oct 10, 2022, https://www.globalinnovationindex.org/analysis-economy
[35] Bart Van Ark "No post-pandemic productivity boost in sight", The Productivity institute, accessed Oct 10, 2022, https://www.productivity.ac.uk/news/no-post-pandemic-productivity-boost-in-sight/
[36] Department for Business, Energy and Industrial Strategy, UK Innovation Strategy, 2021, 11-15, accessed Oct 10, 2022, https://www.gov.uk/government/publications/uk-innovation-strategy-leading-the-future-by-creating-it

Universities

Description and analysis

Universities in the UK play a very important part in the country's overall RDI endeavour. They are independent of Government, but receive major public funding for both research and teaching. They have a broad and deep multidisciplinary research base with demonstrable excellence in many research areas, contributing very positively to the UK RDI ecosystem. The success of the sector is due to its world-leading researchers, who help the UK produce some of the highest quality research in the world and support the development of a pipeline of research and innovation talent in the UK. Comparison with other countries indicates that the UK university research sector is strong, although it faces significant and increasing competition from well-established research universities in North America and continental Europe, as well as emerging research-intensive universities in the Far East.

The ONS has recently indicated that their methodology for calculating R&D expenditure in the higher education sector did not fully capture all the non-governmental R&D spending in the sector. Unfortunately, the substantial amount of R&D both performed and funded by the universities themselves was not recognised and was therefore unavailable in data tables; this has now been revised, such that the figures for the most recent years have been corrected from £8.7bn to £14.0bn in 2018 and from £9.1bn to £14.0bn in 2019, and are calculated to be £13.9bn in 2020[37].

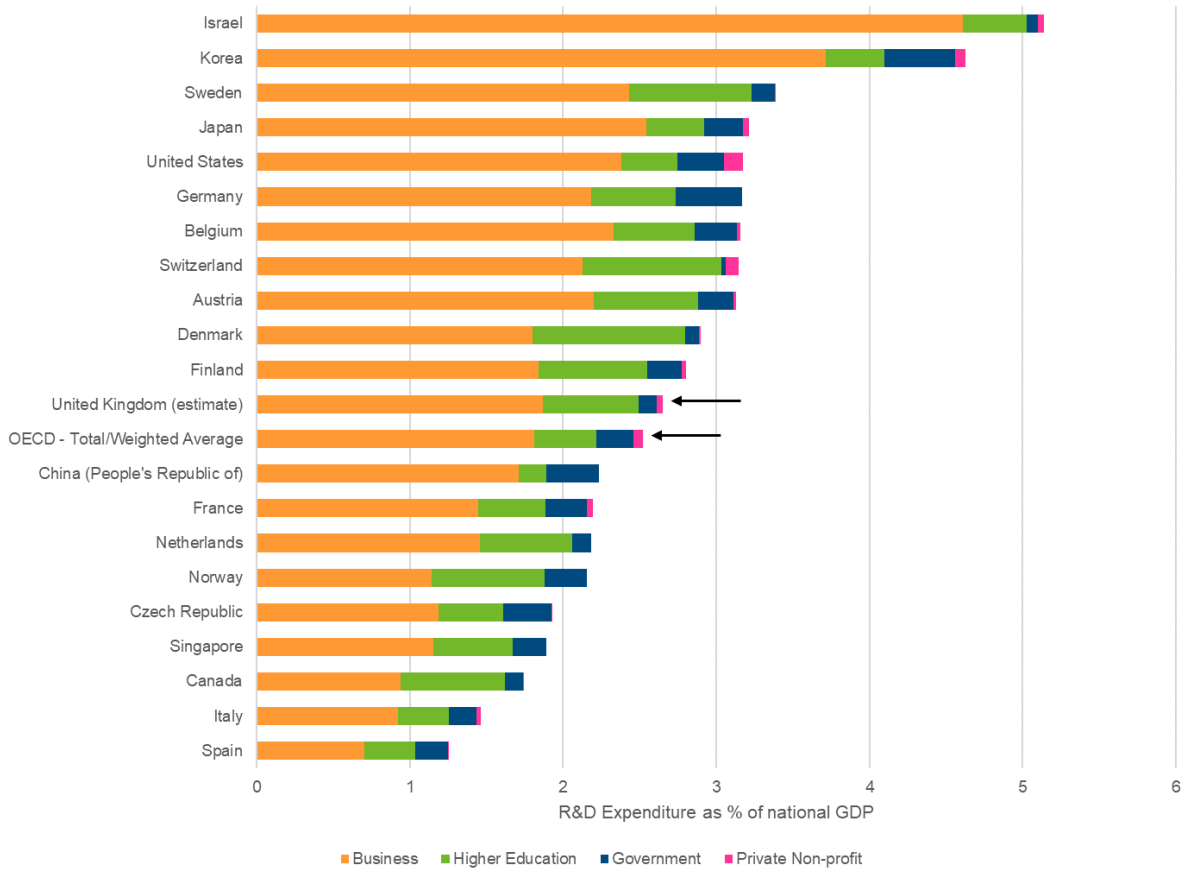
International comparisons of R&D spending in universities as a proportion of GDP are shown in Figure 1. The UK concentrates non-business R&D in universities, which accounts for around 80% of non-business R&D expenditure, a greater proportion than the 45%-60%[38] seen in comparator countries.

[37] "UK gross domestic expenditure on research and development, 2020 (designated as national statistics)", ONS, 2022, accessed on Nov 30, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/datasets/ukgrossdomesticexpenditureonresearchanddevelopment2020designatedasnationalstatistics .

[38] "UK gross domestic expenditure on research and development, 2020 (designated as national statistics)", ONS, 2022, accessed on Nov 30, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/datasets/ukgrossdomesticexpenditureonresearchanddevelopment2020designatedasnationalstatistics.
R&D expenditure performed by higher education as a percentage of non-business R&D (higher education, Government, and Private Non-profit) in 2019: France = 59%, Germany = 56.1%, United States 45.9%, and OECD total/weighted average = 57.7%.

The contributing factors for the dominance of universities in the RDI landscape are varied, but a major reason is past policy choices by government to channel R&D funding through universities, rather than a wider set of Government funded RPOs. Figures 2 and 3 show that R&D expenditure in higher education has increased gradually since the 1980s. In contrast, investment in R&D performed by Government or RPOs directly funded by Government has significantly declined.[39]

Figure 1: OECD data on R&D expenditure in 2019 by sector of performance (as % of GDP), by country[40]. Note the low proportional and absolute spend on UK R&D by the Government

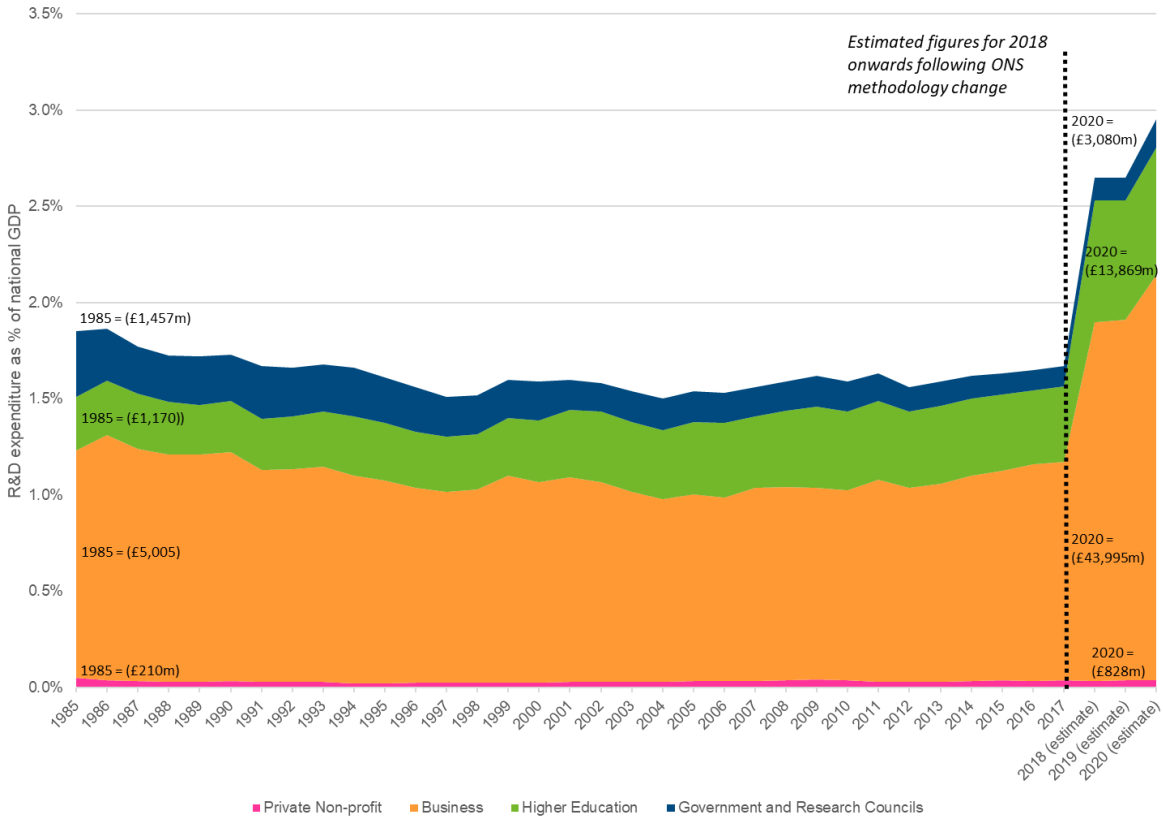


Source: "Main Science and Technology Indicators", OECD, 2020, accessed Oct 10, 2022, https://www.oecd.org/sti/msti.htm. For some countries figures are estimations and definitions differ.

[39] "Gross domestic expenditure on research and development, GERD performed by Government and UKRI and Higher Education, UK: 2019", ONS, 2021, accessed Oct 10, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/ukgrossdomesticexpenditureonresearchanddevelopment/2019 and "Gross domestic expenditure on research and development, UK: 2020", ONS, 2022, accessed Dec 14, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/ukgrossdomesticexpenditureonresearchanddevelopment/2020

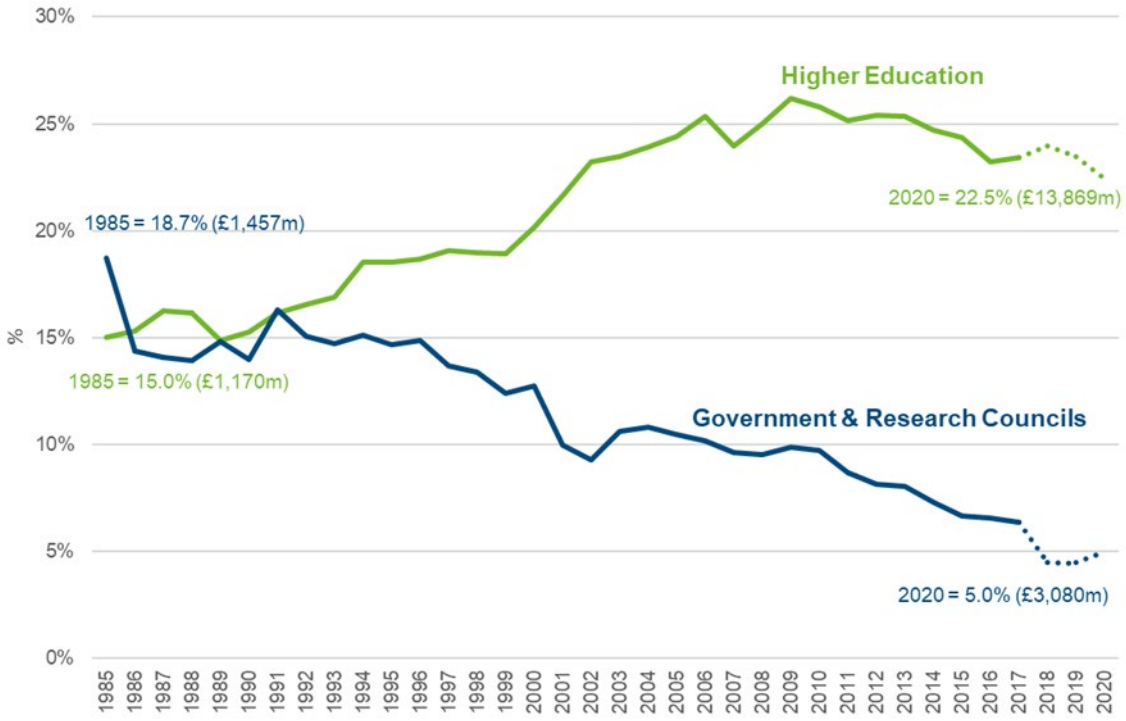
[40] OECD average does not take into account UK's new data based on ONS's revised methodology in Nov 2022. The UK figure is calculated independently by DSIT based on ONS's revised data.

Figure 2: ONS data on total UK R&D expenditure by sector of performance 1985-2020 (as % GDP). Note the significant shrinkage of Government-performed R&D and the increase in higher education-performed R&D in the last 40 years, shown here and in Figure 3.



Source: "Gross domestic expenditure on research and development time series", ONS, 2021, accessed Dec 14, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/datasets/governmentexpenditureonresearchanddevelopment and "Gross domestic expenditure on research and development, UK: 2020", ONS, 2022, accessed Dec 14, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/ukgrossdomesticexpenditureonresearchanddevelopment/2020

Figure 3: Percentage of GERD performed by the Government and higher education in the UK, 1985-2019 [41] Note the significant shrinkage of Government-performed R&D (carried out by Government departments or Research Councils outside higher education) and the increase in higher education-performed R&D in the last 40 years, shown here and in Figure 2.



The emphasis of Government on supporting research in universities has contributed to their research excellence. The UK is internationally competitive on measures of academic excellence and innovation capabilities, ranking first in the G7 for Field Weighted Citation Impact every year since 2007 and fourth among the 132 economies featured in the 2022 Global Innovation Index (GII).[42] However,

[41]"Gross domestic expenditure on research and development, UK: 2019", ONS, 2021, accessed Nov 30, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/ukgrossdomesticexpenditureonresearchanddevelopment/2019; "Gross domestic expenditure on research and development, UK: 2020", ONS, 2022, accessed Nov 30, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/ukgrossdomesticexpenditureonresearchanddevelopment/2020. Dotted lines indicate figures based on ONS's revised methodology published in Nov, 2022.

[42] WIPO, Global Innovation Index 2021, 2021, accessed Oct 10, 2022, 1, https://www.globalinnovationindex.org/analysis-economy

investment in the rest of the public RDI organisational landscape has dwindled, with potential consequences for the wider system.

Incentives in the university research landscape

There are complex incentives at play in the university research landscape which operate at multiple levels from individuals to institutions, and are shaped by Government actions such as public funding initiatives. University research is also affected by the global research community and the wider economy. Better understanding of this complex picture is needed to fully consider the role of university research within the UK landscape, and its future ability to support the UK's RDI.

The dual support system of funding

In common with many other leading research nations, Government funded university research is primarily supported by two streams, termed the 'dual support system'. The first stream comprises competitive grants, awarded for specific research projects and programmes (known as 'response-mode' funding), and also for the support of research students and infrastructure. Much of this competitive funding comes from UKRI and its Research Councils. The second is un-hypothecated quality-related research funding (QR) and its Devolved Administration equivalents, the level of which is linked to the results of the Research Excellence Framework (REF).[43] [44] [45] The dual support funding approach was designed to sustain and drive research activity across the UK, and can empower universities and their researchers to undertake their own specific research initiatives and support their research infrastructure. It plays a significant role in shaping and incentivising the research activities of both researchers and universities.

Quality-related research funding (QR)

QR and its equivalents in the Devolved Administrations are major sources of research income within the UK RDI landscape. In 2021/22, Research England allocated a total of £1.74bn of QR funding to English universities.[46] The un-hypothecated core research funding provided by QR is essential and valuable to

[43] REF gathers data from each university to provide an independent assessment of their research activities

[44] Research England, Research England – how we fund higher education providers, 2020, 10-17, accessed Oct 10, 2022, https://www.ukri.org/publications/research-england-how-we-fund-higher-education-providers/

[45] Department for Business, Innovation and Skills, Dual Funding Structure for Research in the UK: Research Council and Funding Council Allocation Methods, and Impact Pathways, 2013, accessed Oct 10, 2022, 1-14, https://www.gov.uk/government/publications/dual-funding-structure-for-research-in-the-uk-research-council-and-funding-council-allocation-methods-and-impact-pathways

[46] "Funding for 2021 to 2022", UKRI, 2021, 3, accessed on Nov 15, 2022, https://www.ukri.org/publications/funding-for-2021-to-2022/

universities as well as to RPOs elsewhere in the wider research landscape. It provides a source of stable, flexible funding which can be used to support and develop research and allows those close to the actual research activity to make strategic decisions, set programmatic priorities, and support financial sustainability. It is also intended to maintain and build research capabilities and infrastructure. Each Devolved Administration determines the amount and priorities for un-hypothecated university research funding. The Research Excellence Grant (Scotland), and Quality-Related research funding in England, Wales and Northern Ireland are determined by each of the higher education funding bodies, using their own core research funding allocation methodology.

UKRI produces data which outline mainstream QR funding broken down by institution and subject, but the Review has identified opacities in how QR is spent by universities, which makes tracing its uses at an individual university level challenging,[47] and hampers a wider assessment of how public funding impacts the UK RDI landscape. The Review also heard that front-line researchers did not always know how QR was being deployed in their universities, suggesting universities should better communicate this and do more to make the information accessible. The Review learnt that some university leaders were in favour of increasing transparency as it would allow the argument for Government support to be made more easily, while others were concerned that it might encourage Government interference. As a key funding mechanism, it is important that the Government and UKRI examine the influence of QR alongside other incentives detailed below. To aid this, Government and the wider sector must consider more transparent mechanisms to provide assurance and accountability on QR funding to give researchers confidence in the system, while keeping bureaucracy to a minimum.

The REF assessment informs the level of QR funding allocated to a particular university. The REF is a peer review process which puts requirements on institutions to submit evidence for assessment of outputs, impact beyond academia, and their research environment. The REF is highly bureaucratic and is currently under review by the UK higher education funding bodies in the Future Research Assessment Programme, which is expected to report in early 2023; the outcomes of this should be considered in the context of this review.[48] Any practices which are detrimental to RDI should also be considered and corrected.

[47] Public and Corporate Economic Consultants Ltd & the Centre for Business Research, University of Cambridge, A Review of QR Funding in English HEIs, 2014, accessed Oct 12, 2022, xiv, https://www.praxisauril.org.uk/resource/review-qr-funding-english-heis-process-and-impact

[48] UKRI, "Launch of the future research assessment programme", 2021, accessed 1 Nov, 2022, https://www.ukri.org/news/launch-of-the-future-research-assessment-programme/

Competitive grant funding

Public funds are also used for response-mode funding of research projects and programmes, and to support research students and infrastructure. These grants are generally allocated in a competitive fashion and cover a range of disciplines and fields, enabling universities to undertake investigator-led research in areas of interest to the funding body. Response-mode grants, and in some cases funding of students and infrastructure, attract a contribution from Government research funders towards the cost of undertaking the research, calculated in the UK higher education sector using a methodology termed 'full Economic Costing' (fEC).[49] The underlying principle of fEC is to establish the true price of research and for this to inform the amount requested from funders.[50]

fEC was brought in by Government following the 2002 Spending Review due to a recognised chronic underfunding of research.[51] As a result of this reform, Research Councils were able to provide additional funding on the condition that universities demonstrated an ability to manage research on a sustainable basis.[52] Government agreed an approach where Research Councils paid 80% towards fEC to more fully cover the costs of research activity.[53] Since the creation of fEC arrangements, different research funders have paid varying percentages of the total, presently between 70% - 80%. Grants from philanthropic charities generally cover significantly lower levels of fEC than this, requiring further contributions from institutions. The Government's Charity Support Fund was meant to help cover this shortfall but it has not increased in line with research funding from charities. Charities and Government should together discuss how to fund proper end-to-end research support.

As a factor in the wider financial sustainability picture, it is important that the Government and UKRI examine the influences that competitive and response-mode grant funding have on the wider RDI system, and the practicalities of the present provision of fEC, which as argued later, is insufficient.

Wider incentives

Alongside funding mechanisms, there are wider incentives in the university research landscape which influence its operation. The Government explored the importance of

[49] Office for Students, Annual TRAC 2019-20: Sector summary and analysis by TRAC peer group, 2021,accessed Oct 10, 2022, https://www.officeforstudents.org.uk/publications/annual-trac-2019-20/
[50]TRAC, "TRAC guidance for 2021-22 returns", 2021, accessed 1 Nov, 2022, 152, https://www.trac.ac.uk/tracguidance/
[51] University of Reading, "Intro to Full Economic Costing (FEC)", accessed 1 Nov, 2022, The origins of fEC, https://www.reading.ac.uk/research-services/costing-a-proposal/intro-to-full-economic-costing-fec
[52] Bangor University, "Transparency Review", accessed 10 Oct, 2022, https://www.bangor.ac.uk/finance/tr/default.php.en
[53] TRAC, "History of TRAC, accessed 1 Nov, 2022, https://www.trac.ac.uk/about/history/

the R&D workforce in the UK in the R&D People and Culture Strategy,[54] which concluded that frameworks and incentives in the R&D system are a contributing factor to weaknesses in UK research culture. These incentives influence the behaviours of researchers and the delivery and operations of research activity. One example that the Review heard of is an unhelpful focus on the length of a researcher's publication record rather than on the quality and significance of their research activities. In addition, given that the primary mechanism for university researchers to attract more research funding is through response-mode grants, if the associated fEC and QR are insufficient to support all end-to-end total cost requirements, then more grants perversely lead to increasing strain on research infrastructure and capability. A vicious cycle is promoted whereby universities and their researchers prioritise the pursuit of more response-mode grants, and that in turn exacerbates pressure on the other support that research requires if it is to be effective. This can run the further risk of prioritising the quantity of research activity rather than its quality.

Universities are also subject to other drivers. They seek to ensure resources and funding can stretch as far as possible right across the range of their missions. This creates pressures, such as adding additional teaching to researchers' workloads. Universities' missions of teaching and research are intertwined: quality research boosts reputation, which drives staff and student recruitment, and this in turn increases income for research cost recovery. Additional grant income may result in greater success in future REFs but can place added pressures on an institution's short-term ability to cover the costs of research. The current REF formula therefore shapes academic research culture with negative consequences such as increasing investigator numbers at the expense of administrative, support and technical staff as well as the required investments in research infrastructure.

The Review also learned from both university leaders and researchers that individual universities do not always have comprehensive and effective mechanisms in place for the delivery of their research. Generally, the emphasis is on what specific research programmes to pursue, rather than how those programmes can be most effectively delivered. Universities should consider developing clearer strategic roadmaps defining the infrastructural and staffing requirements for overall research excellence. This would assist and influence both local and national RDI activities.

Government should ensure that public funding of RDI is supporting high quality research providing value for money, and generating strategic advantage, economic growth, increased productivity, and societal benefits. It is generally accepted that through independent peer review, researchers are best placed to make individual

[54] Department for Business, Energy and Industrial Strategy, R&D People & Culture Strategy, 2021, accessed Oct 10, 2022, https://www.gov.uk/government/publications/research-and-development-rd-people-and-culture-strategy

decisions on whether research proposals are likely to generate high quality research – what is known as the Haldane Principle. In addition, Government also has strategic priorities that it wants delivered through public funding, although these are predominantly at the applied end of the research spectrum.

Financial sustainability of university research

As outlined above, the incentives at play in the university research landscape can impair its operation and effectiveness. The different drivers influence individual researchers, universities, and funders, affecting financial sustainability at a system-wide level. This results in research activities causing deficits for the higher education sector, a trend which is increasing over time. For the most recent year of data, 2020/21, university research operated at a UK-wide funding deficit of £4.2 billion, with other income surpluses amounting to £2.6 billion from non-public sources[55] partly used to offset this. This support is required despite research funding from the funding councils of £2.2 billion.[56] [57] It should also be noted that freezes on domestic tuition fees mean that domestic student teaching also increasingly requires cross-subsidy, drawing this source of funding away from research activity.

Shortfalls in fEC and in more general research requirements, such as IT and database support, technical cores and facilities, administrative support, provision of the 'well-found laboratory' and modern research buildings, have to be made up by the universities. Additional funding is primarily provided by private sources and to some extent commercial activities, including conference and residential accommodation income, and through Technology Transfer Offices, as well as philanthropy. A substantial proportion of this income comes from international students.[58] While it is a strength of the UK's higher education sector that it can attract large numbers of international students, over-reliance on this large but potentially volatile source of funds, especially if concentrated in specific countries, to underpin UK research, is a cause for concern.

It is critical to understand the concept of 'end-to-end' research support. This Review defines it as the funding required to fully support research activity, encompassing support for individual researchers and staff, training and career development, the provision of administrative services, technical facilities, laboratory facilities, and other

[55] Teaching of students from outside the UK and EU; self-funded home and EU students and other commissioned courses (such as employer-specific 'closed' courses).
[56] Office for Students, Annual TRAC 2020-21: Sector summary and analysis by TRAC peer group, 2022, accessed Oct 10, 2022, https://www.officeforstudents.org.uk/publications/annual-trac-2020-21/
[57] "£2.2 billion investment to support government's R&D ambitions", UKRI,2020, accessed Oct 10, 2022, https://www.ukri.org/news/2-2-billion-research-england-investment-to-support-governments-rd-ambitions/
[58] Office for Students, Financial Sustainability of Higher Education Providers, 2021, accessed Oct 10, 2022, 8, https://www.officeforstudents.org.uk/publications/financial-sustainability-of-higher-education-providers-in-england-2021/

indirect costs. Sustained research support is also required to maintain long-term capabilities and to retain staff, as projects and programmes of research may span multiple grants over several years. Currently, university administrative offices are not always able to cope with the demands put on them by research activity, resulting in significant delays and other problems in provision of support services such as for HR, finance, and legal matters. The Review heard repeatedly that this results in inefficiencies and an excessive burden on researchers, who have to carry out routine administrative tasks in addition to undertaking their research. It is important to recognise that high quality research is difficult to carry out and requires researchers to have the time to think.

Sophisticated technical cores and facilities are increasingly needed for modern research activity. In the physical sciences, large separate centralised infrastructure facilities, such as particle accelerators and telescopes, have traditionally been set up to be accessed by scientists across many universities, as is the case for CERN, for example. However, local core technical facilities are also required at a smaller scale within university research facilities themselves. Some of these have functions relevant for many disciplines, one example being good digital infrastructure, necessary for the natural sciences, arts, humanities, and social sciences. In recent years, a range of technical cores has become an increasing feature of life sciences research due to the advent of more sophisticated technologies. Support of the 'well-found laboratory' is another key feature, ensuring that research buildings and the laboratory facilities within them are fit for modern research in safe and sustainable working environments. Worryingly, the Review heard of examples where universities competing for grants tried to make themselves more attractive to the funder by reducing the support requested for core and infrastructure support, thereby failing to take full account of the 'price' of the activity and increasing the overall financial stress on the system.

Funding agencies and university research operational structures have not kept pace with these various changes and pressures, with public funding sources and cross-subsidy from universities' own income having to stretch further and further. As a consequence, the 'end-to-end' funding of research activities, covering all the above components in the present (short-term affordability) and into the future (longer-term sustainability), has become inadequate.

Other sources of university income such as overseas student fees and philanthropy[59] [60] should be used to support research but as far as possible in a manner which does not create vulnerabilities in the research system. An example of

[59] House of Commons Committee of Public Accounts, Financial sustainability of the higher education sector in England, Eight Report of Session 2022-23, 2022, 11-12, accessed Oct 12, 2022, https://committees.parliament.uk/publications/22593/documents/166272/default/

[60] House of Commons, International students in UK higher education: FAQs, 2022, 22, accessed Oct 12, 2022, https://researchbriefings.files.parliament.uk/documents/CBP-7976/CBP-7976.pdf

how such vulnerability could be reduced would be not to use such income to underpin all 'end-to-end' funding across multiple research programmes, which results in them all being vulnerable, but instead to use it to support one-off expenditures, such as laboratories or buildings, and end-to-end funding of a limited number of specific research projects. It would also be advisable to have reserves in place, should less resilient sources become reduced or lost, so that there is time to respond to loss of income. Finally, care should be taken not to rely too much on particular countries as a major source of overseas students, as there is a risk that policy changes or global events result in a sudden reduction of student numbers.

Japan University Research Endowment Fund

Other research-intensive nations are supporting university research in different ways. The Japanese Government has outlined plans to create a 10-trillion-yen (approximately 70 billion USD) University Endowment Fund to bolster research activity. Universities considered capable of achieving world class research will be allocated a portion of the fund's profits, to provide them with long-term financial support in the order of tens of billions of yen, per year, per university. Support will be aimed at high potential doctoral students, research in selected fields, and regional universities that play a pivotal role in their local area, and will help to nurture innovation by supporting the creation of hubs for research centres and start-up businesses.

Wider economic and international developments, freezes on university fees and other Government policy changes also place additional pressures on the current research environment. These include underestimating the impact of future inflation, which further stretches the public research and teaching budget, and makes shortfalls in the fEC of response-mode and other competitive grants increasingly acute. Cumulatively, the pressures and challenges over recent years mean that the universities' funding framework is increasingly unsustainable. Similar problems with the proper end-to-end funding of research are found in other RDI sectors receiving Government support, so these discussions are also highly relevant beyond the universities.

To solve this problem, the Government should work with research funders and universities to review and reform the operation of competitive grant funding, including the proportion of fEC covered, and also of QR, to ensure that both funding streams are fit for purpose, and do not have perverse incentives or outcomes. Funding research more fully from end-to-end on a sustainable basis needs to be a major outcome of this review.

Research staff in universities

The majority of researchers in universities are early career researchers, such as doctoral students, post-doctoral researchers, and junior faculty. Early career researchers spoken to during the Review expressed significant concerns about career structures. These concerns centred on short training periods, multiple short-term contracts, and poor long-term career prospects. The standard PhD of three years was not considered sufficient time for proper training or to complete a body of publishable quality work for a number of disciplines. Similar concerns were expressed by post-doctoral researchers, some on very short contracts. Universities should have employment plans in place to allow enough time for quality research to be carried out, and for both cohorts to be well trained and given the information and support to decide whether a research career is for them, and if so, in which research sector.

Four-year PhDs to allow research to be advanced to a publishable level should be considered, particularly for laboratory experimental based projects. These changes will require either greater resource or fewer PhD places funded, although the latter should be avoided, as more PhDs will be required if the UK is to reach the investment levels of more research-intensive nations. Post-doctoral posts should be seen as training positions, not just focused on an academic career but taking into consideration the full range of careers available within RPOs, with supplementary support from universities' and funders' other resources if necessary. It should also be noted that short training periods generally decrease value for money: during training, doctoral and post-doctoral researchers improve their specialist research skills such that by the end of their training, their research productivity and hence their cumulative research output can be substantially increased by a relatively small extension of their training period.

Starting research group leaders who are initially funded by externally funded fellowships have related problems. When a group leader is employed on a five-year fellowship, decisions about subsequent long-term employment are usually made at around three to four years, putting short term pressures on researchers at what should be one of the most creative and productive times of their careers.

The number of long-term positions in academic research is substantially lower than the numbers of PhD and post-doctoral researchers in the pipeline. Better management of existing contracts is necessary, but greater career path diversity within the RDI landscape is also essential. University research group leaders responsible for training early career researchers are often only aware of opportunities within universities, the sector with which they are most familiar. They need to be more aware of other parts of the RDI environment, so that the training they give their early career colleagues produces high quality researchers who can enhance the RDI landscape more generally, rather than just preparing them for

careers within the university sector. This will require better promotion of the full range of career options available to early career researchers beyond academia, and much greater permeability and inclusion between different RPOs, including those within industry. Some Research Councils offer the opportunity for doctoral students to undertake professional internships and placements outside academia, to promote awareness of alternative career opportunities and increase permeability of people, skills and ideas across the landscape. Further development of such schemes would be helpful.

Early career researcher training and career pathways are complex matters that require further consideration. There needs to be greater emphasis on quality and not just quantity, more effective research activity, greater support of junior staff, better management of short-term funding, and ensuring that the training is appropriate for the many other opportunities available outside universities for those who have acquired quality research skills and training. Early career researchers are the engine of UK research and need to be better protected in a healthier, more supportive and permeable research ecosystem.

Another category of staff important for the UK research endeavour which is sometimes neglected, is the group of technicians and engineers who provide technical support to front line researchers, including management of the technical platforms needed for research delivery. Technicians and engineers need to be trained with the appropriate skills to perform these essential activities. The universities have a role in this training, as do further education institutions and other RPOs, and plans should be in place to deliver the increased numbers with appropriate skills needed for the Government's plans of an expanded RDI budget. One possible example of how this might be delivered is a new programme in the Midlands focused on the career development of higher education technicians which could inform further programmes nationally.[61] Project and programme managers are also required for effective running of RPOs, and consideration should be given to appropriate career structures and formal training mechanisms for such specialists.

Collaboration and knowledge exchange

Universities collaborate and interact with other UK and international universities, RPOs and industry, forming networks for knowledge diffusion throughout the UK and beyond.[62] Knowledge exchange driving collaborations and interactions is supported by several mechanisms including Knowledge Transfer Partnerships, the Knowledge Exchange Framework (KEF), and the Knowledge Exchange Concordat, developed

[61] MI Talent, "The UK's largest programme on HE technicians commences", accessed 1 Nov, 2022, https://www.mitalent.ac.uk/News/the-uks-largest-programme-on-he-technicians-commences
[62] For example, see "Higher Education Business and Community Interaction", HESA, 2022, accessed Oct 12, 2022, https://www.hesa.ac.uk/data-and-analysis/business-community

by the sector in 2020.[63] Universities work with businesses, charities and others to support research, and facilitate its commercialisation to meet a variety of social and economic goals. This area has been the subject of previous studies including the 2015 Dowling Review of Business-University Research Collaborations, and more recently the 2019 Mike Rees Review on University-Investor links.[64]

GW4 Alliance

Universities can work together as consortia to increase their individual impact. GW4, founded in 2013, is a research consortium of the Universities of Bath, Bristol, Cardiff and Exeter. In addition to providing pilot funding for collaborations, GW4 supports technical infrastructure and equipment sharing across the alliance, delivers professional development for early career researchers and technicians, and coordinates with organisations such as the National Trust, NC3Rs life science clusters, UKRN and the British Academy. GW4 covers both South West England and South Wales. Working with partners such as the pan-regional partnerships the Western Gateway and the Great South West, they are driving innovation and policy change including supporting the regional hydrogen economy to help reach sustainable net zero targets.

Commercialisation mechanisms involve a range of funding streams, Higher Education Innovation Funding (HEIF), the Connecting Capability Fund, and tools like Konfer.[65] They help connect activities between universities and businesses (supported by UKRI and National Centre for Universities and Businesses). Technology Transfer Offices also have roles in IP commercialisation, licensing and spin outs. As identified by the Dowling Review, strategic research partnerships are able to provide significant benefits to the participants.[66] As key enablers to the

[63] "Knowledge Exchange Framework", Research England, accessed Oct 12, 2022, https://kef.ac.uk/; "Knowledge Exchange Concordat: Main Page", Knowledge Exchange Concordat, accessed Oct 12, 2022, https://www.keconcordat.ac.uk/; "Knowledge Exchange Partnerships: Main Page", Innovate UK, accessed Oct 12, 2022, https://www.ktp-uk.org/

[64] See Department for Business, Innovation and Skills, Business-university research collaborations: Dowling review, 2015, accessed Oct 12, 2022, https://www.gov.uk/government/publications/business-university-research-collaborations-dowling-review-final-report and Mike Rees, Independent advice on university-investor links, 2019, accessed Oct 12, 2022, https://www.ncub.co.uk/insight/independent-advice-on-University-investor-links-mike-rees-report/, amongst others.

[65] See "Higher Education Innovation Funding", UKRI, 2022, accessed Oct 12, 2022, https://www.ukri.org/what-we-offer/browse-our-areas-of-investment-and-support/higher-education-innovation-fund/; "Connecting Capability Fund", UKRI, 2022, accessed Oct 12, 2022, https://www.ukri.org/what-we-offer/browse-our-areas-of-investment-and-support/connecting-capability-fund/; "Digital Brokerage – konfer", NCUB, accessed Oct 12, 2022, https://www.ncub.co.uk/solutions/digital-brokerage/

[66] Department for Business, Innovation and Skills, Business-university research collaborations: Dowling review, 2015, 13, accessed Oct 12, 2022, https://www.gov.uk/government/publications/business-university-research-collaborations-dowling-review-final-report

success of the RDI landscape, permeability and collaboration are further discussed later in the Review.

Knowledge distribution

Universities are located throughout the UK, and through both research and the development of human capital, they have an important role to play in helping regions realise and develop their research strengths.[67] Universities' local impact could be increased by strengthening the connections between local industry and public services and RDI capability. Universities are diverse in their research programmes: for example, some are research-intensive across a range of disciplines, others are more specialised in what they offer, and some have established closer research links with their local communities and local industries. Less research-intensive universities can have greater interactions with small and medium sized businesses not just through RDI, but in other related areas such as learning and teaching, problem solving, and training the workforce.[68] Smaller firms also experience greater increases in product and process innovation as a consequence of local university collaboration than do larger firms, with the latter more able to collaborate with partners further afield.[69] This demonstrates a potential role for all universities in improving local productivity.

Universities could expand their support for local economies and industries by helping to set up links with research capability wherever it may be found in the UK; present interactions are generally tailored to the RDI capabilities and needs of a specific local university. In addition, commercial activities with universities can be dominated by short-term financial returns negotiated by university leadership and their technology transfer organisations. This should be shifted to a more longer-term wealth creation strategy, and to universities being a 'gateway' to RDI activities in other RPOs across the country, including in other universities. It is proposed that universities establish a local 'information nexus' connecting local enterprises to relevant research expertise anywhere in the UK. Such information bureaux would be informed by the Government's national mapping of RPOs and market surveillance, discussed and recommended later in the Review. This initiative would support geographic levelling up through greater permeability and information about the entire UK RDI endeavour

[67] "Levelling-up through regional innovation clusters", Russell Group, 2021, accessed Oct 12, 2022, 1-4, https://www.russellgroup.ac.uk/media/6016/levelling-up-through-regional-innovation-clusters-19.pdf
[68] Tomas Coates Ulrichsen, Assessing the Economic Impacts of the Higher Education Innovation Fund: a Mixed-Method Quantitative Assessment: Report for HEFCE, 2015, 38-39, accessed Oct 12, 2022, https://www.ifm.eng.cam.ac.uk/uploads/UCI/knowledgehub/documents/2015_Ulrichsen_HEIF_impact_technical_paper.pdf
[69] Nola Hewitt-Dundas, Areti Gkypali, & Stephen Roper, Accessibility, utility and learning effects in university-business collaboration. *Research Paper* No. 57, (2017), 6, accessed Oct 12, 2022, https://www.enterpriseresearch.ac.uk/publications/accessibility-utility-learning-effects-university-business-collaboration-research-paper-no-57/

as well as through advice about how information and RDI support could be better accessed. This would help to address the issues raised in the Government's Innovation Strategy and Levelling Up White Paper on the need for greater local impacts and diffusion of knowledge.

Promotion of local economies by universities

Lancaster University contributes to regional economic growth within Lancashire and broader Local Enterprise Partnerships (LEPs) across the North, working with regional HEI partners through a series of business innovation collaboration programmes now worth >£100M, predominantly funded via European Structural and Investment Funds (ESIF). These are focused on local, regional and national challenges around healthcare, net zero, entrepreneurial leadership and the cyber secure digital/data driven economy.

Durham University stimulates economic, social and cultural renewal in its local regions including by working closely with regional university partners (Newcastle, Northumbria, Sunderland and Teesside). These universities work collaboratively as part of the Northern Accelerator to strengthen the ecosystem of support for spin out generation, doubling the rate at which companies are spun out from the partner universities. Durham University and Newcastle University anchor an emerging innovation cluster with strengths in AI, data, photonics, energy and environmental technologies. Durham University also works with Business Durham to develop incubation facilities, with part of the High Value Manufacturing Catapult, the Satellite Applications Catapult, and the Offshore Renewable Energy Catapult.

Conclusions

The Review's main findings are:

- Universities are a major strength of the UK RDI landscape but need increased support to continue to be so. As a consequence of current funding models and incentives, research sustainability is being affected by problems such as weak infrastructure and inadequate administrative support. These need to be urgently addressed to ensure the ongoing success of the UK's RDI landscape.
- Proper 'end-to-end' funding is required in universities to fully support research activities with mechanisms that do not have perverse incentives or outcomes, and that consider both the quality as well as the quantity of research delivered. Government and UKRI should work together to review and reform the current mechanisms of competitive and response-mode grant funding, fEC, and QR to ensure research is being funded on a more sustainable and consistent basis.

- Universities do not all have adequate overarching plans that consider how research programmes can best be delivered and what research infrastructure and technical cores are necessary to support their research portfolios.
- The system for development of early career researchers within universities needs to ensure that they are better served in terms of their careers and prospects. The importance of research support staff and technicians is inadequately recognised, as are engineers and others, and they need better training and career structures. This is covered by recommendations later in the Review.
- Universities could further contribute to better geographically equitable regional economic growth by providing an enhanced gateway for their local industries to learn about RDI activities in RPOs and research activities elsewhere in the UK, including other universities.

Recommendations

The Review recommends:

1. Government should take account of the true cost of ‘end-to-end’ research activity to generate a sustainable RDI endeavour. Government, working with UKRI and the UK higher education funding bodies, should review and when necessary reform competitive and response-mode grant funding, QR (and Devolved Administration equivalents), and fEC, and replace them with improved mechanisms. Overall objectives should be to optimise research delivery, remove perverse incentives and outcomes, and ensure the longer-term sustainability of the research system.
2. Universities should develop plans to optimise their operations in support of research, to empower researchers and reduce their administrative loads, and to improve the quality of support services, core technical facilities, and well-found laboratory buildings and infrastructures. Government, working with UKRI, the UK higher education funding bodies and the wider sector, should consider more transparent mechanisms to provide assurance and accountability on QR funding.

Public Sector Research Establishments

Description and analysis

Public Sector Research Establishments (PSREs) are a diverse collection of organisations within the UK's RDI landscape, each sponsored or partly sponsored by a Government department. As well as policy research and technical services such as collecting data and developing and implementing regulatory standards, PSREs deliver RDI programmes covering the whole research spectrum from discovery through translation to application and commercialisation. Their advanced scientific capabilities contribute to the UK's global standing as a leading scientific nation, enabling the UK to cooperate on strategic technical priorities with our allies. The expertise they embody is the product of decades of public investment, although in recent years, this investment has been declining.

The PSRE designation covers a highly heterogeneous group[70] of some 50 organisations, which together deliver a wide range of different missions for Government, business and wider society. PSREs comprise approximately 14%[71] of the total RDI institutions outside of universities, and their sizes vary considerably, ranging from large organisations such as the Met Office, which has around 2,200 staff,[72] to smaller organisations like Forest Research, with around 280 employees.[73] The more research-intensive PSREs have similarities with the institutes and units discussed later in this Review, so the conclusions and recommendations made in that section are also relevant to this one, and vice versa.

PSREs are particularly needed for RDI activities that are too sensitive for Government to outsource, or where there is a requirement for enduring sovereign expertise in the national interest: examples include work carried out by the UK

[70] Department for Business, Innovation and Skills, Research and innovation organisations: functions and policy issues, 2015, 10, accessed Oct 14, 2022, https://www.gov.uk/government/publications/research-and-innovation-organisations-functions-and-policy-issues

[71] Calculated as 50 PSREs as a percent of the total 361 non-HEI owned institutions identified in the RDI landscape. The 361 institutes do not include any that are primarily considered to be in the HE sector, includes hosted organisations. Institutional numbers are based on data from GO-Science, UKRI and institutes identified by the Royal Society found here: 6-7, accessed Oct 26, 2022, https://royalsociety.org/-/media/policy/Publications/2020/2020-09-list-of-public-and-non-profit-research-organisations.pdf To note, this calculation was performed using the best data available; the Royal Society list of PSREs was accurate as of publication in 2020.

[72] Met Office, Annual Report and Accounts 2020/21, 2021, 40, accessed Oct 26, 2022, https://www.metoffice.gov.uk/research/library-and-archive/publications/corporate

[73] Forest Research, Annual Report & Accounts, 2021, 42, accessed Oct 26, 2022, https://cdn.forestresearch.gov.uk/2022/03/Forest_Research_ARA_2020-21_Web_accessible.pdf

Atomic Energy Authority and the Defence Science and Technology Laboratory. Others are a critical national asset to be called upon in times of crisis, with prominent roles in national contingency planning and the UK's emergency responses. PSREs in this category include Natural England, the Environment Agency, and the UK Health Security Agency (UKHSA), which provides scientific and operational leadership, for example during outbreaks of infectious diseases. A further group constitutes those PSREs fundamental to accurate impartial monitoring of the UK's natural environment. For example, the Centre for Environment, Fisheries and Aquaculture Science, sponsored by Defra, monitors UK fisheries and marine habitats to support sustainable fisheries management.[74]

PSREs also deliver scientific mission-oriented programmes for Government, often with the aim of de-risking early-stage technologies where private sector investment may be inadequate. They provide infrastructure to the wider RDI community, developing new technologies and methods, managing large national facilities and infrastructures, holding critical datasets and collections, and undertaking long-term experiments that support the wider RDI system. Examples of such institutions include the National Physical Laboratory and the National Nuclear Laboratory.

PSREs have sites throughout the UK, which often form central components of specialised local or regional clusters. This distribution of sites arises from either the primary function and field of the organisation, is due to historical factors or, in the case of PSREs geared towards environmental and natural research, is the result of the need for appropriate geographical distribution of observation sites.

All PSREs receive public funding, largely in the form of core and programme funding from sponsoring Government departments such as DSIT, Defra or DfT, although some also work with businesses on a contract basis – an example of public-private partnerships delivering translation through a combination of discovery and applied research activities. PSREs are a source of independent, Government-backed expertise, creating a credible and stable operating environment for business, and additionally, can act as innovation hubs through their interactions with businesses and academia. In this, they can function in part as enablers or stimulators of local and regional economic growth. Some of these innovation hubs are in regions which are priorities for levelling up, such as FERA in Yorkshire.[75] Being anchored in the local and regional economies, they have opportunities to support growth locally,

[74] "Centre for Environment Fisheries and Aquaculture Science: about us", GOV.UK, accessed Oct 31, 2022, https://www.gov.uk/government/organisations/centre-for-environment-fisheries-and-aquaculture-science/about.

[75] Fera Science Limited, formerly the Food and Environment Research Agency, is the UK's National Reference Laboratory for application of food and feed law, rules on animal health and welfare, and plant health and plant protection products. BioYorkshire is a partnership between private sector and public RDI bodies like the University of York. ["Delivering world-class science for our partners, for the future", FERA, accessed Oct 31, 2022, https://www.fera.co.uk; "BioYorkshire homepage", BioYorkshire, accessed Oct 31, 2022, https://www.bioyorkshire.co.uk/]

either via their work for businesses or via successful commercialisation of innovations originating at the PSREs themselves.

PSREs provide unique services to Government

PSREs have varying functions within the landscape, including technical and regulatory roles.

The Medicines and Healthcare products Regulatory Agency (MHRA) is the UK regulator for medicines, medical devices and blood components for transfusion, and is responsible for ensuring that they meet applicable standards of safety, quality and efficacy. The MHRA provides advice and support at all stages of the regulatory pathway to innovators across the RDI spectrum from individual academics to large multinational companies, promoting collaboration and efficiency. Although always at arm's length, and maintaining regulatory independence, this relationship allowed MHRA to work flexibly with innovators in vaccines such as Astra Zeneca/Oxford, Moderna and Pfizer/BioNTech during the COVID pandemic. This meant that COVID vaccines, as well as therapeutics and essential devices could be swiftly approved without compromising safety. Sovereign regulators rely on a responsive and agile national research and innovation landscapes to support their statutory role, often over extended periods of time. MHRA is no exception and seeks to collaborate across the UK and internationally to undertake regulatory science research, ranging from lab-based research, clinical trials and data science through to work in economics and social sciences to support policy development.

The Environment Agency is responsible for regulating industry, water quality and resources, fisheries and ecology, and managing flood risk monitoring services. This includes research on understanding and improving the quality of the environment and reducing the impact of hazards such as pollution, floods, droughts and climate change. R&D provides the understanding, tools and techniques needed for expert scientific and technical advice, reports and guidance.

Evidence submitted to the Review suggested that the roles and benefits of PSREs are not always apparent to stakeholders and potential collaborators. Their value can be overlooked or ignored by other organisations, including Government departments — sometimes even the departments that support them. The Review heard that more could be done to raise awareness of the specialist knowledge, skills and facilities housed within PSREs, both within Government and more widely across the RDI landscape. Government has a role to play here in ensuring PSRE capability is more permeable and accessible to the rest of UK research endeavour.

National Physical Laboratory (NPL), PSRE

PSREs can support collaboration between a range of research organisations across the UK's RDI landscape. NPL develops the measurement infrastructure and standards that R&D organisations, universities, and UK businesses use to provide confidence in their data, maximise trade opportunities and accelerate technical innovation, attracting greater investment and getting technologies to market more quickly. NPL plays a vital role in the development and commercialisation of new emerging technologies, such as quantum. NPL employs 1200 staff, scientists, engineers, and apprentices, and co-supervises over 200 postgraduate researchers. It engages with around 1000 different businesses located across the UK every year and has supported over 600 R&D projects in the past three years, providing access to specialist measurement science and engineering support, advice and facilities, to solve technical analysis or measurement problems.

PSREs are generally the least well understood parts of the RDI organisational landscape. They lack annual data collection and surveys, and data at the PSRE level for the Government's own undertaking of research by type of R&D are not publicly available. The Review heard that the research output of PSREs was thought to be variable, and not always of the highest quality. This underscores the importance of rigorous transparent review to maintain confidence in the PSRE sector. The PSRE Value Framework, published in early 2022 by the Government Office for Science,[76] aims to support departments in assessing their PSREs and to lay the groundwork for driving quality, but its effectiveness has yet to be established.

Constraints on organisational agility

The Review heard that the agility of PSREs is constrained by the rules and processes to which they are subject as partner bodies of central Government departments (see also section D in 'Actions for Government to support a thriving RDI landscape' later in this Review). PSREs do not receive or have fewer sources of un-hypothecated and predictable multi-year funding available to them than other organisations in the UK RDI landscape, and are not able to easily make up shortfalls in funded programme costs. The lack of un-hypothecated funding arrangements hampers PSREs' ability to invest in long-term capability development, even in cases where such capabilities are directly in support of long-term core Government needs, and their ability to forge and commit to long-term partnerships with businesses and other organisations in the RDI landscape is constrained. Internal government

[76] Government Office for Science, Public Sector Research Establishment Value Framework, 2022, January, accessed February 2022, https://www.gov.uk/government/publications/public-sector-research-establishment-value-framework

processes such as a blanket requirement to follow full tendering processes lead to delays and uncertainties, hampering agility.

The Review heard that departments wishing to commission PSREs face barriers which may discourage or prevent programmes of work from being agreed in time, leading to loss of opportunities, and that inflexibility or inaccessibility of potential sources of funding can block valuable projects in cases where a sponsoring department was unable to provide complete funding. Recently it was agreed to permit PSREs to bid for funding from UKRI, but further consideration and changes in operational procedures are necessary to make this of real benefit. For example, PSREs may be unable to accept research grants funded under central Government rules[77] as major funders like UKRI fund 70-80% of fEC and many PSREs do not generate or retain surpluses that they can use to address this gap. The result is that PSREs' ability to participate and collaborate in research projects managed by funders that offer grants below 100% fEC, including UKRI, may be limited. Other rules mandate that PSREs follow strict Civil Service pay controls intended for officials at central departments, sometimes making it difficult to attract and to retain valuable subject matter experts and other personnel (see section D of 'Actions for Government to support a thriving RDI landscape' later in this Review). The proposal made in the 'Universities' section of this Review to reform response-mode grants, QR and fEC should also take into account their use in supporting research at PSREs.

PSREs' governance and organisational arrangements have evolved over time to reflect the needs of the government department which sponsors them. The wide variety of governance and organisational set-ups arising from these varied accountabilities may impede inter-PSRE collaboration. Additionally, the Review found that PSREs' multitude of financial structures creates further obstacles to collaborative working.

Generating more value for Government

The Review heard that research capability directly funded by Government departments is not always well coordinated or even readily visible across various departments. This represents a missed opportunity for Government, and more should be done to improve co-ordination and visibility, which would have benefits across the entire landscape. To use departmental research capability more effectively across the whole of Government, for example to enable greater use of PSREs' expertise in horizon scanning, departments need to be well connected with each other's research priorities and readily able to access the outputs from the research they support. While many PSREs have responsibilities that go beyond their

[77] HM Treasury, Managing public money, Annex 5.1, 2022, March, accessed Oct 31, 2022, https://www.gov.uk/government/publications/managing-public-money

sponsoring department, there is no consistent or coordinated approach by which PSREs can contribute to wider Government missions. Disappointingly, the Review even heard that sometimes sponsoring departments were unclear about what their own PSREs should be delivering.

There is clearly a need for closer working between departments and the PSREs under their sponsorship to ensure that the PSREs are effectively delivering what their department or Government as a whole requires. If that is not the case, then an assessment should be undertaken to determine if the PSRE in question should be evolved or closed. To preserve the health and capacity of the RDI system, any savings arising from evolution or closure of PSREs should be recycled into R&D budgets, rather than siphoned off to address shortfalls elsewhere, and if any closures or significant changes to PSREs are pursued, then transition plans should be in place to prevent the loss of nationally-critical skills and infrastructures.

General principles for creation of new RPOs provide a useful guide when considering the potential creation of new PSREs, and are considered later in this Review (section J, in 'Actions for Government to support a thriving RDI landscape').

PSREs enable UK business

PSREs support and undertake research into areas that are underserved by private research, and collaboration with business occurs in many PSREs. Their research also contributes to the functioning of business activities and society more generally, such as national and international standards delivered by the National Measurement System (NMS), or the Met Office's forecasting of weather.

The National Measurement Laboratory (NML), PSRE

PSREs can provide unique services to the RDI landscape. The NML is the UK's designated institute for chemical and bio-measurement. It is based in a private limited company that has held the role since its creation 25 years ago, and interacts across the RDI landscape to bring together diverse groups of stakeholders. It focuses on addressing measurement challenges and providing the resilient and trusted measurement infrastructure to support government and industry and to protect consumers within the UK. As a recent example of its work, the NML led a study to develop a reference measurement procedure to support COVID-19 molecular diagnostics during the pandemic, subsequently leading to the development of an international roadmap to enable a more rapid response and enhanced clinical outcomes in a future pandemic.

PSREs provide national infrastructures for RDI

PSREs own and operate RDI infrastructures which underpin the UK RDI landscape as a whole. In some cases, PSRE-owned infrastructures deliver fundamental capabilities essential for national resilience. For example, the National Timing Centre at the National Physical Laboratory is essential for critical national infrastructure and will enable operation of important technologies such as 5G and autonomous vehicles. In other cases, PSRE-owned infrastructures contribute directly to the UK's international profile in the relevant area: for example, Historic England's role in maintaining digital cultural infrastructures and championing the historic environment and heritage assets. In some cases, PSRE-owned infrastructures are subject to the Government funding and governance problems outlined elsewhere in this Review. It is important that future mapping of the RDI landscape covers PSREs, and that Government ensures PSREs work closely with UKRI on infrastructure planning.

The Met Office, PSRE

PSREs can provide world-leading expertise, creating job opportunities and partnering with others in the RDI landscape. The Met Office relocated from Bracknell to Exeter in 2003 and provides crucial jobs and opportunities in the South West. It has developed strong industrial and academic partnerships, predominately in weather and climate science, which has led to Exeter becoming recognised as a global centre of excellence in environmental science. The Met Office also leads initiatives to build the region's science and technology skills for the future. It has developed apprenticeship schemes with Exeter University and Exeter College and is an employer partner in The South West Institute of Technology.

In terms of supporting links with industry, in 2021 the Met Office signed a ten-year multimillion-pound deal with Microsoft for the provision of the world's most advanced supercomputer dedicated to weather and climate. Twice as powerful as any other in the UK, the new supercomputer will be in the top 25 in the world. This partnership will provide employment, apprenticeship, internship and mentoring opportunities in the region and highly skilled training in digital skills. The two organisations plan to engage SMEs and build skills across the South West.

PSREs often establish close partnerships with their counterparts overseas. The Met Office in Exeter is a key partner in the European Centre for Medium-Range Weather Forecasts (ECMWF), and its expertise enabled the UK to bid successfully to host the ECMWF's new headquarters in Reading.

PSREs and strategic advantage

PSREs' significant technical capabilities in emerging fields contribute to their standing as national assets. The Review found that PSREs' work on advanced and emerging technologies contributes to securing strategic advantage, a UK Government priority. Evidence collected as part of the Review suggests that a number of PSREs work on at least one of the seven technology families introduced in the Government's Innovation Strategy, including climate science and environmental technologies required for net zero.

An effective PSRE landscape is essential for the UK's future health, prosperity and security. No other type of RPO offers Government the same level of strategic input and sovereign control than do PSREs. This matters, because the accelerating pace of technological change means that within the next ten years Government will require sovereign scientific or technical expertise to be established in novel and emerging technological fields. In some cases, this will require the establishment of new PSREs, and guidelines for their successful creation, as well as for other RPOs, are discussed later in this Review (see section J, 'Actions for Government to support a thriving RDI landscape').

Serious consideration needs to be given to how this important sovereign expertise can be delivered successfully and effectively. In addition to the concerns detailed above, the Review heard that Government restrictions, which appear to have their origins in the Treasury, are a significant brake on research in PSREs as well as in institutes predominantly funded by Government, potentially damaging the UK economy and the ability of RDI to benefit the future of the UK.

National Nuclear Laboratory (NNL), PSRE

PSREs can promote strategic advantage and be a source of research, collaboration, and training. NNL is the UK's national laboratory and technical authority for nuclear fission. Its facilities are of national strategic importance and also benefit industry and academics, who can arrange access to NNL facilities for their own work. NNL also provides industrial co-supervision of over 100 PhD students from UK universities. As an example of its importance, NNL recently developed a novel way of extracting Lead-212, a key radioactive isotope used in a type of targeted radiotherapy, from nuclear waste. The new procedure will help to resolve a global shortage of Lead-212, and also provide UK researchers and clinicians with a home-grown supply.

Conclusions

The Review's main findings are that:

- The UK's highly heterogeneous PSREs are national assets that strengthen the broader UK RDI system, and the sector could contribute more if it were expanded. However, PSREs are the least visible RPOs in the landscape, and some have problems relating to research reporting, assessment and quality control.
- PSREs face a siloed and restricted funding environment which both constrains their growth and limits the ability of different Government departments and external RPOs to work with them. Government procurement and financial frameworks and restrictions on issues such as pay are slowing progress and inhibiting agility within the landscape. PSREs are sometimes unable to take longer-term strategic decisions due to a lack of sustainable funding.
- Government should do more to harness the collective human and technical capabilities of PSREs within departments' work, and to improve permeability to other external RPOs. Sponsoring departments should be more active and engaged when working with their PSREs.
- Departments generally do not sufficiently access research undertaken by PSREs sponsored by other departments, and too little is done within Government to build a culture of working with PSREs. Departments should work together more to identify cross-cutting priorities to improve coordination across the system.

Recommendations

The Review recommends:

3. Government departments should clarify the missions of their individual PSREs, allow them greater freedom of action, and ensure their effectiveness. Departments should improve internal awareness of PSREs' capabilities, and use PSREs to inform RDI strategy and policy making, working within and across departments. Permeability and agility would be further improved by increasing the visibility, interactions and partnerships between PSREs, and between PSREs and the rest of the RDI landscape, including commercial organisations.

4. Funding streams for PSREs need to be protected and reformed to ensure long-term sustainability. Constraints, which appear to have their origins in the Treasury, over funding, pay and other conditions of working should be

reduced. The reforms of funding proposed for the universities should also be applied to PSREs.

5. PSREs should be stringently reviewed, and those that have outlived their purpose or are not working effectively should be reformed, reduced or closed, and any savings generated recycled into Government R&D budgets.

Institutes and units

Description and analysis

The portfolio

The UK has a diverse portfolio of research institutes and units of varying scale, created or funded within different sectors of the RDI landscape to address a range of research missions. They fulfil a variety of roles, and though relatively small compared with the universities, form a strategically important part of the UK research endeavour located throughout the research spectrum. Like PSREs, they cover the entire research spectrum from discovery through translation to application and commercialisation. They can be set up in the public, non-profit, or private sectors. UKRI, through its Research Councils, is the major funder in the public sector, supporting over 50 institutes working in areas ranging from the humanities and social sciences to particle physics and AI. Wellcome and Cancer Research UK are significant charitable funders in the non-profit sector, and AstraZeneca and GSK in the private sector. The best UK institutes and units are internationally renowned. They act as a beacon for UK research, attracting the world's best talent and generating outputs that help place the UK at the forefront of science, tackling some of the biggest research problems and global challenges.

MRC Laboratory of Molecular Biology (LMB)

The UK is home to some excellent research institutes, including those that are working with industry to support important discoveries. The LMB is a long established internationally-renowned research institute responsible for major scientific and technological breakthroughs such as DNA sequencing, monoclonal antibodies, and innovative methods in structural biology, which together have won its scientists 12 Nobel Prizes. This has been enabled by core funding from the Medical Research Council allowing the LMB's researchers to concentrate on important and long-term problems. The business case for such an investment has been vindicated by the commercial income generated by the LMB for the MRC, which is greater than all of the funding it has received in its 60 years of existence. The LMB has worked with partners in industry for many years. One example of such a collaboration is the 'Blue Sky' research fund, set up in 2014 by the LMB and AstraZeneca, which supports a range of pre-clinical research projects, sharing knowledge and technologies to improve understanding of fundamental biology and disease.

There is no simple definition of "Institute", and they are also commonly referred to (often interchangeably) as centres, units and, in some cases, Independent Research Organisations (IROs). For the purposes of this Review, the terms 'institute' and 'unit'

are used, although the distinction between them is recognised as being somewhat arbitrary and is based on scale, specifically, the total number of researchers working within them. The smallest viable unit is around 30 researchers; sufficient critical mass is unachievable below this number. The largest institutes have 1000-1500 researchers; above this number it is increasingly difficult for an institute's senior scientific leadership to be sufficiently closely engaged with the research activities. The shift from unit to institute is roughly at a size of around 100-200 researchers.

Institutes and units occupy a position in the research landscape that is distinct from the universities because their activities are focused solely on research. This focused research role is expressed in different ways, and like PSREs, different institutes may fulfil one or more roles within the RDI system, including specific research, translation or innovation missions. They may have a focus on a particular research area as in the John Innes Centre, the Rosalind Franklin Institute or the Faraday Institution; on groundbreaking research and a researcher training mission as in the European Molecular Biology Laboratory (EMBL); on a specific research or innovation mission as with the Dementia Research Institute or DeepMind; focus on applied research and innovation to accelerate the adoption of new platform technologies into the private sector, such as the Aerospace Technology Institute; or on the provision of specialised scientific and technical capability and expertise, as exemplified by the Wellcome Sanger Institute, the EMBL European Bioinformatics Institute and CERN.

Institute for Fiscal Studies (IFS)

There are important institutes supporting crucial social science research. One of the best known of these is the IFS, the UK's leading independent economics research institute, which is a centre of excellence for social science research. UKRI's ESRC has funded a research centre at IFS since 1991. As a trusted impartial source, its research, commentary and analyses are applied to a range of policy issues from Government finances to education and skills, and regularly inform policy decisions and debates. Being recognised as a global centre of excellence, the IFS now has UKRI Research Institute status and funding.

There is a variety of institutes and units in the UK, each with a specific purpose, mission and strategic objectives. The most successful have an intensive research culture, combined with a research-active and research-focused leadership. They provide long-term capabilities supporting a critical mass of diverse expertise and knowledge, technologies and equipment to help fulfil scientific and innovation objectives. Institutes and units can be orientated towards discovery research or to the maintenance and management of critical infrastructure and capabilities. They can help build national and international capability and prestige, forming focal points for leadership in research communities, enhancing the quality and reputation of the UK's RDI system, and acting as a magnet to attract global research talent to the UK. They can build strong discipline-specific communities or critical concentrations of

outstanding researchers more easily than organisations such as universities, which have more complex missions and more dispersed research interests spread through separate departments or divisions. Institutes and units can also deliver a particular mission or objective by fostering interdisciplinary working, with diverse teams working towards a common goal, be it a specific scientific or innovation aim, or to advance a research field. As with some of the other RPOs covered in the Review, there is potential for institutes or units to pursue Government RDI strategic goals by conducting research in priority areas that fit national needs, and by filling capability gaps to support the wider RDI system. They can also easily bridge between discovery, translational and applied research.

The Faraday Institution (FI)

Institutes can promote strategic advantage. Launched in 2018, the FI is the UK's institute for electrochemical energy storage research, skills development, market analysis and early-stage commercialisation. A private company and registered charity, the FI primarily derives its income from UKRI. It has assembled a unique community of over 500 researchers working collaboratively across multiple disciplines and institutions in a distributive model to generate innovations and improvements in battery technologies aimed to place the UK at the forefront globally. The researchers being trained will help to meet the UK's future talent requirements in the energy storage field, and thus far, the FI has also spun out nine companies.

The focused nature of institute and unit research activities means that they can attract high quality scientific leadership who, when free of Government operational restrictions, have discretion over strategic spending decisions, and play a critical role in institutional and scientific success. They have influence over how the research is run and organised, and contribute significantly to shaping the RDI landscape, making these leadership posts attractive to the best researchers, including those from other countries.

Institutes and units also have disadvantages. They can be difficult to close when their mission is no longer relevant or their quality falls from the highest level. There can be problems if they do not have built-in regeneration and turnover mechanisms, such as time-limited specific research missions or ensuring turnover and recruitment of new talent into the organisation. Some large UK institutes have been operational for many decades, and the Review heard it said that they can be viewed as 'too big to fail'. To avoid this problem there should be processes in place to allow continual adaptation to changing circumstances. Institutes and units can also become too self-referential, promoting staff too much from within and distancing themselves from the rest of the RDI landscape. Institutes and units would also profit from the reforms of

competitive, response-mode and QR funding and fEC discussed in the 'Universities' section.

Operational models

Institutes and units are set up and operate in the UK in a variety of ways. Some are wholly owned by UKRI and are subject to public sector pay constraints. Some are independent research organisations, separate legal entities free from public sector constraints that may receive funding from UKRI but lack access to wider funding streams (such as QR). Others are embedded within another organisation and may share resources and support functions with their host but retain a separate identity; many of these still receive funding from UKRI, but their risks and liabilities are shared with their host. A further group comprises commercial operations. Across all of these categories, some institutes involve joint ventures, partnerships and distributed models, where research is performed by building upon capability already embedded across the system, with leadership and coordination provided by a central team. Many are located within or close to a university where they benefit from the increased critical mass and multidisciplinary teams available in that location. However, the Review heard from researchers in institutes and units whose administration was closely linked to universities that the service provided by the universities varied in quality and was not always adequate. Institutes and units can also be co-located with other RPOs or groups of RPOs with different funders, including those that are commercial.

The London Institute of Mathematical Sciences (LIMS)

Institutes have varying governance models, including as Independent Research Organisations. Founded in 2011, LIMS is an independent research institute for theoretical physics and mathematics which specialises in fundamental theoretical research. LIMS collaborates with industry, and has set up an in-house technology incubator, LIMS Ventures, to help researchers who have made a practical discovery turn it into a marketable product.

One operational mechanism used in the UK is the 'hub and spoke' model. The review has identified 13 of these, which all have a central hub institute and spokes made up of units distributed throughout the UK. Hub and spoke models may sometimes be appropriate but can be a compromise outcome when deciding where in the UK to locate a new institute, given the many stakeholders keen to attract investment to their areas, and the ability of the model to distribute funding across the UK. They are a virtual and low-cost way of establishing institutes and improving UK-wide research interactions. However, the dispersed nature of the hub and spoke model does not easily support the critical concentration of research capability, intensive research environment, and effective leadership needed for a successful institute.

Five such institutes which were fairly recently set up gave evidence to the Review: the Alan Turing, Rosalind Franklin, Henry Royce and Dementia Research Institutes, and the Tyndall Centre for Climate Change Research. The Review heard from them that there were significant difficulties in how they were set up and were operating. They seem to have been established in part because there was insufficient funding in place to run an institute, and it was thought to be easier to raise funds locally in the spokes, which are often embedded in universities. The Review heard of a variety of problems: that the focus of the spokes was often to concentrate funding in themselves rather than the Institute as a whole; that there could also be a lack of commitment from funders; and that when applying for competitive and response-mode funding, hub and spoke institutes could find themselves in direct competition with the university hosts of their spokes. Some concerns were also raised about their governance processes.

Such arrangements do not appear to be sustainable or effective, and there needs to be greater clarity about what hub and spoke models are setting out to achieve. The viability, operating models, governance processes and funding arrangements of existing hub and spoke institutes involved in discovery research need to be urgently

The Human Cell Atlas (HCA)

Large-scale research projects can run very efficiently as consortia, with a single small administrative hub coordinating participating institutions and researchers. One example of this is the Human Cell Atlas, an international collaborative consortium founded in 2016 that intends to map every cell type in the healthy body from development to adulthood, and eventually to old age. It hopes to transform our knowledge of the workings of the 37.2 trillion cells in the human body to create a step change in our understanding of biology and disease. It is only possible thanks to global collaboration, technological and computational breakthroughs, and science at great scale.

HCA is open to the entire scientific community worldwide. Its more than 2,600 members come from over 1,000 institutes and 86 countries, bringing together an international community of biologists, clinicians, technologists, physicists, computational scientists, software engineers, and mathematicians.

The HCA is steered and governed by an organising committee, a volunteer body of approximately 30 scientists from around the world. Administrative support for the consortium is provided by a staff of ten people, and funding comes from multiple global sources including Wellcome, UKRI, the Chan Zuckerberg Initiative, NIH and the EU.

assessed, and reformed when found to be ineffective. As a related alternative model, collaborative partnerships with only a light administrative hub have been shown to be effective at promoting interactions, cooperation, and possibly infrastructure sharing, examples being the Human Genome Project, the Millennium Seed Bank, and the Human Cell Atlas.

Funding

Funding for units and institutes comes from a mixture of core funding and competitive and response-mode grants, although the Review heard that core funders can explicitly restrict access to specific grants, and that reviewing committees advising funders on institutes and units applying for competitive and response-mode grants may be reluctant to award more money for additional research projects. As is the case for other organisations in the RDI landscape, long-term, broadly un-hypothecated core funding for institutes and units empowers the local scientific leadership to deliver missions and objectives more effectively, and relieves dependence on successive grant submissions and uncertain short term funding cycles.

Governance and oversight

The governance and oversight arrangements for institutes and units vary. They can be wholly owned by UKRI, which if the relevant Research Council is fully committed to the institute or unit, provides long-term financial stability. However, the Review learnt that when a Research Council is not fully committed, it leads to financial tensions and difficulties. In addition, if fully owned by UKRI, scientific and leadership administrative posts are subject to Government salary and other requirements, which hamper the ability to attract the best talent, and hence affect operational effectiveness. This is a serious problem for recruitment and retention of the best researchers. A second structure is for the institute or unit to be embedded in another organisation, quite often a university. This removes the difficulty of restricting salaries but sometimes leads to administrative problems with service provision as already mentioned in this and the ‘Universities’ section. A third structure is for the research organisations to be independent. These are more distant from Government restrictions and have the freedom to pay the salaries needed and to set up support and administrative structures that are fit for purpose, increasing agility and enhancing the quality of science. However, for this to succeed, the independent institute or unit must have committed and sustained support from their supporting funder or funders. In this context, the Review heard that getting separate funders to work well together was sometimes difficult. Another issue raised was that the bureaucratic and audit focused demands of funders could be excessive. Simpler processes could be put in place based on developing greater trust in the operations of the institute or unit.

An issue raised during the Review was a concern about the dominance in governance and oversight structures of researchers whose experience had been primarily in the university sector. These researchers are generally supported by response-mode grants rather than by core funding, and it was suggested that sometimes grant-supported academics were less sympathetic to those who were core-funded. Though difficult to confirm, this could potentially result in RPOs of different types competing rather than complementing each other. Solutions suggested were more diverse membership of governance structures, and/or separate overall financial allocations for response-mode and core funding.

International comparators

As indicated earlier, the UK public research funding system focuses less on institutes and units. In other European countries there is often significant investment in established families of institutes sharing alignment in purpose and objectives, and identified with a common brand. These cover the range of activities in the RDI landscape. For example, they can focus on industrial research to support particular sectors, such as the Carnot and Fraunhofer-Gesellschafts institutes in France and Germany respectively, or more on discovery research, such as the Centre National de la Recherche Scientifique (CNRS) and the biomedical Institut National de la Santé et de la Recherche Médicale (INSERM) in France, or the Max Planck and Helmholtz Institutes in Germany. These families of institutes are aimed at a wide

International equivalents of PSREs

Other research-intensive nations support research through Government funded labs, which undertake a range of roles. In the US, the 17 Department of Energy National Laboratories have served as leading institutions for scientific innovation for more than 70 years, with a focus on energy, the environment, national defence and physical and computational sciences. With a budget of US$47.5bn (FY 2023), the US National Institutes of Health (NIH) is the largest single public funder of biomedical research in the world, supporting research in a range of organisations including institutes and universities.

Germany has over 1000 publicly funded research institutions spread throughout the country. Together, they cover the whole spectrum of research, from centres devoted to discovery research, such as the 86 Max Planck Institutes and the 40 federal research institutes; those working on complex infrastructure development and operation, exemplified by the 18 Helmholtz Centres; the 97 institutes of the Leibniz Association, which focus on issues of international societal importance; and the 76 world-leading applied research institutes of the Fraunhofer Society.

variety of functions, for example developing national or regional capabilities including skills training, access to technical facilities, acceleration and incubation services and increased knowledge diffusion activities.

In the United States, there is a strong tradition of laboratories operating nationally ranging across the RDI landscape, such as those funded by the Department of Energy and the National Institutes of Health which are major undertakings with high reputations. Similar investments have also been made in the Far East, including in China with the Chinese Academy of Sciences, and South Korea with Korea Advanced Institute of Science and Technology (KAIST). In the USA there has also been recent interest in developing more philanthropically supported institutes free of excessive US Government bureaucracy, with clearly defined missions and significant financial support. They are diverse in nature, some reflecting how Bell Labs in the USA or the Medical Research Council Laboratory of Molecular Biology (MRC LMB) in the UK were originally set up. Examples are the non-profit Howard Hughes Medical Institute (HHMI) Janelia Farm Institute, and others with specific ambitions embracing the ethos of a commercial start-up, sometimes with a time-limited focus, such as the new cadre of 'Focused Research Organizations'. Often philanthropically funded, these non-profit ventures are set up to solve a specific

International: Experimentation with institute models in the USA

Institutes provide an opportunity to use different research models to those found in universities. Based on the early experiences of the MRC LMB in Cambridge, and AT&T Bell Labs, HHMI Janelia Research Campus is experimenting with new methods of conducting biomedical research and developing associated technologies by supporting interdisciplinary project teams to solve experimentally challenging, trans-disciplinary problems. Janelia is fully funded by the Howard Hughes Medical Institute (HHMI), a not-for-profit philanthropic research organisation. While HHMI has funded professors at universities for decades, Janelia was founded to create a unique collaborative scientific environment. The campus fosters small research groups, provides internal funding, support facilities, and infrastructure, and values originality, creativity and collegiality. Janelia now operates on 15-year research cycles: long enough to gain traction but short enough to retain agility to move onto new areas. Janelia takes a team science approach, supporting projects to deliver specific and targeted goals as well as consortia that bring together experts in diverse areas to answer biological questions.

project, such as engineering improvements to underlying infrastructure for a specific discipline.[78] Their missions emphasise the need for multidisciplinary collaboration, highly focused research activity, good technical and scientific support, and accomplished organisational and management capabilities.

There is potential for institutes and units to be supported by joint funding provided by the public, non-profit, and private sectors. Such arrangements could more readily bridge discovery and applied research. Mixed public and private research institutes have been tested in France and cited as a key factor driving France's recent innovation growth.[79] CNRS — one of the largest discovery science agencies in Europe — has helped to set up new mixed research laboratories in association with other institutions both in France and internationally. These units are formed from collaborations between different institutions, such as universities, INSERM, or the private sector. The number of mixed research laboratories has increased from 55 in 2010 to 200 in 2021, contributing to discovery scientists being more open to collaborating with the private sector. Care has to be taken to ensure that there is not a clash in culture, given that discovery research thrives best in an open culture, and commercial activities by their very nature have to be less open, but there are solutions; for example, public and private RPOs can work well together in pre-competitive research relationships, or be closely located or co-located so they are separate but retain permeability. Connecting sectors provides new opportunities: technical cores can be shared, and people and ideas can move more freely in both directions. This is particularly powerful when translation and application is driven by discovery research investigators.

Opening, evolution and closure of institutes and units

A number of new institutes have been created in the UK in recent years, including some whose remit is to advance strategic priorities for national RDI. However, the Review heard that not all of these have been successfully established. Some of the reasons for this are confusion concerning 'ownership'; insufficient sustained core funding; excessive audit and reporting; a failure to act on external scientific independent reviews; and difficulties with hub and spoke funding if the hub is not properly supported. These problems were less pronounced for institutes with adequate core funding, as was the case for the Francis Crick Institute, which is joint funded by UKRI, CRUK and Wellcome. The Crick inherited core funding from the merger of pre-existing UKRI and CRUK institutes so additional new core money was

[78] Adam Marblestone et al., Unblock research bottlenecks with non-profit start-ups, 2022, Nature, 188-190, accessed Oct 31, 2022, https://www.nature.com/articles/d41586-022-00018-5; "Convergent Research: Homepage", Convergent Research, accessed Oct 31, 2022, https://www.convergentresearch.org/

[79] France improved its score on the Global Innovation Index from 22nd in 2011 to 11th in 2021. Nic Fleming, How France ramped up its capacity to innovate, 2022, Nature, accessed Oct 31, 2022, https://www.nature.com/articles/d41586-022-01803-y

less necessary. These experiences emphasise the need for sustained core funding being in place when new institutes and units are set up. Too often the focus has been on providing a building, with not enough thought given to longer term sustainability.

Given the potential and high quality of the best run and funded institutes and units, funding organisations such as UKRI should regularly consider whether new institutes or units are required. Possible new institutes could, for example, be dedicated to research into climate change and its mitigation, antimicrobial resistance, synthetic biology, and artificial intelligence. Such diversification of RDI support would enhance the RDI landscape and the UK research endeavour.

Units provide a stepping stone that could be used to form an institute. A clearly defined pathway could be established to enable units to grow to reach institute status based on their successful operation and continuing relevant mission. While the growth of organisations can be difficult, institutes formed from units with pre-existing successful research endeavours and scientific teams are likely to thrive more quickly than newly-founded entities. The prospect of being selected for expansion might also help with staff retention and motivation and promote greater entrepreneurial instincts. Conversely, a unit or institute should be closed or reduced upon achieving its mission or when clearly defined performance criteria are not met. A related initiative being considered by ARIA is a mode of support called BUILD: scientist-led nucleation of focused research units or institutes, whose support from ARIA may be time-limited but with the potential to attract longer-term funding.

Conclusions

- Research institutes and units play a unique, beneficial role in the UK's RDI landscape and this sector should be expanded to contribute more to the UK's RDI capability.
- Institutes and units can be very high performing if properly led and sustainably funded. Their focused mission is attractive to high quality researchers, and facilitates multi-disciplinary approaches given that there is less need for specialised departments or divisions.
- The success of institutes and units depends on clarity of mission, good impartial governance, sustained funding, and appropriate location. Effective strategies and operational procedures must be in place concerning their creation, missions, governance, funding, administrative support and closure, to guard against complacency, stagnation, or a drop in research quality.
- Units can be set up quickly and should have focused objectives, with defined time limits for their operations. Generally they benefit from proximity to other

research performing organisations. Units can be merged or evolved to form new institutes.

Recommendations

The Review recommends:

6. Institutes and units need sustained financial support, including un-hypothecated funding, to ensure ‘end-to-end’ research support. The funding arrangements of recently established institutes and units, particularly the ‘hub and spoke’ models, must be reviewed to make sure that they are fit for purpose. The reforms of funding proposed for the universities should also take account of the needs of institutes and units.
7. Institutes and units need a well-defined mission and purpose, and should be given the autonomy and funding necessary to achieve their objectives, which may be time limited. There need to be clear and agreed mechanisms by which institutes and units can be adapted, reduced or closed when necessary.
8. Institutes and units must have high quality administrative as well as scientific leadership. They generally benefit from being co-located with other RPOs, but if their overall administration is the responsibility of another co-located or funding organisation, rigorous contractual arrangements must be in place to ensure independence of operation and quality of service.
9. New research institutes and units should be considered when strategic RDI priorities best supported by focused research missions are identified by Government, UKRI and other funders. Possible examples include enhanced activities in climate change and its mitigation, antimicrobial resistance, synthetic biology and artificial intelligence. Themes should be identified through mapping and reviewing, taking account of emerging technologies, scientific areas, and Government priorities. Pre-existing institutes and units could be merged and expanded to create new institutes, and consideration should be given to co-location and co-funding with other RPOs. Establishment of new institutes and units should follow the principles outlined in the Review.

Other components of the RDI landscape

There are many other components of the UK RDI landscape that do not fit neatly into simple sectoral categories. These other organisations fulfil a number of roles, supporting a range of RDI activity from discovery research to innovation across the economy. Some have a prestigious public profile both in the UK and globally, and act as 'connectors' within the RDI landscape. In the discussion that follows, they have been grouped into broad somewhat arbitrary categories: charities; national academies; heritage and collections-based cultural institutions; and translational research organisations. Recommendations for all categories are grouped together at the end of this section.

Charities, national academies and cultural institutions

Charitable and institutional philanthropic funding

Large charitable organisations play significant roles in the funding of certain elements of the UK's RDI landscape. These grant-making and core funding organisations are supported by large philanthropic foundations, industry, bequests, and income from mass support donated directly by the public. Charitable organisations have created important institutes working in major fields of inquiry, such as the Sanger Institute at Hinxton, funded by Wellcome and presently focused primarily on genomic studies, and several cancer-related institutes distributed throughout the UK, funded by Cancer Research UK. Charities also fund research activities through project and programme funding, primarily within the universities and in biomedicine. Other charitable organisations such as the British Science Association and the Royal Institution contribute to the RDI landscape by engaging the public and highlighting the importance of science to society. Good communication about science is critical for the RDI landscape, by ensuring continuing support from the public. This is also promoted in the UK by the Science Media Centre.

The varying contribution of different kinds of charitable giving and the varied interests of the donors influences the balance of charitable funding available for different fields and causes. Members of the public generally donate to charities taking more near-term action to resolve societal issues: medical research, animal welfare and children and young people's charities receive the bulk of donations in the UK,[80] while other

[80] National Philanthropic Trust (NPT UK): "Charitable Giving Statistics in the United Kingdom", National Philanthropic Trust, Which causes?, accessed Oct 31, 2022, https://www.nptuk.org/philanthropic-resources/uk-charitable-giving-statistics/

socially important areas such as climate change and clean technologies receive less support.[81] In 2020, 62% of the British public donated a total of £11.3bn to charity, and HEIs received 12-14% of their income from charities.[82] [83] However, as noted in the 'Universities' section of the Review, grants to universities from philanthropic foundations and charities do not usually cover fEC, requiring universities to use other income sources to top up philanthropic funding. The Charity Research Support Fund (CRSF), a non-REF-audited subset of QR, provides a proportion of fEC for philanthropically-funded research, but is insufficient to cover fEC. As discussed previously, this creates increased pressures on the cross-subsidy of funding within some parts of the university sector. Discussions need to take place between Government and charitable funders on how charity fEC can be better supported.

Science Media Centre (SMC)

Ensuring public trust and accessible communication of science is critical for a well-functioning RDI landscape. SMC is an independent charity which works with journalists and with scientists, engineers, and other experts to support the distribution of accurate and evidence-based information about science and engineering through the news media. SMC also provides expert advice and evidence on issues relating to science in the media, and supports press officers working on complex or controversial science stories.

It should be noted that philanthropic support augments existing investment in RDI but is not a replacement for it. The delivery of research funded by donations depends on the capabilities and skilled workforce produced and supported by taxpayers' and others' investment in the core RDI system.

National academies and learned societies

The UK's national academies and learned societies are an important part of the UK RDI landscape. The four UK-wide national academies — the Academy of Medical Sciences, the British Academy, the Royal Academy of Engineering, and the Royal Society — are each composed of a Fellowship elected on the merit of their scientific or scholarly research achievements. All four are globally renowned and have a significant UK-wide and international role. Via their fellowships, the four national

[81] "It's time for philanthropy to step up the fight against climate change", McKinsey Sustainability, 2021, Exhibit 1, accessed Oct 31, 2022, https://www.mckinsey.com/capabilities/sustainability/our-insights/its-time-for-philanthropy-to-step-up-the-fight-against-climate-change
[82] "Charitable Giving Statistics in the United Kingdom", National Philanthropic Trust, Donating to charity, accessed Oct 31, 2022, https://www.nptuk.org/philanthropic-resources/uk-charitable-giving-statistics/
[83] Charities Aid Foundation, UK Giving Report 2021, 2021, p.19, accessed Oct 31, 2022, https://www.cafonline.org/about-us/publications/2021-publications/uk-giving-2021

academies represent over 6,000 highly distinguished researchers.[84] They provide prestigious affirmation and sometimes support of academics at different stages of their careers, and have great institutional convening power, enabling them to call upon a national and international cast of distinguished scientists and academics across many different disciplines to offer advice and expertise to policymakers, business and civil society. They can also play an important role in promoting 'soft diplomacy' with other nations, which can be of particular importance during times of international tension.

As trusted, credible and independent organisations, national academies have the flexibility to set their own strategic direction and research focus. They are funded by various sources including donors, foundations and Government. Academies are active across the whole spectrum of RDI activity and offer support to entrepreneurs and innovators across the country. The Devolved Administrations also have their own national academies. In Scotland, the Royal Society of Edinburgh[85] convenes and provides funding for academic researchers in multiple fields; the Royal Irish Academy, an all-Ireland body, supports Northern Irish and Irish academics, and the Learned Society of Wales[86] champions Welsh researchers and provides a focal point for Welsh academics.

Learned societies fulfil similar functions to the national academies but with a field- or discipline-specific focus. They are mostly 'membership' rather than 'elected fellowship' organisations, that support researchers and provide platforms and major events to enable researchers to meet. Some are permitted to offer chartered status or other professional accreditation to qualified professionals. In this manner learned societies contribute to the development of the UK RDI skills base by recognising knowledge and excellence. Notable examples of UK-wide learned societies include the Institution of Mechanical Engineers[87], the Royal Society of Chemistry,[88] and the Nuclear Institute,[89] as well as a range of more focused subject-based societies, particularly in but not restricted to the life sciences.

Academies and learned societies play important underlying structural roles in the success of the UK RDI landscape. They play an important role in the UK's international profile as a standard bearer for RDI, for example via connections to leading researchers internationally and via awards and fellowship schemes. They help set scientific and scholarly standards for academic researchers and, by their

[84]The Royal Society, National Academy Presidents write to new Prime Minister, 2019, July 24, accessed Oct 31, 2022, https://royalsociety.org/topics-policy/publications/2019/national-academy-presidents-write-to-new-prime-minister/
[85] "About the RSE", Royal Society of Edinburgh, accessed Oct 31, 2022, https://rse.org.uk/about-us/
[86] "The Learned Society of Wales: home page", accessed Oct 12, 2022, https://www.learnedsociety.wales/
[87] "Institution of Mechanical Engineers: home page", accessed Oct 12, 2022, https://www.imeche.org/
[88] "Royal Society of Chemistry: home page", accessed Oct 12, 2022, https://www.rsc.org/
[89] "Nuclear Institute: home page", accessed Oct 12, 2022, https://www.nuclearinst.com/Homepage

prestige and rigour, contribute to the credibility of the UK RDI system. The academies and learned societies also make valuable contributions to the development of Government policy and strategy, and their convening power allows them to bridge gaps between sectors and disciplines. The deceptively simple power of bringing people together, for example by hosting events to do so, reduces barriers to collaboration and stimulates the growth of interconnection within a fragmented landscape.

Galleries, libraries, archives, museums, and the heritage and cultural sector

Collections-based galleries, libraries, archives, and museums, as well as heritage and cultural sector organisations, all contribute to the RDI landscape through globally significant direct research activities. The interdisciplinary and creative perspectives that these organisations bring contribute to science and technology and to successful translation and commercialisation. The contribution of heritage and culture organisations to the UK's RDI landscape is recognised by UKRI: the Arts and Humanities Research Council (AHRC) supports these organisations as a core part of its mission, and in 2019-20 provided £25m to enable these organisations to upgrade their RDI-related infrastructure.[90]

Organisations such as museums and other cultural venues often have good links with local areas and are found nationwide, helping to distribute their benefits nationally.[91] Organisations in the heritage and culture sector are thus natural translators of research because much of what they do involves engagement with the public. Some institutions, such as the Natural History Museum and Kew Gardens, which are PSREs, are world-class research-intensive institutions, recognised as international centres of excellence in life sciences collections-based research, an area that has been neglected in the recent past and requires better support. Other institutions have high quality RDI capabilities developed over many years, including in the application of science and technology to arts and culture: examples are the Victoria & Albert Museum[92] and the British Museum, which both have significant research activity. The same applies to the British Library with respect to data-based research, relevant across the whole research landscape. The skills and capabilities of the UK's heritage and culture institutions also contribute to the British economy, generating over £111bn in 2018.[93]

[90] UKRI, Building back better or building forward together? 2021, Infrastructure WCL, accessed Oct 12, 2022, https://www.ukri.org/blog/building-back-better-or-building-forward-together/
[91] Department for Digital, Culture, Media and Sport, Strategic review of DCMS-sponsored museums, 2017, Nov 14, 6 accessed Oct 12, 2022, https://www.gov.uk/government/publications/strategic-review-of-dcms-sponsored-museums
[92] "V&A website: *Research"*, accessed June 16, 2022, https://www.vam.ac.uk/info/research/
[93] Department for Digital, Culture, Media and Sport, "UK's Creative Industries contributes almost £13 million to the UK economy every hour", 2020, accessed June 16, 2022,

The heritage and cultural sector supports RDI activity in the private and charity sectors. The creative industries account for 4.3% of private-sector expenditure in R&D in the UK,[94] [95] and the Review heard that public RDI investment in the creative industries has been successful at leveraging private sector investment. Organisations such as galleries and public libraries are widely known, often valued and much visited, creating touchpoints between RDI and the wider world.[96]

British Library Business & Intellectual Property (IP) centres

Cultural institutions in the UK are using their capabilities and public profile to aid the UK RDI and UK enterprise. In partnership with the Intellectual Property Office (a PSRE), the British Library hosts and coordinates a nationwide network of 21 business and IP centres, based in city libraries, and a further 86 'Locals' in neighbouring towns, which offer advice not only on IP but also on all aspects of setting up and running a viable business. The centres provide valuable, reliable and impartial sources of advice and support for business across the country and are founded on the credibility and reach of the British Library.

BBC R&D

The UK is a world leader in broadcasting and other media, and the BBC's R&D division has led the way since the Corporation's establishment. From the BBC's inception it was recognised that its unique capabilities made it ideally positioned to conduct R&D, and support for R&D is enshrined in the Corporation's Royal Charter (Article 65).

The R&D division has produced major breakthroughs in broadcasting such as transatlantic television transmission, and works actively on the latest digital technologies such as use of Machine Learning for visual analytics and public interaction with Artificial Intelligence. Today the R&D division employs over 200 interdisciplinary researchers who work in laboratories around the UK and actively seeks to partner with industry, academia and civil society.

https://www.gov.uk/government/news/uks-creative-industries-contributes-almost-13-million-to-the-uk-economy-every-hour

[94] This figure excludes IT, software and computer services from the creative industries. If included, the figure amounts to 11.5% of BERD.

[95] "The Art of R&D", Creative Industries Policy & Evidence Centre, 2022, 5, accessed June 16, 2022, https://pec.ac.uk/research-reports/the-art-of-r-and-d

[96] UK galleries and museums were visited by nearly 50m people in 2018-19 (the last year for which pre-pandemic data is available). Department for Digital, Culture, Media and Sport, Press release: Record breaking year for museums and galleries in England, 2019, October 24, accessed on June 16, 2022, https://www.gov.uk/government/news/record-breaking-year-for-museums-and-galleries-in-england

Conclusions for charities, national academies and cultural institutions

- Long-term, large-scale charity funding is a valued and essential component of research support in the UK, but the shortfall in the fEC component of charity research grants is damaging the RDI endeavour and must be addressed.
- Academies and learned societies are internationally renowned organisations making wide-ranging and valuable contributions to all aspects of the UK RDI landscape.
- Arts, cultural, humanities and social sciences organisations, together with the heritage and cultural sector, contribute to the UK skills base and business-led RDI activity in related fields, and are a growing segment of the UK economy.[97] Collections held by heritage and cultural organisations are invaluable national assets, but collections-based research is inadequately supported.

Translational research organisations

Bridging the gap between discovery research and the translation of that research into real-world uses is important for the RDI landscape to thrive and to drive innovation. Work in this area is carried out by RPOs including the universities, PSREs, institutes and units discussed earlier, which deliver translational and applied activities often embedded in discovery research endeavours. This section focuses on other translational research organisations, which comprise a heterogeneous group within the landscape, with no classification or agreed terminology. They include Catapults, as well as more specialised organisations such as FloWave, Glass Futures, and even a Scotch Whisky Research Institute.[98]

Translational research organisations promote and implement innovation as well as provide RDI services to businesses. They often carry out pre-commercial research and seek to help businesses navigate the RDI landscape to maximise their RDI activity and exploit the outputs of RDI from other organisations such as universities and PSREs. The Review has found, however, that the success of translational research organisations in meeting these aims can be variable.

Catapults description and analysis

In 2007 the UK set up the Technology Strategy Board, which became a national innovation agency, Innovate UK, in 2014. Following a UK Government Review by Dr Hermann Hauser KBE which considered the institutional gap between scientific

[97] British Academy analysis indicates that the creative arts and humanities-related sectors have grown at twice the rate of the wider British economy since 2014. [Source: The British Academy, “Office for Students Consultation on recurrent funding 2021-22”, 2021, accessed June 15, 2022, https://www.officeforstudents.org.uk/publications/consultation-on-recurrent-funding-for-2021-22/]
[98] “Our members”, AIRTO, accessed Oct 12, 2022, https://www.airto.co.uk/about/members/

discovery and commercial application, the UK established Catapults in 2011, building on existing Technology and Innovation Centres. Catapults are independent

SPECIFIC Innovation and Knowledge Centres

A series of Innovation and Knowledge Centres was established in 2011 to support strategically focused technology areas or sectors with a UK research excellence base and strong potential for future market growth. SPECIFIC IKC aims to create 'Active Buildings' which generate, store and release their own energy, taking basic research and collaborating with partners to scale up the technology. It is based at Swansea University, is supported by UKRI, the Welsh Government and industrial partners such as Tata Steel, BASF/Akzo Nobel, and NSG Pilkington and has developed seven spin-out companies, delivered 31 new products through 177 business collaborations, and supported training of over 987 people.

not-for-profit private sector organisations whose primary function is to de-risk the transition from research to commercial delivery. Catapults also foster collaboration between research organisations in the public and private sectors.[99] They receive roughly a third of their funding from a core grant issued by Innovate UK. Their design incorporates best practice principles taken from Germany's Fraunhofer Institutes and other organisations overseas. There are nine catapults with centres spread across 40 sites throughout the UK.[100] Between 2013 and 2022, Catapults were involved in

Scottish Innovation Centres

Nations in the UK are supporting innovation through different types of organisations. Since 2012, the Scottish Funding Council, with support from Scottish Enterprise and Highlands and Islands Enterprise, has invested in a network of innovation centres to support the connection of Scottish institutes and universities with industry. The centres — Digital Health and Care, Precision Medicine Scotland, Centre for Sensor and Imaging Systems, Industrial Biotechnology, Sustainable Aquaculture, Built Environment-Smarter Transformation, and The Data Lab — are focused on key economic sectors to create jobs and deliver economic and societal benefit. The Innovation Centres are industry demand-led, bringing Scotland's academic base to bear on industry challenges.

[99] "Creating the future through innovation", The catapult network, 2020, accessed Nov 14, 2022, https://catapult.org.uk/wp-content/uploads/2020/12/Catapult-Network-Impact-Brochure-2020-FINAL.pdf

[100] The Catapult Network, accessed Nov 1, 2022, https://catapult.org.uk/about-us/our-centres/

over 18,000 industry collaborations and supported close to 12,000 Small and Medium Enterprises (SMEs).[101] Since 2011, Catapults directed over £2.5 billion of private and public sector investment to support innovators and advance the UK's economic capability in global markets.

Catapults

Catapults have a key role in driving productivity growth and supporting regional activity. The Compound Semiconductor Applications Catapult worked with Cardiff University and other stakeholders to establish the world's first compound semiconductor cluster, CSconnected, in South Wales. The programme integrates research excellence with regional supply chains in advanced semiconductor manufacturing. The cluster aims to develop a competitive advantage in key enabling technologies which will allow the UK to increase trade globally in critical sectors such as optical communication, 5G, autonomous and electric vehicles, aerospace, robotics and medical devices. In 2020, the CSconnected bid, formed of key partners in the cluster, won £25m of funding from the UKRI Strength in Places Fund, supporting the creation of new jobs and increasing the cluster's direct contribution to the local economy.

Catapults can play a key role in supporting industry, including in supporting training and skills. The Cell and Gene Therapy Catapult in Stevenage is the largest cell and gene therapy cluster outside the US, and develops skills capabilities within the UK. It collaborates with businesses to improve efficiency and reduce the cost of development and manufacturing to accelerate commercialisation of Advanced Therapy Medicinal products, and supports their clinical adoption. The Advanced Therapies Apprenticeship Community programme led by the Catapult has deployed over 140 apprentices across more than 40 cell and gene therapy companies across the UK, half of which are within the cell and gene therapy cluster around Stevenage. This cluster is a useful example as it allows for the development of initial manufacturing capabilities, skills and supply chains, and has attracted international investment.

Contributions of Catapults to the overall UK RDI landscape

Evidence collected as part of this Review indicated that Catapults are mostly engaged in experimental development (a term describing the promotion of useful applications), reflecting their role in using existing research and applying it in the development of new products and services. Catapults use their expertise to provide tailored support to SMEs and start-ups, as well as large companies, and build

[101] "Our Impact Journey", The Catapult network, 2020, accessed Nov 14, 2022, https://catapult.org.uk/our-work/our-impact/

capability through partnership and collaboration, providing business support that may not be available due to market failure, commercial risk, or inhibitory costs. An example of this is the Offshore Renewable Energy Catapult's test facility at Blyth, which provides research, test, innovation and validation services to accelerate the deployment of offshore renewable energy technologies, and was a contributing factor in attracting GE Renewable Energy to the UK. The Government's review of Catapults in 2021 recognised that Catapults' roles in business support, collaboration, access to finance, and skills development are viewed positively by businesses and stakeholders.[102] The 2021 Review made recommendations in areas including governance and collaboration, which UK Government, Innovate UK and the Catapults themselves are progressing or have now completed. The 2021 Review also recognised that since their inception in 2011, Catapults have been subject to numerous reviews, and therefore recommended moving away from extensive reviews towards a focus on supporting them to be more effective institutions.

Contributions of Catapults to local economies

Many international stakeholders commented on the role of independent translational research organisations in their countries in strengthening regional research capability. The Review heard that the ability of translational research organisations in the UK to contribute to their local economy is variable depending on their thematic focus and location. Catapults make contributions to their local economies due to their role in working between businesses and academia, and the 2021 Catapult Network Review recommended that Catapults look for further opportunities to support local economies, work with local partners and build innovation clusters.

International translational research organisations

Alongside exploring the characteristics and features of the main categories of translational research organisations in the UK, the Review considered various international models for such bridging institutions. The variety of successful international approaches suggest there is no universally adopted approach to using translational institutions to deliver a wide range of economic and societal goals, such as stimulating growth and developing regional industries. Many models and approaches to bridging institutions work in different sectors, regions, and economic and cultural contexts. For example, some organisations in specific sectors can be better at leveraging private sector investment in RDI, supporting business RDI to respond to a national challenge, helping regional productivity, or driving collaboration between different organisations.

[102] Department for Business Energy and Industrial Strategy, Catapult network review 2021: how the UK's Catapults can strengthen research and development capacity, April 6, 2021, accessed Oct 12, 2022, https://www.gov.uk/government/publications/catapult-network-review-2021-how-the-uks-catapults-can-strengthen-research-and-development-capacity

Kosetsushi centres

In Japan, local public technology institutes (Kosetsushi centres) for testing and research have been successful at fostering the development of regional industries. Kosetsushi centres are technology transfer organisations administered by local governments which bridge the gap between SMEs and RPOs by providing a location for seminars and technical consultation within a particular industry and region, conducting research and licensing patents to local SMEs, and acting as catalysts for local SMEs to develop networks and connect to external knowledge sources, such as universities, when a business problem is too difficult to solve internally. Kosetsushi centres which focus on design are particularly valuable to local SMEs to boost engineering design capability in a region, as solving problems in design is best accomplished face-to-face. This emphasises that a translational organisation focusing on design or engineering should be located close to SMEs that might use it. Kosetsushi centres build understanding among local SMEs of the benefits of RDI, particularly through providing technical consulting services to address problems.[103] The success of Kosetsushi centres as these local, intermediary organisations providing RDI services to industry have been emulated elsewhere, such as through the Steinbeis Foundation in Germany, the Manufacturing Extension Partnership Programme[104] and the Technology and Innovation Centres in the UK (precursors to Catapults), with varying degrees of success.[105]

Ensuring that RPOs and business understand and have greater access to translational research capability is necessary for research to drive the delivery of useful applications for the economy and society. The Review received input suggesting that additional translational research organisations could perform functions such as regional missions ('RDI and Society' section), workforce development missions, and supply chain missions. Other sectors in the RDI landscape can also contribute to these objectives, including PSREs and other institutes and units.

[103] Nobuya Fukugawa, "Roles of Japan's local public technology centres in SME innovation", VoxEU, July 8, 2016, accessed Oct 12, 2022, https://voxeu.org/article/japan-s-local-public-technology-centres-and-sme-innovation
[104] "The MEP National Network", Manufacturing. gov, accessed Oct 12, 2022, https://www.manufacturing.gov/programs/mep-national-networktm
[105] Nobuya Fukugawa, "Knowledge creation and dissemination by *Kosetsushi* in sectoral innovation systems: insights from patent data", Scientometrics, 109 (2016), accessed Oct 12, 2022, https://doi.org/10.1007/s11192-016-2124-x

Conclusions for translational research organisations

- Translational research organisations are a valuable bridge in responding to industry needs, as they can test pre-commercial ideas and address emerging challenges without the need to always make a profit, but their success to date has been variable.
- Many organisations in the landscape have access to or capability as translational research organisations, without that being their primary mission, while others are solely devoted to translational research. The diversity of translational research organisations can lead to confusion about their missions, status and roles in promoting collaboration. Recognising and describing their roles and promoting their work would improve their usage within the landscape.
- The establishment of Catapults has broadened the range of translational research organisations in the UK, but more than one type of organisational model is needed to meet the wide variety of roles for translational research organisations in the UK RDI landscape.
- Translational research organisations have been shown in other countries to increase regional research capability. In the UK, this part of their role could be better developed.

Recommendations

10. Government and the charitable sector should work together to ensure that ‘end-to-end’ funding is provided for research supported by philanthropy.

11. Support for research undertaken by galleries, libraries, archives, museums, and the heritage and cultural sectors should be increased, and support for long-neglected collections-based research put in place.

12. Coherence between translational research organisations, including those embedded within other RPOs, and the rest of the landscape should be increased. Government is advised to optimise translational research organisations by increasing their number, widening access and promoting the benefits of translational research capability, including regionally. Government should explore routes by which RPOs across the RDI landscape, including PSREs, can contribute to translational activities.

Industry and the Private Sector

Description and analysis

The private commercial sector is the largest funder and performer of RDI in the UK. The recent ONS correction of the amount of R&D being performed by UK businesses indicates that in 2021 it was £46.9bn, an increase of £2.9bn since 2020 and £5.9bn since 2018, the first data period produced using the new methodology.[106] Although ONS has not yet calculated an 'R&D as a percentage of GDP' figure as the corrections have not been incorporated into the calculations of GDP, DSIT estimates suggest that the amount being spent by businesses was 1.7% of GDP in 2020 and 1.6% in 2019. This is in line with the estimated average of OECD nations of 1.7% of GDP in 2020 and 1.6% in 2019.[107]

RDI in this sector was already known to be undertaken by large multinational companies, for example in the pharmaceutical, automobile and aerospace sectors, but the newly identified component of business RDI is carried out by small and medium sized enterprises (SMEs), presumably ones that are technically oriented. Further analysis will be required to fully understand the drivers behind business investment in RDI in the UK, its implications for Government RDI policy, and its effects on wider sustainable economic activity and productivity.

Only two UK-based companies are in the top 100 RDI companies worldwide, and both, the pharmaceutical giants GSK and AstraZeneca, are from the same sector.[108] Firms that consistently invest in RDI are 13% more productive than those that do not.[109] The Review also heard that parts of the academic sector do not understand or appreciate the long-term benefits of collaboration with industry for impact, education and research excellence. The two sectors should aim to work better and more efficiently together.

Due to the concentration and availability of research talent, the UK is an attractive destination for multinational companies to invest in and buy RDI. In 2021, around 35% (£16.4bn) of the total expenditure on R&D performed in UK businesses was marked by overseas ownership, with US-owned businesses accounting for the

[106] Office for National Statistics (ONS), released 22 November 2022, ONS website, statistical bulletin, Business enterprise research and development, UK: 2021. Revised estimates of %GDP spent on R&D performed by businesses in the UK will be released in late 2023.
[107] OECD average does not account for ONS's revised methodology and data on Nov 22, 2022.
[108] Global innovation leaders in 2020, FDI Intelligence, 2021, accessed Oct 13, 2022, https://www.fdiintelligence.com/content/data-trends/global-innovation-leaders-in-2020-79672.
[109] Department for Business, Innovation and Skills. Innovation Report, 2014, March 7, accessed Oct 12, 2022, https://www.gov.uk/government/publications/innovation-report-2014-innovation-research-and-growth

largest overseas share (£6.7bn; 14% of total UK business R&D).[110] This activity raises the research intensity of the economy as a whole and leads to spillover benefits for local economies. However, it should be noted that multinational businesses can close their sites in the UK, and may do so rapidly if other countries become more attractive environments for investment.

Business RDI investment is geared towards late-stage research — the 'experimental development' stage, which builds on existing knowledge to prototype new products or production processes. A further contributor to UK business RDI is the market in business-to-business RDI, with firms specialising in supplying RDI as a service to other companies.[111] Often this forms part of a more comprehensive offer of knowledge-intensive business services such as design, consultancy and accountancy.[112]

QUBIS, Queen's University Belfast

Universities' research can lead to spinout companies. QUBIS, Queen's University Belfast's commercialisation arm, is effective at commercialising research, with a spinout portfolio that has a combined annual turnover of £171 million, and has also created 2,700 jobs. Half of Northern Ireland's publicly listed companies were created at Queen's, including Kainos Group Plc, Andor Technology and Fusion Antibodies Plc.

Private sector investment in RDI spreads benefits across society in a variety of ways such as developing new consumer products, healthcare treatments and artforms, and also in its creation of high value jobs, such as RDI managers and leaders, software developers and industry-based researchers, which underpin and enrich the knowledge economy. This is recognised in the Government's Plan for Growth: 'the full benefits of innovation are realised when new ideas and technologies are adopted and diffused by firms throughout the economy'.[113] However, business also supports

[110] "Business enterprise research and development, UK (designated as official statistics)", ONS, 2022, accessed on Nov 30, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/datasets/businessenterpriseresearchanddevelopmentukdesignatedasofficialstatistics

[111] See Table 15, Office for National Statistics, Business enterprise research and development, UK: 2020, 2021, Nov 19, accessed Oct 13, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/businessenterpriseresearchanddevelopment/2020

[112] Jocelyn Probert, David Connell and Andrea Mina, "R&D service firms: The hidden engine of the high-tech economy?", EconPapers, 42, no.6 (2013), accessed Oct 13, 2022, https://econpapers.repec.org/article/eeerespol/v_3a42_3ay_3a2013_3ai_3a6_3ap_3a1274-1285.htm

[113] HM Treasury, Build Back Better: our plan for growth, 2021, March 3, 64, accessed Oct 13, 2022, https://www.gov.uk/government/publications/build-back-better-our-plan-for-growth

discovery research with a clear application objective, a good example being DeepMind.[114]

Investment of business in RDI

Business RDI is influenced by a number of factors. Broadly, businesses are more likely to invest in RDI if their financial position allows and if they can see both short and long-term benefits consistent with their wider strategy. Larger businesses with greater access to liquid capital and higher risk tolerance are more likely to have the means to invest in discovery research and in subsequent development of new product lines and manufacturing processes designed to accelerate growth, save costs, and capture new markets. As mentioned above, in the UK such large RDI-performing businesses are concentrated in pharmaceuticals, automobile manufacturing and aeronautics. RDI is also central to small 'start-up' and scale-up businesses with a strong technical focus. The benefits of investing directly in RDI may appear less obvious to businesses with fewer resources to focus beyond their short-term objectives, and they may need to depend on the results of publicly funded RDI, or use direct Government support to underpin their RDI activities. This is due in part to the long-term nature of investing in RDI; it may take years before returns can be realised.[115]

Businesses also underinvest in RDI on pragmatic grounds. Acquiring firms with new technologies or RDI capability may be more profitable, at least in the short term, than spending capital and time in developing in-house RDI capability, especially as businesses may not recoup all the value of their investment, which may be spilled over elsewhere in the economy.[116] An overheated financial market can lead to businesses prioritising measures that lead to short term growth, such as aggregating businesses and buying out others, rather than long-term sustainable growth, for which RDI plays and essential part.[117] RDI investment can also increase employee entrepreneurship, potentially leading to loss from the business of highly skilled, highly mobile RDI staff to start new ventures.[118]

Incentivising business investment in RDI

Incentivising RDI spending in the private sector is necessary to improve the productivity, innovation and growth of the UK economy. Recent corrections to ONS

[114] https://www.deepmind.com/
[115] UK Innovation Survey Table 10a, https://www.gov.uk/government/statistics/uk-innovation-survey-2021-report.
[116] Gordon Philips and Alexei Zhdanov, "R&D and the incentives from Merger and Acquisition Activity", SSRN (2012), accessed Oct 13, 2022, https://dx.doi.org/10.2139/ssrn.2181152
[117] BIS. The Kay Review of UK Equity Markets and Long Term Decision Making. 2012. P.9-11. https://econpapers.repec.org/article/eeerespol/v_3a42_3ay_3a2013_3ai_3a6_3ap_3a1274-1285.htm
[118] Tania Babina, and Sabrina Howell, "Entrepreneurial Spillovers from Corporate R&D", National Bureau of Economic Research, 2018, 1, accessed Oct 13, 2022, https://www.nber.org/papers/w25360

data suggest that RDI carried out by the private sector has previously been underestimated, especially among small businesses, but despite this, the UK is still behind world leaders on R&D investment. The economy has also performed poorly since the financial crisis against key economic indicators such as productivity and real wages. While R&D investment alone will not solve these challenges, it is a significant contributor and a necessary condition for growth. It is therefore important to encourage further business investment in RDI across the economy, to support productivity, wages and GDP growth throughout the country.[119]

Geovation, Ordnance Survey

Geovation is an initiative established by the Ordnance Survey and backed by HM Land Registry and is an example of open innovation in the public sector. Geovation runs an accelerator programme which provides start-ups with grant funding and offers access to data, geospatial expertise, and land and property information.

This step-change in RDI in the private sector will require investments from business as well as from the Government. The Review heard that one of the important inhibitory factors in small business investment in RDI is access to equity, particularly for start-ups and scale-ups. There are established routes that Government could take to make the UK more competitive in this area, including: making it easier for pension funds to invest in illiquid assets; facilitating more trade sales and IPO exits; making the UK's taxation of share options competitive; improving and standardising IP frameworks to allow founders to retain a bigger share of their companies; and analysing the UK's investment landscape to identify potential gaps in access to capital.

Other important drivers of increased business-led RDI which can help commercial leadership teams appreciate the benefits for their business of investing in RDI include improved margins, the development of innovative products, and better education of the rest of the RDI sector about the benefits of interacting with business. Building this mutual appreciation will require long-term culture change through initiatives including opportunities to make the education system more wide-ranging, improving access to internships for students in successful RDI-intensive businesses, and developing focused business school and university courses. To alleviate the UK's productivity problem and reduce regional inequality, the imbalance

[119] Global innovation leaders in 2020, FDI Intelligence, 2021, accessed Oct 13, 2022, https://www.fdiintelligence.com/content/data-trends/global-innovation-leaders-in-2020-79672.

in high-quality RDI management and technical skills between firms and regions in the UK must also be corrected.[120]

The Government should consider how current business leadership can be made more aware of the advantages of RDI, drawing on examples from international businesses, particularly in the USA. It is also important for Government to understand why some businesses underinvest in RDI, and to provide solutions for their concerns. In turn, businesses need to be clearer about their needs, so that more effective links can be forged with other research organisations in the landscape. Commercial ventures should be bold in embracing new initiatives driven by RDI-generated evidence and knowledge, and back RDI-intensive UK start-ups and scale ups, to retain continued commercial activity in the UK. Government should support businesses to de-risk some of these initiatives, as discussed in earlier reports.[121]

USA, Boston/Cambridge Innovation Hub

Together, Boston and Cambridge in the USA house a very large concentration of universities and colleges, start-ups, tech industries and research centres, making the local area highly attractive for both investors and researchers. With industry, academia, and government working together, the region is a hotbed of outstanding science and innovation that has propelled the development of new therapies, devices, and scientific advances that are improving patient health and well-being in Massachusetts and around the world. An example of public support is the state funded Massachusetts Life Sciences Centre, which uses public-private funding initiatives to support innovation, research and development and commercialisation. Since its creation in 2007, the MLSC has spent more than $700 million, which has resulted in more than $3.1 billion in additional investment in Massachusetts.

Businesses will ultimately choose where and in what types of RDI they invest, but as the RDI they perform will support the wider growth and productivity of the UK, it merits Government encouragement and where appropriate, support. Government has a role in attracting and stimulating private sector investment in RDI, and supporting projects and organisations with a track record in leveraging private sector spend. Current initiatives include Innovate UK's grant funding programme SMART,

[120] Andy Haldane, "The UK's Productivity Problem: Hub No Spokes" (Speech, London, 28 June, 2018), Academy of Social Sciences Annual Lecture, 22, accessed Oct 13, 2022, https://www.bankofengland.co.uk/speech/2018/andy-haldane-academy-of-social-sciences-annual-lecture-2018

[121] Department of Business, Energy and Industrial Strategy, "Research and development: relationship between public and private funding", 2020, accessed 1 Nov, 2022, https://www.gov.uk/government/publications/research-and-development-relationship-between-public-and-private-funding

the EPSRC Shared Prosperity Partnerships, and providing funding to RPOs that work with businesses, including Catapults. Over a billion pounds has been spent on manufacturing centres over the past 10 years,[122] and the Government has worked to create an environment for all businesses to invest in RDI, most recently through the publication and ongoing implementation of the UK's Innovation Strategy.[123]

Invest NI and UKRI grant support – Northern Ireland

Invest NI is Northern Ireland's regional economic development agency, with responsibility for Foreign Direct Investment, exports and business support. Its main RDI intervention, the Grant for R&D, is designed to address specific local market failures and assist businesses of all sizes and stages of development to create new innovative products, processes and services. Invest NI can provide a package of bespoke wraparound RDI and non-RDI support to accelerate business development and commercialisation. Businesses in Northern Ireland can also access wider UK RDI support, mainly through UKRI/Innovate UK's competitive funding calls. This is complementary and additive to Invest NI, and shows the merits of funding packages at both a UK wide and more local level.

Government needs to create favourable conditions for business investment in RDI. Such conditions include ensuring a stable research delivery environment; credible and fair regulatory structures with technological flexibility; a robust intellectual property system; long-term and transparent messaging about priorities and support available for businesses; investment to strengthen the country's skills base; a favourable taxation policy; and a flexible labour market. These measures will generate further benefits, such as encouraging foreign direct investment in innovation, and the formation of innovation clusters, as seen around Cambridge and in other university science parks in the UK. The Government's Innovation Accelerators program, based on the Stanford-Silicon Valley model, aims to build clusters of research excellence, pooling the resources for businesses to invest in RDI. This includes providing technical cores, computational capacity and lab space, and providing opportunities for skilled staff to migrate between different start-ups and

[122] SMART grants: UK registered organisations can apply for a share of up to £25 million for game-changing and commercially viable research and development (R&D) innovation that can significantly impact the UK economy. Source: "Innovate UK smart grants: Jan 2022", UKRI, 2022, Jan, accessed Oct 13, 2022, https://www.ukri.org/opportunity/innovate-uk-smart-grants-jan-2022/; the Small Business Research Initiative brings together government challenges and ideas from business to create innovative solutions. Source: "SBRI: the Small Business Research Initiative", Gov.uk, 2015, accessed Oct 13, 2022, https://www.gov.uk/government/collections/sbri-the-small-business-research-initiative; Source: "Funding awarded to boost UK manufacturing supply chains", UKRI, 2021, accessed Nov 15, 2022, https://www.ukri.org/news/funding-awarded-to-boost-uk-manufacturing-supply-chains/

[123] Department for Business, Energy and Industrial Strategy, UK Innovation Strategy: leading the future by creating it, 2021, July 22, accessed Oct 13, 2022, https://www.gov.uk/government/publications/uk-innovation-strategy-leading-the-future-by-creating-it

companies. For further discussion of enabling factors to support a healthy RDI ecosystem in the UK, see the 'Actions for Government to support a thriving RDI landscape' section.

Government has clear roles as a facilitator, investor and enabler of private investment, and also has scope to use its convening power to actively lead and direct investment. First, it could take a mission-led approach to major challenges, focusing its resource towards ambitious and concrete targets that act as a frame and stimulus for collaboration between academia and industry. Successes such as the COVID-19 vaccine programme show what can be done with clear direction from Government, public buy-in and the best of public and private sector RDI. Second, it could develop a strategic focus on key sectors and technologies where the UK has a realistic and defensible competitive advantage, and provide industry with the financial incentives to drive new, world-leading RDI. Examples include artificial intelligence, engineering and synthetic biology and climate technology. Third, it should use R&D tax credits wisely as a tool to incentivise business R&D investment. In the financial year 2019–2020, total R&D tax relief claimed was estimated to be £6.9bn, and for the financial year 2020–2021 it was £6.6bn. Among OECD nations, the UK's spend on R&D tax credits as a percentage of GDP was the largest at 0.33%, compared to the OECD average of 0.12%. The next highest OECD nations were France at 0.28% and Belgium at 0.21%.[124] A number of reforms to the UK R&D tax credits have recently been announced, including reforming their relative generosity[125]. These tax credits are important, but it is essential that they are delivered in the most effective, transparent and accountable manner, to best support the UK RDI endeavour.

The Aerospace Technology Institute (ATI)

Government has created institutes to work with specific industries. The ATI was created by the UK Government and the commercial aerospace sector through the Aerospace Growth Partnership, to set out the UK's aerospace technology strategy and to fund projects aimed at advancing the development of new aircraft technologies. One of ATI's key goals is to de-risk industry R&D by targeted investments that supports projects aligning with their strategy.

The ATI has been successful in increasing direct research and technology expenditure in the UK and in leveraging further industry investment, accelerating the development of new technologies.

[124] OECD, R&D tax expenditure and direct government funding of BERD – 2019 Data, accessed Dec 2022, https://stats.oecd.org/Index.aspx?DataSetCode=RDTAX
[125] HM Revenue & Customs, Research and Development Tax Credits Statistics: September 2022, accessed Jan 23, 2023, https://www.gov.uk/government/statistics/corporate-tax-research-and-development-tax-credit/research-and-development-tax-credits-statistics-september-2022

Collaboration and interaction

As argued throughout the Review, a well-functioning RDI landscape has to be permeable with respect to people, ideas and skills. This need for permeability, especially of people, has long been recognised to be important, but it is still rare in the UK for people to move between industry and academia. The reasons for this require a deeper analysis, but include the fact that academic hiring and promotion policies can be unforgiving of 'non-standard' career choices that do not result in a continuous track record of publications, so that returning to academia from industry can be difficult.

Training, talent, and knowledge exchange mechanisms are essential to ensure businesses can invest in RDI and apply new information for commercial purposes. However, the Review heard repeatedly from businesses that frequent changes to the organisations, funding mechanisms and policy priorities in the RDI landscape, as well as unclear policy in different sectors, significantly reduces the ability of business to engage with the wider RDI landscape.

International benchmarking of the UK's innovation ecosystem shows it performs relatively well, ranking fourth on the Global Innovation Index.[126] However, the 2021 UK Innovation Survey shows that only 6.5% of all businesses in the UK and around 13.3% of innovative firms reported working with universities or other higher education institutions between 2018 and 2020, and only around 2.6% of all businesses in the UK and 5% of innovative firms considered the research from the government or public research institutes as an important source of information for innovation. Similarly, only 12.8% of innovative firms reported working with universities or other higher education institutions and fewer than 5% considered research from universities as an important source of information for innovation, showing there is room for growth in these interactions[127]. This is surprising, given that through PSREs, Government invests in certain RDI capabilities on which a wide range of businesses depend; an example of this is the Met Office, which provides nationwide access to weather forecasts.

The Review heard that businesses need an improved understanding of the diversity of RPOs in the RDI landscape, to efficiently access and use the research carried out there. Improving this understanding will help businesses and others to use a wider range of RPOs to support their needs, transforming research into viable commercial propositions. For RPOs, sustained collaborations with businesses can allow them to test and apply their research at scale. Collaboration will also bring more

[126] Global Innovation Index Online, accessed June 29, 2022, https://www.globalinnovationindex.org/analysis-indicator
[127] Department for Business, Energy and Industrial Strategy, UK innovation survey 2021: report, 2021, accessed Oct 26, 2022, https://www.gov.uk/government/statistics/uk-innovation-survey-2021-report

comprehensive benefits, reducing duplication of effort, supporting national priorities, and maximising the beneficial impact of research on society and the economy.

The first port of call for businesses looking to innovate, particularly micro and small businesses, is usually within their own business or enterprise group, clients, customers or suppliers.[128] [129] Businesses across sectors and of all sizes reported that they have a limited understanding of how academic and PSRE expertise can serve their business, and are sceptical of investing the resources to find out more and manage interactions with universities.[130] This is obviously an unsatisfactory situation: academic and PSRE sectors must be made more accessible to business.

Some organisations are seeking to reduce these barriers to collaboration. For example, the National Institute for Health and Care Research (NIHR) BioResource signposts opportunities for industry to collaborate with academia in health, and in Scotland, the platform Interface has been set up as a central hub to create mutually beneficial collaborations between Scotland's business and academic communities.[131] [132] In the health care sector, there are opportunities for productive public-private partnerships, which are discussed further in the 'RDI and Society' section. The Innovate UK Commercialisation of University Research (ICURe) Programme provides funding to university research teams to validate their ideas in the marketplace as well as building the entrepreneurial skills of early career researchers. Not only could this help build early industry backing for projects that have demonstrated success, but it also encourages RDI development in regions which lack strong RDI ecosystems. The UK Government has also established a range of initiatives to support businesses to collaborate with academia, such as the Higher Education Innovation Fund and the Knowledge Transfer Partnerships, noted in the 'Universities' section. This is also an aim of the UK Catapults (see 'Other components of the Landscape' section).

Other RPOs can play a brokering role between businesses and academia by establishing initiatives to increase the permeability of staff and projects, and providing funding for projects with demonstrable impacts that support the incubation or development of products and services. However, the Review heard that organisations, mechanisms and schemes for business-academia collaboration are

[128] National Centre for Universities and Business, The Changing State of Business-University Interactions in the UK 2005 to 2021, (NCUB, 2022), 14, accessed Oct 26, 2022, https://www.ncub.co.uk/insight/the-changing-state-of-business-university-interactions-in-the-uk-2005-to-2021/

[129] Department for Business, Energy and Industrial Strategy, UK innovation survey 2021: report, 2021, accessed Oct 26, 2022, https://www.gov.uk/government/statistics/uk-innovation-survey-2021-report

[130] Department for Business, Energy and Industrial Strategy, UK innovation survey 2021: report, 2021, 11-14, 24-25, accessed Oct 26, 2022, https://www.gov.uk/government/statistics/uk-innovation-survey-2021-report

[131] "BioResource", National Institute for Health and Care Research, accessed Oct 26, 2022, https://bioresource.nihr.ac.uk/

[132] "Interface: homepage", Interface, accessed Oct 26, 2022, https://interface-online.org.uk/

often complicated and difficult to understand and access, and the considerable effort required to apply for awards was thought too great, given that the chance of receiving funding was often slim and the bureaucracy excessive. Many businesses also requested that the organisations which provide these brokering and signposting roles should be simpler to access and more aware of what others are doing to avoid duplication of initiatives.

UKRI Creative Industries Challenge Programmes

In 2018, UKRI launched £95m of investment in RDI for the creative industries through two major challenge programmes: The Audience of the Future, and Creative Industries Clusters. The programmes have funded more than 900 businesses, primarily SMEs, and have attracted more than £200m in co-investment from businesses and investors—more than twice the original public sector funding. This figure is still rising as projects funded through the programmes continue to generate co-investment over time.

The Review heard about many different models aimed at leveraging private sector investment in RDI in the UK and abroad to increase collaboration between businesses and other RPOs. RPOs should seek to broadcast their strengths to maximise opportunities for collaboration and investment, including with the domestic and international business communities. They need to be aware of changing developments and have knowledge of international research activities and applications. Similarly, businesses should consider how RDI could improve their processes, products and profits. Sustained support should be available for projects leveraging significant private investment in RDI, and those that demonstrate a strong successful collaboration with strategically important industries could be actively rewarded, for example with simpler access to enhanced funding. Funders should also be willing to reduce or close collaborative projects if they are duplicative or not helping increase business investment in RDI.

Finally, the Review heard that Government has a role in outlining and advertising the UK RDI landscape's capabilities, and in publicising the support available for businesses to invest in RDI and collaborate with the rest of the RDI landscape. This would ease the capacity pressures on businesses to engage with the landscape.

Different businesses encounter different challenges when performing RDI that are, in part, influenced by the type of business and the nature of RDI performed; there is no single solution to unlocking business-led RDI. The recommendations below do not purport to tackle every cause of business underinvestment, and the principles they embody have varying applicability depending on the type of business and nature of RDI performed. They aim to complement existing policies, such as the UK Innovation Strategy.

Conclusions

- Incentivising business RDI spending is necessary and will require investment from business and Government. Government should take a strategic approach to facilitating and enabling private investment in key sectors and technologies where the UK has a competitive advantage.
- Not all businesses are aware of the benefits of investing in RDI, or of the information and support for innovation available from the wide range of RPOs in the landscape. Equally, RPOs in the academic sector can be reluctant to engage with industry. The sectors need to work better together so that the barriers that inhibit exchange and sharing of knowledge, resources and researchers can be broken down.
- Businesses are more likely to invest in RDI when there is long-term policy stability, a set of fair regulatory structures, a robust intellectual property system, Government investment, and a skilled workforce.
- Many models of RPOs, projects and incentives have been established to encourage business investment in RDI. Different models work well in different international, national, local and sectoral contexts.

Recommendations

The Review recommends:

13. Government should use its convening power to create a favourable environment for business to invest in RDI, tackling causes identified by this Review as holding back further business investment, and where expedient, providing financial support. Examples of such support would be funding which leverages private investment or promotes collaboration between industry and the rest of the RDI landscape.

14. To understand the benefits of RDI for commercial activities and the economy, a culture change promoting openness, mutual respect, closer interaction, collaboration and permeability of ideas, technologies and people has to occur in both business and academia. Government has a role in conveying the benefits of RDI investment to businesses, shareholders and academia, embracing practices from countries with high business RDI investment rates. Mechanisms to deliver this should be explored and implemented.

RDI and society

Description and analysis

As well as promoting industry, successful RDI also leads to innovations that are transformational for society more generally. A good example is the internet, which has been estimated to account for 21% of GDP growth in advanced economies in the five years preceding 2011,[133] but has also had major impacts on society as a whole. This section covers RDI in the context of supporting societal benefit, often also engaging commerce and industry, but leading to advancements for society beyond economic growth. Government has a particular responsibility for RDI in this area.

RDI and health care

A prime example of RDI promoting societal good is health research, which not only supports the pharmaceutical and other medically-oriented industries promoting economic growth, but also improves the health of the nation. Health research involves a wide range of collaborations between RPOs and health care delivery organisations, including the NHS, universities, charities, industry, public health and social care structures, and research institutes. The UK's health RDI landscape currently receives public investment from Government, through UKRI and its Research Councils, from the National Institute for Health and Care Research (NIHR), and from charitable and industry funding.

In 2021/22, every NHS Trust in England took part in research, with over a million clinical research participants.[134] The NHS, working with RPOs in the RDI landscape, has the opportunity to become the world's leading research engine for medical and clinical research. The combination of the unitary NHS health care system, the general public's support of the NHS which can be channelled into clinical trial participation, the strength of the pharmaceutical industry in the UK, and the high quality publicly funded life sciences RPOs in the country, all make this an unbeatable proposition for both the UK economy and for society, provided that recent concerns about increases in bureaucracy in the system are addressed. However, the Review heard major concerns expressed by clinical researchers that the demands of their clinical training and health care duties were in conflict with their research training, and for the time needed to carry out research. They argued that research activities are being squeezed out and are on a downward trajectory, weakening the ability of

[133] McKinsey Global Institute, The great transformer: The impact of the Internet on economic growth and prosperity, 2011, accessed Oct 26, 2022, https://www.mckinsey.com/industries/technology-media-and-telecommunications/our-insights/the-great-transformer
[134] "Annual Statistics", NIHR, 2022, accessed Oct 26, 2022, https://www.nihr.ac.uk/about-us/who-we-are/our-research-performance/annual-statistics.htm

the UK to carry out the research needed to make the NHS more effective and efficient, and missing opportunities to boost the economy. The Government needs to tackle this increasingly damaging problem with urgency, to ensure that those clinically trained individuals with the talent to carry out research are able to do so. This will not only strengthen the UK RDI landscape but will also improve the ability of the NHS to deliver more effective healthcare and contribute to the UK economy. Recommendations to achieve this are considered later.

National Institute for Health and Care Research

The DHSC-funded National Institute for Health and Care Research (NIHR), funds translational, clinical and applied health research, and was created to drive progress on innovation and translational research, providing sustained, long-term investment to ensure the NHS and wider health system have the expertise and capacity to support this. It has been widely recognised as having transformed the health research environment in the UK.

NIHR research infrastructure provides the resources, support and facilities that are needed to conduct health and care research from discovery science to evaluation, and can be accessed by both commercial and academic researchers. The infrastructure includes the 20 NIHR Biomedical Research Centres, NHS and university partnerships whose aim is to convert their world-leading early translational biomedical research into NHS practice. The 15 NIHR Applied Research Collaborations bring together regional providers of NHS services and NHS commissioners, universities, and other relevant local organisations including Academic Health Science Networks, and support the evaluation, identification and implementation into routine care of new interventions that are effective and appropriate for use in the health system.

The RECOVERY Trial

The NHS is a unique and precious social asset, but it is also a globally recognised powerhouse for testing, evaluating and delivering innovation for health. The importance of research in the NHS was demonstrated in the pandemic, including through the RECOVERY trial, which identified dexamethasone as the first effective treatment for patients hospitalised with severe COVID-19. The trial was funded by the UKRI MRC and the National Institute for Health and Care Research, and ran across 176 NHS Trusts, recruiting over 11,000 participants with the support of the NIHR Clinical Research Network. The pragmatic trial design and involvement of both NHS R&D and clinical staff was remarkable, and is an example of how embedding research clinical pathways can be used to generate important clinical research data at scale to save lives.

Given the long lead times required for discoveries in the life sciences to be developed into commercial and societal benefits, there is an important role for appropriately regulated public-private partnerships in the RDI health care sector. This spreads the risk for initiatives that can have great benefit for both society and commerce, but might be difficult to justify for either alone. Greater consideration should be given to developing such partnerships.

How RDI can contribute to equitable regional economic growth

Another example of a positive impact of RDI on society is economic growth, which promotes equitable regional economic growth more generally throughout the UK. Investment in translation of research into innovation, greater productivity, and improved prosperity is unevenly dispersed across the regions.

The UK Government has signalled its intention to shift the balance in equitable regional economic growth through its recent Levelling Up White Paper.[135] RDI has to be integral to the Government's regional economic and industrial policy and will play an important role in addressing the UK's regional imbalances, in combination with the Government's overall industrial policy.[136]

As set out in the 'Industry and Private Sector' section of the Review, not all UK businesses are fully aware of the benefits of investing in RDI or in using the capabilities of RPOs elsewhere in the landscape. Lack of permeability between organisations in the local landscape restricts RDI investment in traditionally low RDI performing areas, due to limitations in the capacity and desire of the local business base to take up and use RDI.[137] [138] For RDI to be effective, attention should be paid to local circumstances and demand, including the ability of business to respond to innovation. Business RDI investment is important in terms of raising economic productivity and growth, but often requires pre-competitive investment from Government. In considering such funding, it should be noted that locally relevant RDI may well be different to what is rated highly by solely academic criteria, given that relevant objectives are also to support local, civic and community needs, to promote local industry, and help enhance public services such as education, transport, and healthcare delivery.

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[135] Department for Levelling Up, Housing and Communities, Levelling Up the United Kingdom, 2022, Feb 2, accessed Oct 26, 2022, https://www.gov.uk/government/publications/levelling-up-the-united-kingdom

[136] The British Academy, Lessons from the History of UK Science Policy, 2019, accessed Oct 26, https://www.thebritishacademy.ac.uk/publications/policy-histories-lessons-history-uk-science-policy/

[137] Christine Ougthon et al., The regional innovation paradox: Innovation policy and industrial policy, Journal of Technology Transfer 27, (2002), 97–110, accessed Oct 27, 2022, https://doi.org/10.1023/A:1013104805703.

[138] NIESR, "From Ideas to Growth: Understanding the drivers of innovation and productivity across firms, regions and industries in the UK",2021, accessed Oct 26, 2022, https://www.niesr.ac.uk/projects/understanding-drivers-innovation-and-productivity-across-firms-regions-and-industries-uk

RDI capability is underpinned by the interest within an area. Different regions, and local areas within the same region, will have diverse innovation landscapes, and while central Government has an essential advisory and supportive role, an emphasis on local expertise and knowledge is preferable.[139] Local outcomes are more likely to be successful when Government policy targets existing local strengths, for example in particular manufacturing sectors, and the expertise and knowledge of local areas or institutions drives the strategy behind an intervention.[140] [141] A partnership approach should be taken between the UK Government and Devolved Administrations to ensure a coordinated approach for initiatives within and across Scotland, Wales and Northern Ireland.

Glasgow City Region

The Glasgow City Region has developed a virtuous cycle of attracting RDI investment and capability, with a strength in translational research organisations. This includes four universities (Strathclyde, Glasgow, Glasgow Caledonian and the West of Scotland) two Catapults, five Scottish Government Innovation Centres, two Innovation Districts, the UK's only Fraunhofer Centre, and PSREs. Glasgow City Region has also been announced as one of three pilot Innovation Accelerators.

Local roles of universities and other RPOs

RPOs are a source of RDI capability to their local area. As previously discussed, universities, which are located throughout the UK and often have significant interactions with their local economies, have a key role in planning and supporting long-term growth and development of regions. Universities should enhance their roles as convenors, helping in the coordination of other RPOs and industry to leverage local strengths. This can help to create regional clusters capitalising on particular strengths. As proposed in the 'Universities' section, universities can act as an 'information nexus', networking across disciplines outside of their individual strengths by assisting local industries in setting up links with relevant research capability, wherever it is found in the UK. Regional research consortia, such as the GW4 Alliance and the Eastern Arc also pool regional expertise to become more than

[139] HEPI, Catching the wave: harnessing regional research and development to level up, (HEPI, 2021) , accessed Oct 27, 2022, https://www.hepi.ac.uk/2021/10/21/catching-the-wave-harnessing-regional-research-and-development-to-level-up/
[140] HEPI, Catching the wave: harnessing regional research and development to level up, (HEPI, 2021) , accessed Oct 27, 2022, https://www.hepi.ac.uk/2021/10/21/catching-the-wave-harnessing-regional-research-and-development-to-level-up/
[141] "Levelling Up Innovation: Boosting R&D in Underperforming Regions", *Tony Blair Institute for Global Change,* Sep 14, 2020, accessed Oct 27, 2022, https://institute.global/policy/levelling-innovation-boosting-rd-underperforming-regions

the sum of their individual parts. Such local innovation and technological spillover effects from universities have been documented.[142] [143] [144] [145] [146]

The Review found that in addition to universities, other publicly funded RPOs can be important to local firms, but are generally underused. With sufficient scale and expertise, the whole range of RPOs could serve as beacons within local clusters, providing specialised technical cores, key RDI infrastructure, and access to highly trained staff with specialised research and engineering expertise.

Cumbria as Centre for Nuclear Excellence

Clustering of RPOs can support the local economy. Cumbria hosts world-leading nuclear expertise in both PSREs and industry, such as the National Nuclear Laboratory (NNL), Nuclear Decommissioning Authority (NDA), Low Level Waste Repository (LLWR) Ltd, Sellafield Ltd, Britain's Energy Coast Business Cluster (BECBC), and Westlakes Science & Technology Park. The nuclear sector employs 27,000 people in Cumbria and supports more than 400 Cumbrian companies within its supply chain. It is also linked to academic and training facilities such as Manchester Dalton Facility, Energus, National College for Nuclear, Gen2 and the Energy Coast UTC, supporting over 2,000 trainee graduates and apprentices.

The Review heard that RPOs could complement existing expertise and develop links across the country. The University of Nottingham has taken this approach, providing scale-up capacity and test bed and demonstrator facilities for industry alongside the Power Electronics and Machines Centre and the GSK Carbon Neutral Laboratories for Sustainable Chemistry. Such specialised technical cores and collaboration with industrial partners can increase local employment and productivity through innovation.

[142] Eastern Arc: homepage, accessed Oct 27, 2022, https://easternarc.ac.uk/
[143] Roland Andersson et al.,Urbanization, Productivity, and Innovation: Evidence from Investment in Higher Education. Journal of Urban Economics, 66, 2-15 (2009), accessed on Oct 27, 2022, https://doi.org/10.1016/j.jue.2009.02.004.
[144] Enterprise Research Centre, Accessibility, utility and learning effects in university business collaboration, 2017, accessed Oct 27, 2022, https://www.enterpriseresearch.ac.uk/publications/accessibility-utility-learning-effects-university-business-collaboration-research-paper-no-57/
[145] Otto Toivanen and Lotta Väänänen, 'Education and Invention,' Review of Economics and Statistics 98, no. 2 (2016): 382–396, https://doi.org/10.1162/REST_a_00520
[146] Richard K. Lester, Universities, innovation, and the competitiveness of local economies, A summary Report from the Local Innovation Systems Project: Phase I. Massachusetts Institute of Technology, Industrial Performance Center, Working Paper Series, 05-010 (2005), accessed Oct 27, 2022, http://web.mit.edu/lis/papers/LIS05-010.pdf

Setting up new initiatives

This Review has described the UK RDI landscape's strength in diversity and supports experimentation in potential new organisational structures which expand the UK's translational capacity and specialise in the application of research. However, careful consideration should be given before setting up new RPOs whose goal is to provide support to their local areas. When establishing new RPOs, multiple factors need to be taken into account, including national RDI need, local RDI strengths and capability, and the potential for positive impact on the local economy and community. Founding an RPO in an area without existing capability and connections is unlikely to achieve objectives efficiently. Without a carefully understood and well evidenced picture of local strengths, the addition of new RPOs may not bring the desired opportunities and wider societal benefits to the local area.

The Review notes the upcoming pilots for Innovation Accelerators which will take place in Greater Manchester, the West Midlands, and the Glasgow City Region over a three-year period. This model sees industry, local government, and RDI institutions work together alongside national Government to nurture and expand local RDI investment and capabilities. It must be noted that this model is being piloted in three large metropolitan areas with existing RDI capability and it may need to operate differently if applied to other parts of the UK with different characteristics.

Innovation Greater Manchester

Local communities have a pivotal role in driving RDI in their areas. Greater Manchester is participating in a UK Government Innovation Accelerator pilot. Innovation Greater Manchester is a private-public partnership organisation led by industry, the Greater Manchester Mayoral Combined Authority, and universities. It includes the delivery, in partnership with UK Government, of an Innovation Accelerator pilot (set to run from 2022-2025). It complements the Greater Manchester Local Industrial Strategy, aiming to provide the leadership, coordination and delivery capacity to grow the RDI landscape and productivity in Greater Manchester, including in more deprived boroughs such as Rochdale, which hosts the Advanced Machinery and Productivity Institute and has been supported by UKRI's Strength in Places Fund.

Allocation of public funding should be driven by evidence of what works best from the perspective of improving RDI capability and impact. Robust evaluation of schemes from all UK nations and international best practice (such as Kosetsushi Centres in Japan, as described in 'Other components of the RDI landscape', and Fraunhofer Institutes in Germany) will be key.

The Productivity Institute

Institutes can provide practical support to local areas. Since it launched in Autumn 2020, The Productivity Institute (funded by UKRI'S Economic and Social Research Council, ESRC) aims to use academic research and knowledge to help create practical solutions to transform UK productivity. The research community in turn learns from business leaders and policymakers to fully inform the research agenda. The Productivity Institute has a select number of strong partnerships at a national level but its core approach is eight Regional Productivity Forums (RPFs). Each are led by a university partner and chaired by a high-profile regional leader with significant business experience. These forums give the Productivity Institute reach across the whole UK (including the Devolved Administrations) and are the main route through which businesses and regional policymakers are engaged in the work of the Institute. The objective of the RPFs is to help scope and commission the institute's research, ensure that local contexts are considered and enable the sharing of insights.

RDI in the pursuit of net zero and climate adaptation

RDI has a critical role to play in combatting the threats of climate change and the reduction of biodiversity. RDI is essential to develop new technologies,[147] to improve existing technologies, and to understand what solutions will be feasible to bring about effective climate change forewarning, mitigation and adaptation. To bring about net zero, the UK is pursuing these developments via UKRI and PSRE programmes and the government's Net Zero Innovation Portfolio (NZIP). Research across a range of fields will be crucial. Bold, well-coordinated and properly resourced RDI activities are necessary which need to be rapidly translated and commercialised. This Review's recommendations will help the RDI landscape to evolve so that the UK can best contribute to the global effort to deal with climate change. More attention needs to be paid to biodiversity loss and how this can be reduced by research into how to better manage natural ecosystems and their associated wildlife.

Other societal benefits from RDI

Health care delivery, equitable regional economic growth throughout the UK, and the delivery of net zero, are just three examples of areas that have strong societal impacts, as well as driving economic growth. There are other possible initiatives that could be explored, for example aspects of education, agricultural practice, transport systems, and town planning. RDI is helpful to these and other activities, and

[147] The International Energy Agency (IEA) estimates that almost half of the greenhouse gas reductions required under the Paris Climate Agreement depend upon the scale-up of technologies which are only at prototype or demonstration stage. [Source: "Innovation A critical driver of clean energy transitions", *IEA*, accessed Aug 4, 2022, https://www.iea.org/topics/innovation]

Government should identify opportunities through its departments and PSREs to make use of the RDI landscape to promote the relevant RDI delivery.

Conclusions

- RDI provides benefits for economic growth and societal benefit, both locally and nationally. Government has a particular responsibility for promoting societal benefit because it cannot be driven effectively by commercial activities alone.
- Relevant Government departments should be more active in ensuring that RDI is in place and informing development of policies with societal benefit. Good examples of such policies are in health care, equitable regional economic growth, delivery of net zero, and increasing biodiversity, but there are others, including education, care for the environment, transport and town planning.
- There are significant opportunities in the UK for improving health care through RDI, and opportunities for public-private initiatives in this sector should be considered. However, clinical researchers are finding it increasingly difficult to combine a research career with the demands of their clinical training and NHS duties. This is damaging medical research, with negative consequences for both health care and the economy, and these problems need to be urgently resolved.
- The RDI landscape should be permeable in knowledge, skills and expertise across the UK. Poor permeability can prevent local areas and businesses from engaging with and benefitting from their local RPOs, and this is likely to be a limiting factor in addressing regional RDI imbalances.
- Setting up orphan RPOs in areas with little existing research capability is unlikely to be successful. Interventions to promote regional RDI capability require a partnership approach between central government, RPOs and local universities, communities and institutions, and will need time, robust evaluation, and sustained funding.

Recommendations

15. Government should take particular responsibility for driving RDI that provides societal benefit as well as economic growth. Examples are health care delivery, equitable regional economic growth throughout the UK, and the delivery of net zero. Where appropriate, public-private partnerships should be encouraged.

16. Government and RPOs should partner with local communities to support RDI relevant to their needs, to bring about greater equitable regional economic growth based on local expertise and demands and driven by community benefit as well as academic criteria. Universities and other RPOs should support their local community and economy by enhancing their role as an information nexus and by helping local industries link to research capabilities wherever they are in the UK.

17. There is an urgent problem with the current mechanisms for clinician scientists to effectively develop and undertake their research careers. The Government, taking into account devolved competencies, must rectify this to both improve the ability of the NHS to deliver more effective health care and to help the UK economy.

Actions for Government to support a thriving RDI Landscape

This Review has explored the characteristics of the major categories of RPOs within the UK RDI landscape, and has covered the interactions of industry and civic society within that landscape. These analyses have revealed a range of wider 'enabling factors', which if developed by Government and others, will improve the effectiveness of the UK's RDI endeavour. This section focuses mainly on the role of Government but the analyses also apply to other research funders and RPOs. There are 10 parts (A-J) in this section, and the recommendations for all of these are given together after part J.

A. The overall role of Government

Description and analysis

The UK Government and the Devolved Administrations are responsible for safeguarding the RDI landscape based on the development and implementation of good policy. This includes upholding what is known as the Haldane Principle, which states that researchers must be able to make specific research decisions free of political control; this principle is enshrined in the Higher Education and Research Act 2017.[148] While some elements such as strategy development may also be undertaken by other bodies, no other body in the UK RDI landscape has Government's policy ownership, legal authority, financial resources or diplomatic mandate. It is essential that the Government assumes an explicit role as a strategist, convener, facilitator and when required as an investor. This must all be coupled with a long-term commitment to RDI that should lie at the heart of this and future Governments. RDI is generally not political, and cross-party agreement for policy would help the long-term stability requested by both RPOs and business. The recently established DSIT and the NSTC together provide an important opportunity to coordinate at Cabinet level the delivery of overarching RDI policy. These developments could also improve alignment and reduce barriers on issues over and above the existing roles and responsibilities of Departments, including facilitating and co-ordinating cross-Government on matters that are not currently examined or decided elsewhere.

[148] Higher Education and Research Act 2017. (c.29). https://www.legislation.gov.uk/ukpga/2017/29/section/103/enacted

A central place for RDI in government priorities is the key to guaranteeing that the country has a knowledge-based economy generating benefits for all of the UK. Promoting RDI will showcase the UK both nationally and internationally as a great place to do research, to set up innovative businesses, and to act as a trusted partner for science. This will strengthen partnerships with our allies and enhance the country's global profile. The UK policy landscape must be capable of developing, sustaining, enhancing and using a suitable mix of RPOs to support these goals, and also to maintain Government departmental knowledge and capabilities necessary to ensure that scientific knowledge informs all the country's activities and societal needs.

As the UK's largest public funder of research and innovation, UKRI has a major role to play in the development of the RDI landscape. UKRI's reach is wide — in 2020-21 UKRI provided funding to nearly 3,900 separate UK organisations.[149] UKRI is a delivery body for distributing RDI funding, but also contributes its detailed expertise, including knowledge of other RDI funding organisations and overview of the RDI system, to the development of overall decision making on RDI in the UK. It is a critical part of the Government's RDI policy development architecture. The recent Independent Review of UKRI, led by Sir David Grant, recognises that UKRI has so far partially met its objectives in helping to maintain the UK's position as a world leader in research, but that gaps remain. The Grant Review recognised the added value that UKRI has had in delivering funds that go above and beyond the work of individual Research Councils, particularly when tackling cross-cutting problems, and has made recommendations for how UKRI can maximise its value as a single organisation working effectively with its network of stakeholders across the RDI landscape.[150] Government and UKRI should consider these recommendations in detail, including how they relate to the wider changes to the landscape proposed in this Review.

The Government's overall policy responsibilities are: to cover funding across the RDI landscape, ensuring public sector financial and operational controls support rather than hinder RDI; to have in place appropriate review and reporting of RDI activities; to generate collaboration and interactions across the RDI landscape; to develop and attract talent; to promote UK RDI strengths across the globe; to map the RDI landscape nationally and internationally; and to identify and support research capability and specific high level programmatic and technological initiatives. These various areas will be considered in detail in the next section of the Review.

[149] UKRI, Performance Metrics 2020-21, 2021, July 15, accessed Oct 27, 2022, https://www.ukri.org/publications/ukri-performance-metrics-2020-to-2021/
[150] Department of Business, Energy and Industrial Strategy, UKRI Independent Review: Final Report and Recommendations, 2022, July, accessed Oct 27, 2022, https://www.gov.uk/government/publications/independent-review-of-uk-research-and innovation-ukri/independent-review-of-uk-research-and-innovation-ukri-final-report-and-recommendations

Conclusions

- At all levels of the RDI endeavour, from Cabinet to the operations of individual RPOs and funding organisations, particularly UKRI and the NSTC, there needs to be a systematic coordinated approach to RDI strategy and policy setting with clear accountability and a focus an overall safeguarding of the RDI landscape.
- A coherent, stable and long-term supra-political Government vision for science and research in the UK will boost confidence within the components of the UK's RDI landscape, and give RPOs, industry, investors, global companies and researchers the certainty they need to be able to operate, interact and invest within the UK's RDI landscape. This can be developed and implemented by the new DSIT, and the NSTC.

B. RDI Landscape mapping and programmatic and technological initiatives

Description and analysis

The Review heard from stakeholders, particularly those from industry and from other countries, that they require both better understanding of the UK RDI landscape and a reduced volatility of policies from Government concerning long-term national programmatic and technological initiatives. They commented on the volume and frequency of Government RDI strategies, which they said led to confusion over where to focus and prioritise their resources, and also damaged confidence in the RDI landscape. Some nations have responded to similar challenges by defining their long-term scientific priorities, and regularly mapping and gathering information about their RDI landscapes. For example, Switzerland has a regular report on Research and Innovation, and Germany has a centre for studying its innovation system.[151] The Review heard that stability around priority setting, initiatives and funding, and clear definition of areas of Government research interest and capability can also be effective at attracting talent and investment and fostering collaborations, as well as providing confidence for researchers.

The Review heard that the UK's diversity of research organisations, policy, and those promoting UK RDI internationally, can make the research system challenging to navigate. Countries with a clearly defined lead Government organisation or point of contact for international science cooperation are better able to advertise their RDI strengths to the rest of the world. The Review heard of examples of other countries which have effective signposting mechanisms for their research, such as Israel's Start Up Nation Central and the international advertising of their capabilities by Germany's Max Planck Institutes.[152] [153] While the UK has signposting sites, such as Konfer and Interface, these are not well known nationally or internationally, and apparently do not go as far as is necessary in serving the needs of businesses, researchers and policymakers.[154]

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[151] SERI, Research and Innovation in Switzerland 2020, accessed Oct 27, 2022, www.sbfi.admin.ch/r-i_report https://www.sbfi.admin.ch/dam/sbfi/en/dokumente/2020/10/f-i-bericht-2020-kurz.pdf.download.pdf/f-i-bericht_en.pdf

[152] "Start-up Nation Finder", Start-up Nation Central, accessed Oct 27, 2022, https://finder.startupnationcentral.org/

[153] "Max Planck Institutes abroad", Max-Planck-Gesellschaft, accessed Oct 27, 2022, https://www.mpg.de/272329/Max_Planck_Institutes_abroad

[154] "Interface: Homepage", Interface, accessed Oct 27, 2022, https://interface-online.org.uk/ ; "Digital Brokerage", NCUB, accessed Oct 27, 2022, https://www.ncub.co.uk/solutions/digital-brokerage/

China and its ambition to secure strategic advantage through science and technology

Other nations outline how they will strategically support science and technology across their economies in overarching strategic documents. China's latest five-year plan (FYP 2021-2025) brings forward its target to become a science and technology superpower by investing 2.8% of GDP in R&D by 2025 (from 2.4% in 2020) and increasing R&D funding by more than 7% year on year.[155] The plan prioritises technologies in seven sectors, sets out structural reforms, and outlines the creation of new R&D universities and institutions. The FYP also highlights where successful science and technology relies on enabling conditions and how China will improve those: such as investor diversification actions, the reorganisation of state labs, and flexible employment mechanisms.

Better understanding of the RDI landscape would be facilitated by mapping, horizon scanning and trend analysis of Research Performing Organisations (RPOs) in the UK, characterising their function and capabilities as well as their geographical location. This must include accurate reporting of the funding of different RDI sectors. Such mapping by Government has taken place in recent years, including partly through the annual UK Innovation Survey, but these efforts have been incomplete, and were not regularly updated.[156]

An agreed shared picture of the RDI landscape should be produced, together with a commitment to regularly update it. The map should consider how to do so most effectively to increase permeability, building on existing initiatives or digital tools if effective. As argued in Section G (Collaboration), any such mapping should be gathered and disseminated in a form that can be practically used, including to support the Government in making better informed choices about RDI. This will inform long-term strategy setting including the geographical location of RPOs. It should be combined with domestic and international horizon-scanning, identification of emerging trends, research fields, and new RPOs. Such mapping and characterisation would generate a more contextualised and informed approach to RDI policy and funding decisions made by Government as well as research funders and UK RPOs. It should also include accurate estimates of the levels of investment in different sectors of the RDI landscape to facilitate high quality policy development.

[155] "China Country Dashboard", The Organisation for Economic Cooperation and Development, accessed Nov 14, 2022, https://stip.oecd.org/stip/interactive-dashboards/countries/China'; "China announces major boost for R&D, but plan lacks ambitious climate targets", Science, accessed Nov 14, 2022, https://www.science.org/content/article/china-announces-major-boost-rd-plan-lacks-ambitious-climate-targets

[156] Department for Business, Energy and Industrial Strategy, UK Innovation Survey, 2012, Dec 6, accessed Oct 27, 2022, https://www.gov.uk/government/collections/uk-innovation-survey

Decision making, policy setting and governance in the RDI policy landscape would be further strengthened by greater input from a wider range of sectors and RPOs in the RDI landscape. The membership of boards, review panels, and funding councils should be broader and more inclusive to avoid dominance of governance by a particular RDI sector, reducing the possible risk of distorted decision making in favour of that sector. For example, policies that apply across the RDI landscape but which are designed with only one sector in mind might not be applicable to other sectors. RPOs could consider setting up loose representative bodies across the RDI landscape to advocate for their collective voices in governance structures, for example in groups of universities, PSREs, institutes or independent RPOs.

Particularly at the applied end of the research spectrum, Government should give industry and commercial stakeholders greater stability by identifying which long-term national programmatic and technological research initiatives they will support. Clearer definition and sustained adoption of such initiatives and support for any related applied research activities would provide increased certainty for commercial long-term planning, and would assist priority setting, initiatives and funding. This in turn would attract investment, research capability and entrepreneurs, and foster collaborations and interaction across the RDI landscape.

Battery Research in North America and the EU

Competitor nations in Europe and North America are funding energy storage R&D at increasingly higher levels and over longer timeframes than the UK, signalling their commitment to strengthen national and regional energy storage ecosystems across the battery supply chain. Research and innovation in battery manufacturing is one of the EU's priority goals, so funding levels are also significant: the European Commission has approved €3.2 billion of state funding to support battery research and innovation across EU countries. Through recent legislation, the US will invest more than $135bn to build the nation's electric vehicle future, including critical minerals sourcing and processing and battery manufacturing. From this, the US Department of Energy will invest $73.9m in R&D on battery recycling and second life alone. The Federal Consortium for Advanced Batteries brings together several departments across the US government to accelerate the development of a robust and secure domestic industrial base. Although the UK Government has made a start in this area, the scale of activity is small compared with the USA and EU.

There are international examples of this. Singapore has regular Research, Innovation and Enterprise plans with associated long-term and stable funding which

set out ministerial and agency responsibilities.[157] Similarly, Japan has regular Science and Technology Basic Plans, underpinned by the Science and technology Basic Law. In the US, the White House's Office of Science and Technology Policy and the White House National Science and Technology Council are supported by the US Science and Technology Policy Institute (STPI), which conducts research and provides analysis on science and technology policy, economic analysis, and regular mapping and trend analysis in the US and abroad of social and economic trends in science and technology policy. It has a specific remit, but is free of public sector constraints, and is primarily funded by the National Science Foundation, a Federal Agency.[158]

Conclusions

- Due to its diversity, the UK's RDI landscape can be challenging to navigate. Improved knowledge, mapping, accurate reports of funding and better shared understanding of the landscape will improve visibility both nationally and internationally of the RPOs within the system, and support better planning and decision making for UK Government RDI policy. Gathering information on globally competitive RPOs will also help Government effectively develop future RDI plans and policies.
- The Government should take a longer-term view for identifying national programmatic and technological research initiatives particularly at the more applied end of the research spectrum. This would assist industry and commerce and give them the confidence to invest, operate and interact with the UK's RDI landscape.

[157] Information contributed by international correspondents with the Landscape Review
[158] "Office of Science and Technology Policy", The White House, accessed Oct 27, 2022, https://www.whitehouse.gov/ostp/

C. Funding across the RDI Landscape

Description and analysis

The UK public funding system is complex, with multiple players, overlapping objectives and convoluted funding relationships. As explained earlier in the 'Ambitions of the Review and Government' section, total UK RDI funding is expected to roughly equal or exceed the OECD average of 2.5% GDP in 2019 and 2.7% in 2020. Precise figures are uncertain partly due to ONS methodological errors in data collection which will be fully corrected later in 2023, although DSIT have made their own calculations (rounded to one decimal point). What is clear however is that Government funding of its own RDI activity is well below the OECD average. For 2019, the last year that GDP data were not affected by the shrinkage in the economy caused by the COVID-19 pandemic, RDI performed by UK Government entities was 0.12% of GDP (DSIT estimate 0.1%), around half the OECD average of 0.24%. Total RDI funding by the UK Government was around 0.46% of GDP in 2019 (DSIT estimate 0.5%), putting the UK in 27th place in the 36 OECD nations. For comparison, the OECD average is around 0.6% and research-intensive and commercially successful nations such as South Korea, Germany and the United States funded 0.66-0.96% in 2019. The UK Government has recently committed to increasing its RDI investment, despite the context of challenging broader public spending constraints. This is welcome, and reflects the importance of increased Government RDI investment in underpinning the UK's future sustainable economic growth and improved productivity. A summary of the origin of R&D funding in 2020, and where it is performed in the UK is given in Figure 4.

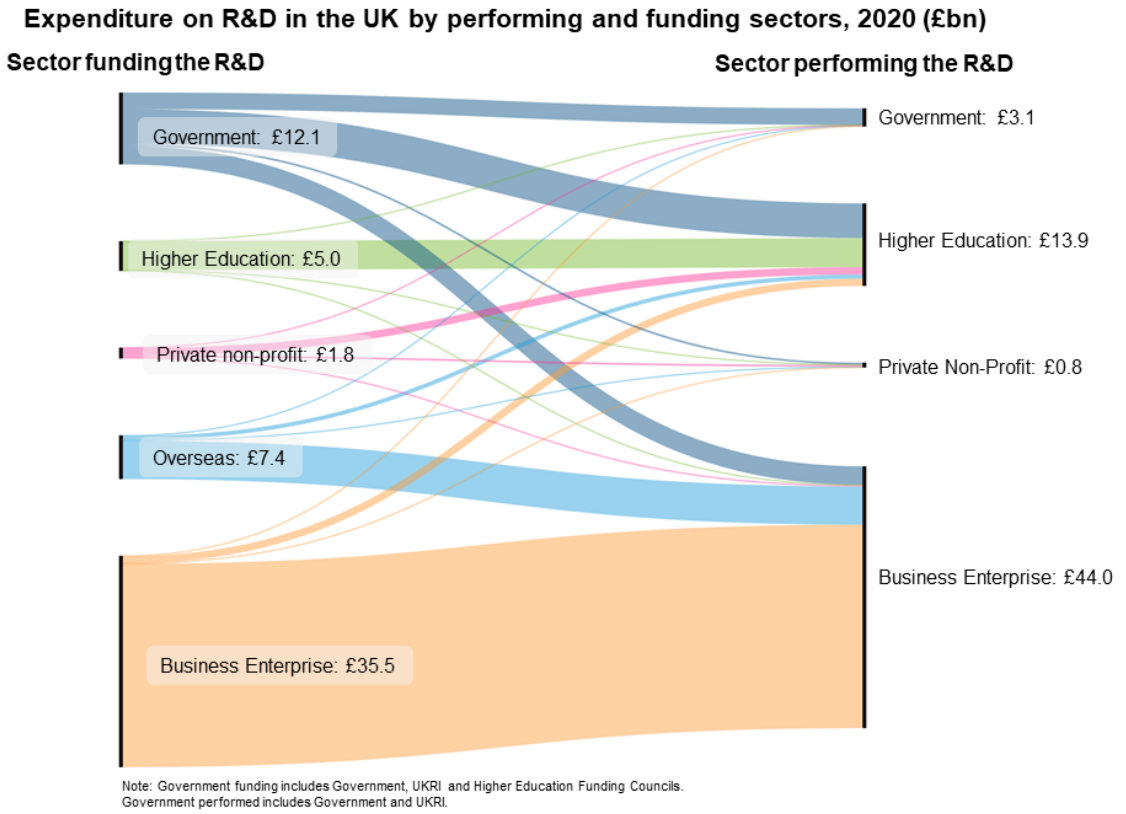
There is a wide distribution and variety of funding arrangements across different RPO types, comprising a mixture of 'core' research funding and project-based funding. There is also significant competition for funding between RPOs. The duration of public funding settlements offered to RPOs from the UK Government and Devolved Administrations is dictated by fiscal events, primarily Spending Reviews, with the final settlement ultimately allocated and disbursed by the specific spending department, such as DSIT, or funding body, such as UKRI. Stakeholders frequently noted that the recent annual fiscal events limited the ability for RPOs to plan effectively. Such settlements should be made longer term.

RPOs operate using a range of funding arrangements, described elsewhere in the Review, including direct funding from Government and charities, and commercial activity. The Review noted the differences in funding for non-university RPOs, such as PSREs, some institutes and units, and Catapults. Importantly, some, similar to the universities, have the benefits of a 'dual support' system, with its un-hypothecated funding element, and others do not. The Review heard that these differences can

significantly impact the RDI activities undertaken by these organisations, particularly the interactions between them, if support beyond direct costs is funded differently or not at all in the different organisations. Numerous stakeholders outlined the significantly improved opportunities that un-hypothecated core funding from the public sector for currently ineligible RPOs would create. More un-hypothecated core funding would mean these types of organisations could expand and capitalise on their research capability, and potentially lower the barrier to 'market entry' for new ones. It would help them to increase their applications for project and programme grants, which currently do not cover all costs, to provide continuity for staff costs, and to allow greater collaboration across the RDI landscape, because RPOs in different sectors could operate in similar ways.

The Review found instances of RPOs, particularly some institutes, being established with an 'underfunded mandate'. This underfunding results in wasted effort in keeping them operational. It would be preferable to establish fewer RPOs and fund them sufficiently and sustainably.

Figure 4: Flows of research and development funding in the UK in 2020[159]



[159] "Office for National Statistics, UK Gross domestic expenditure on research and development, 2020", 2022, accessed Dec 14, 2022, https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/datasets/ukgrossdomesticexpenditureonresearchanddevelopment2020designatedasofficialstatistics

Conclusions

- At 0.46% of GDP (DSIT estimate 0.5%), direct Government funding of domestic R&D[160] is less than the OECD average and lags behind that of the best research-intensive and commercially successful nations, as does the 0.12% (DSIT estimate 0.1%) of GDP spent on Government-performed R&D, which is half the OECD average. This is incompatible with the UK being a global science superpower, which is needed to drive the future success of the country.
- There are significant incompatibilities and differences between different funding streams and RPOs in the UK, which add to the complexities of the UK RDI landscape, reducing effectiveness, the ability of different organisations to collaborate, and sometimes, financial sustainability.
- The current research funding system creates advantages and disadvantages for RPOs depending on the organisation type. Organisations compete for funding, which can be a driver for quality but can also have a negative influence on collaboration and the delivery of properly priced research programmes. The availability of un-hypothecated core funding, or access to wider resources which can be used for core funding, varies for the different organisations across the landscape. These factors are negatively affecting sustainability, operations and agility in responding to newer emerging priorities, and are also inhibiting permeability, interactions, and collaborations throughout the RDI landscape.

[160] Direct Government funding of domestic R&D includes funding from Government, UKRI, and higher education Funding Councils.

D. Financial controls

Description and Analysis

Many RPOs, such as PSREs and UKRI-funded research institutes and units are public sector bodies, which means they have certain Government financial and operational controls applied to them that restrict their freedom of action. The Government's role in applying controls to specific organisations delivering public services is aimed at ensuring public monies are appropriately spent and accounted for, to limit the misuse of funds and to ensure value for money and a return to the taxpayer. For public sector bodies within the RDI landscape, these controls are applied via rules at both Government department and/or funding body levels, resulting in RPOs being affected by three broad categories of constraint: financial controls, derived from the Treasury, Cabinet Office controls and associated pay-related controls. The Review has heard that public bodies in the RDI landscape are particularly hampered by pay-related controls, which are further explored below.

The Cabinet Office Pay Remit Guidance sets rules on public sector pay. It limits the rate at which public sector salaries are allowed to increase year-on-year. In addition, the Treasury owns a separate control on senior pay, placing a salary cap at £150,000, above which a body must seek special clearances from the Chief Secretary to the Treasury. In 2014, a case was successfully made by the then BIS Science Minister to the Chancellor to exempt public sector RPOs from the Pay Remit. The detail was agreed in an exchange of letters, and publicly referred to in the 2015 Budget and 2015 Autumn Statement.[161] [162] However, the exemption was not implemented in PSREs after UKRI was created, except in museums and galleries. The Review did not hear any evidence that this was intentional, but as a consequence, pay controls have created perennial hiring and staff retention problems. These problems were very common themes in the evidence gathered by the Review, and are echoed by the findings of the Independent Review of Research Bureaucracy and the Independent Review of UKRI.

[161] HM Treasury, Budget 2015: 1.188, 2015, March 18, accessed Oct 28, 2022, https://www.gov.uk/government/publications/budget-2015-documents
The Government will also provide the UK's world-leading Research Institutes with greater freedoms to attract the brightest minds, re-invest commercial income, and develop cutting-edge technology.
[162] HM Treasury, Spending Review and Autumn Statement 2015: 1.188, 2015, November 27, accessed Oct 28, 2022, https://www.gov.uk/government/publications/spending-review-and-autumn-statement-2015-documents/spending-review-and-autumn-statement-2015 *The Spending Review and Autumn Statement extends the freedoms granted to Research Institutes at Budget 2015 to all Department for Business, Investment and Skills (BIS) Sector Research Establishments which are not public corporations, and will also grant access to accumulated reserves of commercial income, subject to a cap*

Case Study 1: A prestigious Government funded UK institute is struggling to compete on pay with other labs. At the post-doc stage, their maximum salary on offer is £35,143. This is 14.7% less than their neighbours in a university (£40,332), and 33.7% less than at a nearby firm (£47,000). The gap widens with seniority. In the last two years they have lost 7% of their Group Leaders to overseas universities and research institutions. In attempting to recruit a Group Leader from the USA, the institute's maximum offer of £80k was completely inadequate to compete with the candidate's current salary of $200k.

Case Study 2: For a recently approved ~£100m Government programme in a key strategic technology area, resourcing is the number one delivery risk. The programme mapped their salary costs against others competing for jobs in the same field. Across all roles, the average discrepancy was -27%.

Case Study 3: A laboratory providing world-leading research and technology development and test facilities recently had to withdraw from two multi-million-pound contracts due to a lack of staff because of pay restrictions.

Case Study 4: In a key strategic partnership between UKRI, MOD, academia and industry bringing together world-class interdisciplinary expertise, there are currently 50% vacancies in key roles due to an inability to offer salaries at market rate. If the situation continues, they anticipate a minimum of 1.5 years delay costing £3.5m or paying an extra £3.85m to employ an external design house. Conversely, paying staff at market rate would only cost £2.55m.

In theory, the current system does allow exceptions to general pay rules. Departments can submit a business case to Cabinet Office to seek exemptions on elements of the pay remit guidance, and to the Treasury for senior salary clearance above £150k. In practice though, organisations told the Review that there are barriers to gaining these exceptions, and institutions find it very challenging to navigate them with the rapidity required for successful high-level recruitment. In addition, when organisations do ask for pay flexibility, they are met with significant bureaucracy. The Review heard examples of senior RDI pay cases sitting with the Treasury for months without clearance, in some cases stifling what were initially live negotiations with an interested candidate; when there was engagement, the basis for assessment was unclear. These problems mean that organisations are dissuaded from seeking clearance at all, leading to a chilling effect on the hiring of high calibre candidates.

There are two limiting factors in play here. The first, as outlined above, relates to bureaucratic problems influencing the time associated with submitting pay flexibility cases and the time taken for their approval. The second is the Government's overall strategic approach to public pay policy in the RDI sector. The Review strongly

recommends that the policy of pay controls is abandoned in public sector funded RPOs. The Review was unable to find any economic evidence for why applying public sector pay controls in these circumstances provides value for money; in fact, the reverse is true.

It is important to recognise that such reforms would not necessarily require significant increases in total budget, but could offer increased value for money, with higher quality overall performance. In some situations, there are already other routes in place: for example, the Clinical Excellence Awards offer non-salary payments to high performing clinical researchers on the condition that they retain a public sector presence, effectively subsidising public sector work without breaching the Pay Remit. An equivalent scheme targeting high performing scientists might also be useful. RPOs are also subject to certain central Government processes that can unintentionally hinder their productivity and agility, with a negative impact on UK RDI output.[163] [164] For example, stakeholders highlighted that some procurement processes can directly or indirectly delay buying new equipment. Government should assess the potential impact of mandated procurement processes on the operations of RPOs.

Conclusions

- The operating conditions of public sector RPOs can be negatively influenced by their proximity to Government. Pay controls for public sector RPOs have created perennial hiring and staff retention problems, and other mandatory processes such as those relating to procurement can be slow, bureaucratic and unnecessarily restrictive. Creating more flexibility in the operating environment for public sector RPOs, particularly on pay, will be necessary to improve their agility, collaborative capability and capacity.

[163] Government Office for Science, Realising our ambition through science: A review of Government Science Capability, 2019, Nov, accessed Oct 28, 2022, https://www.gov.uk/government/publications/government-science-capability-review
[164] Department for Business, Innovation & Skills, Ensuring a successful UK research endeavour, A Review of the UK Research Councils by Paul Nurse,2015, Nov 19, 26-30, accessed Oct 28, 2022, https://www.gov.uk/government/publications/nurse-review-of-research-councils-recommendations

E. Review, reporting and audit

Description and analysis

The Review heard that access to research funding in the UK generally comes with a burden of frequent and repetitive reviews, reporting and audit of research activities. These can be extremely time intensive, placing unnecessary bureaucratic and financial demands on organisations within the RDI organisational landscape, instead of allowing them to focus on carrying out high quality research. They also convey a sense of distrust in RPOs' abilities to conduct RDI. This Review heard that reporting which is focused on the quality and relevance of research being carried out by RPOs is required, which would lead to greater resource being dedicated to RDI. There may be a tendency to favour some reporting measures because they are easy to quantify, even if they may lead to adverse outcomes or to a limited view of the research being carried out. Other measures that are not so easily quantified may be overlooked despite being better for reviewing and reporting. There may also be perverse incentives in place. Those responsible for the reporting and audit may feel they are judged by the speed with which they can respond to a question from Government or Parliament. As a consequence, they request information from RPOs which is often never needed, but is collected 'just in case' and without proper regard for the extra burdens placed on the RPOs. The frequency of reporting should also be proportionate. The issue of repetitive reporting and audits within the RDI landscape has been recognised and commented on in the Independent Review of Research Bureaucracy.[165]

The UK's new independent research body, the Advanced Research and Invention Agency (ARIA), aims to take a flexible and innovative approach to supporting scientific research, one that is bold and tolerant of risk (a much better description, by the way, than the cliché of promoting the pursuit of 'risky research'; there is never a good reason to pursue research simply because it is risky) with the freedom to identify and fund transformational science and technology with speed and minimal bureaucracy. It makes no sense to restrict this approach to just part of the Government funded RDI landscape and the approach should be adopted throughout the UK RDI ecosystem. This would effect wholesale reform of the cumbersome processes for review, reporting and audit currently in place.

[165] Department for Business, Energy and Industrial Strategy, Independent Review of Research Bureaucracy: Final Report, 2022, July, accessed Oct 28, 2022, https://www.gov.uk/government/publications/review-of-research-bureaucracy

Advanced Research & Invention Agency (ARIA)

The US Defence Advanced Research Projects Agency (DARPA) was established in 1958 with the aim of expanding the frontiers of technology and science and is credited with stimulating the creation of breakthrough technologies such as the internet and GPS. The Advanced Research Projects Agency – Energy (ARPA-E; founded in 2009), and the Advanced Research Projects Agency – Health (ARPA-H; founded in 2022) were modelled on DARPA to advance energy technologies and accelerate biomedical and health research, and all three agencies have the agility and flexibility to quickly shift focus to tackle emergent situations. The UK and Germany have recently emulated the DARPA and ARPA models by establishing the Advanced Research and Invention Agency (ARIA) and SPRIN-D respectively, to fund high risk, high potential research and future disruptive technologies.

ARIA has a funding and governance model that is unprecedented in the UK. In 2022, the UK Parliament passed legislation to underpin some of the new organisation's freedoms. The Act includes the provision of a risk tolerance to allow for projects to fail in pursuit of significant gains, as well as an exemption from procurement regulations. It contains measures to prevent ARIA from being closed before 10 years have elapsed, allowing ARIA to enjoy a higher level of certainty than others in the landscape. Two features distinguish ARIA's governance from that of established RPOs. First, ARIA's financial flexibility and operational freedom will permit it to invest effectively in long-term programmes without unnecessary bureaucracy and approvals from central government. Second, strategic, scientific and cultural autonomy allows the agency to make decisions about its areas of research and programme design independent of government direction. These principles should be more widely implemented for Government funded research in the UK.

In addition to supporting standard ARPA-style programmes, ARIA is considering a new model, BUILD, which will support scientist-led nucleation of focused research units or institutes that can serve either as limited-time activities or as trials towards longer-standing public or private institutions. This proposal aligns with the analyses and recommendations made earlier in this Review concerning PSREs, units and institutes.

Conclusions

- Review and reporting processes are too audit regulated and do not put enough emphasis on the quality and effectiveness of research conducted by RPOs. Assurance mechanisms grounded in earned trust rather than detailed repeated audit by the RPOs and their funders, combined with an increased focus on measuring quality will facilitate a higher performing RDI landscape.

F. RDI infrastructures

RDI infrastructures contribute significantly to the strength of the UK RDI landscape.[166] Government has a clear role in their long-term resourcing to maximise their benefits: they can take several years to plan, design, and build, and may then have operational lifespans of decades.[167] RDI infrastructures may be of local, regional, national and international significance, and are often integral to the technical cores of RPOs. This means regional or national RDI systems require sustainable infrastructures and strategic Government policy choices. RDI infrastructures are also important sites for training and collaboration, and staff are often extremely diverse in nationality and discipline, meaning that RDI infrastructures can be excellent sites to foster talent mobility, international collaborations, new research avenues and economic opportunities. For example, engineers working at the JET nuclear fusion reactor at the Culham Centre for Fusion Energy developed capabilities in remote handling robotics using new materials, and were able to use these robotics skills to create start-ups specialised in elderly care and nuclear fission decommissioning. Multinationally supported research infrastructures are covered in Section H: Opportunities and Obstacles for International Collaboration.

Government decisions over policy and financial frameworks influence decisions over new and existing RDI infrastructures, the makeup of which is a deciding factor in the direction and balance of the UK RDI landscape. A long-term plan is needed if RDI infrastructures and the RDI activities they enable are to thrive in the UK, and Government should set direction and understand which RDI infrastructures are aligned with national needs. As a convenor, Government should bring together different bodies in the RDI landscape to develop a common strategy without impinging on organisations' operational independence. As a facilitator, Government should support projects of national significance and facilitate discussions with local authorities. As an investor, Government should be far-sighted and adopt valuation methodologies which appreciate and respect the long-term landscape-wide benefits of RDI infrastructure and take into account rising operational costs.

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[166] "European Research Infrastructures", *The European Commission,* accessed, Oct 12, 2022, https://ec.europa.eu/info/research-and-innovation/strategy/strategy-2020-2024/our-digital-future/european-research-infrastructures_en The Review defines RDI infrastructures as "Facilities, resources and services used by the research and innovation communities to conduct research and foster innovation in their fields. They include: major scientific equipment (or sets of instruments), knowledge-based resources such as collections, archives and scientific data, e-infrastructures, such as data and computing systems and communication networks and any other tools essential for excellence in research and innovation.

[167] UKRI's 2019 survey found that 60% of infrastructures responding had expected operational lifespans of over 25 years. Source: UK Research and Innovation, The UK's research and innovation infrastructure: Landscape Analysis, 2019, accessed Oct 11, 2022, The UK's research and innovation infrastructure: Landscape Analysis.

G. Fostering collaboration and interaction

There is tension in the UK's RDI landscape between collaboration and competition. Many organisations compete for funding, which can drive excellence but can also discourage or inhibit collaboration. The Review has explored the impacts of these tensions, and outlines recommendations that would contribute to the creation of a more enabling environment for collaboration between RPOs.

Encouraging multifaceted collaboration, inclusion and permeability has been a long-standing ambition of successive Governments and the wider RDI community. For UK research to be competitive on the world stage, it is necessary to support varied approaches and productive collaborations and interactions. Commentary submitted to the Review argued for the importance of multidisciplinary approaches to solve problems. For example, the natural sciences are developing new technologies towards goals such as net zero, and these require insights from the social sciences to assess potential economic, psychological and social impacts on society, and from the arts and humanities to ensure wide usage and acceptance. Some examples of such partnerships and collaboration between RPOs throughout the RDI landscape are showcased in the case studies below.

UK Dementia Research Institute (UK DRI)

Launched in 2017, the UK DRI was co-founded as a hub and spoke institute by the MRC, Alzheimer's Society and Alzheimer's Research UK, with the aim of translating basic research into treatments for those with dementia and other neurodegenerative conditions. The UK DRI draws on the expertise of researchers across multiple disciplines and universities to drive interdisciplinary collaborations and acts as a convener to help de-fragment the research landscape. In its first five years, the UK DRI Business and Innovation team established five major industry partnerships, launched a spinout which achieved US$80m of investment, filed 27 patents, and negotiated over 350 industry collaborations, non-disclosure agreements, Memoranda of Understanding (MoUs) and translational projects. These deals were facilitated by a competitive IP structure, which combines all UK DRI Centres under a single contractual framework. However, the DRI has faced difficulties due to funding problems.

Living With Machines

Living With Machines is an interdisciplinary research partnership between the AHRC, the Alan Turing Institute, the British Library and several universities. The project brings together the humanities, AI and data science to study the human impact of the Industrial Revolution. Drawing on the history of society's relationship with machines, the project asks new questions about the ways in which technology has changed human experience. The knowledge and methods produced will not only shed new light on a pivotal period of our past but also on contemporary debates about the social and human consequences of AI and automation. Articles, books, an exhibition, and a programme of press and broadcast pieces will share the new discoveries from this research and the innovative means by which they were reached, with the tools developed becoming open source, furthering future archival research.

Centre for Collective Intelligence Design

The Centre for Collective Intelligence Design, established by Nesta, who describe themselves as the UK's innovation agency for social good, is an approach to RDI which combines people, data and networks with the aid of digital technologies. The Centre's multidisciplinary team brings skills in participatory methods, research, community mobilisation, data science, design and AI to develop bespoke tools and projects that allow communities to respond collectively to challenges that they face.

Innovation Brokerage

A more comprehensive understanding of the digital tools available to signpost and enable collaboration is essential. Nesta analysed around 150 examples of these tools and built a publicly viewable database of them.

Innovate UK has also developed an online innovation hub that businesses can use to search for the wide variety of government support across the innovation landscape.

There are existing positive examples of permeability in the UK's RDI landscape promoting collaborations and interactions. However, input gathered for the Review suggests that more could be done to improve awareness of the wider landscape across interested organisations, including Government, RPOs, and customers of the

RDI landscape such as business, industry, and society more generally. Collaboration and interaction are important drivers of innovation, improving the quality of research by avoiding unnecessary duplication of effort and supporting appropriate competition for funding and researchers. An open and collaborative landscape will better demonstrate the strengths of the UK system to encourage foreign direct investment and trade.

A better understanding within Government of the UK's complex RDI landscape will improve engagement and interactions across the landscape, and support Government planning and decision-making. However, it is critical that such understanding is gathered and disseminated in a form that is actually used. There are currently limited data available for understanding the interactions between RPOs in the UK's RDI landscape, and better knowledge would support the Government in making informed choices about RDI. DSIT, together with UKRI, should ensure this is put in place.

More can be done to improve links between universities and other RPOs in the landscape. Because universities are a dominant feature of the UK landscape and other research institutions operate differently from them, mutual understanding can be limited and interactions between the universities and other RPOs are not always fully explored and can even be antagonistic. These other RPOs include PSREs, publicly funded research institutes and units such as those supported by UKRI, government departments, and industrial research facilities, as well as small to medium-sized business enterprises (SMEs), and research-intensive industries, all of which profit from increased RDI activities. Researchers in these other sectors raised potential difficulties in forming productive relationships with university researchers due to a lack of interoperability, with a low level of mutual institutional understanding and complexities in the funding being major factors. For these reasons, productive interactions between universities, local communities, industries and public services can be difficult to establish. Local business and social interactions may be stronger in the 'civic universities' as a consequence of their origins within strong and mutually supportive civic communities. As argued earlier in the report, more should be done to improve the connections between local industry, public services, and RDI capability.

Attracting private investment into RDI is a focus of the present Government, as set out in part in the Innovation Strategy.[168] Earlier work such as the Dowling Review addressed some of the key challenges preventing collaboration between industry and organisations such as universities.[169] In this Review, stakeholders identified the

[168] Department of Business, Energy and Industrial Strategy, UK Innovation Strategy: leading the future by creating it, 2021, July 22, accessed Oct 11, 2022, https://www.gov.uk/government/publications/uk-innovation-strategy-leading-the-future-by-creating-it

[169] Department for Business, Innovation & Skills, Business-university research collaborations: Dowling review - final report, 2015, July 2, accessed Oct 11, 2022,

value of organisations bridging the gap between the public and private sector to support businesses to perform RDI and encourage collaboration and interaction. This Review heard about international models to incentivise such collaboration to ensure the diffusion of research and innovation into businesses and to raise the RDI intensity of the economy as a whole, alongside further roles in encouraging local growth, facilitating skills sharing and training, explored earlier in the report.

Another factor promoting collaboration with industry is geographical — particularly, the degree of co-location between industry and RPOs. Proximity can help align RDI priorities and coordinate activities that may be necessary when tackling complex cross-cutting problems. Other advantages of co-location may include academics benefitting from corporate experience enabling discovery research to be more readily applied, and the easing of pathways for academic and industry researchers to move between different sectors.

The Review found that many businesses are not aware of opportunities for collaborating with RPOs. There needs to be better signposting of the mechanisms and tools that connect businesses with the RDI landscape, such as co-location opportunities. This would encourage cross-sector working to address complex challenges by drawing on different sectors' capabilities. Konfer, a platform that helps businesses discover collaborative projects, is in place, but the Review heard that it and other presently available tools are not considered particularly effective.

Conclusions

- Mutual understanding between universities and other RPOs across the RDI landscape is sometimes limited, and interactions can be difficult for many reasons. Universities and other RPOs should work together to build more fruitful connections.
- Creation of a shared understanding of the operation of the RDI landscape and its RPOs will identify new opportunities for business RDI investment and activity and encourage better communication and cooperation between all sectors.
- Building on ongoing efforts across the landscape, a greater focus on collaboration and sharing of knowledge and resources between RPOs will improve the spread of benefits of research across the UK and within local communities.

https://www.gov.uk/government/publications/business-university-research-collaborations-dowling-review-final-report

H. Opportunities and obstacles for international collaboration

Description and analysis

Research is an international endeavour, and if the UK is to succeed as a science superpower, it needs to maintain and strengthen relationships with its international partners. International collaboration is important for global challenges, such as pandemics and climate change, which are best tackled by a multinational, coordinated response, as well as for fields requiring a level of technological capacity beyond what is possible for a single country. There are also national benefits to be gained by convening and leading international consortia in areas of particular strength or expertise (such as AI, green technologies and aspects of medical research) which enhance the global influence and reach of UK researchers and RPOs. Research, certainly in the discovery part of the spectrum, is also an important 'soft power' tool for diplomacy and international relations.

International collaboration takes many forms, but the Review particularly notes the important contribution to the global RDI landscape of multinationally supported institutes and international research infrastructures, which provide critical support and technological capability to large communities of scientists across the globe, including in the UK. Historically, these have mostly supported physical scientists with sophisticated technologies, for example CERN (see case study below), but institutes such as EMBL are increasingly important in the life sciences. Multinationally supported institutes are powerful research organisations with strong training missions, promoting long-term international collaborations which also bring benefits to the host country, but their establishment requires a strength of purpose and resolve generally reserved for solving problems of global importance such as climate change. The UK, with its strong scientific tradition and close links with other leading research nations, is in a good position to lead such initiatives.

Unfortunately, there are obstacles in the way of international collaboration. The political decision to leave the European Union has had the unintended consequence that the UK may not be able to access funding from Horizon Europe, the EU's highly regarded principal funding programme for research and innovation, and the involvement of UK-based researchers in European research consortia has already been damaged by this. This is very important, as Europe, largely made up of EU member countries, is one of the three major science communities in the world. The UK was a prominent participant in previous EU programmes, receiving over €7bn, 12.1% of all the funds awarded, from the 'Horizon 2020' programme between 2014 and 2020. It should be noted that a substitutional domestically funded programme,

even with similar levels of funding, will not be able to reproduce the collaborative and reputational benefits of Horizon Europe and associated research and training programmes such as those supported by the European Research Council and Erasmus. Also, alternative international collaborations that include only limited numbers of small and sometimes distant countries will not be attractive. It is the political issue concerning the Northern Ireland Protocol that is preventing association with Horizon Europe. Recent developments indicate that this may well be rapidly resolved, and if that is the case, association should be an immediate priority. If it is not resolved, it is important to ensure that short-term science funding decisions made by the Government do not jeopardise the long-term and more important need to associate with Horizon Europe.

The European Organisation for Nuclear Research (CERN)

CERN is a European research organisation that operates the largest physics laboratory in the world. Supported by 23 member states and ten associate member states, CERN employs nearly 3000 scientific, technical, and administrative staff members, and hosts about 12,000 users from institutions in more than 70 countries. CERN's primary purpose is to provide the breadth of infrastructure needed for high-energy physics research, such as its famous particle accelerators. A hub of worldwide science collaboration, the work carried out within CERN has led to many breakthroughs in physics such as the discovery of the Higgs and W and Z bosons alongside computer science, including the development of the World Wide Web.

Some UK-based researchers with origins in other countries have told the Review that the UK is no longer perceived as a welcoming place to work. There have been problems with immigration bureaucracy and some have left the country for jobs elsewhere. The failure to implement association with Horizon Europe has damaged the UK's standing, and risks increasing the barrier to recruiting international talent. Given the global competition for excellent researchers, the UK must act swiftly to prevent further damage to its reputation as a first-rank research destination.

As discussed in a recent House of Lords Science and Technology Committee Report,[170] the cut in Official Development Assistance (ODA) announced in March 2021 has also affected the UK's ability to properly participate in projects of international importance, particularly for developing nations. Restoring ODA spending to 0.7% of GDP should happen as quickly as possible to avoid further

[170] Science and Technology Committee, "Science and Technology Superpower: More than a slogan?", 2022, Aug 4, accessed Oct 11, 2022, https://publications.parliament.uk/pa/ld5803/ldselect/ldsctech/47/4702.htm

damage to ongoing projects, and the diplomatic advantages associated with those projects.

Conclusions

- The UK should play a leading role as a convener and collaborator in globally important research. Loss of international collaboration will damage the UK RDI landscape, and the benefits of international collaboration for UK RDI cannot be replicated by domestic research programmes.
- Given that the UK is now outside the European Union, one of the world's three major science communities, relationships with European collaborators need to be protected, maintained and expanded, so that the free exchange of researchers, ideas and data established in recent years, which are all vital to UK RDI, is not damaged. This requires association with Horizon Europe, because domestic alternatives will not be able to reproduce its advantages.
- There are research areas of global strategic importance where new multinationally funded institutes or international research infrastructures could be contemplated, an obvious example being an institute of climate change built on the EMBL model. Such institutes are powerful tools for multilateral collaboration, and bring great benefit not only internationally, but for the host nation.

I. Talent

Description and analysis

Attracting the best RDI talent to the UK is another key enabler for the success of the UK's RDI landscape. For UK RDI to reach its full potential there must be a breadth of talent, from early career researchers to the leaders of organisations within the landscape, with a diversity of experience and backgrounds. These themes were developed in the UK Government's 2021 People & Culture Strategy. Throughout this Review's engagement process, we consistently heard from stakeholders a desire to see more support for front-line researchers, technicians, engineers and clinicians. The importance of allowing RDI researchers to focus on their core RDI activities, instead of being distracted by a need to personally perform routine administrative tasks, was highlighted as one particularly important element of that support.

Early career researchers expressed a desire to see alternative approaches explored for their training, and a more inclusive training environment. Short-term contracts and inappropriate pathways for career progression based for example on publications in 'high-impact' journals within some parts of the RDI sector have contributed to the notion that there is a poor career structure in the RDI sector as a whole.[171] Extended research contracts can also increase productivity. These are discussed more fully in the earlier 'Universities' section. The lack of permeability between different RPOs in the landscape results in a loss of talent from the system and slows knowledge and skills diffusion. Improved visibility of the full range of career options available, with more career path diversity would reduce precarity and improve permeability and inclusiveness between RPOs.

In academia, diversity of thought creates new proposals and approaches to research activity, which in turn develop wider skills in the research workforce.[172] Economic growth research shows that increasing the quantity and quality of ideas used by a country is key to long-term growth of GDP per person, and that an important route to increase these ideas is to increase the diversity of the innovation workforce, for example by reducing barriers for women inventors.[173] One example is engineering, which contributes widely to the RDI landscape, from researchers in leading universities, to driving industrial research capability, as well as through

[171] Department for Business, Energy and Industrial Strategy, R&D People & Culture Strategy, 2021, 25, accessed Oct 10, 2022, https://www.gov.uk/government/publications/research-and-development-rd-people-and-culture-strategy
[172] Schneider, J., et al, 2016, "The Difference Makes a Difference: Team diversity and innovative capacity", 2016. Accessed 1 Nov, https://www.oecd.org/sti/015%20-%20SKY_Schneider_Eckl_201607025.pdf
[173] National Bureau of Economic Research, "The Past and Future of Economic Growth: A Semi-Endogenous Perspective", 2021, 2-29, accessed 1 Nov 2022, https://www.nber.org/papers/w29126

entrepreneurs and innovators. Advances in engineering contribute to many of the solutions to global challenges, examples being in cleaner and affordable energy, mitigating and adapting to climate change and making cities more sustainable.[174]

With training in technical skills as a core function for Further Education Colleges, they are well situated to enhance the RDI skills of the workforce, particularly as skills shortages are often reported in technical vocations. Growing the UK RDI sector to a level comparable with that of the most research active and commercially successful nations will require an increase in the RDI workforce at all levels, including technicians and research assistants, who have a crucial role in all areas of the RDI landscape, but are currently in short supply. Further Education Colleges are also often integrated into their local communities, and collaborate with firms in their regions for work placements and training, so can develop a skilled workforce for firms in the local economy, with skills that can help business needs.[175]

Science and Technology Facilities Council (STFC) apprenticeship programme

STFC's apprenticeship programme has been running since 1992, providing a vocational career route into STFC's facilities and national labs. Apprenticeships can be in a range of disciplines, including electrical and mechanical engineering and scientific computing, with the opportunity for apprentices to undertake a higher education qualification and to move into a technician role on completion, with many continuing to develop their careers at STFC.

Long-term educational planning is required to ensure that talent is developed to provide a pipeline of researchers and technicians to fuel the future RDI endeavour of the UK. That education begins in primary schools, and it is important to support early years teachers to find new and exciting ways to spark the interest of young pupils in science and to foster a sense of awe and wonder in the world around them. Schools need to make science fun for 7 to 11 year olds, and to inspire teenagers with stimulating teachers and science textbooks. This is not only necessary to provide a pipeline of researchers and technicians who will eventually specialise in science, but is also needed to help develop a citizenship which is comfortable with science and is willing to engage with and support the RDI endeavour, so science can fulfil its full potential to improve lives and protect the environment. Quality reporting of science in the mass media as catalysed by the Science Media Centre (see the Science Media

[174] Royal Academy of Engineering, "Engineering skills for the future, The 2013 Perkins Review revisited", 2019, accessed 1 Nov 2022, https://raeng.org.uk/publications/reports/engineering-skills-for-the-future

[175] Innovation Caucus, "Rethinking the role of further education colleges in innovation ecosystems,", accessed 1 Nov 2022, https://innovationcaucus.co.uk/2021/10/21/new-report-rethinking-the-role-of-further-education-colleges-in-innovation-ecosystems/

Centre case study in the 'Other components of the RDI landscape' section) is also required for this purpose.[176]

Conclusions

- Ensuring high-quality training, tackling the perceived lack of long-term job prospects, and creating a better understanding of the range of opportunities to move careers between RPOs are important to ensure the sustainability of the RDI landscape.
- The training programmes of early career researchers should be reviewed and improved to reduce pressures, increase productivity, and to keep more exceptional talent in the system. In some disciplines such as laboratory science, this should include extending the three year PhD to four years, and giving minimum three to four year contracts to postdoctoral researchers.
- Better training and career progression must also be in place for technicians and other essential facilities support staff and should be included as part of any long-term sustainable research strategy.

[176] "The Science Media Centre", *The Science Media Centre,* accessed 16 Nov 2022 https://www.sciencemediacentre.org/

J. Growing the landscape: consideration of proposed new RPOs

There is a clear role for Government in establishing guiding principles for the creation of new RPOs, either stand-alone or embedded in another organisation. The Review recommends adoption of the following guidelines:

- **Assessment of scientific or strategic need**: Themes should be identified through mapping and reviewing, taking account of emerging technologies, scientific areas and Government priorities. There must be rigorous assessment of the potential impacts on scientific and scholarly activities, and the applications of the research.
- **Consideration of evolving existing excellence**: Expansion and evolution of pre-existing RPOs should first be considered. This should include the possibility of creating new focused research activities by reconfiguring successful existing RPOs.
- **Proximity to inter-related expertise**: Decisions about the location of a new RPO must take account of the proximity of existing expertise and infrastructures on which the new organisation could draw. ‘Orphan’ RPOs rarely succeed.
- **Institutional model:** Local and international exemplars should be studied to establish the best institutional model, which will depend on the purpose and position in the research spectrum of the RPO. Hub and spoke structures for discovery research RPOs should be viewed with caution.
- **Life cycle planning**: Full consideration must be given to providing sufficient financial support for the whole life cycle of any new organisation. If a new RPO has a time-limited mission, comprehensive agreement on what will happen to staff members, infrastructure and facilities after it has achieved its purpose should be developed.
- **Stable, assured core funding:** Government, or other sponsoring bodies, must commit for the long-term, ideally to un-hypothecated end-to-end funding, which enables strategic planning, high-level technical and administrative support, and the recruitment of the best scientists and support staff.
- **Sponsorship within relevant sponsoring bodies**: The scope and structure of a new organisation’s sponsorship within Government or its founders should be well-defined from the start to enable the new organisation’s senior leadership to access key decision-makers.

- **Excellent leadership**: RPOs require scientifically excellent leadership combined with sensitive and intelligent management. if the RPO's overall administration is the responsibility of another co-located or funding organisation, rigorous contractual arrangements must be in place to ensure independence of operation and quality of service.
- **Light-touch review and reporting processes:** RPOs should have internal processes for stringent scientific review in place, so that external frequent, repetitive, and multi-layered auditing can be replaced by light-touch review.
- **Support for researchers**: Extended contracts to allow the research of early career group leaders, postdoctoral fellows and PhD students to flourish should be put in place. Salaries and stipends should be high enough to attract the best candidates at all levels.

Actions for Government to support a thriving RDI Landscape: recommendations

The Review recommends:

18. Government must work with UKRI and the wider RDI community to consider more stable and properly costed funding structures, aimed at ensuring the quality of the existing landscape and its sustainability.

19. Government must increase its long-term commitment to invest more in RDI. In addition to reviewing incentives in public funding for university research, Government should review the balance of funding across the landscape, and explore how planned increases in RDI public funding can provide more un-hypothecated core funding for RPOs, to allow them to deliver their mission more effectively, to promote collaboration and interaction across RDI sectors, and to empower local RPO leadership and researchers.

20. Government should ensure that international collaboration is protected and encouraged, and should resolve problems damaging the UK RDI landscape's international links. This is particularly relevant to our close scientific collaborators in the EU, and it is essential that the UK associates with Horizon Europe. Government should take action, including consultation with devolved administrations, if its broader policy objectives on areas such as immigration, ODA and education are hindering wider objectives for long-term RDI policy.

21. The UK should consider opportunities to host new intergovernmental multinationally funded institutes, and international research infrastructures.

22. DSIT should define the overall architecture and governance for cross-Government RDI policy, setting out accountabilities from Cabinet and below. This should involve the National Science and Technology Council (NSTC), as well as other key RDI spending departments, UKRI and other funders, to ensure roles are complementary and to improve alignment on policies.

23. From Cabinet level downwards, all interested parties in Government must take responsibility for the high level and effective safeguarding of the future success of the UK RDI landscape. This oversight should include an authoritative working group set up by DSIT, operating across Government, the RPOs and the funding organisations, which will take long-term responsibility for implementation of the recommendations of this Review.

24. Government should establish a research vision and strategy including long-term programmatic, infrastructure and technological initiatives, which is especially relevant at the applied end of the research spectrum. This will give

RPOs, investors and global companies the confidence to invest, operate and interact with the UK RDI landscape.

25. Government needs to develop effective mapping of UK RDI, covering the missions, financial investment in different sectors, research capabilities, and locations of RPOs, and also monitor international RDI activities to identify successful features and models. DSIT, working with UKRI and other interests across Government, could carry out this function. An agreed shared picture of the RDI landscape should be produced, together with a commitment to regularly update it.

26. Government should increase efforts to link the different elements of the UK RDI landscape together with the commercial, industrial and societal components that benefit from research. To spread the benefits of research through communities across the UK, partnerships, collaborations and interactions must be built so that all components are mutually aware, and permeable with respect to ideas, information, technologies and people.

27. Government must replace frequent, repetitive, and multi-layered reporting and audit by Government departments and UKRI with a culture of confidence and earned trust, as also referenced by the Independent Review of Research Bureaucracy. Reporting and reviewing of RPOs should focus on the quality and appropriateness of the research being carried out. The framework by which ARIA will operate should be applied to other components of the RDI landscape.

28. Public sector controls which reduce the agility and performance of RPOs need to be reformed. Salaries must be internationally competitive. Where Government-imposed pay limitations are damaging the mission of an RPO, they must be revised, and the decision-making mechanisms made more flexible.

29. Government should ensure that there is a well-trained RDI workforce available at all levels, and long-term educational planning to ensure a future pipeline of researchers and technicians. Career pathways for those roles that underpin effective research delivery, including technicians and project and programme managers, should be strengthened so the importance of these roles is better recognised. Training and career structures for early career researchers, including PhD students, post-doctoral researchers and starting faculty, need to be reviewed and reformed. Career path diversity and permeability between different RPOs should be encouraged.

Review implementation

This Review's recommendations as a whole form a blueprint that can bring about the changes needed to ensure a revolution in the UK RDI endeavour. A Government response is expected to follow in due course, setting out in more detail how the problems identified will be tackled. The arrangements needed to secure the delivery of longer-term change outlined in this Review should be considered, including an authoritative working group with the power to ensure implementation of the Review's recommendations as soon as possible. The Review covers a wide territory with significant numbers of recommendations, all of which require careful consideration and planning, and work needs to begin immediately to bring about the Government's ambition to be a science superpower.

Some immediate quick wins are possible, with practical short-term measures that can be undertaken even in this current period of financial stress. These measures can be rapidly set up and include small-scale pilot projects to test how to apply the principles of the Review, in preparation for the more extensive long-term changes that are essential to drive UK RDI success. They have the added advantage of bringing immediate significant benefit and profile.

- Five research institutes, the Alan Turing, Rosalind Franklin, Henry Royce and Dementia Research Institutes, and the Tyndall Centre for Climate Change Research, have been set up in recent years. They have reported significant difficulties related to how they were set up and now operate, principally due to poor governance and ineffective funding arrangements (described in the Review, p70). These and other institutes should be "rescued" by giving them longer term end-to-end core funding, investing in infrastructure, and reformulating their governance to give them proper independence and distinct identities. With this re-invigoration, they could then be relaunched and rebranded. These relatively simple measures would make institutes a more identifiable and visible grouping, paving the way for a more ambitious diversification of RDI through units and institutes in the future, in line with the recommendations made in this Review.
- Similar measures to the above could also be applied to a selection of the more successful research-intensive PSREs, to remedy the problems the Review discusses in this sector. The bureaucracy and restrictions which damage their ability to operate also need to be reduced, which should be easy to deliver.
- To begin to address the problems of perverse funding incentives and financial sustainability in the university sector, universities should identify pockets of research excellence for potential entry to a pilot programme offering end-to-

end funding, which will trial the effects of improved administrative, infrastructural and researcher career support on research output and value for money.

- The projected institute for biomedical research in Edinburgh currently under discussion has the potential to be an exemplar of how a large-scale research endeavour could be set up, but may be in danger of becoming a conventional compromise trying to satisfy too many different stakeholders. Working with UKRI and with other funders such as CRUK to assess its suitability, there is an opportunity for Government to establish it as an independently run, focused high quality discovery research institute located on a single site. This discovery institute could be linked through a hub and spoke grouping to enable translation of the Institute's research discoveries in a range of clinical settings in Scotland.
- Recommendation 16 of the Review states that universities and other RPOs should support their local community and economy by enhancing their role as an information nexus, helping local industries link to research capabilities wherever they are in the UK. A number of universities in disadvantaged areas of the UK with existing strong links to the local communities should be funded and assisted to run pilot projects assessing how best to achieve this.
- Associate quickly with Horizon Europe, delivering the long-standing Government policy which, given the improved relations and progress with the Northern Ireland protocol, now looks attainable. Association will prevent the loss of some of the UK's most talented researchers and will help attract the best talent to the UK, as well as reversing the current disruption of all the collaborations set up over many years with one of the largest and most powerful research communities in the world. Domestic alternatives to Horizon Europe, including those involving limited numbers of sometimes small and distant countries, are not attractive to any of the best international and domestic researchers, which is why association is so important for the future of the UK RDI endeavour.

Concluding remarks

Research in the UK is one of the jewels in our crown. The UK has a great reputation in science, and research in science and other disciplines is central for our future success. But it is under threat. Funding, particularly that provided by Government, is limited and is below other competitive nations, and the way the UK delivers and supports research is not optimal. This can be corrected. This Review provides a guide to the reforms that are needed, which if properly and comprehensively implemented will provide an RDI landscape and research endeavour that drives the future success of our country. It is all deliverable, but requires political leadership, researcher engagement, and support across all disciplines from the sciences to the arts and humanities, and critically, adequate funding similar to competitive research-intensive nations throughout the world. Together, these will deliver an effective RDI landscape that in turn will help ensure a successful future for the UK. But this is only possible if political leadership is prepared and able to deliver this outcome.

Full list of recommendations

1. Government should take account of the true cost of ‘end-to-end’ research activity to generate a sustainable RDI endeavour. Government, working with UKRI and the UK higher education funding bodies, should review and when necessary reform competitive and response-mode grant funding, QR (and Devolved Administration equivalents), and fEC, and replace them with improved mechanisms. Overall objectives should be to optimise research delivery, remove perverse incentives and outcomes, and ensure the longer-term sustainability of the research system.

2. Universities should develop plans to optimise their operations in support of research, to empower researchers and reduce their administrative loads, and to improve the quality of support services, core technical facilities, and well-found laboratory buildings and infrastructures. Government, working with UKRI, the UK higher education funding bodies and the wider sector, should consider more transparent mechanisms to provide assurance and accountability on QR funding.

3. Government departments should clarify the missions of their individual PSREs, allow them greater freedom of action, and ensure their effectiveness. Departments should improve internal awareness of PSREs' capabilities, and use PSREs to inform RDI strategy and policy making, working within and across departments. Permeability and agility would be further improved by increasing the visibility, interactions and partnerships between PSREs, and between PSREs and the rest of the RDI landscape, including commercial organisations.

4. Funding streams for PSREs need to be protected and reformed to ensure long-term sustainability. Constraints, which appear to have their origins in the Treasury, over funding, pay and other conditions of working should be reduced. The reforms of funding proposed for the universities should also be applied to PSREs.

5. PSREs should be stringently reviewed, and those that have outlived their purpose or are not working effectively should be reformed, reduced or closed, and any savings generated recycled into Government R&D budgets.

6. Institutes and units need sustained financial support, including un-hypothecated funding, to ensure ‘end-to-end’ research support. The funding arrangements of recently established institutes and units, particularly the ‘hub and spoke’ models, must be reviewed to make sure that they are fit for purpose. The reforms of funding proposed for the universities should also take account of the needs of institutes and units.

7. Institutes and units need a well-defined mission and purpose, and should be given the autonomy and funding necessary to achieve their objectives, which may be time limited. There need to be clear and agreed mechanisms by which institutes and units can be adapted, reduced or closed when necessary.

8. Institutes and units must have high quality administrative as well as scientific leadership. They generally benefit from being co-located with other RPOs, but if their overall administration is the responsibility of another co-located or funding organisation, rigorous contractual arrangements must be in place to ensure independence of operation and quality of service.

9. New research institutes and units should be considered when strategic RDI priorities best supported by focused research missions are identified by Government, UKRI and other funders. Possible examples include enhanced activities in climate change and its mitigation, antimicrobial resistance, synthetic biology, and artificial intelligence. Themes should be identified through mapping and reviewing, taking account of emerging technologies, scientific areas, and Government priorities. Pre-existing institutes and units could be merged and expanded to create new institutes, and consideration should be given to co-location and co-funding with other RPOs. Establishment of new institutes and units should follow the principles outlined in the Review.

10. Government and the charitable sector should work together to ensure that ‘end-to-end’ funding is provided for research supported by philanthropy.

11. Support for research undertaken by galleries, libraries, archives, museums, and the heritage and cultural sectors should be increased, and support for long-neglected collections-based research put in place.

12. Coherence between translational research organisations, including those embedded within other RPOs, and the rest of the landscape should be increased. Government is advised to optimise translational research organisations by increasing their number, widening access and promoting the benefits of translational research capability, including regionally. Government should explore routes by which RPOs across the RDI landscape, including PSREs, can contribute to translational activities.

13. Government should use its convening power to create a favourable environment for business to invest in RDI, tackling causes identified by this Review as holding back further business investment, and where expedient, providing financial support. Examples of such support are funding which leverages private investment or promotes collaboration between industry and the rest of the RDI landscape.

14. To understand the benefits of RDI for commercial activities and the economy, a culture change promoting openness, mutual respect, closer interaction, collaboration, and permeability of ideas, technologies and people has to occur in both business and academia. Government has a role in conveying the benefits of RDI investment to businesses, shareholders and academia, embracing practices from countries with high business RDI investment rates. Mechanisms to deliver this should be explored and implemented.

15. Government should take particular responsibility for driving RDI that provides societal benefit as well as economic growth. Examples are health care delivery, equitable

regional economic growth throughout the UK, and the delivery of net zero. Where appropriate, public-private partnerships should be encouraged.

16. Government and RPOs should partner with local communities to support RDI relevant to their needs, to bring about more equitable regional economic growth based on local expertise and demands and driven by community benefit as well as academic criteria. Universities and other RPOs should support their local community and economy by enhancing their role as an information nexus and by helping local industries link to research capabilities wherever they are in the UK.

17. There is an urgent problem with the current mechanisms for clinician scientists to effectively develop and undertake their research careers. The Government, taking into account devolved competencies, must rectify this to both improve the ability of the NHS to deliver more effective health care and to help the UK economy.

18. Government must work with UKRI and the wider RDI community to consider more stable and properly costed funding structures, aimed at ensuring the quality of the existing landscape and its sustainability.

19. Government must increase its long-term commitment to invest more in RDI. In addition to reviewing incentives in public funding for university research, Government should review the balance of funding across the landscape, and explore how planned increases in RDI public funding can provide more un-hypothecated core funding for RPOs to allow them to deliver their mission more effectively, to promote collaboration and interaction across RDI sectors, and to empower local RPO leadership and researchers.

20. Government should ensure that international collaboration is protected and encouraged, and should resolve problems damaging the UK RDI landscape's international links. This is particularly relevant to our close scientific collaborators in the EU, and it is essential that the UK associates with Horizon Europe. Government should take action, including consultation with devolved administrations, if its broader policy objectives on areas such as immigration, ODA and education are hindering wider objectives for long-term RDI policy.

21. The UK should consider opportunities to host new intergovernmental multinationally funded institutes and international research infrastructures.

22. DSIT should define the overall architecture and governance for cross-Government RDI policy, setting out accountabilities from Cabinet and below. This should include the National Science and Technology Council (NSTC), as well as other key RDI spending departments, UKRI and other funders, to ensure roles are complementary, and to improve alignment on policies.

23. From Cabinet level downwards, all interested parties in Government must take responsibility for the high level and effective safeguarding of the future success of the UK RDI landscape. This oversight should include an authoritative working group set up by DSIT, operating across Government, the RPOs and the funding organisations, which

will take long-term responsibility for implementation of the recommendations of this Review.

24. Government should establish a research vision and strategy including long-term programmatic, infrastructure and technological initiatives, which is especially relevant at the applied end of the research spectrum. This will give RPOs, investors and global companies the confidence to invest, operate and interact with the UK RDI landscape.

25. Government needs to develop effective mapping of UK RDI, covering the missions, financial investment in different sectors, research capabilities, and locations of RPOs, and also monitor international RDI activities to identify successful features and models. DSIT, working with UKRI and other interests across Government, could carry out this function. An agreed shared picture of the RDI landscape should be produced, together with a commitment to regularly update it.

26. Government should increase efforts to link the different elements of the UK RDI landscape together with the commercial, industrial and societal components that benefit from research. To spread the benefits of research through communities across the UK, partnerships, collaborations and interactions must be built so that all components are mutually aware, and permeable with respect to ideas, information, technologies and people.

27. Government must replace frequent, repetitive, and multi-layered reporting and audit by Government departments and UKRI with a culture of confidence and earned trust, as also referenced by the Independent Review of Research Bureaucracy. Reporting and reviewing of RPOs should focus on the quality and appropriateness of the research being carried out. The framework by which ARIA will operate should be applied to other components of the RDI landscape.

28. Public sector controls which reduce the agility and performance of RPOs need to be reformed. Salaries must be internationally competitive. Where Government-imposed pay limitations are damaging the mission of an RPO, they must be revised, and the decision-making mechanisms made more flexible.

29. Government should ensure that there is a well-trained RDI workforce available at all levels, and long-term educational planning to ensure a future pipeline of researchers and technicians. Career pathways for those roles that underpin effective research delivery, including technicians and project and programme managers, should be strengthened so the importance of these roles is better recognised. Training and career structures for early career researchers, including PhD students, post-doctoral researchers and starting faculty, need to be reviewed and reformed. Career path diversity and permeability between different RPOs should be encouraged.

Glossary

List of acronyms

Acronym	Definition
AHRC	Arts and Humanities Research Council
ARIA	The Advanced Research & Invention Agency
BEIS	Business, Energy and Industrial Strategy (Dept of)
CERN	The European Organization for Nuclear Research
CZI	Chan Zuckerberg Initiative
DSIT	Department for Science, Innovation and Technology
fEC	Full economic costings
GERD	Gross domestic expenditure on R&D
HEI	Higher Education Institution
KEF	Knowledge Exchange Framework
MRC	Medical Research Council
NIH	National Institutes of Health
NIHR	National Institute of Health and Care Research
NSTC	National Science and Technology Council
ODA	Overseas Development Assistance
OECD	Organisation for Economic Co-operation and Development

Acronym	Definition
ONS	Office for National Statistics
PSREs	Public Sector Research Establishments
RDI	Research and Development and Innovation
REF	Research Excellence Framework
RPOs	Research Performing Organisations
SMEs	Small to Medium Sized Enterprises
STEM	Science, Technology, Engineering and Mathematics
STFC	Science and Technology Facilities Council
UKRI	UK Research and Innovation

Definition of terms used for the purposes of this Review

Term	Description
Agility	The ability of an organisation to respond to new emerging priorities, challenges and opportunities.
Applied research	Original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective.[177]
Catapult	An organisation that seeks to accelerate the application of research. There are currently 9 Catapults in the UK.

[177] "Frascati Manual 2015", OECD, accessed 11th November 2022, https://www.oecd.org/innovation/frascati-manual-2015-9789264239012-en.htm

Term	Description
Competitive grant funding	Grants for specific research programmes (including 'response-mode' funding), people and infrastructure, mostly awarded in the UK by UKRI and its Research Councils, but also by other funders.
Diffusion	The spread and usage of new technologies and science.
Discovery research	Experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. Also termed basic research by the Frascati manual (2015).[178]
Dual support system	The two strands of Government funding for university research, comprised of competitive grant funding for projects and programmes, infrastructure and people, and un-hypothecated Quality Research (QR) Funding.
End-to-end research support	The funding required to fully support research activity, encompassing support for individual researchers and staff, training and career development, the provision of administrative services, technical facilities, laboratory facilities, and other indirect costs.
Horizon Europe	The European Union's research and innovation funding programme spanning 2021-2027.[179]
Hub and spoke institutes	An operational model which has a central hub institute alongside a set of dispersed units termed spokes.
Industry	Private sector organisations, with particular reference to those that undertake or could benefit from undertaking Research, Development and Innovation.
Information nexus	A hub for information regarding RDI organisations and infrastructure, acting as a means to better join up industry and the research capabilities of the UK.

[178] "Frascati Manual 2015", OECD, accessed 11th November 2022, https://www.oecd.org/innovation/frascati-manual-2015-9789264239012-en.htm
[179] https://research-and-innovation.ec.europa.eu/funding/funding-opportunities/funding-programmes-and-open-calls/horizon-europe_en

Term	Description
Innovation	An innovation is a new or improved product or process (or combination thereof) that differs significantly from the previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process).[180]
International research infrastructures	As described in the definition of 'research infrastructure', but where multiple countries share the cost, where geographical requirements require multiple sites (such as oceanography or climate sensor systems), or where there is significant federation of access to data, archives, or resources.
Knowledge Exchange	The transfer of new and useful knowledge generated through research across the RDI landscape for the benefit of the economy and society.
Permeability	The scope for ideas, talent and technologies to move freely across organisations in the RDI landscape.
Public Sector Research Establishments (PSREs)	A diverse collection of public bodies carrying out research which support a wide range of government objectives, including informing policy making, statutory and regulatory functions and providing a national strategic resource in key areas of scientific research.
Quality Related (QR) Research Funding	Research funding based on a formula, calculated and distributed based mainly on a university's quality of research and number of full-time equivalent research active staff.
Research and Development (R&D)	Creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge.[181]

[180] "Frascati Manual 2015", OECD, accessed 11th November 2022, https://www.oecd.org/innovation/frascati-manual-2015-9789264239012-en.htm
[181] "Frascati Manual 2015", OECD, accessed 11th November 2022, https://www.oecd.org/innovation/frascati-manual-2015-9789264239012-en.htm

Term	Description
Research clusters	A research cluster refers to multiple RDI organisations operating in the same or similar field and located in a small geographical area.
Research Development and Innovation	A broader term than R&D which also encompasses the term innovation.
Research infrastructure	Facilities, resources and services that are used by the research and innovation communities to conduct research and foster innovation in their fields. They include: major scientific equipment (or sets of instruments), knowledge-based resources such as collections, archives and scientific data, e-infrastructures, such as data and computing systems and communication networks, and any other tools that are essential to achieve excellence in research and innovation.[182]
Research Institutes and units	The distinction between the terms 'institute' and 'unit' is somewhat arbitrary in this report and is based on the total number of researchers working within them. The shift from unit to institute is roughly at a size of around 100-200 researchers. Institutes and units occupy a position in the research landscape that is distinct from the universities because their activities are focused solely on research.
Researchers	Refers to those working in all disciplines who produce reliable knowledge and insights about the natural world, ourselves, and our societies.
Research Performing Organisation	Any organisation which performs research, development or innovation. These include but are not limited to the organisations commented on in this review, such as universities, Public Sector Research Establishments, and institutes and units.

[182] "The UK's research and innovation infrastructure: opportunities to grow our capability", UKRI, 2020 https://www.ukri.org/wp-content/uploads/2020/10/UKRI-201020-UKinfrastructure-opportunities-to-grow-our-capacity-FINAL.pdf

Term	Description
Response-mode funding	Also, “responsive mode” funding. Programme or project grants awarded in response to research proposals from investigators or consortia.
Spillover effects	The indirect benefits from the use and development of products and services by RDI performing organisations to other organisations.
Sustainability	The ability of an RPO to maintain its RDI capability (in terms of research outputs, skills, infrastructure and funding) in the longer term.
Systems mapping	A proposed analysis of the UK RDI landscape as it currently exists, encompassing organisational types and the RDI performing organisations themselves, investment and geography.
Technical Cores	Specialised laboratories with unique (usually expensive) instruments and services, managed by scientists with the technical expertise and experience to help others who need these capabilities.[183]
Translational research	Systematic work, drawing on knowledge gained from research and practical experience and producing additional knowledge, which is directed to producing new products or processes or to improving existing products or processes. Also termed experimental development by the Frascati manual (2015).[184]
Translational research organisations	A heterogeneous group of organisations which promote and/or implement innovation and may provide RDI services to businesses. Catapults are one example, but RPOs within the landscape may also have some capability translating research.
Un-hypothecated research funding	Funding for research with no explicit direction for how it must be spent.

[183] Philip Hockberger, Jeffrey Weiss, Aaron Rosen and Andrew Ott, “Building a Sustainable Portfolio of Core Facilities: a Case Study”, J Biomol Tech. 2018 Sep; 29(3): 79–92, accessed 15 November, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6078059/

[184] “Frascati Manual 2015“, OECD, accessed 11th November 2022, https://www.oecd.org/innovation/frascati-manual-2015-9789264239012-en.htm

Term	Description
Well-found laboratory	The provision of equipment, facilities and staff required to adequately support research activities.

Appendix 1: Terms of Reference

Context

The UK is home to many world-class research, development and innovation (RDI) organisations and has a strong reputation for the quality of its research. The QS World University Rankings shows that UK universities are globally recognised, with four providers in the top 10 and 18 providers in the top 1002, and the UK also has internationally renowned research institutes. This research translates into practical outcomes such as the Covid-19 vaccine, partly developed as a result of the UK's strength in scientific and medical research. We need to build on and retain these strengths.

However, the world is changing fast with competitive advantage in RDI increasingly contested. The UK Government is committed to securing and advancing the UK's status as a global science superpower and leader in new fields of research and cutting-edge technologies. The UK Government wants to build on the manifest strengths of the RDI system across the UK and nurture its diversity, ranging from the pipeline of pioneering, visionary blue-skies research through to practical support for innovators to commercialise their ideas.

This will generate a RDI system that drives UK Government initiatives to improve the nation's health and quality of people's lives, protect the environment and the natural world, and promote industries that attract substantial amounts of investment, underpinned by highly innovative discovery research and UK leadership in international research collaborations.

Goals

The goals of the Review are to:

- explore the features and characteristics in the existing ecosystem of RDI-performing organisations across the UK, learning from the best in the world and drawing on transformative examples;
- identify whether improvements to the organisational research landscape are required to deliver the Government's objective for the UK to be a science superpower at the forefront of critical and emerging fields of science and technology, and drive economic growth and societal benefit;
- futureproof the UK landscape of organisations undertaking all forms of RDI, from pioneering, visionary blue-skies research to practical support for innovators to commercialise or implement their ideas, and ensure an agile and sustainable system that can respond to future priorities and developments.

Independent Review of the Research, Development, and Innovation Organisational Landscape

Purpose & Scope

The Review will consider the full and varied policy and funding context within which RDI-performing organisations are set up and operate. The Review is focused on the landscape of organisations that deliver research rather than on mechanisms for funding research and will:

- analyse how the various organisations that contribute to the ecosystem of RDI-performing organisations across different parts of the UK – including universities, institutes and laboratories, across UK Government and the Devolved Administrations, public, private and non-profit sectors – compare to each other and that of other countries with strengths in RDI.
- learning from international examples, consider the role that different mixes of organisations can play in delivering economic and societal impact from RDI, and the mechanisms and business models that will best enable the UK to capitalise on emerging and new fields of science and invention.
- consider how best to secure an organisational landscape now and in the future that delivers high-quality RDI outputs, and which is sustainable and cost-effective.
- consider options to support the UK's strengths and what targeted interventions in the public sector might enhance the quality and diverse mix of RDI-performing organisations through our policy framework and the policies of the Devolved Administrations.

Timing

The Review will publish a final report in Spring 2022.

Governance

- The Review will report to the UK Government's Secretary of State for Business, Energy and Industrial Strategy.
- The Review will be supported by a Secretariat within BEIS, a wider advisory group, with diverse representation from key experts, and stakeholders in the research system and industry, across the UK and internationally.
- The Review will work closely with the Welsh Government, the Scottish Government and the Northern Ireland Executive to ensure a comprehensive understanding of the landscape of organisations for which those governments are responsible, respecting the devolved nature of areas of responsibility within this landscape. Lead reviewer Sir Paul Nurse will consult with Ministers from the Devolved Administrations during the review and the team will meet with officials and Chief Scientific Advisers from the Scottish Government, Welsh Government and Northern Ireland Executive.
- The UK Government will work closely with the Scottish Government, Welsh Government and Northern Ireland Executive to agree a response to the Review, with each Devolved Administration setting out their response to the areas on which they lead.

- In conducting investigations and making recommendations, the Review will take account of the requirements of the Public Sector Equality Duty.

Appendix 2: Acknowledgements

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- Dr Demis Hassibis
- Sir Anton Muscatelli
- Dr Grazia Vittadini
- The Rt Hon Lord David Willetts

Sounding and Challenge Group

- Professor Fabiola Gianotti
- Professor Peter Gruss
- Dr Paul Howarth
- Professor Adrian Johnston
- Ayantika Mitra
- Professor James Naismith
- Professor Erin O'Shea
- Sir Menelas Pangalos
- Dr Hayaatun Sillem
- Professor Hywel Thomas
- Professor Andrew Thompson
- Dr Anna Valero
- Professor Harold Varmus

Organisations directly engaged during the Review process

- Abertay University
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- Academy of Medical Sciences
- Airbus Group
- AIRTO

- Alan Turing Institute
- Arts and Humanities Research Council
- Association of Medical Research Charities
- Association of Independent Music
- Astrazeneca
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- Bangor University
- BEIS Chief Scientific Adviser
- BEIS Science Expert Group
- Belfast City Council
- Belfast Harbour
- BRE Group
- Bristol Robotics Lab
- British Film Institute
- Business Durham
- Cambridge University
- Campaign for Science and Engineering
- Cancer Research UK
- Cancer Research UK Manchester Institute
- Cardiff Capital Region City Deal
- Cardiff Metropolitan University
- Catalyst
- Catapult Network
- Centre for Technology, Innovation and Economic Research
- Cell and Gene Therapy Catapult
- City Belfast
- Civic Universities Network
- Compound Semiconductor Catapult
- Confederation of British Industry
- Connected Places Catapult
- Coventry & Warwickshire Local Enterprise Partnership
- Creative UK

- Department for Environment, Food and Rural Affairs
- Department for Health and Social Care
- Department for International Trade
- Digital Catapult
- Energy Systems Catapult
- Entrepreneur First
- Federation of Small Businesses Cymru
- FinTech Scotland
- Fraunhofer UK
- Funders of UK Research & Innovation
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- Glasgow Innovation Districts
- Glasgow School of Art
- GO Science
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- Government Chief Scientific Advisers Network
- Henry Royce Institute
- Heriot-Watt University
- High Value Manufacturing Catapult
- Higher Education Funding Council for Wales
- Home Office
- House of Commons Science & Technology Committee
- Huawei
- Imperial College London
- Industrial Biotechnology Innovation Centre
- Industry Wales
- INEOS
- Innovate UK
- Institute for Fiscal Studies
- Institute of Physics
- Intellectual Property Office (IPO)
- Interface

- Invest Northern Ireland
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- Makers Alliance
- Massachusetts Institute of Technology
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- Medical Research Council
- Medicines Discovery Catapult
- Merian Ventures
- Ministry of Defence
- Moredun Research Institute
- MRC Laboratory of Molecular Biology (LMB)
- National Institute of Agricultural Botany (NIAB)
- National Oceanography Centre (NOC)
- National Physical Laboratory (NPL)
- National Quantum Computer Advisory Committee
- National Space Academy
- National Trust
- Natural Environment Research Council
- Natural History Museum
- Natural Resources Wales
- Nesta
- Net Zero Technology Centre
- No. 10
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- Northern Ireland Executive
- NSF International
- Offshore Renewable Energy Catapult

- Oxford Robotics Institute
- Queens University Belfast
- Robert Gordon University
- Rosalind Franklin Institute
- Royal Academy of Engineering
- Royal Botanical Gardens, Kew
- Royal Conservatoire of Scotland
- Royal Society
- Royal Society of Chemistry
- Royal Society of Edinburgh
- Russell Group
- Satellite Applications Catapult
- Science and Technology Facilities Council
- STFC UK Astronomy and Technology Centre (UKATC)
- Scotland's Rural College
- Scottish Enterprise
- Scottish Funding Council
- Scottish Government
- Scottish Research Partnership in Engineering
- Scottish Universities Life Science Alliance
- SRUC
- Singapore National Research Foundation
- Swansea University
- Swiss National Science Foundation
- Taylor and Francis
- The British Academy
- The Faraday Institution
- The Health Innovation Research Alliance Northern Ireland
- The Young Foundation
- Tokamak Energy
- Tyndall Centre
- UK Atomic Energy Authority (UKAEA)

- UK Business Angels Association
- UK Collaboratorium for Research on Infrastructure and Cities
- UK Dementia Research Institute Cardiff
- UK Research Partners and Investers Fund
- UK Space Agency
- UKRI
- Ulster University
- Universities Scotland
- Universities UK
- Universities Wales
- University College London
- University of Aberdeen
- University of Birmingham
- University of Dundee
- University of Edinburgh
- University of Exeter
- University of Glasgow
- University of Lancaster
- University of Leeds
- University of Manchester
- University of Nottingham
- University of Salford
- University of Sheffield
- University of Southampton
- University of St Andrews
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Individuals directly engaged during the Review process

- Dr William Boone Bonvillian
- Eliza Easton
- Professor Kieron Flanagan
- Dr Tom Forth
- Alex Glennie
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- Juan Mateos-Garcia
- Dr Ilan Gur
- Dr Janet Metcalfe
- Professor Rob Miller
- Sir Geoff Mulgan
- Janak Nabar
- Dr Diarmuid O’Brien
- Dr Ellen Ochoa
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Responders to the Public Invitation for Views

- ABPI
- Academy of Medical Sciences
- ADS Group
- AIRTO
- Alan Turing Institute
- Arts and Humanities Research Council (AHRC)
- Association of Medical Research Charities (AMRC)
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- National Measurement Laboratory
- National Nuclear Laboratory
- National Oceanography Centre
- National Physical Laboratory
- Nesta
- Northumbria University
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- Scotland's Rural College
- Scottish Enterprise
- SETsquared Partnership
- Taylor & Francis
- The British Library
- The Institute of Cancer Research
- The Northern Health Science Alliance
- The Psychological Society
- The Roslin Institute
- The Royal Society
- The Royal Society of Edinburgh
- UK Dementia Research Institute
- Unilever
- Universities UK
- University Alliance
- University College London
- University of Birmingham
- University of East Anglia
- University of Edinburgh
- University of Glasgow
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