MAXIMISING THE POSITIVE IMPACT OF INTERNATIONAL RESEARCH COLLABORATION

FINAL

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APPENDICES

List of Definitions

Abbreviation	Definition
AD	Anaerobic Digestion
aHSS	arts, Humanities and Social Sciences
AMR	Anti-Microbial Resistance
BEIS	Department for Business, Energy & Industrial Strategy
BERD	Business Enterprise Research and Development
BIS	Business Innovation and Skills
BME	Black and Minority Ethnic
BRD	Bovine Respiratory Disease
CHE	Council for Higher Education
CPD	Continued Profession Development
CRUK	Cancer Research UK
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CWTS	Centre for Science and Technology Studies
DAERA	Department of Agriculture, Environment and Rural Affairs
DAFM	Department of Agriculture, Food and the Marine
DfE	Department for the Economy
DORA	Declaration on Research Assessment
DSC	Differential Scanning Calorimetry
EIS	European Innovation Scoreboard
EPSRC	Engineering and Physically Sciences Research Council
ERC	European Research Council
ERDF	European Regional development Fund
EU	European Union
FDI	Foreign Direct Investment
FEC	Full Economic Cost
FIC	The Fund for International Collaboration
FWCI	Field-Weighted Citation impact
GCRF	Global Challenge Research Fund
GDP	Gross Domestic Product
GFA	Good Friday Agreement
HEFCW	Higher Education Funding Council for Wales
HEI	Higher Education Institutes
HESA	Higher education statistical Agency
HRB	Health Research Board
HSC	Health and Social Care
IP	Intellectual Property
ISCF	Industrial Strategy Challenge Fund
ISHMII	International Society for Structural Health Monitoring of Intelligent Infrastructure
KE	Knowledge Exchange
MOS	Metal-Oxide-Semiconductor
MRC	Medical Research Council
NCUB	National Centre for Universities and Business
NGO	Non-Governmental Organisation
NI	Northern Ireland
NIFA	National Institute of Food and Agriculture
NIGEAE	Northern Ireland Guide to Expenditure Appraisal and Evaluation
NIH	National Institutes of Health
NIHEF	NI Higher Education Innovation Fund
NSF	National Science Foundation
ODA	Official Development Assistance
OECD	Organisation for Economic Co-operation and Development
OFS	Office for Students
OSTP	Office of Science and Technology Policy
PCT	Patent Cooperation Treaty
PfG	Programme for Government
PI	Principal Investigator
QR	Quality Related
QUB	Queen's University Belfast

Abbreviation	Definition
R&D	Research and Development
RD&I	Research Development and Innovation
RDEC	Research and Development Expenditure Fund
REF	Research Excellence Framework
SEIPD	Science, Evidence and Innovation Policy Division
SFC	Scottish Funding Council
SFI	Science Foundation Ireland
SHM	Structural Health Monitoring
SIN	Science and Innovation Network
SME	Small-Medium sized Enterprise
TGA	Thermogravimetric Analysis
TRL	Technology Readiness Level
TTO	Technology Transfer Office
UBC	University Business Collaboration
UKRI	UK International Research and Innovation Strategy
UOAs	Units of Assessment
VfM	Value for Money
WARP	Windows Advanced Rasterization Platform

List of Definitions

Item	Definition
Field-Weighted Citation Impact (FWCI)	Field-weighted citation impact is a measure of how much impact a set of publications have had. It compares the actual number of citations received by publications with the expected number of citations for a similar document. Expected citations are the average number of citations a publication published in the same year, discipline, and of the same document type (book, article, review, conference paper) receives. Where a publication is classified in two or more subjects, its actual citations are evenly split between the subjects and respectively compared to the expected number of citations for each subject. A harmonic mean is then used to calculate the FWCI. FWCI, therefore, accounts for differences in citation accrual over time (older publications have more time to be cited than recent publications), as well as differences in citation rates across disciplines and types of document. A value of 1.0 represents the world average. The overall FWCI for a set of publications is the average of each specific publication's FWCI within the set
H-C	Highly-cited
Highly-cited articles	Highly-cited publications in this release are classed as those in the top-cited 1% of all publications across the world. Data has been field-weighted to account for differences in citation accrual over time (older publications have more time to be cited than recent publications), as well as differences in citation rates across disciplines and types of document.
Highly-cited articles as a share of domestic publications (%)	(No. of highly-cited publications for entity x / Total publications for entity x) *100
International Collaboration (%)	This is the proportion of entity x's publications that were the result of international collaboration. i.e. (Entity x international publications/Entity x total publications) *100
International publication	An international publication is a publication that was co-authored by at least two researchers affiliated with institutions in different countries.
Pubs	Publications
Share of the world's most highly-cited publications (%)	(No. of highly-cited publications for entity x / Total world highly-cited publications) *100
Share of total world publications (%)	(Total publications for entity x / Total world publications) *100
Total international publications	This is the total number of international publications produced by entity x
Total publications	This is the total number of publications produced by entity x

EXECUTIVE SUMMARY

Introduction

The Department for the Economy ('DfE' or 'the Department') has commissioned Cogent Management Consulting LLP ('Cogent' or 'the Research Team') to research 'Maximising the Positive Impact of DfE Policy, Programmes and Funding in support of International Research Collaboration'.

The Department wishes to ensure that it is making the best possible use of the resources it allocates to promoting international collaboration and that it is pitching the quantum of funding at an appropriate level. To this end, the research has the following aim:

To provide evidence-based advice to the Department on the policy, programmes, and funding to promote international research collaboration likely to maximise the return on its investment of resources.

In the context of this research assignment, DfE advised that maximising the return on the Department's investment of resources should not necessarily be interpreted as meaning a financial return on the investment, or indeed a measurable economic return.

The Importance of International Research Collaboration

Investment in science and technology and the role that international research collaboration can play in strengthening activity are recognised by governments across the World, but also more specifically within the UK and Northern Ireland.

International collaboration is integral to creating world-class research with impact - international collaboration is increasingly synonymous with excellent research. Research shows that international research collaboration is vital for individual institutions that aim to produce outstanding research and that the increase in such collaboration has been very rapid. In this narrower paradigm, envisaged effects include:

- Contribution to building institutional capacity in research organisations;
- Contribution to the quality of science (through cross-fertilisation, competition, combining complementary knowledge, access to world-class researchers, facilities and groups);
- International collaboration increases citation performance because combined talents produce more innovative and useful outcomes. Encouraging the global reach of NI's universities is, therefore, a source of strength that increases the quality and efficiency of the research base;
- Solving specific scientific problems that need input from various international teams;
- Increase of the scope of research (combining complementary knowledge, pooling funding and human resources, sharing risks, increasing computational power);
- Better access to scarce human resources for research;
- Increase of (international) productivity and visibility of research;
- Faculty access to specialised research facilities that are not available at the home institution or country.

Working internationally enables individual academics to increase their impact and nations to pool talent and resources to address global challenges that no country can tackle alone.

International research collaboration is therefore not an optional activity; it is essential and particularly so for smaller countries, such as NI. Over half of the scientific papers produced in the UK have international co-authors. It is likely, therefore, that if NI's research output is to have a considerable impact, international partners will be essential. The USA and the Republic of Ireland, as well as the UK's three other jurisdictions, have considerable international research standing, and as such, each offers considerable opportunity to form impactful partnerships with NI's universities and research organisations.

Indeed, the UK has recently developed a bespoke strategy that sets out how the UK will develop its international research and innovation partnerships to help achieve the targets in the Industrial Strategy. Alongside this strategy, the Government commissioned Professor Sir Adrian Smith to provide independent advice on the design of potential future UK funding schemes for international innovation and curiosity-driven blue-skies research, in the context of the UK's future ambitions for international collaboration on research and innovation. In the context of a complex and changing research landscape, the Research Team considers that there would be merit in the development of an NI International Research Strategy that would focus on defining the pathways by which the NI research base engages on an international level, ensuring that the NI research base is maximising the opportunities that are being created at the UK-level for international collaborative research (such as the Fund for International Collaboration (FIC) and the work of the Science and Innovation Network) and within that maximising the opportunities afforded by the programmes supported by DfE to leverage further research funding into NI and to maximise the potential for impact.

Programmes Focused on Promoting International Research Collaboration

Northern Ireland's Department for the Economy (DfE) is responsible for policy and funding related to all three of our universities' strategic missions, namely teaching/learning, research, and knowledge exchange. As part of this remit, the Department manages the NI element of two programmes focused on promoting international research collaboration (outside of promoting EU Framework / Horizon Programme collaborations through its Collaborative Research Support Fund):

1. The US-Ireland Research & Development (R&D) Partnership; and
2. Pilot rounds of the SFI-DfE Investigators Programme.

The US-Ireland Research & Development (R&D) Partnership Programme

To encourage collaboration and focus on common interests, the 1998 Good Friday Agreement (GFA) had promoted cross-border work on a variety of shared issues (including in sectors such as health, environment and agriculture). Whilst the GFA did not specifically identify R&D as a potential area of cooperation, the US-Ireland R&D Partnership programme was developed on the GFA's principles of *"equality, partnership, and mutual respect"*. It was launched in 2006, following the earlier work of a taskforce established at the US-Ireland Business Summit in Washington, DC, in 2002, which recognised the strong link between high-quality research environments and economic development.

The Programme aims to promote innovative tri-partite collaborative research projects which create value above and beyond individual efforts. It helps link scientists and engineers in partnerships across academia to address crucial research questions; foster new and existing research activity (typically basic research/research at low Technology Readiness Levels i.e., TRLs 1-3) that could make an important contribution to the respective economies, and expand educational and research career opportunities in science & engineering.

The following thematic areas (as of March 2020) have been prioritised as important research grand challenges for the health and prosperity of the citizens of the United States, Republic of Ireland and Northern Ireland:

- Nanoscale Science & Engineering;
- Sensors & Sensor Networks;
- Telecommunications;
- Energy & Sustainability;
- Cybersecurity;
- Agriculture (funded by DAERA in NI); and
- Health (funded by the HSC R&D Office of DoH in NI).

Of note, it was agreed from the beginning that a 'single-proposal, single-review' mechanism using the merit review systems of the USA's National Science Foundation (NSF) and National Institutes of Health (NIH) would be used to ensure that only quality proposals would be funded. The merit review systems of these two agencies were recognised as having worldwide respect.

The Partnership was expanded in 2015 to allow for 'Centre-to-Centre (C2C) Partnerships'. This mechanism links SFI-funded Research Centres, NSF-funded Engineering Research Centres (ERCs) and researchers in Centres in Northern Ireland. It currently applies only to the DfE-funded areas of Sensors & Sensor Networks, Nanoscale Science & Engineering, Telecommunications, Energy & Sustainability, and Cybersecurity.

The SFI-DfE Investigators Programme

In 2014, the Department (known then as the Department for Employment & Learning - DEL) and SFI announced a ground-breaking collaboration that allowed NI universities to participate as full academic partners in Science Foundation Ireland's (SFI's) prestigious "Investigators Programme". The Collaboration Agreement covered the 2014 and 2015 calls only.

The SFI Investigators Programme aims to support the development of world-class research capability and human capital in areas of science, technology, engineering and mathematics (STEM) that demonstrably support and underpin enterprise competitiveness and societal development. To this end, the Investigators Programme funds outstanding people with innovative ideas and strategic partnerships, recognising that excellence remains a paramount criterion. For this Programme, scientific excellence is both necessary and paramount but is not sufficient in isolation; applications must also be able to clearly articulate the potential for economic and societal impact.

The "SFI-DfE Investigators Programme Partnership" supported collaborative projects involving universities from both jurisdictions to undertake internationally peer-reviewed, leading-edge, discovery and fundamental research.

Stakeholder Feedback

The Research Team has considered activity undertaken and feedback from both PIs that have been involved and stakeholders relating to both the US-Ireland Research & Development (R&D) Partnership Programme and Pilot rounds of the SFI-DfE Investigators Programme. Key findings include:

- From the time of its launch in 2006 to 10th March 2020 (up to project reference USI 146), 58 projects, with a cumulative value c£79m had been supported under the US-Ireland Research & Development (R&D) Partnership. 40 of the 58 projects were supported by DEL/DfE, with 7 of these projects being Centre-to-Centre projects.
- 14 projects have been supported under the pilot rounds of the SFI-DfE Investigators Programme.
- The thematic or sectoral areas within which projects have been supported under both programmes provide a high degree of complementarity with NI's recently published '10x Economy' (Economic Vision) document which includes areas such as nanotechnology, telecommunications, energy and sustainable food production and processing.
- The majority of projects supported under both programmes have started at low TRLs (typically 1-3, which represent basic research);
- The Research Team's review of materials dating back to the launch of the US-Ireland Research & Development (R&D) Partnership indicates that a variety of outputs have been achieved. However, it should be noted that the outputs identified may underestimate the actual numbers achieved, as DfE's Quarterly Progress Reports were revised only in April 2018 to explicitly capture many of the metrics that the Research Team sought to quantify. Before that date, PIs had not been explicitly required to provide such data. Nonetheless, outputs identified include:

  <u>The 40 DfE-supported USI projects had generated:</u>

  - 174 journal publications, albeit some may not have been published on a collaborative basis (which also applies to some of the other outputs identified for the 40 DfE-supported USI projects);
  - 88 conference publications;
  - 177 international presentations (albeit the NI PI may not have been involved in the delivery of some of the presentations cited);
  - The NI partner on 12 of the 40 USI projects secured follow-on funding, amounting to just under £9.7m, that they attribute in some way to the USI project.

- Across the 40 US-Ireland Research & Development (R&D) Partnership projects, two-thirds (N=27 or 68%) have not yet (in May 2020) reported any substantive economic, commercial or industrial impacts, although, as noted above, this may not be unexpected given the low TRLs of the projects supported. None of the 13 remaining projects reported a monetary value associated with the impact, albeit some of the impacts would appear to lend themselves to such impacts being able to be reported.
- 22 of the 40 US-Ireland Research & Development (R&D) Partnership projects report specific 'student and/or educational' impacts as a result of the project. These included the following types of impacts:
    - Student exchanges;
    - Exposure to 'cutting-edge technology and applications';
    - Training opportunities;
    - One PhD student successfully secured a 5 Year Royal Academy of Engineering Fellowship at QUB with a value of £620k. Two undergraduate projects were related to this work and one MSc project. The MSc project went on to win the best project and was awarded £800 prize money from the civil engineering industry sponsor; and
    - Supply of skilled individuals to the labour market in areas where there had been skills gaps.

The 14 SFI-DfE projects had generated:

- 179 journal publications. Albeit it should be noted that the monitoring materials indicate that only 40% (72) could be 'primarily attributable' to the SFI-DFE project. As such, and also true of other outputs identified for the SFI-DfE projects, it is unclear what role the SFI-DfE projects played in the development of the majority of publications recorded in the monitoring materials.
- 16 conference publications;
- 305 conference presentations, of which the Research Team was only able to identify 28 instances where an NI partner was involved in the presentation. Similar to other aspects of the SFI-DfE project reporting, the results identified are likely to be influenced by the RoI partner being responsible for preparing and submitting the progress reports to SFI (on behalf of both partners).
- 12 of the 14 SFI-DfE projects received follow-on funding totalling c.£203,652,463 (allowing for conversion to Sterling) of which £31,476,915 (15%) was listed as being 'primarily attributable' to the SFI-DFE project. The c£203m was associated with 104 further projects, of which 21 (20%) were noted as having an NI partner involved. The value of follow-on funding awarded to NI partners could not be discerned.
- Across the 14 SFI-DfE Investigators Programme projects, two-thirds (N=9 or 64%) have not yet (in May 2020) reported any substantive economic, commercial or industrial impacts. Again, this is perhaps not to be unexpected given the low TRL nature of the research projects supported under this programme. None of the 5 remaining projects reported a monetary value associated with the impact, albeit some of the impacts would appear to lend themselves to such impacts being able to be reported.
- Six of the 14 SFI-DfE Investigators Programme projects report specific 'student and/or educational' impacts as a result of the project, including awards and further training provided.

Amongst both the 54 PIs, HEI management and strategic stakeholders that the Research Team consulted with, the feedback received relating to both the US-Ireland Research & Development (R&D) Partnership and the pilot rounds of the SFI-DfE Investigators Programme was very positive, with the Research Team noting the following key conclusions:

- The complexity of identifying opportunities for and developing international research collaboration projects was outlined by most consultees. For this reason, amongst others, the consultees considered that both the US-Ireland R&D Partnership programme and the pilot rounds of the SFI-DfE Investigators Programme had been considerably successful.
- Indeed, in specific relation to the US-Ireland R&D Partnership programme, stakeholders, including those from the US, noted that it was held in very high regard, and for the most part, represents best practice concerning international research collaboration. Indeed, it was noted that it is the model that the US science partners are largely seeking to develop with other countries.
- Indeed, the strength of the collaborative projects is reflected by feedback from the US National Science Foundation which reported at a meeting of the US-Ireland R&D Partnership Steering Group that the approval rating (30%) for US-Ireland proposals was 'almost unheard of in NSF' for standard US-only proposals.

- A key impact that was attributed to the US-Ireland R&D Partnership was that it *"legitimises universities on the Island in the eyes of US businesses"* and many have begun to contract research directly with universities on the island of Ireland as a result.
- Indeed, one of the NI universities noted that whilst the US-Ireland R&D Partnership programme represented only a small portion of its research activity, it was disproportionately important due to the quality of research undertaken and the associated prestige offered by the programme.
- Both the university and strategic stakeholders considered that the US-Ireland R&D Partnership and the SFI-DfE Investigators Programme have had wider socio-political social impacts, albeit most suggested that such impacts are difficult to explicitly define. Nonetheless, the types of social impacts attributed to the two programmes included:

  - Facilitating a deeper understanding of not just the expertise that is available on the Island, but of its people and its culture;
  - Developing a spirit of collaboration and sharing of knowledge to achieve goals and address challenges of mutual interest;
  - Providing reassurance to prospective Foreign Direct Investment businesses that relevant expertise and a pipeline of skilled personnel is available;
  - Supporting projects that go beyond purely commercial interests and that consider the welfare of the whole population (perhaps best reflected by the joint actions taken forward to address challenges emerging from the COVID-19 pandemic);
  - Contributing to the achievement of foreign policy objectives, strengthening alliances on a transatlantic basis (with it noted that the US-Ireland R&D Partnership has provided, since its inception, the platform for several NI politicians to meet US politicians and dignitaries);
  - Strengthening national security interests (e.g. through a shared focus on cybersecurity).

- Apart from DfE's support, there are very few support mechanisms available to NI PIs to support collaborative activity with researchers in the USA. The direct access which DfE and its predecessor Departments have been able to secure, along with SFI and the other NI/RoI partners, allowing universities here to participate in NSF programmes, is highly unusual and not something which many other funders, either nationally or globally, have been able to secure. The Good Friday Agreement (GFA), and the key role of the then US President and his Special Envoy played in securing that international Agreement, created a unique window of opportunity and policy prerogative to pursue greater trans-Atlantic cooperation in the context of encouraging increased collaboration on the island of Ireland. The US-Ireland R&D Partnership flowed directly from this and so remains an enduring legacy of the GFA.
- The US-Ireland R&D Partnership has been the catalyst for several long-term and successful collaborations between NI universities and researchers in both the Republic of Ireland and the USA, often going beyond the initial focus of a singular research project.
- The longevity of the US-Ireland R&D Partnership programme had provided underlying stability to the PIs' endeavours to seek to identify and build partnerships with their US peers.
- Indeed, all of the Principal Investigators that were consulted with were of the view that both initiatives had enhanced the research activity that was taken forward in their university, with it indicated that in the absence of both initiatives opportunities to undertake similar collaborations would be highly curtailed (or in the case of US-Ireland R&D Partnership projects, potentially not feasible at all), indicating a high degree of 'activity additionality' associated with both programmes;
- Of note, few of the PIs were able to identify policies, programmes or activities relating to international research collaboration that are implemented elsewhere in the World (including other areas of the UK) that might have merit in the Northern Ireland context. Indeed, many suggested that the US-Ireland R&D Partnership represented best practice.
- However, whilst it is noted that since April 2018, DfE has sought to capture a variety of project impacts through the revision of the structure of its US-Ireland R&D Partnership reporting templates – both for quarterly reports and completion reports – while also introducing new annual impact reports to capture outcomes achieved not only through 'live' projects, but also for the five years following the completion of the DfE-funded activities, both the PIs and other representatives from the two universities considered that such metrics might be more readily and uniformly applied to projects undertaken through the US-Ireland R&D Partnership Programme (or the SFI-DfE Investigators Programme for which monitoring is undertaken by SFI) through the use of online tools such as Researchfish.

- Furthermore, whilst stakeholders acknowledged that the recently introduced US-Ireland R&D Partnership Centre-to-Centre projects offer greater opportunities for industrial engagement, there was a view that greater emphasis could be placed on this across all projects supported. From an NI perspective, it was suggested that some PIs may require training on the commercialisation of R&D (and that completion of such training should be a pre-requisite before the receipt of funding), and further that the universities' Technology Transfer Offices may not be sufficiently linked into the various projects that are delivered under both international research collaboration programmes.
- Whilst the universities considered that both a larger available funding pot and a higher level of award per US-Ireland R&D Partnership project would be welcome, it was acknowledged that the average project value of c£300,000 is equivalent to a *"decent-sized UKRI research grant"*, and did not present a particular barrier to the quality of research that could be undertaken. It was noted that such a sum of money could broadly cover the employment cost of a PDRA and a PhD student for 3 years and allowed £50k-£60k for overhead costs. Indeed, it was noted that some other research funds do not allow the costs associated with PhD students to be covered, so this was considered to be a *"hugely beneficial"* aspect of the US-Ireland R&D Partnership. For PI-led projects, it was noted that ideally there should continue to be parity with the level of support that is provided to the RoI partner (currently capped at €350,000 by SFI which is approximately equal to £298,000 at December 2021 exchange rates). However, it was noted by some stakeholders that the £300,000 budget for Centre-to-Centre projects was restrictive in trying to involve businesses or other organisations.
- In the context of risks associated with the Brexit process, all consultees were of the view that NI needed to maintain a focus on developing international research collaboration. Indeed, both NI universities noted the continuing importance of maintaining access to Horizon Europe, noting that it takes years to fully develop international relationships and highlighting the risk that existing relationships with research bodies in the EU could be lost. It is a positive development, therefore, that continuing access to European research has been secured in the EU-UK Trade and Cooperation Agreement of December 2020 (which confirmed that the UK will have 'associated status' allowing it to access Horizon Europe going forwards).
- Of importance, several NI stakeholders advised that NI needs a research strategy, and within that, a strategy for international research collaboration, which would allow for longer-term planning and that would provide assurances as to the level of available funding.

Conclusions

The Research Team's conclusions relating to the Department's policy, programmes, and funding used to promote international research collaboration likely to maximise the return on its investment of resources are provided below:

International Research Collaboration's Importance

The persistent focus on excellence in the funding of research and innovation in the UK has paid huge dividends. Excellent research delivers high levels of economic and social impact across the country. It is a magnet for foreign direct investment in R&D which is vital to increasing overall investment in the UK and it attracts talented researchers from around the world who go on to deliver further excellent work. There is therefore a compelling case for that focus remaining in future.

The '10x Economy' (Economic Vision) document (2021) seeks to optimise Northern Ireland's comparative advantages across a range of sectors. In the international research collaboration arena, this means playing to strengths, building capacity in areas of research priority, and working on shared research challenges.

International research collaboration is a key feature of the Northern Ireland research landscape and is integral to its future. Increasing the international connectedness and depth of international engagement of research are both fundamental to the long-term competitiveness of domestic research, and to ensure that research drives economic and social advancement. The prioritisation of spending in this area is recognised both by the UK Government and the NI Executive.

International collaboration fundamentally enhances and transforms scientific research; it is driven by three main factors:

- Quality: The added value gained by bringing together different skills, knowledge and perspectives (manifested in the increased citations of papers with international collaborators). Scientists search out suitable collaborators in their field wherever they are located, to progress their research, bringing together a range of relevant and complementary skills and resources.
- Efficiency and effectiveness: The drive to combine intellectual, financial and infrastructural resources, to achieve more than one nation could manage alone.
- Necessity: To address high-level global challenges such as climate change and pandemics which do not recognise national boundaries, and which require large-scale cooperation and the mobilisation of resources to tackle them, as well as the application of global knowledge to local manifestations of these problems.

However, the challenge for governments, scientists, civil society and others, is how to reap the maximum benefit from international research collaboration.

Northern Ireland's participation in both the US-Ireland R&D Partnership and the pilot rounds of the SFI-DfE Investigators Programme have undoubtedly benefited its science, research and innovation landscape. However, there are some aspects of the systems currently utilised which prohibit the Research Team from determining the full extent to which resources have been maximised.

Given the current economic context, in which the global economy has been severely impacted by the Covid-19 pandemic and there remains a degree of economic uncertainty following the EU-UK Trade and Cooperation Agreement (albeit that continuing access to Horizon Europe has been secured as part of this agreement), the Research Team considers that it is important to stabilise the NI research environment, as much as is possible, and build on the capability that has been established through the DfE supported international partnerships to date.

Although an association with Horizon Europe has been confirmed in the EU-UK Trade and Cooperation Agreement of December 2020, leaving the EU has other significant potential impacts on the UK's research and innovation ecosystem, not least in regions such as Northern Ireland where strands of EU structural funds and regional development support have been combined with research and innovation funding to play a vital role in developing the local economy. This creates a need to explore how the Government's new UK Shared Prosperity Fund (UKSPF) can be developed to support further integration of research and innovation into regional economic development.

Why we should Engage?

How universities contribute to innovation is increasingly well recognised, stretching well beyond their roles in expanding the stock of codified knowledge, translating fundamental research into inventions that can be commercialised, and as educators. Through their increasingly direct linkages with universities, firms can develop and enhance the capabilities and competencies that feed into their innovation processes (e.g. tacit and codified knowledge, know-how, practices and processes, tools and techniques), and do so at different stages of the value chain, from early-stage technology development to scale-up, production, logistics, marketing and sales. These linkages touch many sectors of the economy, stretching well beyond manufacturing and technology-product driven firms, to include those within the services and public sectors, and often well beyond the regional boundaries of universities.

Increasing attention is also being given to the proactive and strategic initiatives and activities within universities aimed at strengthening the system-wide conditions in which innovation takes place. Indeed, as evident by proposals under NI's City Deals, the two NI universities are increasingly seeking to become knowledge hubs in the economy, to become even more deeply embedded in innovation systems, and to actively foster interactions and spillovers to link research with application and commercialisation, and taking on roles of catalysing and animating economic and social development. While these roles are often framed in a regional context, these 'system development' roles are evident in sectoral and technological systems.

Developing the universities' research capability and capacity is therefore of importance for NI's further prosperity and growth. However, such an opportunity will not be maximised without international collaboration.

Engaging in international collaborative research also indicates to the rest of the World that Northern Ireland is a global, outward-looking nation. It helps to demonstrate that we have a world-leading research and enterprise environment that can attract collaboration from across the globe.

To attract and retain the most highly skilled individuals, NI must provide a competitive landscape and offer to researchers, innovators and investors, one where it is recognised that ideas can be turned into new global businesses.

How we should Engage?

To 'maximise the positive impact of DfE Policy, Programmes and Funding in support of International Research Collaboration', DfE must adopt a new coherence and sharper focus to its international research and innovation effort.

As the UK redefines its relationship with the European Union in the wake of the December 2020 EU-UK Trade and Cooperation Agreement, it is recognised that the UK Government is committed to pursuing a far-reaching relationship with the EU, and with individual member states, on science, research and innovation as an integral part of its approach. NI must be ready to maximise the opportunities that this new relationship will present.

The UK has secured association with Horizon Europe as part of the EU-UK Trade and Cooperation Agreement and is continuing to actively shape the development of that programme. However, it would be prudent for NI to continue to explore credible and ambitious alternative collaborations and partnerships internationally to deliver positive outcomes for science, research and innovation.

The Research Team, therefore, considers that the Department and NI's two universities should jointly develop a strategy that will establish a roadmap as to how it is anticipated NI will maximise the opportunities that are available to engage in international research collaboration through, amongst other means:

1. UK-wide support structures;
2. Island of Ireland structures;
3. The US-Ireland R&D Partnership Programme; and
4. Other mechanisms including the Executive's international engagements and the universities' international networks.

Strategic planning of international research collaboration should allow the Department to make informed decisions about when, where and how to invest to maximise the range of values that come from international research collaboration.

Collaborations undertaken through such an approach should reflect the capabilities, ambitions and longer-term vision of Northern Ireland.

Of note concerning the development of such a strategy, it may be of limited benefit to develop overly complex strategic analyses of 'who Northern Ireland's best research partners' would be. For example, a good link for engineers may not be a good link for clinicians.

How do we measure success?

The concept of research excellence is ubiquitous, but its meaning depends on context, and often the meaning attributed to the notion of excellence differs markedly among both academics and policymakers alike.

In addition, many reports argue that there are substantial shortcomings in the existing mechanisms for science's quality control system, which undermine trust in assessment practices around scientific excellence.

Nonetheless, whilst considering the robustness of the peer review system is beyond the scope of this research, the research team notes that **the peer-reviewed system employed by the NSF is widely regarded as being amongst the most robust employed globally.** This provides comfort that the science proposed under the US-Ireland R&D Partnership, in particular, is likely to be of a very high standard. Indeed, the National Science Foundation employs two criteria in the merit review of proposals:

- What is the intellectual merit of the proposed activity?
- What are the broader impacts of the proposed activity? (This considers factors such as the promotion of teaching and learning, the inclusion of under-represented groups and other benefits to society.)

However, these criteria do not provide guidance as to the types of research outcomes that might be considered as being excellent from a Northern Ireland perspective. On that basis, the Research Team's first recommendation is that the Department examine whether research excellence can be 'institutionalised' in the form of a range of stable research excellence indicators that it can use to assess the merits of basic and applied research projects/programmes, including those with an international collaborative aspect, and as such broaden the notion of research excellence beyond the internal academic value system to include wider socio-economic impacts as well. This would see the creation of a set of indicators, which would coexist with expert reviews as measures of quality.

We recommend that a 'range' of indicators be selected as there is a risk, in stripping away some aspects (and focusing on others), that a distorted view on the phenomenon of interest might arise, with potentially severe consequences for policy decisions derived from them. This recognises that basic research cannot often be defined in a single-best, fixed and objective way from the outset.

Although the existing evidence (in terms of macro-economic rates of return and evidence that public sector investment in R&D 'crowds in' private sector R&D investment) provides a compelling case for the benefits that R&D can deliver, particularly to the economy, there are many benefits that come from investment in R&D that are not well measured or, in many cases, well understood.

Indeed, notwithstanding the recognised importance of international research collaboration, the mechanisms to understand and measure the benefits and values of international research collaboration are, at present, limited. This, however, is not unique to Northern Ireland and is a situation that is recognised across many countries. International research collaboration is constituted by a range of activities, often interrelated, which are not always amenable to quantitative evaluation, and which are likely to be realised in complex ways across the innovation system.

However, whilst case study examples exist (for example those created as part of the REF assessment) that seek to demonstrate the myriad ways in which R&D enriches our society, improves our quality of life through improved social cohesion, through broader and deeper cultural experiences, through improved safety and security, and richer and more engaging education, often the evidence for the role international research collaboration plays in helping to realise these has not been fully articulated or measured.

Many metrics and indicators might feasibly be used to demonstrate and evidence the benefits of international research activity, knowledge exchange and impact. The decision about which of these to use should be informed by consideration of what it is a programme/project is trying to achieve and which qualitative or quantitative measures provide meaningful evidence of progress against that goal. However, it should be recognised that in some cases, it may only be possible to find proxy indicators for the impacts of a programme/project, but these should nevertheless be as relevant and as robust as possible.

Bibliometrics is the mechanism most often used to capture the impact of international research collaboration. However, in the Research Team's view, it provides a limited evidence base that cannot capture the many modes of collaboration outside co-authorships or outputs from across the research spectrum. Moreover, bibliometrics do not allow us to identify the value of international research collaboration and its system-wide effects.

Taking the position that NI cannot maximise the return from international research collaboration until it can adequately measure its impact, an aim of this report is to inform the development of a more comprehensive

approach to measuring the impact and value of international research collaboration across the publicly-funded research sector, one that is responsive to different disciplinary practices across the research system, and to the range of different activities and levels of engagement.

The Research Team considers that this will require moving beyond frameworks that focus on simple counts of incidence, to frameworks capable of tracking the complex systems and changes that are involved in international collaboration and the broad range of values that flow – in other words, a shift from focussing on questions of 'what' happened and to 'whom', to questions of 'why' and 'how'.

Measuring value will require utilising approaches that encompass quantitative and qualitative methods. Evaluation should be seen as an integral part of planning, and involve steps such as identifying the aims and intended outcomes of collaboration, developing agreed indicators for measuring progress towards achieving pre-set goals, and introducing a feedback loop for learning and adjustments into research design and programme implementation.

Evaluation frameworks that take account of the diverse values that flow from international research collaboration and the deep and complex networks that are involved must also take account of a broader range of data to complement measurement and evaluation processes. There are currently significant collections of data that could be usefully repurposed into an appropriate evaluation framework, and indeed discussion with both universities indicates that they would be open to their use in the context of DfE supported research.

The research team acknowledges that the construction/selection of appropriate indicators is in itself a complex process, as might be the process of agreeing on a shared meaning of research excellence in the context of Departmental funded projects and programmes. For that reason, we consider that to the extent possible, the Department should seek to work within frameworks that the universities are already familiar with, albeit recognising that any chosen indicators/definition of research excellence and its implications for quantification should be positioned against the background of the specific goals and interests that a project/programme is anticipated to serve.

The Research Team has explored many different mechanisms that are used to measure the impact of university R&D and international research collaboration and are of the view that there is considerable scope to make full use of Researchfish for analysis of the impact of university research that is supported by the Department (be that of an internationally collaborative basis or otherwise). As a unique and relatively comprehensive longitudinal dataset, there is scope for particularly informative analysis to be undertaken. Researchfish collects data throughout the lifetime of a research grant and after completion, allowing for long-term follow up on the way that outcomes and impacts develop. The Research Team, therefore, recommends that the indicators captured by Researchfish are used as the basis for the selections of the aforementioned recommended 'range' of indicators to be selected.

Importantly, the Research Team recommends that a strong focus is not placed on 'citations' or 'publications' over other potential indicators, albeit recognising that they should be considered, given their continuing importance to the university sector.

Furthermore, the Department should always use more than one research metric as the quantitative input. This reduces opportunities to 'game the system' and drives desirable outcomes. Bibliometric information should be seen as representing only one element within a broader range of information sources available to support decision making in a research management context.

A key benefit of this approach is its ability to provide a longitudinal analysis of impacts, rather than a 'snapshot' end of project report which only evidences time-limited impact, rather than looking at changes in impacts over a long period. However, R&D impacts may be short- or long-term, and so the time window covered by data collection is critical.

We further recognise that capturing the outcomes and impacts of (internationally collaborative) research is complex, and the indicators that might be selected (if our previous recommendations are adopted) will seek to put into numbers phenomena that are hard to measure. However, indicators necessarily de-contextualise

information. For this reason, the indicators should be accompanied (at the application and evaluation stage) by sufficient narrative to help ensure that research impact is fully captured and not lost through over-simplification.

Combining such information with a case study approach would, in the Research Team's view, allow for more nuanced and cross-disciplinary analysis and provide for a more comprehensive picture of the range and nature of benefits from R&D, whilst minimising the level of additional burden on researchers or research users through additional data collection.

Because several (potential) impacts can only be captured with qualitative information, the proposed approach encompasses the strengths of both the metrics and narrative approaches to present illustrative case studies of the impact of research projects on the regional innovation ecosystem. The narrative case study should be supported by indicators to identify, categorise and explain the (potential) impact that the project will have/has had on the regional innovation ecosystem. This 'multi-method, multi-sources' approach allows for a greater degree of objectivity, comparability and tracking of progress over time.

Our suggested approach would help ensure that there is a focus on understanding the process of creating research impact, including critical events and their linkages.

Our recommended approach, therefore, has the advantage of blending two of the key types of approach to assessing R&D project portfolios[1]:

- Aggregations of project-level metrics - typically derived by summing up data collected from individual projects or studies; and
- Narrative portfolio assessments which utilise primarily qualitative approaches to take stock of a given portfolio and its results.

Each form of assessment has its advantages and disadvantages, so a blended approach may offer the best potential to capture all the benefits that result from a project or programme.

The adoption of such an approach should ensure that supported projects report on their (anticipated) impact to NI specifically, beyond their contributions to academia (albeit these should also be ascertained) i.e. the anticipated research impact should also be considered from the perspective of its demonstrable contribution to the economy, society, culture, national security, public policy or services, health, the environment, or quality of life etc.

Given the variables involved, such considerations must be incorporated into the planning of projects, programmes or policies. To this end, to fully develop the framework and methodology proposed, the Department should develop a set of standard guidelines for evaluating international research collaboration in policy, programme and project settings.

In specific relation to post-project evaluation, consideration could be given to creating expert review panels. Such panels should be sufficiently broad and diverse to consider projects in various sectors and should as a minimum encompass both scientific and economic appraisal/evaluation understanding (i.e. the appropriate skill set to assess the proposed 'impact pathway' or 'logic model'). The latter is recommended as scientific peers have been found to be not necessarily good at judging socio-economic impacts. The notion of 'innovation impact' is not as well understood as 'scientific impact'. The fact that key concepts and notions are still in flux, and may not be understood the same by all experts, suggests the application of expert panel reviews, which would allow for contesting and conflicting opinions that can be played out and negotiated for consensus-seeking.

Concerning the monitoring of projects supported by *'single proposal – single review'* programmes, such as the US-Ireland R&D Partnership, the lead agency which conducts the original scientific review of the proposals, might be particularly well placed to develop core metrics in consultation with the other international funders

[1] Research-Portfolio Performance Metrics, RAND 2019

(including DfE) for use at both the in-project monitoring and post-project evaluation stages. Indeed, for such projects, the lead agency which conducted the original scientific review at the proposal stage, and has the appropriately scientifically qualified desk officers, would be best placed to lead on the scientific evaluation of projects, post-completion. We would recommend, though, that DfE seeks to augment these with NI-specific metrics to ensure that local impact can be captured.

Support Required

Internationally collaborative science should continue to be encouraged, supported and facilitated. Even in difficult economic times, governments need to maintain investment in their science base to secure economic prosperity, tap into new sources of innovation and growth, and sustain vital connections across the global research landscape. Sustained investment builds a nation's capacity to assimilate excellent science, wherever it may have been conducted, for that country's benefit.

Well-structured and flexible funding mechanisms should therefore be in place to support collaboration. It is important that NI-based researchers have the ability, support and resources to collaborate with the best partners – wherever they may be.

NI's universities already collaborate with partners in a range of countries, both EU and non-EU. The emphasis is on working with the best partners, those that are most appropriate for the specific research being undertaken. However, the importance of collaboration with EU partners should not be underestimated. Even with the securing of associate status concerning Horizon Europe under the EU-UK Trade and Cooperation Agreement, it will still be important that NI has as much flexibility as possible to create effective international collaborations (with the potential for impact) wherever appropriate partners are found – and this must include both EU and non-EU partners.

The importance of both policy and funding stability in nurturing effective research partnerships should be recognised.

Of note, high-quality research partnerships may be enabled by international agreements, but they are implemented via the willing and mutually beneficial agreement of Principal Investigators (PIs) and their research groups. This aspect is of key importance, and steps should be in place to ensure that researchers receive the support to enable them to both identify and take forward appropriate collaboration projects. To this end, there may be merit in the Department reintroducing its support for PIs to explore research relationships with PIs in other countries.

Careful design of international research collaboration programmes, preferably with evaluations, could help improve the conditions for the translation of research and to drive innovation. Interventions should, where possible, ensure that all pertinent enabling and institutional factors interact (for example HEIs' TTOs) to enable the effective translation of research to occur.

To ensure that collaborations are 'win-win' an underlying principle should be that all partners must derive a benefit that is commensurate with their contributions. Concerning this, risk mitigation measures should be clearly articulated such as how ownership of background and foreground knowledge/IP will be managed.

In relation to the quantum of monies/funding required, the Research Team considers that the 'market' for international collaborative research is in a considerable state of flux, but given its aforementioned importance, the sum available should be no less than that that is currently available. However, if possible, and allowing for what might be constrained public sector funding in coming years, efforts should be made to increase the total sum available to NI HEIs and businesses.

Recommendations

The Research Team considers that the implementations of the following recommendations will improve the effectiveness and efficiency of international research collaboration activity in Northern Ireland:

1) Develop an International Research Collaboration Strategy - A strategy is required to align activities that will grow Northern Ireland's international research connectivity and enhance its reputation as a hub for international research talent. The development and implementation of such a strategy will require not only the Department, but also the two universities, and other economic development and research/innovation ecosystem stakeholders to cultivate a coordinated approach that delivers identifiable results. Such a strategy should anchor the focus of international research collaboration to local needs.
2) If establishing an international research collaboration programme with other international funders, ensure to set out from the outset:

- The intent of the Department's involvement in the collaboration activity e.g. curiosity-driven science, foreign policy concerns, industrial competitiveness, a specific mission of the government, or another factor;
- A clear rationale for government involvement that sets the activity apart from activity taken forward by the universities otherwise (i.e. additionality and added value);
- Clear aims and objectives of the fund/programme;
- Articulate the purpose, objectives, strategies and associated priorities, and performance indicators of a programme through clearer linkages between strategic plans, programme documentation and available budget;
- The application assessment process and eligibility criteria from a Northern Ireland perspective;
- A plan as to how collaboration activity will be facilitated e.g. how will the prospective partners in both NI and the other country become aware of each other's knowledge and experience;
- An appropriate monitoring framework to ensure that the original intent is being carried forth into actual planning and execution;
- A clear plan as to how collaborations will be both monitored and evaluated, especially given the difficulty of quantifying basic research outcomes. Ideally, the evaluation criteria should be built into the project and monitored accordingly.

3) DfE should consider the reintroduction of support for activities such as travel that might be necessary to develop international research collaboration networks.
4) Maintaining a stable source of funding should be considered a baseline requirement for any international programme. This should provide the necessary confidence to allow researchers to explore research collaboration opportunities.
5) A logic model approach should be used to help design both formative assessments and summative evaluations (after a project's completion).
6) Work with the universities and other funders to agree on a comprehensive list of performance indicators and on a minimum set of 'key performance indicators' drawn from those captured by Researchfish and also additional quality criteria for monitoring/evaluating international research collaboration projects.
7) The selection of metrics for outcome and impact measurement needs to consider the trade-offs associated with their use and balance the efforts needed to collect data to inform these metrics with their utility to key stakeholders, as well as their intended use. This recommendation reflects lessons learned from the literature and our judgment that, in a world of research constraints and performance-measurement demands, there is an opportunity to make explicit choices about the metrics used at each stage represented by the logic model.
8) Consider developing outcome and impact tracking and measurement in an incremental fashion. It might not be feasible to simultaneously introduce a broad suite of outcome and impact metrics. Instead, their gradual implementation, focusing initially on a small number of selected metrics, might be more realistic.

9) At the application stage, the universities could be asked to also describe "how" the proposed collaborative research is anticipated to have a positive impact on the NI regional innovation ecosystem, potentially beyond what is captured by the available performance indicators. For example, this could relate to the project's anticipated contribution to:

   - Technological development, knowledge transfer and commercialisation;
   - Entrepreneurship and support for enterprise development;
   - Education and human capital development;
   - Regional orientation, strategic development and knowledge infrastructure.

10) Subsequently, the project's monitoring should be informed by a 'narrative with numbers', in which indicators of the innovation performance of the project are contextualised and supported qualitatively. This evidence base could be supplemented with information on observed impacts or descriptions of specific impact pathways.
11) The Department should consider the resourcing, in terms of staffing across an appropriate range of background/qualifications, to ensure that such programmes can be delivered/monitored as envisaged by the above recommendations.
12) The Department should consider setting aside at least the same level of funding per annum, but preferably more, dedicated to university-based international research collaboration. This recommendation is made based on the importance placed on international research collaboration elsewhere and the potential which programmes, such as the US-Ireland R&D Partnership programme or the SFI-DfE Investigators Programme, could play in linking with and maximising research activity in NI, such as that proposed under the City Deals, and particularly through mechanisms such as the Centre-to-Centre activity.
13) Related to the previous recommendation, NI funding for Centre-to-Centre project activity should be set at an equivalent level to our US and RoI partners, so as to not disadvantage the NI partner.

1. INTRODUCTION AND BACKGROUND

1.1 Introduction

The Department for the Economy ('DfE' or 'the Department') has commissioned Cogent Management Consulting LLP ('Cogent' or 'the Research Team') to research 'Maximising the Positive Impact of DfE Policy, Programmes and Funding in support of International Research Collaboration'.

The Department wishes to ensure that it is making the best possible use of the resources it allocates to promoting international collaboration and that it is pitching the quantum of funding at an appropriate level. To this end, the research has the following aim:

To provide evidence-based advice to the Department on the policy, programmes, and funding to promote international research collaboration likely to maximise the return on its investment of resources.

In the context of this research assignment, DfE advised that maximising the return on the Department's investment of resources should not necessarily be interpreted as meaning a financial return on the investment, or indeed a measurable economic return.

Associated objectives of the research include:

- Take into account the size and scale of the research landscape and infrastructure in NI.
- Be mindful of the overall size of the Departmental budget.
- Consider current policy, funding and programmes in the Department, in particular the US-Ireland Programme, which is key to the Department's commitments under the PfG Outcomes Delivery Plan and the draft Northern Ireland Industrial Strategy (subsequently superseded by 10x Economy).
- Compile and analyse the views of key stakeholders, including the universities, Science Foundation Ireland and US National Science Foundation colleagues, the Matrix panel, Invest NI, and Departmental innovation colleagues.
- Benchmark against best practice in a selection of appropriate comparator countries.
- Whilst direct economic impact is important, the research should take into account the pure, far from market nature of much university research; this means that direct financial impacts cannot be guaranteed and, where they do follow, this can be some years after the initial investment in research. For this reason, the research should take account of the importance of the wider spillover benefits associated with international research collaboration, such as enhanced quality and efficiency of research outputs; increased domestic capacity and skills; increased success in attracting alternative sources of research funding; enhanced international reputation; and increasing the attractiveness of the region to developing and growing businesses.
- Make recommendations on potential adjustments, if appropriate, to DfE's policy, programmes or funding quantum to maximise return on Departmental investment. Whilst this research is being commissioned by the DfE, the research might feasibly make wider recommendations for NI PLC that the Department could promote as part of its role in leading on Outcomes 1 and 5 of the Programme for Government.

Bearing in the mind the objectives of the research, and to set the subsequent research in context, this section of the report:

- Considers the Department's relevant commitments under the PfG Outcomes Delivery Plan, 10x Economy and the Innovation Strategy; and
- Defines international research collaboration.

1.2 The Department's Commitments

While it will be for the current Executive to set out its priorities, the former Executive had agreed to develop a Programme for Government focused on achieving outcomes of societal wellbeing. The Draft Programme for Government 2016-21 featured a framework with 14 strategic outcomes which, taken together, the Executive believed best described the society we wish to have. Research, Development, and Innovation (RD&I), and within that international research collaboration, has the potential to contribute positively to a number of those outcomes including:

- We prosper through a strong, competitive, regionally balanced economy (Outcome 1);
- We are an innovative, creative society, where people can fulfil their potential (Outcome 5);
- We have more people working in better jobs (Outcome 6);
- We are a confident, welcoming, outward-looking society (Outcome 10);
- We have created a place where people want to live and work, to visit and invest (Outcome 12).

Indeed, stimulating RD&I is specifically identified as being a key driver for the achievement of Outcomes 1 and 5, whilst key drivers for Outcomes 10 and 12 respectively are the achievement of an increase in our economic, social and cultural links with the wider world and working to build our reputation on an international stage.

The latest Outcomes Delivery Plan (December 2019) identifies that the aim of Outcome 1 is to build a thriving, competitive, regionally balanced economy based on having more companies with an international outlook, increasing numbers of businesses recording high growth, greater levels of innovation and entrepreneurship, and with industries backed by locally-based, world-class research. Of note, one of five population indicators used to quantify progress against Outcome 1 is the rate of innovation activity measured by the percentage of companies engaging in innovation activity.

Relevant actions featured in the December 2019 Outcomes Delivery Plan include:

- Administer the US-Ireland R&D Partnership in Northern Ireland to provide our universities with funded opportunities to establish early-stage world-class international research collaborations in the areas of Sensors and Sensor Networks, Nanoscale Science and Engineering, Telecommunications and Energy and Sustainability[2];
- Support Northern Ireland's participation in Horizon 2020 by funding university-based advisers to work with the wider research community to encourage and facilitate applications, to enable local businesses and institutions to engage in research with the best European researchers, to sustain and develop a vibrant, world-class research base in support of a growing economy;
- Through the delivery of the NI Higher Education Innovation Fund (HEIF), support the engagement of NI universities with local businesses to stimulate knowledge exchange, and the commercialisation of the academic research base.

As illustrated above, the US-Ireland R&D Partnership is recognised as being the Department's main programme for promoting international research collaboration.

Reflecting the importance placed on stimulating RD&I, DfE's '10x Economy' economic vision (published May 2021) aims to encourage greater collaboration and innovation to deliver a ten times better economy with benefits for all our people. It is anticipated that this ambition will be realised by focussing on innovation in technology areas where Northern Ireland is considered to have real strengths, as featured overleaf (and which align closely with the thematic areas addressed by the US-Ireland Research and Development Partnership programme):

[2] The 2018/19 Outcomes Delivery Plan identified that the Department aimed to invest up to £2m in the US-Ireland R&D partnership during the year 2018/19.

Figure 1.1: 10X's Enabling Technologies

The Innovation Strategy for Northern Ireland 2014 – 2025 further established that Northern Ireland required a complete step-change in its culture, priority and performance in respect of innovation. However, it recognised that the challenge in achieving such a transformation should not be underestimated since NI has, for a long time, languished at or close to the bottom of most UK league tables on innovation.

The Innovation Strategy set out the key long term actions necessary to make that transformation and ensure that innovation plays its full part in realising NI's economic vision, and in doing so deliver a vision that: *"Northern Ireland, by 2025, will be recognised as an innovation hub and will be one of the UK's leading high-growth, knowledge-based regions which embraces creativity and innovation at all levels of society"*.

The importance of collaboration is reflected throughout the Innovation Strategy document, as is its international dimension. The Strategy states that *"innovation is an international process where knowledge, resources and personnel freely move across borders. Local researchers, businesses and officials need to more actively engage and collaborate at the UK, EU and global levels. Through greater collaboration, Northern Ireland can enhance knowledge and build networks by forging strategic partnerships which will help local businesses access new markets and improve the quality of commercially-focused research"*.

The Innovation Strategy notes that international collaborations are essential if Northern Ireland is to establish a global reputation for excellence in key markets and technologies, and features a target to *"Support key research institutes to further develop international agreements"*.

In support of international partnerships and collaborations, the Innovation Strategy outlines that innovation is an international process where knowledge, resources and personnel freely move across borders. It advises that local researchers, businesses and officials need to more actively engage and collaborate at UK, EU and global levels. Through greater collaboration, it is anticipated that Northern

Ireland can enhance knowledge and build networks by forging strategic partnerships which will help local businesses access new markets and improve the quality of commercially-focused research. It further advises that these collaborations are essential if we are to establish a global reputation for excellence in key markets and technologies, noting that NI's strategic approach will include:

- Promoting our research and high technology sectors overseas to attract FDI;
- Promoting NI as a great place to live, work and invest;
- Supporting our businesses and researchers to access international markets and collaborative research networks;
- Ensuring Northern Ireland continues to attract globally mobile capital, technology and highly skilled people; and
- Building strategic links with high growth economies.[3]

1.3 Defining R&D and International Research Collaboration

To understand how best to maximise investment in international research collaboration it is important to first understand the components of R&D and international research collaboration which are a subset of the broader range of R&D activities.

1.3.1 Research & Development

The Frascati Manual is an internationally recognised methodology for collecting and using R&D statistics. It defines research and experimental development (R&D) as comprising creative and systematic work undertaken to increase the stock of knowledge – including knowledge of humankind, culture and society – and to devise new applications of available knowledge. To qualify as R&D, an activity must be all of the following:[4]

- Novel;
- Creative;
- Uncertain;
- Systematic;
- Transferable and/or reproducible.

The term 'R&D' covers three types of activity: basic research; applied research; and experimental development.

- **Basic research** is experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundation of phenomena and observable facts, without any particular application or use in view.
- **Applied research** is an original investigation undertaken to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective.
- **Experimental development** is 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.

Of note, in some jurisdictions, classifications of the technology readiness level (TRL) are used in the description of projects. TRLs measure the maturity level of technology throughout its research, development and deployment phase progression. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology. In reality, R&D projects fall on a continuum of development and tend to move up and down this spectrum depending on the project's performance. However, defining such a continuum is not practical, hence the TRL scale is considered the best approach to capturing this information.

[3] A further aspect of the approach, which was drafted before the Brexit Referendum was identified as strengthening NI's engagement with initiatives within the European Union.
[4] Frascati Manual 2015, OECD 2015

The EU defines the nine levels as follows[5]:

TRL	Description	Example[6]
1	Basic principles observed	TRL 1 is the origin of technology creation. Scientific research commences to underpin basic concepts and properties which will then be translated into future research and development.
2	Technology concept formulated	Technology at this stage of the scale is speculative as there is no experimental proof or detailed analysis available to support the conclusion of the initial research findings. However, the basic properties have been defined and practical applications can be applied to the scientific research.
3	Experimental proof of concept	Analytical and laboratory studies should take place in TRL 3. This level determines whether the technology is feasible and ready to progress into the development stage. From the evidence collated in the studies, a proof-of-concept model is usually constructed which verifies that the technology has practical potential.
4	Technology validated in lab	Once the proof-of-concept technology is confirmed, multiple components can be tested with each other. The testing of multiple components helps to critically test environments, to define performance predictions in the final operating environment. The results provide evidence that envisioned application performance requirements might be attainable.
5	Technology validated in a relevant environment	As a continuation from TRL 4 at this stage, the technology is usually identified as a breadboard technology. The breadboard technology should undergo more rigorous testing in environments as close to reality as possible. Once this is complete the tech can advance to TRL 6.
6	Technology demonstrated in a relevant environment	A fully functional prototype of the technology should be developed. This prototype should be operated in a simulated environment to demonstrate full-scale realistic issues.
7	System prototype demonstration in an operational environment	The working model or prototype should be operated in the actual operational environment or platform to demonstrate performance.
8	System complete and qualified	The final product has been successfully tested and is now "flight qualified" for its intended operational environment. This technology is now ready to be integrated into an already existing technology or technology system. In most cases, this TRL represents the end of development.
9	The actual system is proven in an operational environment	The final product has operated successfully in the environment for its intended use and is now a TRL 9 technology. The system/model is proven and ready for full commercial deployment.

Typically, universities, along with government funding sources, focus on TRLs 1-4, while the private sector focuses on TRLs 7-9. The term 'Valley of Death' represents the often neglected addressing of TRLs 4 through to 7, where neither academia nor the private sector prioritises investment. Consequently, many technologies, albeit promising, finish their maturity journey before deployment. To bridge the valley of death, collaborative efforts are often required.

It should be noted however that the Frascati Manual advises that as a result of the multiplicity of TRL classification systems and their generic description, it is not possible to provide a concrete and generally applicable mapping of TRLs – or more specifically, the work conducted to bring the programme to a

[5] Horizon 2020 – Work Programme 2014-2015. Extract from Part 19 - Commission Decision C(2014)4995.
[6] Source of examples: https://grantedltd.co.uk/funding-blog/what-is-trl/

higher readiness level – to the types of R&D (basic research, applied research and experimental development) as defined in the manual.[7]

Nonetheless, within the UK, R&D Grant Funds are often divided into three categories defined by the TRL levels:

TRL 1-3 = Fundamental Research (broadly analogous to 'basic research' using Frascati terminology);
TRL 4-6 = Industrial Research (broadly analogous to 'applied research' using Frascati terminology);
TRL 7-9 = Experimental Development (broadly analogous to 'experimental development' using Frascati terminology).

Understanding the stage of research undertaken whether alone or in collaboration is a key factor in understanding the types of outputs and outcomes that might reasonably be expected.

1.3.2 International Research Collaboration

Collaborative research has been described as occurring where researchers and/or research organisations engage with each other for mutual support and contribution to the conduct of research.

The term 'collaboration' in academic research is usually thought to mean an equal partnership between two academic faculty members who are pursuing mutually interesting and beneficial research.[8] However, in practice, collaborative research is difficult to define as many collaborations involve researchers of differing stature, funding status, and types of organisations.

Collaborative research can take on a wide variety of forms. On one extreme, anyone who offers advice about a particular research project could be a 'collaborator'. In this case, the entire international research community is one big collaboration that works together to advance scientific knowledge. On the other extreme, only researchers that are involved in all main research tasks could be considered 'collaborators'. Using this definition, in a highly interdisciplinary project where each researcher is delegated a small part of the whole project, no researcher would satisfy the criteria of a 'collaborator'.

Collaborative research thus takes on a meaning that is somewhere in between these two extremes. It can be defined as including projects where researchers work together throughout a large part of the duration of a project, or who make a substantial contribution. Collaborators can include people who are responsible for a key part of the research.[9]

According to a study published in *Medical Education,* collaborative research can be classified in three ways:[10]

Institutional Context	Research can be represented by the number of administrative units involved. A simple group involves multiple researchers from the same administrative unit. A complex group involves multiple researchers from different administrative units. A multi-sector group involves researchers from multiple sectors, which can include government, industry, and community.

[7] For example, TRL to R&D mapping may be most difficult in relation to the various stages that involve the demonstration of projects/systems in diverse, more realistic, use environments, resulting in new specification requirements for the projects/systems. Chapter 2 of the Frascati Manual indicates that when a prototype performance is assessed by actual operational usage, this assessment is unlikely to represent R&D. However, efforts to address major flaws identified through operations or new requirements may, however, represent R&D.
[8] https://ori.hhs.gov/education/products/rcradmin/topics/colscience/tutorial_1.shtml
[9] https://artificialheartarchive.weebly.com/what-is-collaborative-research.html
[10] Collaborative research in medical education: a discussion of theory and practice - Patricia S O'Sullivan, Hugh A Stoddard, Summers Kalishman (Medical Education, 11 November 2010)

Number of Academic Fields	Research can be homogeneous or heterogeneous. Homogeneous collaboration involves researchers from a single discipline working together to solve a problem. This is considered unidisciplinary research. Heterogeneous collaboration involves researchers from multiple disciplines working together to solve a problem.
Disciplinarity	Heterogeneous research can be multidisciplinary, interdisciplinary, and transdisciplinary. Unidisciplinary research can be considered collaborative if it occurs between multiple administrative units. Multidisciplinary research occurs when researchers from different disciplines work separately in their discipline to solve a joint problem. Interdisciplinary research occurs when researchers work together to solve a problem but still focus on their disciplines. Transdisciplinary research occurs when researchers work together using a shared conceptual framework.

Similar to the stage of research undertaken, understanding the type of collaborative research undertaken is a key factor in understanding the types of outputs and outcomes that might reasonably be expected.

While collaboration has always been important in conducting research, the nature of collaboration is evolving from being intra-group/department/discipline/institution to being inter-group/ department/discipline/institution and even beyond, through collaborations between academia and industry, community, and government.

International research collaborations are projects that involve the active participation of investigators/researchers whose primary institutional affiliations are in different countries. Although there may be substantial variability in the scope of international projects, they are all characterised by the joint nature of the research process across national boundaries. These international research collaborations can come in the form of two dimensions: academic to academic collaborations or academic to industry collaborations. In each case, these cross-national teams jointly initiate, perform and report empirical research in an area of common interest. Many international collaborative R&D projects are centred around the development of new scientific knowledge that might or might not be used for the development of new products or services.

International research collaborations can occur as a response to top-down policy, or through bottom-up, researcher-led initiatives. A top-down policy might be, for example, where Government fosters international research collaborations to gain access to new and emerging markets; bottom-up activities might take the form, for example, of two academics partnering on an international research grant based upon a common research interest. [11]

Research and innovation are fundamentally international endeavours. The research and innovation community operates in cosmopolitan international networks, bringing together knowledge and expertise from across the planet to address problems and explore the frontiers of knowledge at global, national and local levels[12]. As such, Governments around the world recognise the value of international collaboration through policies, including around science and research diplomacy, and designing programmes that aim to foster international cooperation.

International research collaboration encompasses a broad range of activities that occur at different levels of the research system, to greater and lesser intensities and across different timeframes. For example, international science and research diplomacy – where research is used to further diplomatic relations or foreign policy objectives – requires deep relationships that are developed across long timeframes, and its effects are felt nationally. By contrast, a single project may be completed within a year between two

[11] Measuring the Value of International Research Collaboration - Report Prepared for the Department of Industry and Science (Australian Academy of Humanities, May 2015)
[12] Changes and Choices - Advice on future frameworks for international collaboration on research and innovation, commissioned by the Minister of State for Universities, Science, Research and Innovation (Professor Sir Adrian Smith and Professor Graeme Reid, July 2019).

researchers and may have the most immediate discernible effect on their careers which translate into longer-term benefits for the nation[13].

International research collaboration is not new. It is deeply embedded in the research and innovation community across the UK. Of note, international collaboration is not considered to be an optional extra. **It is fundamental to high-quality research and business innovation.** Importantly, international collaboration is considered to allow the UK's (and by turn, Northern Ireland's) innovation ecosystem to work at a greater scale than it could alone.[14]

Indeed, the outward-facing and internationally collaborative nature of the UK's research and innovation sector are considered to be key factors in its global success. International collaboration enables researchers to work with global experts in their field, enhancing the quality and efficiency of their outputs, while building domestic capacity and skills. By bringing together international talent and resources it is anticipated that researchers can achieve faster progress on shared challenges, resulting in more innovative and impactful outcomes.

There are several reasons why collaboration has been growing, including:

- **The increasing cost of conducting fundamental science at the research frontier -** The costs for maintaining research facilities has increased with the introduction of more complex technology that is used in experimentation. As a result, funding agencies cannot provide research facilities to every research group in a particular field and have had to pool resources at the regional, national, or even international level, forcing researchers to collaborate more closely.
- **The decreasing cost of travel and communication -** Beginning in the 1950s-60s, the costs of travel have decreased appreciably, which is reflected by a trend toward collaboration. Through advances in technology, scientists can easily communicate their findings. They can access online databases that offer up-to-date information and opportunities to review past publications.
- **An increasing need for specialisation -** As scientific knowledge advances, there is an increasing need for specialisation in scientific disciplines. A large amount of available knowledge inevitably results in researchers who have more knowledge depth than breadth. As a result, many complex experiments require the collaboration of multiple researchers, each with a unique task or skill.
- **The growing importance of interdisciplinary fields –** Emerging fields like biotechnology and biomaterials extend among several disciplines. Since very few individuals have knowledge of all the necessary skills, these fields force scientists from different disciplines to collaborate. Governments across the world recognise the value of interdisciplinary research and now provide support for projects requiring the collaboration of researchers in different disciplines. As a result, research groups containing members of various disciplines now have more opportunities for obtaining research funding.

However, the primary driver of most collaboration is the scientists themselves. In developing their research and finding answers, scientists are seeking to work with the best people, institutions and equipment which complement their research, wherever they may be. The connections of people, through formal and informal channels, diaspora communities, virtual global networks and professional communities of shared interests are important drivers of international collaboration. These networks span the globe. Motivated by the bottom-up exchange of scientific insight, knowledge, and skills, they are changing the focus of science from the national to the global level. Yet little is understood about the dynamics of networking and the mobility of scientists, how these affect global science and how best to harness these networks to catalyse international collaboration[15].

In recognition of its importance, the promotion of international collaboration in science, research and innovation now contributes to a range of Northern Ireland and UK strategic policy objectives and is an area of particular interest in the context of EU Exit where, despite the UK having secured association to Horizon Europe under the EU-UK Trade and Cooperation Agreement of 24th December 2020, it remains

[13] Measuring the Value of International Research Collaboration - Report Prepared for the Department of Industry and Science (Australian Academy of Humanities, May 2015)
[14] Changes and Choices - Advice on future frameworks for international collaboration on research and innovation, commissioned by the Minister of State for Universities, Science, Research, and Innovation (Professor Sir Adrian Smith and Professor Graeme Reid, July 2019).
[15] Knowledge, Networks and Nations: Global scientific collaboration in the 21st century. Royal Society Policy document 03/11. Issued: March 2011

committed to pursuing opportunities which reach beyond the boundaries of Horizon Europe and the boundaries of the EU.

1.4 Report Structure

The remainder of this report follows the following structure:

Section	Content
2	Section 2 focuses only on those policies and activities within the UK and more specifically with NI that are considered to be of most importance to the furtherance of international research collaboration.
3	Section 3 considers why countries typically engage in international research collaboration and provides an overview of the values that are generally anticipated to flow from international research collaboration. The values are discussed against several broad categories including: - Research excellence and global reputation; - Economic value; and - Delivering policy objectives.
4	Section 4 considers, where information is available, NI's performance in international research collaboration.
5	Section 5 builds upon Section 4 and discusses the mechanisms used to understand and measure the benefits and values of international research collaboration, and limitations therein.
6	Whilst much of the earlier sections of the report focus on university-university collaboration, Section 6 recognises that knowledge transfer from universities to industry is an important goal of many governments, including the NI Executive. For that reason, Section 6 specifically considers university-business collaboration (UBC) and the processes through which the knowledge developed and maintained in universities becomes the knowledge used by businesses in current operation and/or future strategy.
7	Section 7 specifically considers the activities undertaken, and impacts realised through these two programmes that the Department for the Economy (DfE) has used to promote international research collaboration (outside of promoting EU Framework / Horizon Programme collaborations through its Collaborative Research Support Fund): 1. The US-Ireland Research & Development (R&D) Partnership; and 2. Pilot rounds of the SFI-DfE Investigators Programme. In addition, it considers feedback received from strategic stakeholders involved in those programmes and also from 27 of the 45 NI Principal Investigators (PIs) that have been involved in a research project(s) delivered under one and/or other of the two initiatives.
8	Section 8 considers elements of good practice, identified through the research and consultations process, that are implemented elsewhere.
9	Section 9 presents the Research Team's conclusions and recommendations relating to the Department's policy, programmes, and funding used to promote international research collaboration likely to maximise the return on its investment of resources.

2. CURRENT POLICY, FUNDING & PROGRAMMES

2.1 Introduction

A wealth of economic literature describes the impact of knowledge on economic performance.[16] For example, studies have shown that technological change drives up income levels,[17] the relationship between high levels of patenting and GDP growth,[18] and the positive impact of innovation on business productivity and performance.[19] This body of evidence has underpinned the efforts of governments the world over to stimulate economic performance by investing in science and technology - from undirected academic science to research of strategic national importance conducted in government laboratories, to support for near-to-market technologies in the private sector.

For those reasons, investment in R&D has been of importance to the UK economy for many years. Increasingly that focus is recognising the importance of international research collaboration. This section considers current policy, funding and programmes relating to international research collaboration.[20]

The section focuses only on those policies and activities that are considered to be of most importance to the furtherance of international research collaboration. However, the reader should be mindful that there are levels of detail in individual business sectors and research disciplines that will be vital to the success of any plans but are beyond the scope of our high-level review.

2.2 The UK Context

2.2.1 UK International Research and Innovation Strategy

At the UK level, science, research, and innovation are at the heart of the Industrial Strategy. The Government is bringing forward the largest investment in R&D for four decades and is committed to reaching 2.4 per cent of GDP invested in R&D by 2027 and three per cent of GDP in the longer term.

The Industrial Strategy has established four Grand Challenges to put the UK at the forefront of the industries of the future: Artificial Intelligence and Data, Clean Growth, the Future of Mobility and the Ageing Society. However, in meeting these challenges, the Industrial Strategy recognises that partnerships with global reach are required. Indeed, given its importance, a bespoke strategy has been published which sets out how the UK will develop its international research and innovation partnerships to help achieve the targets in the Industrial Strategy[21].

[16] See Romer D (1990). Endogenous technical change. Journal of Political Economy 98, 5, S71–102; Mokyr J (1992). The lever of riches: technological creativity and economic progress. Oxford University Press: Oxford, UK; Lipsey R, Carlaw K & Bekar C (2005). Economic transformations: general-purpose technologies and long-term growth. Oxford University Press: Oxford, UK; Hall B & Rosenberg N (eds) (2010). Handbook of the economics of innovation. Elsevier: Amsterdam, The Netherlands.

[17] Freeman C (2002). Continental, national and sub-national innovation systems—complementarity and economic growth. Research Policy 31, 2, 191–211.

[18] See Chen D & Dahlman C (2004). Knowledge and development: a cross-section approach. World Bank Policy Research Working Paper No. 3366. This paper argued that between 1960 and 2000, a 20% annual increase in the number of patents granted in the USA—whether the technologies originated locally or overseas—produced an increase in economic growth of 3.8 percentage points. World Bank: Washington, DC, USA.

[19] NESTA (2009). The innovation index. This report showed that two thirds of the productivity growth in the UK's private sector between 2000 and 2007 was attributable to innovation including technological advances. National Endowment for Science, Technology and the Arts: London, UK.

[20] It should be noted that this report has been drafted during the period of the Coronavirus (COVID-19) pandemic. It has been written on the assumption that the Government's broad strategy will remain the same, albeit the outworkings of the pandemic may have implications, not least on public expenditure.

[21] International Research and Innovation Strategy (HM Government, May 2019)

The 'UK International Research and Innovation Strategy' establishes that we are at a pivotal moment in a rapidly changing world. We face pressing global challenges, and we are on the brink of technological transformations that will impact us all. On that basis, HM Government advises that the importance of global cooperation to find solutions and to drive our long-term prosperity has never been greater. At the UK level, the Government intends to use international partnerships to generate impact in all areas of research and innovation. From fundamental scientific discoveries to the development of cutting-edge technologies; from innovating practical solutions to shared challenges and to strengthening global governance frameworks.

Pertinent facts identified within the Strategy document include:

- With only 0.9 per cent of the world's population and 4.1 per cent of researchers, the UK accounts for 10.7 per cent of citations and 15.2 per cent of the world's most highly cited articles.
- Over half of the scientific papers produced in the UK have international co-authors;
- Half of published UK research is the result of international collaboration[22]
- 72 per cent of active researchers in the UK are internationally mobile[23].
- Since 2014, the UK Research Councils have funded 4,254 international research and innovation collaborations totalling £3.3bn[24].
- Innovative UK SMEs lead the way in the OECD for collaborating with higher education or research institutions[25];
- The proportion of UK SMEs which engage in international collaboration for innovation is the 2nd highest in OECD.
- As reflected in Table 2.1, 13 of the Top 20 countries that the UK collaborates with, on co-authored publications, are in Europe.

Table 2.1: Top 20 Countries with the Highest Number of Co-Authored Publications with the UK between 2013 and 2017[26]

Rank	Country	No. Co-authored Publications
1	United States	139,221
2	Germany	72,707
3	France	51,821
4	Italy	50,470
5	China	48,327
6	Australia	47,304
7	Netherlands	41,417
8	Spain	40,213
9	Canada	35,356
10	Switzerland	29,252
11	Sweden	24,976
12	Belgium	21,103
13	Japan	18,626
14	Denmark	17,859
15	Brazil	14,420
16	Ireland	13,983
17	Norway	13,586
18	Greece	13,465
19	India	13,002
20	Austria	12,977

[22] Digital research reports (2016), 'The implications of International Research Collaboration for UK Universities', https://www.digital-science.com/resources/digital-research-reports/digital-research-report-the-implications-of-international-research-collaboration-for-uk-universities/
[23] Elsevier (2016) https://www.elsevier.com/__data/assets/pdf_file/0018/507321/ELS-BEIS-Web.pdf
[24] UKRI (2019)
[25] OECD (2017), 'OECD Science, Technology and Industrial Scoreboard 2017', http://www.oecd.org/sti/oecd-science-technology-and-industry-scoreboard-20725345.htm, p. 128
[26] Source: SciVal c/o Universities UK (featured in the UK's International Research and Innovation Strategy)

The UK's international engagement will be led by the Science and Innovation Network teams in the UK's Embassies and High Commissions across the world. The Strategy notes that this engagement will include the UK's regions and Devolved Administrations and the wider science and innovation communities.

It is anticipated that the Government's implementation will be guided by Professor Sir Adrian Smith's advice on the UK's future frameworks for international research and innovation collaboration, announced alongside this strategy[27]. It is envisaged that this advice will ensure that the Government's implementation will align with this strategy's goal for the UK to be the partner of choice for international research and innovation for the long term (see Section 2.2.4 for further details).

A key theme of the Strategy is for the UK to be recognised as *"A partner for open, excellent and entrepreneurial research and innovation"*. To achieve this 'Global Partner' status, the Strategy identifies that the UK wishes to build and promote international partnerships and openness, **guided by the research and innovation principles of excellence and impact:**

- Partnership: The UK wants to build strategic government and institution level agreements for deep and long-term research and innovation collaboration. It will also support universities and other research and innovation organisations to develop their international partnerships and collaborations.
- Excellence: The UK will build partnerships that recognise the importance of curiosity-led and interdisciplinary research and knowledge exchange.

The Government has therefore made the following commitments:

- To seek out opportunities for bilateral collaboration to deliver shared objectives, guided by excellence and impact.
- To continue to collaborate with European partners on major science, research and technology initiatives. The UK wants to explore association with EU research and innovation programmes, including Horizon Europe and Euratom Research and Training, networks and infrastructure.
- It has introduced new research and innovation partnership funding, including the £110m Fund for International Collaboration.

The Fund for International Collaboration (FIC) supports UKRI's aims of promoting the UK as a world-class destination to generate and access research and innovation. The principal objectives of the FIC are to:

- collaborate with the best international partners;
- carry out world-leading research and innovation which delivers new knowledge, and societal and economic impact, to the mutual benefit of the UK and partner countries;
- support BEIS and wider Government objectives, including science diplomacy, enabling the UK to strengthen its collective voice in research and innovation policy.

It will develop existing and create new collaborative research and innovation programmes that target countries with high performing research and innovation sectors to engage in joint-funded bilateral or multilateral agreements, which will deliver new knowledge, societal and economic impact, to the mutual benefit of the UK and partner countries. FIC aims to build the capacity and capability of UK-based institutions, supporting BEIS and wider Government objectives, enabling the UK to strengthen its collective voice in research and innovation policy, stimulating, consolidating and growing its international collaborative activity.

The FIC enables UKRI to positively respond to partner countries expressing a strong interest in strengthening and deepening their research and innovation partnerships with the UK; and acts as a catalyst for collaborations that deliver higher-quality research, enhance the UK's reputation and leadership, and attract new investment. UKRI, in consultation with BEIS, has identified countries of focus as part of an

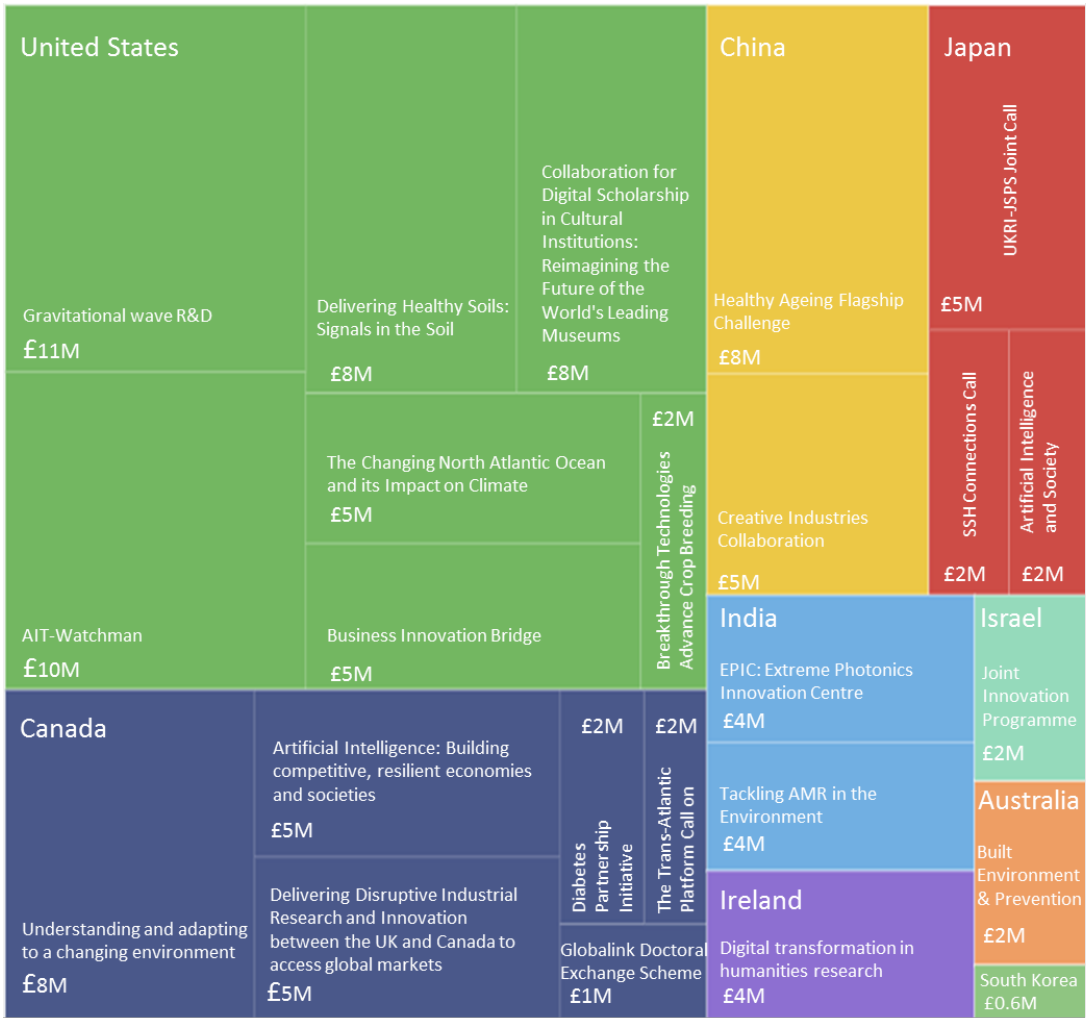
[27] Professor Sir Adrian Smith was commissioned during 2019 by the Secretary of State for Business Energy and Industrial Strategy and the Minister of State for Universities, Science, Research, and Innovation to provide independent advice on the design of future UK funding schemes for international collaboration, innovation and curiosity-driven blue-skies research.

evolving framework for international investment (e.g. USA, Canada, Japan, Australia, Israel, South Korea, Singapore, China and India).

The competitive bidding process for FIC Wave 1 and 2 was open (January and August 2019 respectively) to all 9 UKRI Councils operating individually or in partnership. A summary of the FIC Wave 1 & 2 Support for Bi-lateral Collaborations by Country is provided in Figure 2.1 below:

The FIC aims to build a portfolio that captures a diversity of international partners and research areas. Consequently, the FIC consists of a diverse range of research and innovation activities at various stages of development. Also, the nature and maturity of the partnerships vary between programmes. 29 of the 32 FIC programmes have now been launched (in January 2020). 147 research grants have been awarded so far and further funds have been invested in infrastructure.

Figure 2.1: FIC Wave 1 & 2 UKRI Support for Bi-lateral Collaborations by Country



2.2.2 UK Science and Innovation Network

Recognising that international collaboration is essential to maintaining the excellence of the UK's research base and the competitive advantage of its innovative businesses, for filling capability gaps and for ensuring value by leveraging international resources, the UK has created the Science and Innovation Network (SIN).

SIN is jointly funded by the Department for Business, Energy and Industrial Strategy and the Foreign & Commonwealth Office. SIN works across the entire UK science and innovation landscape supporting UK stakeholders to make international connections, set up strategic collaborations and leverage research

and innovation funding. It has approximately 100 officers in over 40 countries and territories around the world building partnerships and collaborations on science and innovation.

SIN teams develop country-specific action plans and work to the following global objectives:

- Prosperity – enhancing UK growth and exports; connecting innovative UK industries and scientific expertise with international opportunities;
- Security – delivering solutions to global challenges such as anti-microbial resistance (AMR), health, energy, the conservation and sustainable use of oceans, and enhancing resilience to natural disasters;
- Influence – strengthening the UK's foreign policy influence through science and innovation;
- Development – supporting international development goals and matching UK expertise to international needs.

SIN is pursuing these objectives via a series of thematic programmes:

- Health and Life Sciences
- Clean Energy
- Food and Agriculture
- Future Manufacturing
- Cyber and Information Communications Technology (ICT)
- Quantum Technology
- Future Cities
- Resources and resilience
- Polar Regions
- Space
- Oceans

2.2.3 UK Research and Innovation (UKRI)

The Higher Education and Research Act 2017 formally established UK Research and Innovation (UKRI) in April 2018. UKRI brought together seven research councils, Innovate UK[28], and the research elements of the Higher Education Funding Council for England -now called 'Research England' [29].

The Higher Education and Research Act 2017 states that the role of UKRI includes advising Ministers regarding the balance between the dual support funding streams. Under the 'dual support' system, Research England will provide annual funding for English institutions in the form of a 'block grant', and UK Research Councils provide funding for specific research projects and programmes. UKRI envisaged ongoing work to analyse and understand what constituted a reasonable balance.

The Research Team considers that the outworkings of such analysis could provide valuable information in informing the Department for the Economy's thinking as it also has responsibility for overseeing the 'dual support' system and administering the 'block grant' in Northern Ireland.

It is further noted that in its case for the creation of UKRI, the Government highlighted a range of benefits stemming from integrating the various research and innovation functions within a single body. These included:

- improved collaboration between the research base and the commercialisation of discoveries in the business community;
- improved quality of evidence on the UK's research and innovation landscape through the pooling of multiple datasets and information sources, underpinning effective funding decisions.

The creation of UKRI is intended to build on *"existing strengths"* to use data *"in new ways to look across the research and innovation landscape to understand the impact of our investments and maximise the return we get"*. This also recognised that **evaluation of the return on investment was *"notoriously***

[28] Innovate UK works with people, companies and partner organisations to drive science and technology innovations, for example through the Knowledge Transfer Network (KTN). Innovate UK is also responsible for the Catapult network of R&D centres which connect businesses with research and academic communities.
[29] The Department for the Economy is NI's devolved administration equivalent of Research England (a Higher Education Funding Council).

difficult", due to *"long lags, difficulties in obtaining a true baseline, and difficulties in correctly attributing benefits"*. Nonetheless, UKRI will "*monitor a broad set of outcomes with a wide range of quantitative and qualitative indicators"*. [30] These include:

- **Pushing the frontiers of human knowledge and understanding**: New research tools, and methods; high-quality people; and improved knowledge sharing;
- **Delivering economic impact**: New products, businesses, and services; increased business growth and jobs; links between the research and the innovation, business and investment communities; and
- **Creating social and cultural impact**: Improved wellbeing; health outcomes; improved policymaking and public services; improved security, resilience, and cost avoidance.

2.2.4 *Future Frameworks for International Collaboration on Research & Innovation - Professor Sir Adrian Smith's 'Changes and Choices' report*

Under the EU-UK Trade and Cooperation Agreement of December 2020, the UK Government has secured association to Horizon Europe[31], having made clear its desire to do so consistently and repeatedly throughout its negotiations with the EU. The UK Government, therefore, continues to actively shape the development of that programme. However, it will also continue to explore credible and ambitious alternative collaborations and partnerships internationally to deliver positive outcomes for science, research and innovation. Such opportunities reach beyond the boundaries of Horizon Europe and the boundaries of the EU.

The Government recognises that the global landscape for science and innovation is changing, and access to knowledge, markets, skills and partners now takes place on a global basis. Global R&D capacity is expanding and non-Organisation for Economic Cooperation and Development (non-OECD) countries account for a growing share of global R&D, both in terms of researchers and investment. Consequently, the Government recognises that a better understanding is needed on whether the UK's current funding mechanisms, resources and bilateral and multilateral partnerships will be fit for purpose when set against the projected trends in international research and innovation, and new technology and industry roadmaps and the forecast social, economic and environmental trends.

To this end, the Minister of State for Universities, Science, Research and Innovation commissioned Professor Sir Adrian Smith to provide independent advice on the design of potential future UK funding schemes for international innovation and curiosity-driven blue-skies research, in the context of the UK's future ambitions for international collaboration on research and innovation.

The resulting 'Changes and Choices' report[32] **- which was drafted *before* association to Horizon Europe was confirmed in the EU-UK Trade and Cooperation Agreement -** recognised that finances present only part of the picture, noting that there are several intangible (i.e. non-financial) benefits that have been identified as a result of participating in EU Framework Programmes, as follows:

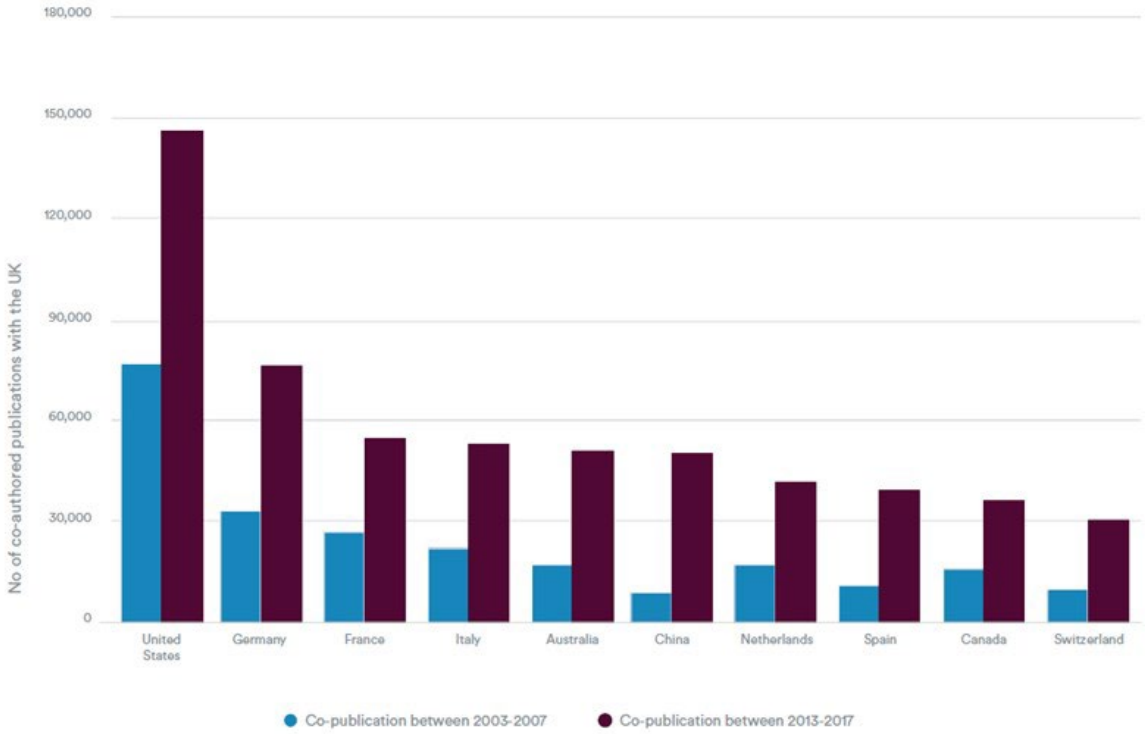
Table 2.2: Benefits of Framework Programme participation[33]
• Access to complementary and state-of-the-art knowledge;
• Building networks with other European research organisations;
• Increasing international co-publications with European partners which generally have a higher scientific impact than national publications;
• Access to customers and suppliers through collaborative projects for firms;
• A positive effect on the higher education modernisation agenda.

[30] UKRI Strategic Prospectus
[31] Horizon Europe is the successor to Horizon 2020 and will run from 2021 to 2027
[32] Changes and Choices - Advice on future frameworks for international collaboration on research and innovation, commissioned by the Minister of State for Universities, Science, Research and Innovation (Professor Sir Adrian Smith and Professor Graeme Reid, July 2019).
[33] Based upon Research Council of Norway findings

Other pertinent findings featured in the report include:

- In 2017, over half of all peer-reviewed publications by UK researchers were co-authored by at least one non-UK researcher. The UK is ranked as the second most collaborative country amongst similar research-intensive comparator countries after France. In 2007, 36% of such publications had an international co-author and the UK was ranked as the fourth most collaborative country;
- Figure 2.2 shows the UK's top ten collaborative partners between 2013 and 2017. Compared to 2003-2007, the UK's top collaborative partners remain broadly unchanged[34], with levels of collaboration increasing by almost 140% across these countries. Five of these top ten partners are outside the EU. The highest levels of growth in co-authorship were with China, Australia and Spain.

Figure 2.2: UK's top 10 collaboration partners by volume of internationally co-authored publications[35]



- BEIS spends around £440m a year on its Official Development Assistance (ODA) focussed on research and innovation, and around £230m on its other international research and innovation programmes;
- The UK Government also contributes to the cost of international EU Research and Innovation programmes, including Horizon 2020, Euratom Research and Training, ITER (Latin for 'the way' focussing on fusion energy research), Copernicus (the EU's earth monitoring initiative) and Galileo (the EU's Global Satellite Navigation System) through the EU budget. The cost to the UK of these activities cannot be calculated explicitly. Assuming a proportional share of the EU budget attributed to the UK is applied to the budgets for these EU programmes, BEIS estimates the collective expenditure on research and innovation to be just over £1.5bn a year;
- Some respondents to Professor Sir Adrian Smith's 'Changes and Choices' report highlighted the European Research Council (ERC) as being a highly effective and respected facilitator of excellence-driven blue-skies research in the UK. Many of those respondents cited the unique characteristics that the ERC offers as underlining its success. The key characteristics highlighted by consultees, which were considered to be well aligned with the capabilities and aspirations of world-leading researchers in the UK included:

[34] Between 2003-2007, Japan was ranked the 10th most collaborative country with the UK. This has now changed to Japan ranking the 13th most collaborative country. China on the other hand has rapidly moved up the rankings from 12th position to the 6th.
[35] Source: Elsevier Scival Database

- Size of the grants;
- Length of the grants;
- Open to all nationalities;
- Over a decade of precedent and familiarity has led to prestige;
- Freedom to explore ideas as they emerge;
- Freedom to move institute and country;
- Covers different career stages;
- Prestige due to the rigour of the peer review process;
- Excellence as the sole criterion for evaluation.

- It was widely agreed that in the absence of association, new arrangements would be needed to support excellence-focused blue-skies research in the UK. Current domestic funding schemes, including the overall balance of funding in UKRI, were described as focusing on specific missions and challenges at the expense of blue skies research. Only the public sector will support blue-skies research on a national scale, so UKRI must provide such support. There was wide agreement that a domestic blue-skies funding scheme could reflect and improve many of the best features of ERC, **including using excellence as the sole criterion for evaluation**.
- Many respondents valued the Haldane Principle and the general view was that future funding initiatives for both blue-skies research and international collaboration should usually have independence from Government – not least because the shape and scale of international collaborations will be agreed upon between researchers in different countries rather than being determined by the UK alone[36];
- The need for quality peer review was emphasised by many. The ERC peer review system, where subject panels consisting of academic experts review applications, was frequently mentioned as a model for internationally recognised peer review. Many respondents highlighted that UKRI has expertise in this area and others pointed to the National Academies as having well developed and highly respected mechanisms for peer review;
- Operating principles - There was widespread recognition that **the purpose and key principles of new funding arrangements need to be established before the detailed administrative arrangements can be designed**. Frequently suggested principles included support for excellence, independence from Government, supporting and supplementing existing collaborative relationships, establishing long-term stable commitments to funding, and providing grants across the different research career stages. There was widespread concern that new international schemes could be too highly specified by funders rather than challenging researchers to identify the most compelling fields of enquiry;
- Industrial strategy and the 2.4% agenda - There was wide agreement (amongst respondents to Professor Sir Adrian Smith's 'Changes and Choices' report) that the agenda for any new funding arrangements should be set within the context of raising overall investment levels in the UK to 2.4% of GDP by 2027. Many highlighted the strategic role universities could play in this agenda due to the international networks and structures many have already established. Increasing support for

[36] In British research policy, the Haldane principle is the idea that decisions about what to spend research funds on should be made by researchers rather than politicians. Although it should be noted that there is currently a debate about the extent to which the principle is still applied in practice. In a written ministerial statement on 10 December 2010, The Minister for Universities and Science (David Willetts) further elaborated on the definition of the Haldane Principle. Broadly he defined the principle that the tactical implementation of government funding, i.e. which projects to fund should be a decision for academics using a process of peer review. He stated that this would involve evaluating the quality, excellence and likely impact of science and research programmes but considered that Ministers should have no input and suggested that this had been crucial to the international success of British science. David Willetts also gave a further definition of how this tactical implementation might be guided. *"Overall, excellence is and must remain the driver of funding decisions, and it is only by funding excellent research that the maximum benefits will be secured for the nation."*

However, the Higher Education and Research Act 2017, which merged the research councils and the research part of the Higher Education Funding Council for England into UK Research and Innovation, enacted the Haldane principle as section 103(3): The "Haldane principle "*is the principle that decisions on individual research proposals are best taken following an evaluation of the quality and likely impact of the proposals (such as a peer review process)*. However, the law did not use David Willetts' definition as reflected above.

university-business collaborations and match-funding contributions for international businesses looking to invest in UK R&D were frequently raised as mechanisms to incentivise R&D investment including Foreign Direct Investment;

- It was widely recognised that **the UK's reputation for outstanding blue-skies research is fundamental in attracting business investment to the UK**. It attracts the world-leading talent that businesses want to access. It was suggested that maintaining a balance between blue-skies and innovation-led research is important to continue to attract R&D investment, as well as maintaining the breadth of world-class research that the UK has to offer;
- In specific relation to international collaboration, the 'Changes and Choices' report stated that:

  - One frequently cited issue was the substantial body of international collaboration that takes place 'spontaneously' and 'organically' within the research community. These spontaneous collaborations are widespread, varied, and dynamic and occur outside any formal funding mechanisms. However, quantifying them is difficult. Spontaneous collaboration was highlighted as an essential foundation for UK participation in formal schemes such as Global Challenge Research Fund (GCRF) and EU programmes. Many highlighted Quality-related Research (QR) funding as the key facilitator of these collaborations and emphasised that increased investment in UK universities, through QR funding or similar, is needed to continue to support spontaneous international collaboration. It was suggested by several consultees **that a QR fund could be developed to incentivise and support international collaboration**, similar to the business QR fund and charity QR fund.
  - Other mechanisms highlighted by which spontaneous collaboration can be supported included workshops and conferences, secondments, and university level collaboration. Capturing fast-moving opportunities for business collaboration required the flexibility of QR funding.
  - Collaborative networks - There was widespread consensus across sectors, from academics through to research-intensive businesses, that access to the collaborative networks the EU facilitates is vital to supporting R&D in the UK. For academics, these collaborations allow access to the essential infrastructure, facilities, resources, databases, talent and skills. Businesses and SMEs emphasised that collaborative networks help projects to be scaled-up and, for some businesses, the ability to form partnerships and be involved in projects is more important than the funding.
  - Many respondents recognised that Official Development Assistance (ODA) funds[37], such as Newton and the Global Challenge Research Fund (GCRF), successfully support international collaboration. Respondents highlighted that these funds are good at supporting multi- and inter-disciplinary projects; they showcase UK R&I internationally; they contribute to the UN Sustainable Development Goals, and provide the UK with opportunities to engage and influence research agendas in ODA eligible countries. However, respondents frequently raised concerns around the restrictions on ODA funds and stated that these restrictions can be inhibitory when it comes to building collaborations. Issues raised included that the overall budget is too small and the lack of funding for building collaborative projects between ODA and non-ODA countries;
  - Lead agency funding and schemes with non-ODA countries - There was wide recognition that more funding is needed to support collaboration with non-ODA countries. Respondents frequently highlighted the benefit of schemes where two or more international Research Councils form a lead agency agreement to jointly fund research[38]. Lead agency agreement schemes were praised due to the collaboration they facilitate and the avoidance of 'double jeopardy' where applications must be approved by both agencies. However, many respondents highlighted that these schemes are rare and international collaboration would benefit from them being more widely available. It was emphasised by many that, outside of these trans-national lead agency agreements, collaboration with non-European countries is hampered by the lack of available funding schemes. Many respondents agreed that new mechanisms are required to facilitate international collaboration beyond Europe, even if the UK associates to Horizon Europe, and priority funding alliances with key countries should be developed.

[37] Official development assistance (ODA) is defined by the OECD Development Assistance Committee (DAC) as government aid that promotes and specifically targets the economic development and welfare of developing countries.
[38] The Biotechnology and Biological Sciences Research Council, part of UK Research and Innovation, BBSRC-NSF (National Science Foundation, USA) was cited as a successful funding initiative for Biological Sciences.

- Combining funds - A common theme that emerged from the evidence submitted under the 'Changes and Choices' exercise was that researchers combine funds from multiple sources at any given time to support international research. Some respondents highlighted difficulties around eligibility requirements. It was suggested that new UK **funding arrangements should recognise the challenges of harmonising funding** and learn from UKRI's experiences of collaborating with funding agencies overseas. It was clear from many responses that **the distinctive challenges of creating international collaboration require distinctive arrangements for managing research and innovation funding**;
- Regional and Devolved Issues within the UK - The unique characteristics of R&D in Scotland, Northern Ireland, Wales and of many regions of England were emphasised by respondents. It was highlighted that the types of R&D funding received, how funds are spent, and the nature of R&D carried out were distinct for these regions. There was recognition of the vital role EU structural funds, for example, the European Research Development Fund (ERDF), play in many parts of the UK. These funds are concentrated in areas of economic need and often lie at the interface between business and research. They support R&D infrastructure and enable R&D activities. **Reliance on these funds was highlighted in Northern Ireland, among others.** A pressing need to include similar support under any new funding arrangements was emphasised;
- Northern Ireland and the Irish border - Northern Ireland respondents emphasised the extensive collaborative relationships across the Irish border. They highlighted that '**North-South' collaboration has helped build highly valued networks across all disciplines and has helped advance areas of common interests such as manufacturing, artificial intelligence (AI), and climate change. The strong cross-border collaborative relationship is a complex issue that needs to be recognised and addressed**. Respondents highlighted **the need for future funding arrangements to continue to facilitate, incentivise and build on North-South research collaborations as they play a critical role in adding scientific value as well as community building**.
- There was wide agreement that an open, supportive immigration system is vital to support R&D in the UK. The transparency of immigration policy, the visa application process, cost of visas and regulations regarding dependencies were all raised as policy areas that need to be conducive to researchers;
- Additional interdependencies frequently highlighted included higher education and the need to attract overseas students to the UK, ISO standards, taxation, and intellectual property strategies.

Key aspects of Professor Smith's conclusions in his (*pre*-EU-UK Trade and Cooperation Agreement) 'Changes and Choices' research report are summarised below:

Funding Issues	If the Government decides not to associate with Horizon Europe because the terms of association do not deliver sufficient benefit to the UK, then the authors were not convinced that a persuasive case can be made for sizeable levels of public spending on activities that replicate, line by line, EU research and innovation arrangements in the UK. However, they considered that there are compelling arguments for public sector investment to stabilise and protect the assets, infrastructure and capabilities that have been created by previous decades of participation in EU research and innovation. If the UK does not associate with Horizon Europe, then the authors also see powerful arguments for additional UK public investment – redirecting funds that previously went to the EU - on wider forms of international collaboration. Taken together, the authors recommend that **funding for stabilisation, protection and wider forms of international collaboration would be at about the same scale as the UK has received in the past from participation in EU programmes** - around £1.5bn per annum[39]. Professor Smith's recommendations are based on the availability of at least that level of funding.

[39] The report notes that EU government research income represented 11% of the collective research grant income to Russell Group universities in 2017/18.

A new vision	Whether or not the UK associates with Horizon Europe, the report recommended that EU Exit be used as a stimulus for an exciting new vision for the UK. This should focus on the Government's commitments to raise overall levels of R&D investment, to reduce regional disparities in wealth and opportunity and to work towards a new global positioning for the UK. Concerning a prospective vision, the report recommends that it should include (amongst other items): • An international version of the highly successful UK Research Partnership Investment Fund, which should run competitions with sizeable rewards for the universities or research institutes that attract large amounts of foreign direct investment in R&D to the UK. • A coherent Global Talent Strategy, combining reforms to immigration policy with a suite of fellowship and postgraduate programmes to attract and retain many of the world's most talented researchers in the UK; • Substantial additional funding for basic research, recognising that significant levels of support for this important work currently come from EU collaborations; • A flagship programme of research fellowships offering large awards over long periods for exceptional researchers in all disciplines to expand the frontiers of knowledge in areas they have identified. Awards would be overseen by a prestigious international faculty of peer reviewers, recruited through national academies in several countries.
Opportunities for all regions of the UK	Integration of the forthcoming Shared Prosperity Fund with the Innovate UK agenda and ensuring direct connectivity with the university sector. The report notes that Innovate UK has the potential to manage distinctive new investment streams, responding to any reduction in support for UK SMEs under Horizon 2020.
Greater agility	Two major new funding streams to capture fast-moving and unexpected opportunities: a) The first of these should provide additional financial support through Quality-related Research (QR) funding - and devolved equivalents - for the spontaneous, organic collaborations that are woven into the fabric of research and innovation but can so easily be inhibited by funding models that are tied to specific projects. b) The second should be an 'Agility Fund' with distinct strands: - The first should enable the UK to invest in emerging international programmes of significant potential benefit to UK research. - The second is to capture opportunities that arise unexpectedly, including during interactions with other countries at Ministerial levels.
Funding bodies	The report recognised that international collaboration on the scale proposed will require distinctive administrative structures. Much of the funding will be deployed in partnerships with funding agencies and businesses in other countries, rather than under the exclusive control of the UK. The report offers a set of principles for the design of such administrative structures and several high-level options for the structures themselves. Of course, some of these principles already operate in domestic funding arrangements: • Robust governance to ensure effective stewardship of public funds and maintain the confidence of BEIS and HMT; • Independence and transparency to maintain the confidence of new investors from other countries and the research community in the UK; • Expertise in the distinctive nature of international collaborations as well as access to expertise and administrative support on research and innovation funding; • Maintain or enhance the diversity of funding sources for research and innovation in the UK; • Introduce the lowest extra costs of administration consistent with the four principles above.

	It was beyond the scope – and authority - of the review to design detailed arrangements for management and governance. However, it did identify several options for the management of new funding streams within these principles. These options included: 1. Creating a new, stand-alone public body that would manage most or all of the new funds, becoming a 'champion' for international collaboration. 2. Allocating the funding across the existing nine councils of UKRI so that several Councils each led appropriate parts of the international agenda. 3. Creating a new cross-cutting funding stream at the UKRI centre alongside the Industrial Strategy Challenge Fund (ISCF) and Global Challenges Research Fund (GCRF) that work in collaboration with existing UKRI Councils where appropriate. 4. Creating a new, independent Council within UKRI, (along the lines of a science and humanities Council as defined in the 2017 HE & Research Act) that would be a champion for international collaboration, manage much of the new funding itself and work in collaboration with existing Councils where appropriate. The report noted that different components of funding might well be managed through different options.

2.3 The NI Context

2.3.1 The Programme for Government

As reflected in Section 1, the Draft Programme For Government 2016-21 features a framework with 14 strategic outcomes which, taken together, the Executive believed best described the society we wish to have. Stimulating RD&I is specifically identified as being a key driver for the achievement of Outcomes 1 and 5:

- We prosper through a strong, competitive, regionally balanced economy (Outcome 1);
- We are an innovative, creative society, where people can fulfil their potential (Outcome 5).

2.3.2 A 10X Economy

The Vision set out in the '10x Economy' economic vision is for a decade of innovation that will encourage greater collaboration and innovation to deliver a ten times better economy with benefits for all our people. Overall, it is anticipated that we will see a positive impact on our economic, societal and environmental wellbeing.

Relevant guiding principles that underpin this vision include:

- Deliver positive economic, environmental and societal outcomes;
- Support a greener, sustainable economy;
- Position NI amongst the most competitive small, advanced economies in the world;
- Focus on increasing innovation in high value-added areas and priority clusters resulting in higher wages;
- Position NI as an optimum place to work, invest, live and visit.

The Vision document notes that measurement of our performance on a global stage, building international economic relationships in the right areas and learning from international best practice will be important drivers towards realisation of our vision. Even more important will be ensuring that the programmes and policies we implement are designed and implemented in a manner that drives out the top level improvements we need to see. It advises that DfE is designing an approach to monitor the quality and performance at programme and policy level which will ensure we are making the right progress.

2.3.3 The dual support system

Concerning its support for RD&I activities taken forward with NI's universities, the Department for the Economy operates a 'dual support' system, similar to the rest of the UK. This system is widely regarded to be a key feature of UK research funding. Through this combined approach, the Department offers competitive project-based funding, whilst Quality-related Research (QR) block funding is based on quality assessment through the UK Research Excellence Framework (REF) and gives greater flexibility for use and longer (seven-year) periods of assured funding. As the QR funding is un-hypothecated, universities are free to direct it as they wish rather than specifically to the research area for which its 'excellence' is awarded, thus allowing cross-subsidisation into other research areas (for instance those with emerging potential or a history of under-investment).

As the only form of public funding for research that gives universities a high degree of autonomy over its deployment, QR is considered to allow universities to:[40]

- **Respond quickly to emerging opportunities**, giving them a strategic edge against international competitors;
- **Support research in areas which may become key priorities in the future**, such as the work at Durham University on low-carbon heating solutions, which has become increasingly important due to the Industrial Strategy;
- **Engage in long-term strategic planning**: as a regular and predictable source of funding, QR allows universities to commit to long-term investments or partnerships with businesses, unlike project funds, which can be short-term in nature.
- **Leverage funding from businesses and engage in collaborations with new partners**: QR funding allows universities to share risk with businesses via co-funding. For example, Queen's University Belfast invested around £3 million of its QR funding to support a joint venture with Wrightbus to establish the Wright-Tech Centre research facility. The university's funding attracted more than £6 million in investment from Wrightbus and led to an additional grant of over £3 million from Innovate UK.
- **Support businesses to grow and innovate**, such as at the Queen Mary University of London, where QR funding together with funding from the Greater London Authority (GLA) was invested to set up and support the Queen Mary Bio-enterprises Innovation Centre, the largest purpose-built commercial laboratory space available for rent in London.
- **Support staff**, in particular, new academic staff who may not yet have won independent research funding, but who show potential; they may be early-career academics or researchers joining universities from overseas or the private sector, for example.

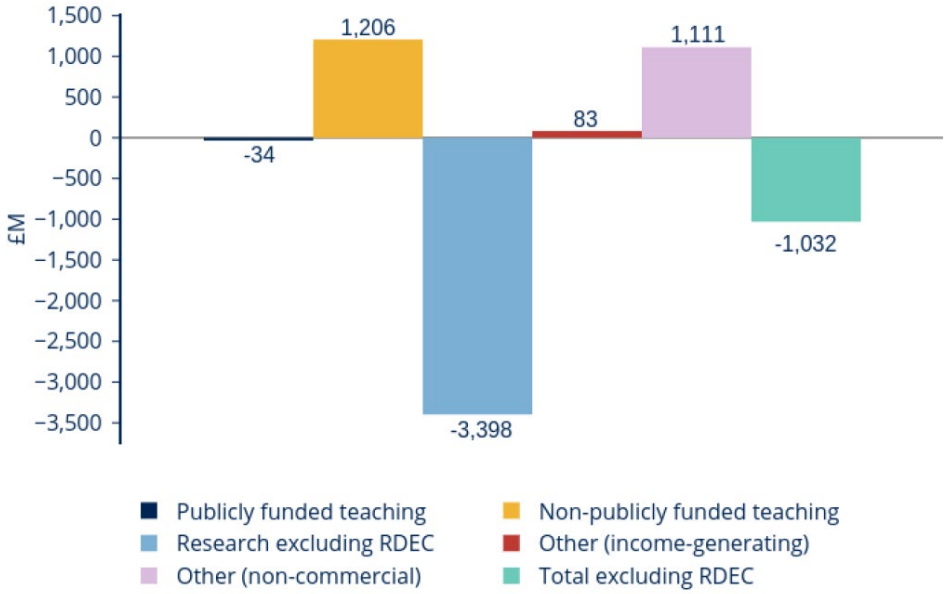
Of note, discussion with the Department for the Economy indicates that the QR funding that it provides to the universities has seen a decrease in its value in real terms over recent years.

Related to this, according to data published by the Office for Students (OfS), there is a *"substantial deficit"* in research funding, amounting to nearly £3.4bn in 2016/17 (data for England and Northern Ireland only) with universities unable to recover the full economic costs (FEC) of conducting research from any sponsor – including the Research Councils, government departments and charities.[41] The OfS notes that whilst universities in England and Northern Ireland (the only level this data is available for) were able to recover 77.8% of FEC for research in 2010/11, this dropped to 70.7% in 2016/17 once a small one-off benefit from the Government's Research and Development Expenditure Credit (RDEC) scheme had been accounted for. This suggests that there is increasing financial pressure on universities as they seek to perform one of their core missions.

[40] Russell Group response to Commons Science and Technology Committee inquiry into the balance and effectiveness of research and innovation spending
[41] OfS Annual TRAC 2016-17 Sector analysis: https://www.officeforstudents.org.uk/publications/annual-trac-2016-17-sector-analysis/

As one of the few areas of university activity that generates a surplus (see Figure 2.3), income from international student fees plays an important role in maintaining the sustainability of research.[42]

Figure 2.3: TRAC full economic cost surplus/(deficit) by activity, 2016-17 (higher education institutions in England and Northern Ireland)



2.4 Programmes Focused on Promoting International Research Collaboration

The Department for the Economy (DfE) is responsible for policy and funding related to all three of our universities' strategic missions, namely teaching/learning, research, and knowledge exchange. As part of this remit, the Department manages the NI element of two programmes focused on promoting international research collaboration (outside of promoting EU Framework / Horizon Programme collaborations through its Collaborative Research Support Fund):

1. The US-Ireland Research & Development (R&D) Partnership; and
2. Pilot rounds of the SFI-DfE Investigators Programme.

2.4.1 The US-Ireland Research & Development (R&D) Partnership Programme

To encourage collaboration and focus on common interests, the 1998 Good Friday Agreement (GFA) had promoted cross-border work on a variety of shared issues (including in sectors such as health, environment and agriculture). Whilst the GFA did not specifically identify R&D as a potential area of cooperation, the US-Ireland R&D Partnership programme was developed on the GFA's principles of *"equality, partnership, and mutual respect"*. It was launched in 2006, following the earlier work of a taskforce established at the US-Ireland Business Summit in Washington, DC, in 2002, which recognised the strong link between high-quality research environments and economic development.

[42] https://www.officeforstudents.org.uk/media/1866c816-2c9f-423f-8f28-fe37a232e477/ofs2018_28.pdf. Note that the two main surplus bars on this figure relate to international student fee income above costs and to non-commercial income such as investments, donations and endowments.

The overall goal of the US-Ireland R&D Partnership is: *"to increase the level of collaborative R&D among researchers and industry across the three jurisdictions in the areas prioritised that will generate valuable discoveries and innovations some of which are readily transferable to the marketplace or will lead to enhancements in health promotion, disease prevention and healthcare".* [43]

The Partnership is guided by a Joint Steering Group composed of senior representatives from government and academia across the three jurisdictions. InterTradeIreland, one of the six all-island bodies set up following the GFA, was identified as being ideally placed to provide a Secretariat role, within Northern Ireland and Ireland, for the partnership.

To facilitate the achievement of the programme's goal, the Steering Group has the following strategic objectives: [44]

1. To facilitate the exchange of contacts across the highest levels of decision-making in Ireland, North and South and the US, through shared conferences, workshops and scientific exchanges leading to the establishment of more formal networks of interested, selected participants initially across the approved priority areas.
2. To pursue three-way, transnational, collaborative, peer-reviewed research projects that build on networks already established and have a focus on knowledge development with the potential to result in the creation of sustainable business ventures and/or improved healthcare provision.
3. To open links to resources that support collaborative, economically relevant R&D.
4. To stimulate the creation of new forums for dialogue among academics, researchers, scientists, business leaders and government officials across the three jurisdictions.
5. To embed the spirit of co-operation developed among the three partners into their universities, and into the perspective of future generations, by engaging researchers and graduate students in formal R&D partnerships.

The Programme's aim is therefore to promote innovative tri-partite collaborative research projects which create value above and beyond individual efforts. It helps link scientists and engineers in partnerships across academia to address crucial research questions; foster new and existing research activity (typically basic research/research at low TRLs i.e., TRLs 1-3) that could make an important contribution to the respective economies, and expand educational and research career opportunities in science & engineering.

While the development of the R&D partnership evolved from the GFA's confidence building, all-island objectives, the partnership created its guiding principles that have been fundamental to its success:

1. The first principle of the partnership is that any project must have **significant research participation** from each of the three jurisdictions. These must be **well-balanced**, collaborative research partnerships.
2. The second ground rule for any joint project is simple and remains at the heart of the success of the partnership - **quality matters**. Only high-quality research is funded.
3. The third principle is that **each jurisdiction funds only the activities of its own researchers**. The US-Ireland R&D Partnership is not considered to be a development programme. It is a research partnership. It was anticipated that this clear delineation of funding responsibilities from the very start would avoid confusion and ensure each jurisdiction's commitment to and ownership of the projects in the selected areas of strategic relevance.

[43] Source: US-Ireland R&D Steering Group - Terms Of Reference & Membership (As Proposed By Ireland, North And South) - updated February 2020' version.
[44] Source: US-Ireland R&D Steering Group - Terms Of Reference & Membership (As Proposed By Ireland, North And South) - updated February 2020' version

The following thematic areas (as of March 2020) have been prioritised as important research grand challenges for the health and prosperity of the citizens of the United States, Republic of Ireland and Northern Ireland:

- Nanoscale Science & Engineering;
- Sensors & Sensor Networks;
- Telecommunications;
- Energy & Sustainability;
- Cybersecurity;
- Agriculture (funded by DAERA in NI); and
- Health (funded by the HSC R&D Office of DoH in NI).

The Steering Group may review these areas on an ongoing basis and, as the Partnership develops, propose and advance other areas for strategic collaboration as appropriate.

The partner agencies involved in the programme are:

In the USA	• The National Science Foundation (NSF); • The National Institutes of Health (NIH); and • The National Institute of Food and Agriculture (NIFA).
In Republic of Ireland	• Science Foundation Ireland (SFI); • The Health Research Board (HRB) who are only involved in the Health theme; and • The Department of Agriculture, Food and the Marine (DAFM).
In Northern Ireland	• The Department for the Economy (DfE) supports projects in the eligible areas of Sensors and Sensor Networks, Nanoscale Science and Engineering, Telecommunications, Cybersecurity and Energy/Sustainability which fall under the jurisdiction of the NSF in the US; • The Health and Social care (HSC) R&D Division of the Public Health Agency supports health-related projects which fall under the jurisdiction of the NIH in the US; • The Department of Agriculture, Environment and Rural Affairs supports agriculture-related projects which fall under the jurisdiction of the NIFA in the US.

The Partnership facilitates university researchers to submit joint research proposals in the identified priority areas. A minimum of one co-principal investigator from each jurisdiction – Northern Ireland, United States and the Republic of Ireland, must be named on the proposal to be deemed eligible for funding under the Partnership. The scientific application with supporting materials will be jointly prepared by the co-investigators.

It was agreed from the beginning that a 'single-proposal, single-review' mechanism using the merit review systems of the USA's NSF and NIH (across a large variety of their existing funding programmes) would be used to ensure that only quality proposals would be funded. **The merit review systems of these two agencies were recognised as having worldwide respect**, and it was agreed that these processes would be accepted by all. With a single merit review step conducted by the NSF or the NIH, as appropriate for any project proposal, it was considered that the possibility of "double jeopardy" would be avoided.[45] Consequently, applicants must design their proposal based on the guidelines and criteria outlined in the relevant NSF programme call and associated documentation.

Importantly, it is anticipated that each Partnership will add significant value to each research project than would be achievable by the Principal Investigator (PI) in each jurisdiction working alone.

[45] In this context, it is understood that 'double jeopardy' is intended to mean the risk of one stakeholder body supporting a proposal for funding, but another not supporting it.

Of note, the Partnership was expanded to allow for 'Centre-to-Centre (C2C) Partnerships' with the first such collaboration supported in 2015. This mechanism links SFI-funded Research Centres, NSF-funded Engineering Research Centres (ERCs) and researchers in Centres in Northern Ireland. This opportunity, building upon previous individual investigator-driven collaborations between US researchers and colleagues in both the Republic of Ireland and Northern Ireland, seeks to build Centre-based research collaborations. Funding decisions are based upon standard NSF Review Criteria in addition to the relevant ERC specific criteria in support of its vision, strategic plan and ongoing activities. The C2C mechanism currently applies only to the DfE-funded areas of Sensors & Sensor Networks, Nanoscale Science & Engineering, Telecommunications, Energy & Sustainability, and Cybersecurity.

As Northern Ireland does not have large-scale Research Centres like the NSF and SFI Research Centres, the Department assesses Northern Ireland applications on a case by case basis. NI applicants applying under the Centre-to-Centre agreement must be part of a Centre or Research Institute. Due to budget restrictions, the total budget for each NI Centre-to-Centre project is capped at £300,000 per project. Until recently, NI Centres/Research Institutes were only allowed to hold one Centre-to-Centre award at a time (albeit, this was subject to review on a case-by-case basis). This rule has recently been amended in Northern Ireland by DfE to now allow up to two concurrent proposals/projects, both for investigator-driven collaborations and for C2C collaborations.

Discussion with DfE indicates that successful Centre-to-Centre Partnerships must demonstrate, at the proposal stage, strong evidence of collaborative partnership and a clear roadmap for industry engagement (ideally with letters of support from industry partners). Each proposal must outline each partner's unique role, the complementarity of expertise and how the partnership will add significant value to each research programme above that achievable by the Centre in each jurisdiction working alone. Also, each proposal must detail plans for workforce development and upskilling early-career researchers, including details of anticipated international exchanges.

Appendix II provides further details on the operation of the US-Ireland R&D Partnership programme and the NSF.

The Research Team notes that one important distinction between the activity that is taken forward through an initiative such as the US-Ireland R&D Partnership programme, vis-à-vis that which the NI universities can take forward through the QR funding received, is that the QR funding can support true 'curiosity-driven' research which are activities proposed by scientists and conducted, usually as basic research, because the subject is not well understood and where the application of the scientific method of observation and experimentation may add to the stock of knowledge.

However, the activity taken forward through the US-Ireland R&D Partnership programme is characterised more so as 'mission-oriented' research, which are activities that are defined by government agency officials who commission research that will advance the knowledge needed for an agency to carry out its mission. In the case of the US-Ireland R&D Partnership programme, the 'missions' of the individual programmes to which applications are submitted are set by the USA's NSF and NIH, albeit in sectoral areas of interest to Northern Ireland.

2.4.2 The SFI-DfE Investigators Programme

In 2014, the Department (known then as the Department for Employment & Learning - DEL) and SFI announced a ground-breaking collaboration that allowed NI universities to participate as full academic partners in SFI's prestigious "Investigators Programme". The Collaboration Agreement covered the 2014 and 2015 calls only.

The legal remit of SFI is to promote, develop and assist the carrying out of oriented basic and applied research in strategic areas of scientific endeavour that concern the future development and competitiveness of industry and enterprise in the Republic of Ireland. Oriented basic research is *"research that is carried out with the expectation that it will produce a broad base of knowledge that is likely to form the background to the solution of recognised, or expected, current or future problems or*

possibilities". Additionally, applied research is defined as *"an original investigation undertaken to acquire new knowledge and is directed primarily towards a specific practical aim or objective. The results of applied research are intended primarily to be valid for a single or limited number of products, operations, methods, or systems"*.[46]

The SFI Investigators Programme aims to support the development of world-class research capability and human capital in areas of science, technology, engineering and mathematics (STEM) that demonstrably support and underpin enterprise competitiveness and societal development in the Republic of Ireland. To this end, the Investigators Programme funds outstanding people with innovative ideas and strategic partnerships, recognising that excellence remains a paramount criterion. For this Programme, scientific excellence is both necessary and paramount but is not sufficient in isolation; **applications must also be able to clearly articulate the potential for economic and societal impact**. The programme objectives included[47]:

- To support excellent scientific research that has potential economic and societal impact aligned to Innovation 2020 enterprise themes;
- To build capacity, expertise and relationships that will allow researchers based in Ireland to lead consortia and to win further support through various non-Exchequer funding schemes, such as Horizon 2020;
- To support relevant collaborations and partnerships between academia and industry;
- To maintain Ireland's top-20 position in international bibliometric rankings through an increase in the number and quality of journal publications;
- To allow Ireland-based researchers to win top-tier international prizes (e.g., the Nobel Prize, the European Science Prize, the Lasker Award, etc.);
- To facilitate partnerships with other agencies.

The "SFI-DfE Investigators Programme Partnership" supported collaborative projects involving universities from both jurisdictions to undertake internationally peer-reviewed, leading-edge, discovery and fundamental research[48].

Successful projects from the 2014 call started in August 2015 and were expected (before the onset of the COVID-19 pandemic) to finish in July 2020. The successful projects from the 2015 call started in August 2016 and February 2017 and were originally expected to finish in July 2021 and January 2022. Under both calls, several projects have been subsequently granted 'no-cost extensions', although, in Northern Ireland, where DfE administers the funding to Queen's University and Ulster University via the Block Grant as a top slice of QR, the equal monthly funding payments for each '2014 call' project ceased by 31 July 2020 and ceased for each '2015 call' project by 31 July 2021.

2.5 Summary Conclusions

This section of the report has demonstrated that investment in science and technology and the role that international research collaboration can play in strengthening activity are recognised by governments across the World, but also more specifically within the UK and within Northern Ireland. Within the UK, the landscape for international research collaboration is in a state of flux, and it will be important that all stakeholders within NI maintain a close watching brief on developments, and just as importantly seek to maximise the opportunities that will arise over the coming years. As will be discussed further in subsequent sections of this report, work supported to date through both the US-Ireland R&D Partnership and the SFI-DfE Investigators Programme could provide a useful foundation from which to avail of those opportunities.

Of importance, this section has reflected that international research collaboration is not an optional activity; it is essential and particularly so for smaller countries, such as NI. Over half of the scientific papers produced in the UK have international co-authors. It is likely, therefore, that if NI's research output is to have a considerable impact, international partners will be essential. The USA and the

[46] SFI Investigators Programme 2016 Call Documentation
[47] https://www.sfi.ie/funding/funding-calls/sfi-investigators-programme/
[48] https://www.economy-ni.gov.uk/articles/higher-education-international-research-0

Republic of Ireland, as well as the UK's three other jurisdictions, have considerable international research standing, and as such, each offers considerable opportunity to form impactful partnerships with NI's universities and research organisations.

Whilst the topic will be returned to later, the Research Team notes that the UK has recently developed a bespoke strategy which sets out how the UK will develop its international research and innovation partnerships to help achieve the targets in the Industrial Strategy. Alongside this strategy, the Government commissioned Professor Sir Adrian Smith to provide independent advice on the design of potential future UK funding schemes for international innovation and curiosity-driven blue-skies research, in the context of the UK's future ambitions for international collaboration on research and innovation. In the context of a complex and changing research landscape, the Research Team considers that there would be merit in the development of an NI International Research Strategy that would focus on defining the pathways by which the NI research base engages on an international level, ensuring that the NI research base is maximising the opportunities that are being created at the UK-level for international collaborative research (such as the Fund for International Collaboration (FIC) and the work of the Science and Innovation Network) and within that maximising the opportunities afforded by the programmes supported by DfE to leverage further research funding into NI and to maximise the potential for impact.

3. WHY COLLABORATE INTERNATIONALLY?

3.1 Introduction

Over recent years, a large body of research has reported that significant benefits are anticipated to accrue from international collaboration at the research system, institution and individual researcher levels. Benefits include access to research expertise, research scale, cooperation on societal challenges, cost-sharing, risk reduction and access to international funds.

Indeed, as reflected by the Government's recent commissioning of a report to provide independent advice on the design of potential future UK funding schemes for international, innovation and curiosity-driven blue-skies research[49], international collaboration is considered to be of crucial importance in the context of the UK's future ambitions for research and innovation. Increasing the international connectedness and depth of international engagement of research is widely considered to be fundamental to the long-term competitiveness of domestic research, and to ensure that research drives economic and social advancement. However, the stated motivations for countries engaging in international collaboration are diverse. A recent survey of the research internationalisation policies of twenty leading research countries found that the drivers are as varied as broadly 'tackling global societal issues and challenges' to a focus on 'achieving research excellence in a globalised world'[50].

This section provides an overview of the values that are generally anticipated to flow from international research collaboration. The values are discussed against several broad categories including:

- Research excellence and global reputation;
- Economic value; and
- Delivering policy objectives.

3.2 Research Excellence and Global Reputation

When international research teams collaborate, they bring together different cultural perspectives and methodological approaches, widening the perspective of analysis and interpretation. Such engagement enables the pooling of resources to create more extensive networks of knowledge; international collaboration increases the reach and impact of a country's research and has significant career implications for researchers. Global connections between researchers and institutions are therefore generally considered to have sizeable social, cultural and economic impacts, with benefits often extending beyond academe.

The most immediate impact of international research collaboration is its potential to derive benefits for individual universities and their faculties.

It is widely accepted that international research collaboration increases the reach and academic impact of domestic research, as can be measured through proxies such as citations between academic articles, or citations in patent literature. However, the value of increasing research excellence is considered to be more broadly observed than simply increased citations and operates in complex ways across the innovation ecosystem, including:

- Maximising the ability to take advantage of international spillovers and knowledge transfer;
- Enhancing the global reputation of researchers and institutions;
- Informing global research rankings;
- Leveraging reputation to access international funding;
- Attracting and retaining international research talent.[51]

[49] Changes and Choices - Advice on future frameworks for international collaboration on research and innovation, commissioned by the Minister of State for Universities, Science, Research and Innovation (Professor Sir Adrian Smith and Professor Graeme Reid, July 2019)
[50] European Commission (2009), Drivers of International Collaboration in Research: Final Report. Publications Office of the European Union. http://ec.europa.eu/research/iscp/pdf/publications/drivers_sti.pd
[51] Measuring the Value of International Research Collaboration - Report Prepared for the Department of Industry and Science (Australian Academy of Humanities, May 2015)

International collaboration enhances the reputation of participating institutions/organisations and countries, which in turn has been reported to attract increased inward R&D investment, particularly by global corporations with large R&D budgets as they seek relevant research expertise worldwide.[52] At the same time, it may result in negative flow-throughs as international R&D investment moves to other countries.

International reputation is considered to play a crucial role in a country's research base's ability to participate in global R&D, and international research collaborations are a key driver of this. In addition to significant benefits in terms of traditional research imperatives (i.e. increasing the sum total of knowledge, increased research productivity and research that is of higher academic impact when measured by traditional bibliometric indicators) there are equally important, though less quantifiable values that research institutions experience from international engagement.

International collaborations are an opportunity to showcase research institutions' capacities on the world stage. Besides increased awareness and prestige, international reputational surveys form a significant component of leading world-university ranking systems (for instance, the QS (Quacquarelli Symonds) World University Rankings and Times Higher Education World University rankings). On the back of research rankings results, NI universities seek to leverage their reputations in particular research disciplines to become a research partner of choice for overseas researchers and companies.

Global reputation and research networks are also considered to further assist in attracting the best international academic staff, undergraduate and postgraduate students to NI universities. The relatively small budgets of NI's research institutions mean that it is prudent that they seek to leverage international networks to gain access to the best research skills, technology, infrastructure and data. In medical research, access to global data is particularly important, as it often relies on large population study cohorts and international clinical trials.

Importantly, while institutional reputation based on research excellence increases opportunities for inter-institutional collaboration, individual researchers are still at the centre of these important networks, and the role of individuals in establishing and maintaining research relationships cannot be overlooked. Indeed, many large-scale research collaborations are instigated from existing individual-to-individual researcher connections, with institution-level collaborations emerging from these relationships. Research Councils UK (now UK Research and Innovation - UKRI) recognised that one of the key drivers for engaging internationally is to build networks for future use – particularly for early career researchers: *'this experience provides them with different skills and ideas and lays the foundation for career-long collaborations'*.[53]

Such value is considered to go well beyond individual esteem and research excellence. Developing intercultural experience and understanding exposes researchers to new perspectives and reveals new applications for their research. It also provides a nuanced understanding of global issues and a practical knowledge of how to facilitate complex research projects and relationships. Such researchers are valuable resources, providing expertise to government, connectedness for industry and informing public debates on issues of global importance. To this end, the UK Government's Science and Innovation Strategy outlines the value of mobility for academic employment.[54]

Overall, international research collaboration has the potential to create significant reputational value for NI researchers and institutions. This is translated into important opportunities for additional value creation across a broad range of areas, including international spillovers and knowledge transfer, improved performance in global research rankings, accessing international capital and attracting world-class researchers to NI. These values are derived from individual interactions but can be scaled up through inter-institutional and inter-governmental relationships.

[52] https://www.ukri.org/about-us/strategic-prospectus/best-environment-for-research-and-innovation/
[53] Research Councils UK, Our Vision for International Collaboration.
[54] Our plan for growth: science and innovation. Department for Business, Innovation & Skills, December 2014

From the perspective of individual researchers, the reported rationales for wishing to collaborate internationally include:[55]

- To progress their science, researchers seek to work with the most outstanding experts in their field, or indeed other fields, many of whom will not be based in the UK.
- Collaborations allow scientists to access skills and knowledge that complement their own, stimulating new ideas and developing expertise.
- To gain access to state-of-the-art equipment - Cutting edge scientific equipment is expensive; it may be first available only in one country, or it may be affordable only if several countries combine to pay for it. Scientists often gain access to this equipment for their research through collaboration.
- To pool resources and reap benefits of scale - Global scientific achievements demonstrate the value of collaboration on big projects (for example, as experienced through the Human Genome Project and the discovery of the Higgs Boson).
- To tackle global challenges - International collaborations can enable the research base to tackle global challenges and act quickly in emergencies, such as when there was an outbreak of Ebola in West Africa in 2013, and indeed as is being seen with the international endeavours to create a COVID-19 vaccine.
- To develop their careers - Working with different researchers and joining up with the best research groups, wherever they are found, can help scientists to develop their experience. Internationally mobile researchers have been found to produce more papers on average than those who have only ever worked in the UK.

Additional evidence shows that global researcher mobility directly impacts the domestic rate of knowledge and technology transfer and that there are significant benefits for the 'home' country to researchers spending time abroad.[56]

3.3 Economic Value

Many direct and indirect, economic and commercial values are anticipated to flow from international research collaboration. Direct economic values come in many forms but include investment into research and development by overseas firms and organisations, as well as funding derived through international competitive processes. Via organisations such as the Organisation for Economic Cooperation and Development (OECD), such values and their measurement have become popular drivers of international collaboration. The most basic of these values is Business Expenditure on Research and Development (BERD) from abroad[57]. This statistic is considered to provide some evidence that international research collaboration presents opportunities to leverage additional and substantial funding on the back of public investment.

There are additional and significant indirect economic benefits that flow from international research collaborations, including:

- Research and non-research job creation;
- Leveraging domestic funding to receive international funding;
- Encouraging trade and investment opportunities;
- Sharing risks associated with large infrastructure; and
- Getting projects to scale.

Such indirect benefits, while difficult to fully account for and calculate are significant drivers of investment into international research collaboration.

[55] UK research and the European Union - The role of the EU in international research collaboration and researcher mobility. The Royal Society

[56] Edlera, J., Fierb, H., and Grimpec, C. (2011), 'International Scientist Mobility and the Locus of Knowledge and Technology Transfer', Research Policy, 40(6), pp. 791–805.

[57] It is noted that the latest ONS data indicates that overseas funding of R&D in the UK continues to decline, falling 20% (£813 million) since 2014 to £3.2 billion. Source: https://www.ons.gov.uk/economy/governmentpublicsectorandtaxes/researchanddevelopmentexpenditure/bulletins/businessenterpriseresearchanddevelopment/2018#quality-and-methodology

International collaboration may also act as an important translation point for new technology, particularly in a country like Northern Ireland, where foreign exposure may be limited by geography. Japanese companies such as Toyota and Sony are good examples of this – the success of these companies can be attributed to lessons learned by Japanese researchers who established links with US companies, participated in knowledge sharing, and licensed technologies from them. Freeman (1995) points to Japanese technology imports as a defining characteristic contributing to its success. The contributions of international technology imports and international spillovers have been empirically shown to account for income differences between countries (Acharya and Keller, 2007).[58]

3.4 Delivering Policy Objectives

International research collaboration can also serve to help deliver policy objectives. For example, bilateral research collaborations have the potential to bolster existing bilateral government agreements and facilitate future arrangements. They are also considered to offer anticipated future economic benefits from access to developing markets and partnerships with emerging innovation leaders. [59]

Furthermore, using research collaboration to deliver strategic development priorities and capacity building aims between developed and developing nations is gathering increasing support internationally. The OECD has reported extensively on the effects of international research cooperation between developed and developing countries. It has been found that links between science policy and aid policy are increasing in some countries, and are moving beyond 'traditional technology transfer' to 'support scientific collaboration for development goals and to strengthen research capacity'. [60]

3.5 Summary Conclusions

As reflected above, when analysing the rationale underpinning international research collaboration activity, one can distinguish between a narrower institutional/researcher perspective and a broader socio-economic perspective.

International collaboration is integral to creating world-class research with impact - international collaboration is increasingly synonymous with excellent research. Research shows that international research collaboration is vital for individual institutions that aim to produce outstanding research and that the increase in such collaboration has been very rapid. In this narrower paradigm, envisaged effects include:

- Contribution to building institutional capacity in research organisations;
- Contribution to the quality of science (through cross-fertilisation, competition, combining complementary knowledge, access to world-class researchers, facilities and groups);
- International collaboration increases citation performance because combined talents produce more innovative and useful outcomes. Encouraging the global reach of NI's universities is, therefore, a source of strength that increases the quality and efficiency of the research base;
- Solving specific scientific problems that need input from various international teams;
- Increase of the scope of research (combining complementary knowledge, pooling funding and human resources, sharing risks, increasing computational power);
- Better access to scarce human resources for research;
- Increase of (international) productivity and visibility of research;
- Faculty access to specialised research facilities that are not available at the home institution or country.

Working internationally enables individual academics to increase their impact and nations to pool talent and resources to address global challenges that no country can tackle alone.

[58] Measuring the Value of International Research Collaboration - Report Prepared for the Department of Industry and Science (Australian Academy of Humanities, May 2015)
[59] Measuring the Value of International Research Collaboration - Report Prepared for the Department of Industry and Science (Australian Academy of Humanities, May 2015)
[60] OECD (2013) Main Science and Technology Indicators 2013.

4. HOW ARE WE PERFORMING?

4.1 Introduction

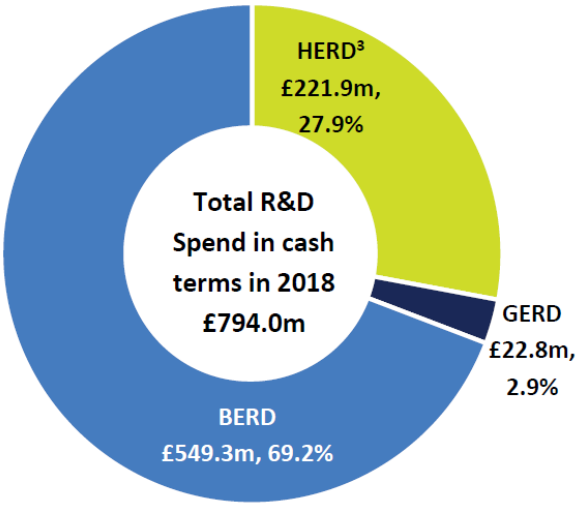
This section considers, where information is available, NI's performance in international research collaboration.

4.2 Who is Performing R&D in NI?

There is broad consensus across the political spectrum of the need to increase total investment in UK research and development (R&D). The Government has committed to meet a target of 2.4% of GDP invested in UK R&D by 2027, and a longer-term goal of 3%. To achieve this, the UK must create a vibrant environment that fosters and encourages research and innovation across public services, universities and business, as well as attracting global investment. This section considers the current research and innovation landscape in Northern Ireland.

In 2018, £794 million was spent on R&D by Businesses, Higher Education and Government in Northern Ireland. Of the £794m, 69.2% was spent by Businesses, 27.9% by the Higher Education sector and 2.9% by Government departments.[61]

Figure 4.1: Northern Ireland R&D spend in cash terms



Key points to note include:

- Total R&D spend increased by 3.2% in real terms[62] between 2017 and 2018. Higher Education and Government expenditure on R&D both increased over the year by 11.1% and 10.1% respectively. Business expenditure on R&D has been relatively constant in real terms over the previous 3 years.
- Since 2013, there has been a 13.7% increase in total R&D spending in real terms (Business: +5.5%, Higher Education: +39.0%, Government: +24.7%).
- Of the 961 R&D performing companies during 2018, 15% were externally owned companies, but they accounted for just over half (£285.0m) of all BERD in 2018.
- BERD consists of two broad components; in-house and purchased R&D. In-house expenditure accounted for 95.4% of total BERD spend in 2018 and purchased BERD for the remaining 4.6%.
- The two components of in-house R&D expenditure are non-capital (salaries & wages and other costs) and capital expenditure (land & buildings and plants & machinery).

[61] Northern Ireland Research and Development 2018, NISRA, 21st November 2019. https://www.nisra.gov.uk/system/files/statistics/RD2018-Publication.pdf

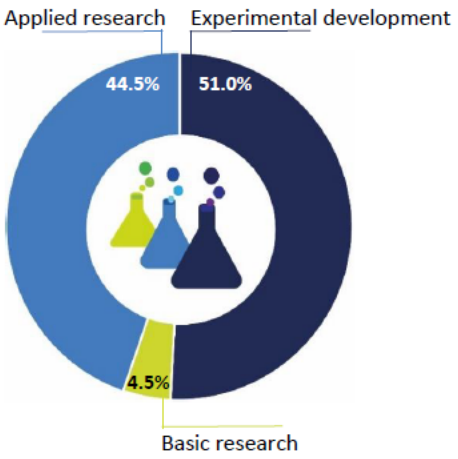
[62] GDP deflator used to convert cash terms to real terms: 2013 (92.068), 2014 (93.753), 2015 (94.298), 2016 (96.314), 2017 (98.136), 2018 = 100.00

- Non-capital expenditure, including spending on salaries and wages, materials, supplies and services accounted for 90.2% of total BERD and 94.5% of in-house BERD.
- Capital expenditure including spending on land, buildings, equipment and machinery accounted for 5.5% of in-house spending.

- Non-capital expenditure can be analysed in terms of the nature of the research carried out:

  - 'Experimental development' accounted for half of non-capital spending in 2018 (51.0%, £252.5m).
  - 'Applied research' accounted for 44.5% (£220.6m); and
  - 'Basic research' for 4.5% (£22.3m).

Figure 4.2: Share of non-capital BERD expenditure by research type



- In 2018, 51 R&D spending companies reported that their R&D work was part of a joint project with a source outside of their company. Of these 51 projects, 25 were with another business, 10 with a higher education establishment and 16 with both.
- Higher Education Research & Development (HERD) expenditure increased by £26.3m over the year to £222.9m in 2018.[63] This increase was composed of increases in both capital (+ £8.7m) and non-capital expenditure (+ £17.7m).
- Within NI, HERD accounted for 27.9% of all R&D expenditure in 2018. For the UK as a whole, HERD accounted for 24% of total R&D expenditure in 2018. However, this was up one percentage point from 23% in 2017.[64]
- Block grants remained the largest source of funding for HERD work (45.5% of total HERD funding).[65]

[63] NISRA carries out an annual survey of R&D expenditure in Higher Education Establishments in Northern Ireland. The figures provide combined results from the two Northern Ireland universities - i.e. Queen's University Belfast (QUB) and the Ulster University (UU). The data collected refers to the academic year i.e. 2017/2018 ending 31/7/2018. The universities have made data available for this period on the basis of Transparency Review data collected within each respective institution.
[64] Gross domestic expenditure on research and development, UK: 2018, ONS, 2 April 2020.
[65] Expenditure for 2018 includes £1.0 million of expenditure funded by Northern Ireland Businesses (£0.5m in 2017). Therefore, net HERD in 2018 was £221.9m. All university expenditure on R&D is in-house expenditure i.e. R&D work carried out within the university.

Table 4.1: NI HERD source of funding (£million)			
Source	**2016**	**2017**	**2018**
Government block grant	97.8	89.0	101.5
OST/UKRI research councils	30.2	29.5	34.7
UK-based charities	12.7	15.0	16.0
UK central government/local authority/health trusts	30.1	38.6	43.0
UK ind/comm/pub corp	4.8	5.0	4.6
EU government	10.5	12.9	16.3
EU other	2.8	2.2	2.6
Other overseas	4.6	3.3	3.4
Other sources	1.2	1.0	0.8
Total	**194.7**	**196.5**	**222.9**

- Taken together, EU and other overseas funding accounted for 10% (£22.3m) of HERD funding in NI during 2018. This compares with 17.9% (£1,562m) of overall HERD activity in the UK during 2018.

Table 4.2: UK HERD source of funding (£million)	
Sector funding the R&D	**2018**
Government	380
UK Research & Innovation	2,600
Higher Education Funding Councils	2,492
Business Enterprise	389
Private Non-Profit	1,318
Overseas	1,562
Total	**8,740**

4.3 Recognised Indicators of Research Excellence and Collaboration

Traditionally, global scientific output has been measured through the analysis of published papers in peer-reviewed journals. Peer review means that the science that is published has been subjected to independent scrutiny and approved by qualified scientists, and thereby assuring its quality and credibility. However, the Research Team notes that the volume of scientific literature in peer-reviewed journals is vast. Individual articles are abstracted and collected onto databases which are then searchable by their users, usually through a subscription. The most comprehensive of these services are Scopus (maintained by Elsevier) and Web of Science (maintained by Clarivate).[66] These services provide access to information about titles, authors, abstracts, keywords and references for thousands of journal articles each year. These data are used to assess the quality of research and, through its use as measured by citations, its impact - recognition by an author's peers is considered to indicate that the scientific community values the work that has been published.

[66] Of note, over the last decade, Elsevier has emerged as a key partner in this fast-developing field. Scopus, the largest abstract and citation database of peer-reviewed research information, has been used to calculate the influential QS World University Rankings and has been adopted for US World News & World Report's Best Arab Region Universities rankings. The database has also been chosen to provide data to the 2015 Times Higher Education (THE) World University Rankings and all subsequent rankings by that organisation.

Bibliometric analysis can yield different types of information. Important types of information include[67]:

- Scientific output: Information about the number of publications produced by a research unit.
- Scientific impact: Information about the number of citations that publications have received.
- Scientific collaboration: Information about co-authored publications, focusing for instance on national and international collaboration or university-industry collaboration.
- Mobility: Information about researchers that change their affiliation.
- Interdisciplinarity: Information about the interdisciplinarity of publications, usually based on the fields that are cited by a publication.
- Gender: Information about the gender of the authors of publications.
- Open access publishing: Information about the open-access status of publications, distinguishing for instance between gold open access, green open access, and no open access.

The level of detail at which information is presented in a bibliometric analysis can be adjusted to the objective of the analysis.

It should, however, be recognised that they are a lagging indicator, as well as a sometimes crude one.[68] For example, the scientific impact is typically analysed by counting the number of citations that publications have received. There are many different impact indicators, with the journal impact factor and the h-index being the best-known examples. Citations occur for a variety of reasons. Some citations indicate that the citing publication builds on the cited publication. These citations may be seen as an acknowledgement of the impact of the cited publication on the citing one. Negative citations are of an opposite nature. They reflect the citing publication's critical perspective on the cited publication. However, many citations are neither positive nor negative. These citations often reflect a more superficial connection between the citing and the cited publication. They are sometimes referred to as perfunctory citations. Given the diversity of citations, citation counts provide only an approximate indication of scientific impact.[69]

Citation counts are also sometimes interpreted as indicators of scientific quality rather than scientific impact. However, this interpretation is of an even more approximate nature. The quality of a publication can be expected to influence the number of citations the publication will receive, but a high-quality publication on an obscure topic is likely to receive fewer citations than an average-quality publication on a popular topic. Compared to impact indicators based on a direct count of citations, impact indicators based on counting highly cited publications are less sensitive to publications that have received a very large number of citations. **Impact indicators based on counting highly cited publications are therefore more robust, which is often seen as an advantage of these indicators.**[70]

Importantly, if citations are being considered as an indicator for a programme that might support research in several different areas of study, different scientific fields have different citation practices. Because of this, there are large differences between fields in citation density, that is, in the average number of citations received per publication. For instance, the average number of citations received by publications in mathematics is about an order of magnitude smaller than the average number of citations received by publications in some fields in the life sciences. When a bibliometric analysis of scientific impact covers multiple fields, it is often desirable to correct for differences between fields in citation density. Performing such a correction is called field normalisation. Field normalisation is usually carried out by comparing the number of citations of a publication to the number of citations of other publications in the same field.

[67] Bibliometrics for Research Management and Research Evaluation - A Brief Introduction. The Centre for Science and Technology Studies (CWTS) at Leiden University, March 2018
[68] Knowledge, Networks and Nations: Global scientific collaboration in the 21st century. Royal Society Policy document 03/11. Issued: March 2011
[69] Bibliometrics for Research Management and Research Evaluation - A Brief Introduction. The Centre for Science and Technology Studies (CWTS) at Leiden University, March 2018
[70] Bibliometrics for Research Management and Research Evaluation - A Brief Introduction. The Centre for Science and Technology Studies (CWTS) at Leiden University, March 2018

Similarly, older publications have had more time to be cited than more recent publications. On average, older publications, therefore, tend to have received more citations than more recent publications. Again, normalisation can be performed to correct this. Such normalisation is carried out by comparing the number of citations received by a publication to the number of citations received by other publications from the same year.

Of specific note concerning international research collaboration, in most scientific fields, a large majority of publications are co-authored by multiple researchers, often also affiliated to multiple research institutions and residing in multiple countries. This leads to the problem of credit allocation. When a publication is co-authored by multiple research units, how should the credits of the publication be allocated to the different research units? The two most commonly used approaches for addressing the issue of credit allocation are referred to as the full and the fractional counting approach. In the full counting approach, the credits of a publication are fully allocated to each of the co-authoring research units. For instance, in the case of a publication co-authored by three research units, each unit receives 100% of the credits of the publication. In the fractional counting approach, the credits of a publication are fractionally allocated to each of the co-authoring research units. So now, in the case of a publication co-authored by three research units, each unit receives just one-third of the credits of the publication.

Furthermore, there are notable gaps in the coverage of the bibliometric databases. In some cases, this may mean that the official publication figures underrepresent the true extent of scientific activity. For example, many peer-reviewed journals do not appear in the indexing services. Regional, national and local journals in the non-English-speaking parts of the world are often not recognised and, as a consequence, journals, conferences and scientific papers from some countries are not well represented by abstracting services.[71]

Much scientific literature is also produced for non-peer-reviewed publications (and hence not covered by Scopus or Web of Science). Often referred to as 'grey' literature, this can include technical reports from government agencies and NGOs; working papers from research groups or committees; government white papers; conference proceedings and symposia; and a growing level of publication on internet sites. All of these are potentially valuable contributions to the global stock of knowledge, but they are not accounted for in traditional assessments of research output.

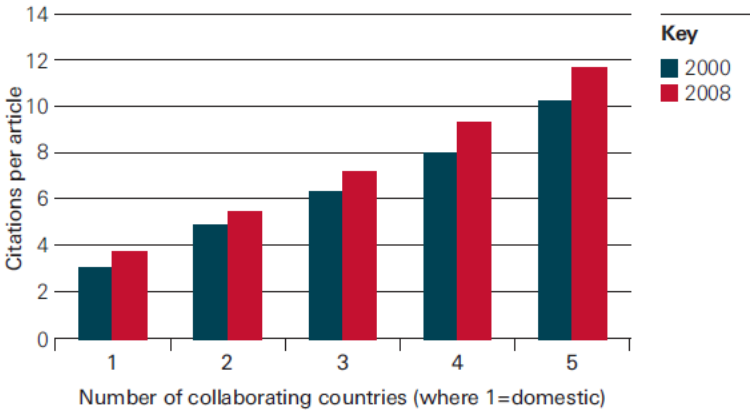
Also, as research output has grown, so have the levels at which researchers cite one another's work.

The Research Team considers that it is clear that bibliometric data alone do not fully capture the dynamics of the changing scientific landscape and may not fully reflect its quality. However, the Research Team notes that they presently offer the only recognised and most robust methodology for doing so on an international basis.

In citation terms, research collaboration is beneficial. For each international author on an article, there is a corresponding increase in the impact of that paper (see Figure 4.3), up to a tipping point of around 10 authors, after which the relative impact of extra country authors is less clear (in part, due to the smaller numbers of articles which are produced with this quantity of countries involved).

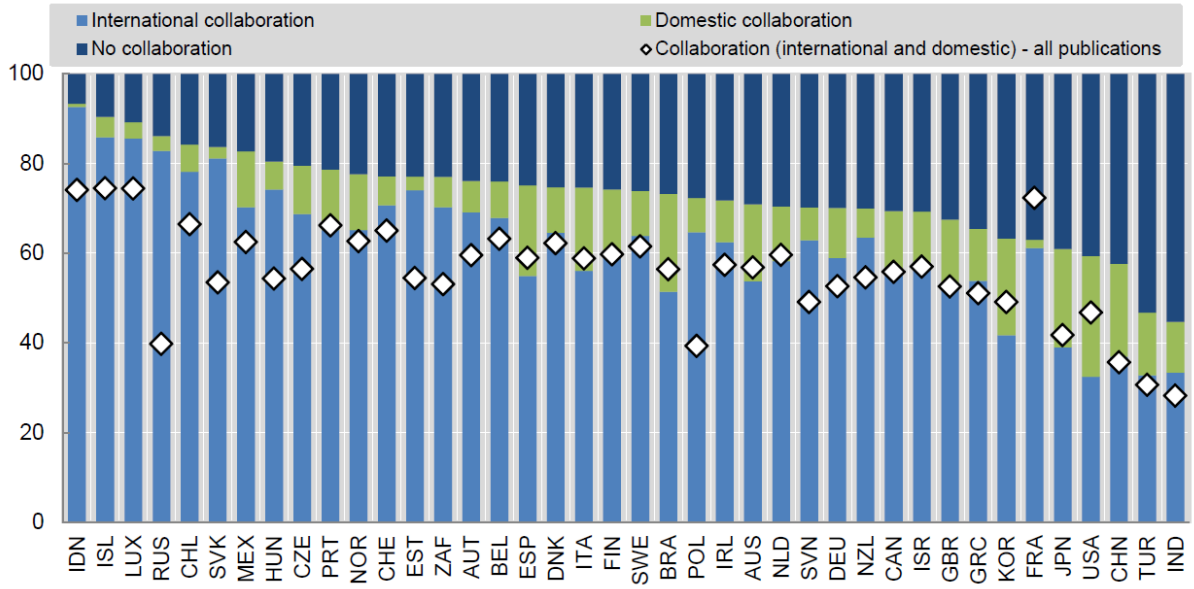
[71] Knowledge, Networks and Nations: Global scientific collaboration in the 21st century. Royal Society Policy document 03/11. Issued: March 2011

Figure 4.3. Citations per article versus the number of collaborating countries[72]



The inclusion of international co-authors on scientific papers has been observed to increase citation rates. Such observations are common across the globe, where the proportion of the world's most highly cited science for most countries is comprised mainly of internationally co-authored papers. Except for Korea, Japan, the United States, China, Turkey and India, more than 50 per cent of the top-cited publications in each comparator country (Figure 4.4) represent international collaborations[73].

Figure 4.4: Top-cited publications, by type of collaboration (2003-11) as a percentage of top-cited and all documents (OECD, 2013)



Nonetheless, **it should be borne in mind that citation impact is not a direct measure of quality**. A multi-authored piece may provide a 'network effect' in that it is seen by more people (perhaps as a result of having multiple international authors) and therefore becomes more cited. This does not necessarily mean it is of higher quality than one which is cited less. However, citation is a commonly used indicator for quality and how well 'used' a piece of research may be.

It is noted that during 2011, Queen's University Belfast (QUB) noted an interesting trend. That is, its publication volume was growing faster than that of its peers, but there was room for improvement in its

[72] Data from Elsevier's Scopus. Featured in Knowledge, Networks and Nations: Global scientific collaboration in the 21st century. Royal Society Policy document 03/11. Issued: March 2011

[73] Measuring the Value of International Research Collaboration - Report Prepared for the Department of Industry and Science (Australian Academy of Humanities, May 2015)

global league table performance. Subsequently, the university commissioned Elsevier to help it to understand the situation. This led to a unique three-year partnership between the two organisations.

QUB set the objective of increasing both citation impact and international reach through the development of institutional partnerships in focus countries. With Elsevier's support, the university sought to embed an understanding of citation indicators into its research strategy development. The objective was to improve the understanding of bibliometrics: what they mean, how they are used, how they drive league table performance and, most importantly, how that information can be made useful for research decision-making.

A resulting strategy has subsequently been rolled out across QUB, helping academics develop specific, evidence-based action plans which collectively contribute to the institution's research strategy. The result has been an innovative approach to informing an institution's research strategy using publication and citation metrics. It is understood that the programme has enabled university faculty to interrogate data, deepen their understanding of methodology, draw out key lessons for enhancing citation impact and create evidence-based action plans that are focused on effecting change at the research group level.[74]

4.4 Bibliometric Data – Use in the European Innovation Scoreboard

The annual European Innovation Scoreboard (EIS) provides a comparative assessment of the research and innovation performance of the EU Member States and selected 'Third Countries' and the relative strengths and weaknesses of their research and innovation systems. It helps countries assess areas in which they need to concentrate their efforts to boost their innovation performance.

The EIS measurement framework distinguishes between four main types of indicators and ten innovation dimensions, capturing in total 27 different indicators.

1. *Framework conditions* capture the main drivers of innovation performance external to the firm and cover three innovation dimensions: Human resources, Attractive research systems, as well as an Innovation-friendly environment.
2. *Investments* capture public and private investment in research and innovation and cover two dimensions: 'finance and support' and 'firm' investments.
3. *Innovation activities* capture the innovation efforts at the level of the firm, grouped in three innovation dimensions: Innovators, Linkages, and Intellectual assets.
4. *Impacts* cover the effects of firms' innovation activities in two innovation dimensions: employment and sales impacts.

Of note, and as illustrated below (in bold) three of the indicators use bibliometric data, which is extracted by Science-Metrix from Scopus, a large abstract and citation database of peer-reviewed literature from Elsevier.

Table 4.3: Measurement framework of the European Innovation Scoreboard

Indicator	Innovation Dimension	Sub-Indicators
Framework conditions	Human resources	1 New doctorate graduates 2 Population aged 25-34 with tertiary education; 3 Lifelong learning
	Attractive research systems - measures the international competitiveness of the science base	**4 International scientific co-publications** **5 Top 10% most cited publications** 6 Foreign doctorate students
	Innovation-friendly environment	7 Broadband penetration 8 Opportunity-driven entrepreneurship

[74] Elsevier and Queen's University Belfast: a metrics-driven approach to research success. Featured in State of the Relationship report 2014. National Centre for Universities and Business.

Table 4.3: Measurement framework of the European Innovation Scoreboard		
Indicator	**Innovation Dimension**	**Sub-Indicators**
Investments	Finance and support	9 R&D expenditure in the public sector 10 Venture capital expenditures
	Firm investments	11 R&D expenditure in the business sector 12 Non-R&D innovation expenditures 13 Enterprises providing training to develop or upgrade the ICT skills of their personnel
Innovation activities	Innovators	14 SMEs with product or process innovations 15 SMEs with marketing or organisational innovations 16 SMEs innovating in-house
	Linkages	17 Innovative SMEs collaborating with others **18 Public-private co-publications** 19 Private co-funding of public R&D expenditures
	Intellectual assets	20 PCT patent applications 21 Trademark applications 22 Design applications
Impacts	Employment impacts	23 Employment in knowledge-intensive activities 24 Employment fast-growing enterprises of innovative sectors
	Sales impacts	25 Medium and high-tech product exports 26 Knowledge-intensive services exports 27 Sales of new-to-market and new-to-firm product innovations

Through the EIS, the performance of EU national innovation systems is measured by the Summary Innovation Index, which is a composite indicator obtained by taking an unweighted average of the 27 indicators. Based on the most recent year's results, the Member States fall into four performance groups:[75]

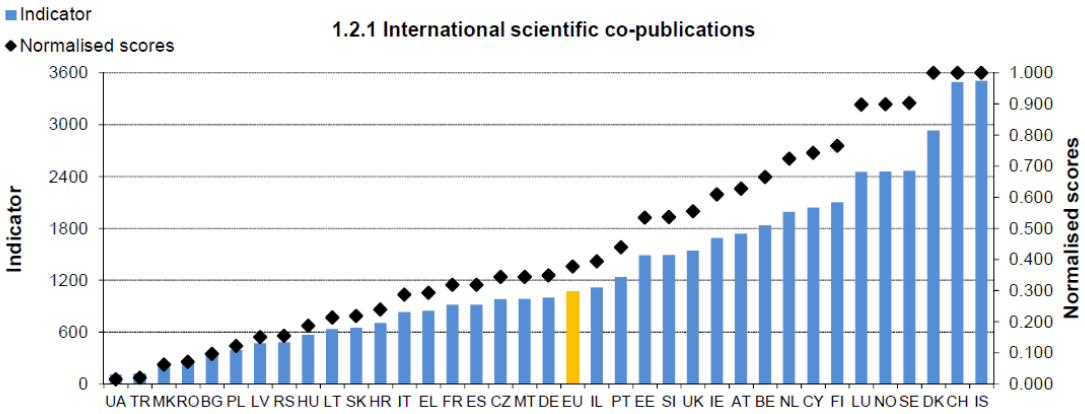
1 The first group of **Innovation Leaders** includes 4 Member States where performance is above 120% of the EU average. The Innovation Leaders are Denmark, Finland, the Netherlands, and Sweden[76];
2 The second group of **Strong Innovators** includes 8 Member States with a performance between 90% and 120% of the EU average. Austria, Belgium, Estonia, France, Germany, Ireland, Luxembourg, and the United Kingdom are Strong Innovators;
3 The third group of **Moderate Innovators** includes 14 Member States where performance is between 50% and 90% of the EU average. Croatia, Cyprus, Czechia, Greece, Hungary, Italy, Latvia, Lithuania, Malta, Poland, Portugal, Slovakia, Slovenia, and Spain belong to this group;
4 The fourth group of **Modest Innovators** includes 2 Member States that show a performance level below 50% of the EU average. This group includes Bulgaria and Romania.

As illustrated above, two of the three indicators that relate to the 'attractiveness of the research system' and which seek to measure the international competitiveness of the science base refer to bibliometric data. How this data is interpreted is explored further below:

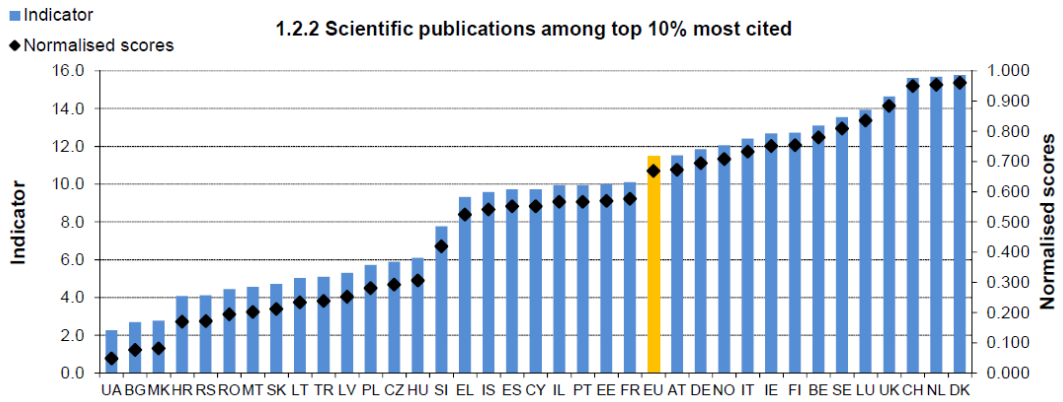
[75] European Innovation Scoreboard 2019
[76] NB Switzerland, which is not an EU member, is the overall Innovation Leader in Europe, outperforming all EU Member States.

Indicator	Interpretation
International scientific co-publications per million population	The numerator utilised is the number of scientific publications with at least one co-author based abroad (where abroad is non-EU for the EU28). Under this indicator international scientific co-publications are a proxy for the quality of scientific research as collaboration has been found to increase scientific productivity.
Scientific publications among the top-10% most cited publications worldwide as a percentage of total scientific publications of the country	The numerator utilised is the number of scientific publications among the top-10% most cited publications worldwide. The indicator is considered to be a measure of the efficiency of the research system, as highly cited publications are assumed to be of higher quality.

Concerning the first indicator (International scientific co-publications per million population), the EIS found that there is a high spread in performance, with Switzerland and Iceland having close to 3,500 international scientific co-publications per million population, and three countries having less than 250 international scientific co-publications per million population.[77]



Concerning the second indicator (Scientific publications among the top-10% most cited publications worldwide as a percentage of total scientific publications of the country), the EIS found that about 11.5% of the scientific publications in the EU are among the top-10% most cited publications worldwide. The best performance is observed for Denmark, the Netherlands and Switzerland, where more than 15% of publications are among the top-10% most cited publications worldwide. [78]



[77] Performance for 2018 or most recent year available. Statistical outliers: Denmark (+), Iceland (+) and Switzerland (+). European Innovation Scoreboard 2019
[78] Performance for 2016 or most recent year available. European Innovation Scoreboard 2019

Of note, the European Innovation Scoreboard places importance upon how the research base links with the business base. One of the three indicators under 'linkages' relates to research collaboration between the private and public sector, and uses bibliometric data as its measurement tool, as noted below:

Indicator	Interpretation
Public-private co-publications per million population	The numerator utilised is the number of public-private co-authored research publications. The definition of the "private sector" excludes the private medical and health sector. Publications are assigned to the country/countries in which the business companies or other private sector organisations are located. This indicator captures public-private research linkages and active collaboration activities between business sector researchers and public sector researchers resulting in an academic publication.

The 2019 EIS included a forward-looking analysis of EU innovation performance discussing more recent developments, trends, and expected changes. The analysis suggested that EU innovation performance will continue to increase for most indicators, leading to an increase in overall EU innovation performance compared to 2011 from 109 in 2018 to 114 in two years. Concerning the two bibliometric indicators of 'research system attractiveness' the report indicates that the EU's performance on:

- International scientific co-publications will increase by between five and 10 per cent; whilst
- Scientific publications among the top-10% most cited will increase more moderately between one and five per cent.

Table 4.4: Changes in two years in EU innovation performance

Attractive research systems	Current Score	Expected change in two years	Methodology for estimating Expected change
International scientific co-publications	1070.4	5-10% increase	Linear regression
Most-cited scientific publications	11.5	1-5% increase	Linear regression

4.5 International Comparison of the UK Research Base

Over recent years, the UK Government has published several reports that compare the UK's research base with those from a range of countries and international benchmarks. Comparators include all G7 countries (Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States), as well as Brazil, China, India, Russia, and South Korea. The EU 27, the OECD and the world are also included as benchmarks.

The data has primarily been drawn from Scopus, an abstract and citation database provided by Elsevier and is made up of several different bibliometric indicators.[79] The database covers multi-lingual and global peer-reviewed literature, published in journals, book series and conference proceedings.[80] The most recent was published during 2019, with earlier publications in 2013 and 2016.[81]

The following sub-sections consider key findings from the international comparative studies.

[79] Other key data sources included the OECD (R&D expenditure and human capital) and the World Intellectual Property Organisation (WIPO) for patent information.

[80] The database is drawn from approximately 5,000 publishers and 70 million core records. For further information, see: https://www.elsevier.com/solutions/scopus/how-scopus-works/content. Scopus uses a sophisticated author-matching algorithm to precisely identify articles by the same author. The Scopus Author Identifier gives each author a unique ID and groups together all the documents published by that author, matching alternate spellings and variations of the author's last name and distinguishing between authors with the same surname by differentiating on data elements associated with the article (such as affiliation, subject area, co-authors, and so on). This is enriched with manual, author-supplied feedback, both directly through Scopus and also via Scopus' direct links with ORCID (Open Researcher & Contributor ID).

[81] Please note that not all indicators were tracked across each publication (within the published information), so some information presented was not available for the period to 2018.

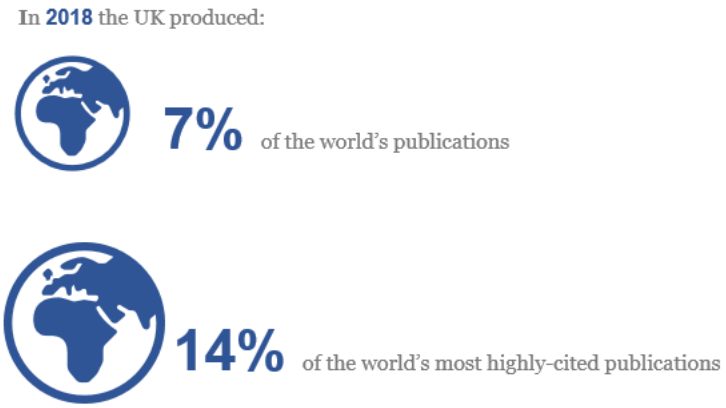
4.5.1 Publication Shares

The UK is considered to be a well-rounded research nation, with substantial activity across all major research fields (albeit activity in Engineering, Physical Sciences and Mathematics are below the global baseline[82]).

In 2018, the UK published 212,876 publications, an 11% increase on the 191,626 produced in 2014 (representing a compound annual growth rate of 2.66%). This was the third-highest number of publications among comparator countries, behind China (606,219) and the US (686,263).[83]

The US, China and the UK have been the three largest producers of publications each year since 2004 when China overtook Japan. In 2018, the US produced 22%, China 19%, and the UK 7% of the world's publications. For context, the UK's population is 0.87% of the total world population.

Figure 4.5: The UK's Publication Shares 2018



During the four year-period 2010-2014, the UK's four constituent countries broadly maintained their relative shares of publications and citations, with some slight variations (see Figures 4.6 and 4.7 respectively), albeit England and Scotland showed higher percentage shares of citations compared to shares of articles. The number of citations received by an article from subsequently-published articles is broadly considered to be an indicator of the quality or importance of the cited research.

Figure 4.6 - Share of UK articles for constituent countries, 2010-2014[84]

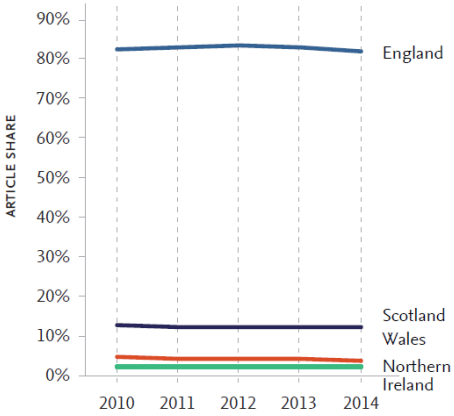
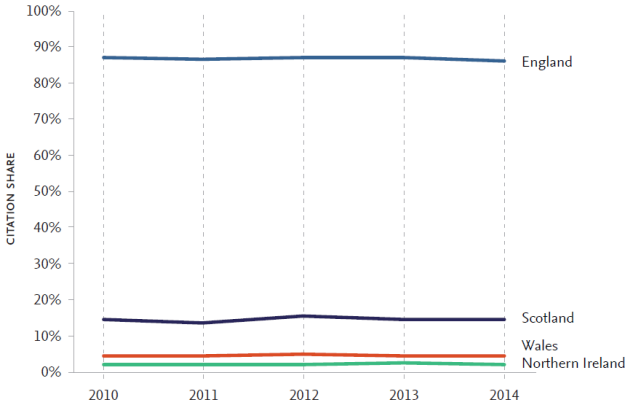


Figure 4.7 - Share of UK citations by constituent country 2010-2014.

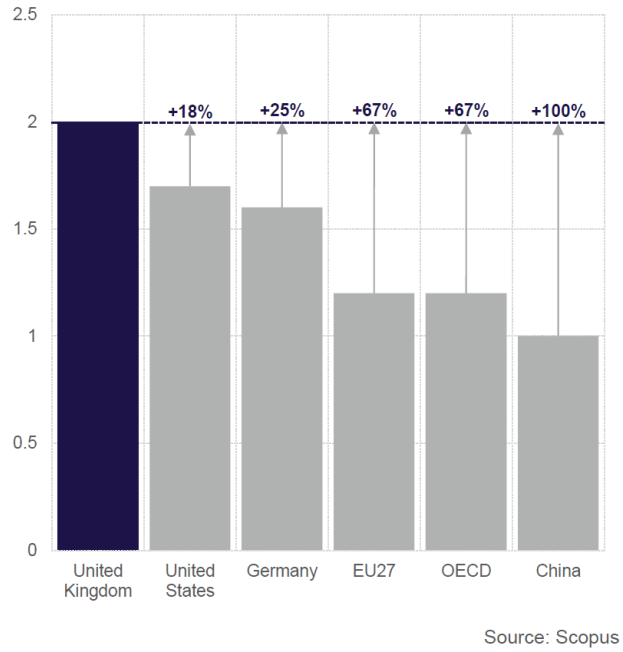


[82] The Activity Index is defined as a country's share of its total article output across subject field(s) relative to the global share of articles in the same subject field(s).
[83] Articles, reviews, conference papers, and books are all classed as publications.
[84] Shares may not add to 100% owing to co-authorship of some articles between constituent countries and not all UK articles containing sufficient publishing information to map to the constituents.

Highly-cited publications are classed as those in the top-cited 1% of all publications. Data has been field-weighted to account for differences in citation accrual over time (older publications have more time to be cited than recent publications), as well as differences in citation rates across disciplines and types of document. In 2018, the UK had a 14% share of the world's most highly-cited publications, which is double its overall article share.

The three countries with the largest shares of the world's most highly-cited publications are the US (37%), China (20%), and the UK (14%). The US and China both have large shares of the world's highly-cited publications partly because they produce significantly more publications overall than other countries. Figure 4.8 adjusts for this size effect and shows the proportion of a comparator's research that is among the world's most highly-cited. Of note, UK publications are more likely to be highly-cited. In 2018, the UK had 2% of its publications among the most highly-cited in the world. This was double China's share (1%), over two thirds higher than both the EU and OECD's 1.2% shares, and a quarter higher than Germany's 1.6%. Since 2010, the UK has had a larger proportion of its research among the most widely cited in the world than any other comparator.

Figure 4.8: Share of own research among the world's most highly-cited publications. 2018 % [85]



[85] Figure 4.8 also shows the percentage increase required for comparator to equal UK

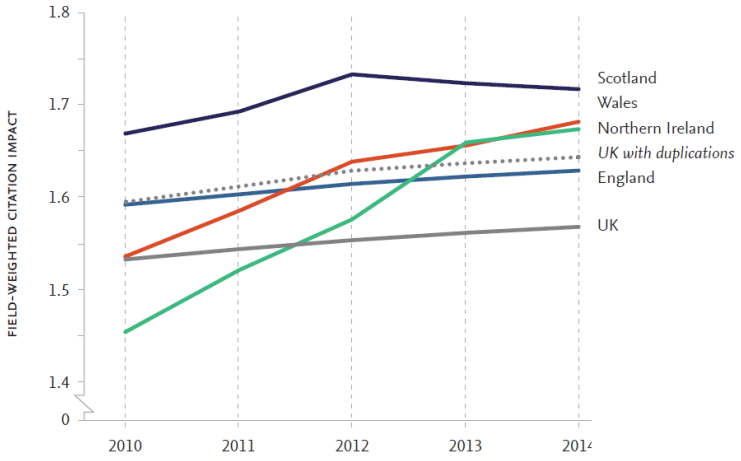
4.5.2 Citation Impact

Field-weighted citation impact (FWCI)[86], an established measure of research impact, is a bibliometric indicator that can be used to provide a meaningful analysis of research performance across countries of different sizes. It is considered to overcome the challenges in data analysis created by the accumulation of citations over time and fields of study that use different citation practices.

In 2018, the UK's FWCI was the highest in the G7 and higher than the report's comparator countries.[87] This has remained the case since 2007 when the UK initially overtook the US to become the highest-ranked comparator. With a value of 1.56 in 2018, the UK's FWCI remains over 50% higher than the world average and 30% higher than the EU 27 average.

A look at the UK's FWCI in the four constituent countries during the period 2010-2014 shows increasing values for all constituents except Scotland, which showed a decline after peaking in 2012 (see Figure 4.9). The field-weighted citation impact for all the nations was consistently higher than the UK overall from 2012. This is due to two reasons: the first being that collaborations between constituent nations are of particularly high impact, and secondly, these high impact collaborations are included when calculating the international collaboration FWCI for the constituent nations. However, these collaborations are not included in the UK's international collaboration publication corpus as collaborations between constituent nations are not considered international collaborations, but rather national collaborations.

Figure 4.9 - UK field-weighted citation impact, 2010-2014, per constituent country, with each contributor to inter-constituent co-authored articles receiving credit for those articles.



The solid red line denotes the UK's FWCI over the period and is calculated by counting each publication once. The dashed grey line denotes the UK's FWCI over the period but is based on multiple counting of articles, once for each of the constituent countries that contributed to it.

Of note, Northern Ireland's FWCI increased the most between 2010 and 2014, ending the reporting period just below that of Wales.

[86] Field-weighted citation impact (FWCI) is a measure of how much impact a set of publications have had. It compares the actual number of citations received by publications with the average number of citations a publication published in the same year, discipline, and format (book, article, review, conference paper) receives. A value of 1.0 represents the world average. The overall FWCI for a set of publications, in this case all of the UK's 2018 publications, is therefore the average of the FWCI for each specific UK publication.

[87] However, many smaller countries, such as Denmark, Switzerland, the Netherlands, and Belgium, have much higher FWCI than the UK and the other comparators.

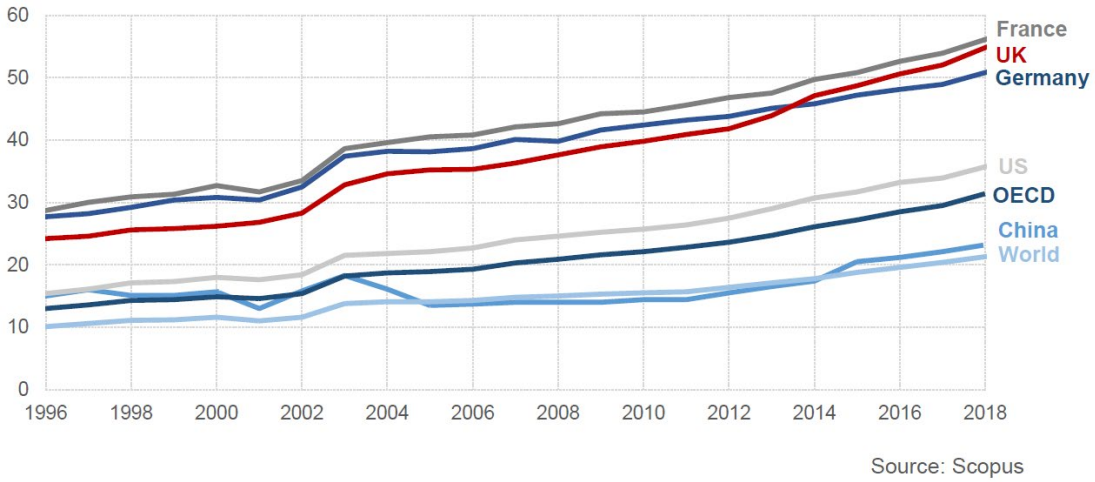
4.5.3 International Collaboration

The UK is a key partner for global research collaboration and researcher mobility. International research collaboration and international researcher mobility are interrelated and interdependent and shaped by collaborative interactions that take place across multiple institutions, borders, continents, and time zones. The UK's most prolific international partnerships are associated with greater FWCI per article, relative to the overall international collaborative output of either the UK or its partner countries, including the Newton Fund partners[88].

It is generally expected that countries that exhibit high levels of research collaboration also have high levels of researcher mobility, and the UK is no exception. As a whole, UK researchers are highly mobile internationally, although two groups are likely to be less mobile: those with short publication histories, less than 10 years since their first appearance as an author, who are, therefore, still establishing their networks; and women researchers, at any stage in their careers, are likely to be less mobile than men researchers. UK researchers are also mobile across sectors, both nationally and internationally, with the Business Enterprise sector gaining most researchers from UK academia and international industry. Although the UK's level of growth in overall researcher numbers generally is low and slowing down, the growth rate of UK PhD graduate numbers is high and increasing faster than many comparators.

Figure 4.10 and Table 4.5 (overleaf) show that countries across the world have seen the proportion of their publications that resulted from international collaboration rise over the past two decades.[89] In 2018, 21% of the world's publications were internationally co-authored, compared with 11% in 1998. **Since 2016, the UK has seen over half its publications result from international collaboration each year**. In 2018, 55% of UK publications were the result of international collaboration. This makes the UK the second most internationally collaborative country in the G7, second to France (56%) and significantly higher than the OECD average (31%).

Figure 4.10: Share of publications that resulted from international collaboration (%)



[88] The Newton Fund builds research and innovation partnerships with 17 active partner countries to support their economic development and social welfare, and to develop their research and innovation capacity for long-term sustainable and equitable growth. By fostering world-class collaborations between academics and innovators in the UK and developing countries it aims to address critical development challenges including poverty, access to healthcare, climate change, and peace and security.

[89] For a publication to have resulted from international collaboration it must have been co-authored by at least two researchers affiliated to institutions in different countries

Research indicates that the US is the UK's top collaborative research partner. Of all the research published by UK researchers during the period 2005-2014, 12% was with a US co-author. However, the USA's total research output is much greater than that of the other countries. To account for this fact, the Royal Society undertook analysis applying Salton's cosine, a method that can be applied to normalise the data by the volume of output for both partners, giving a size-independent indicator of the strength of collaboration. Once this was applied, **the strength of collaboration between the UK and Germany was shown to be greater than that between the UK and the USA**.[90]

Table 4.5: International collaboration %

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Brazil	31	29	29	28	28	25	26	27	27	27	24	24	24	23	23	24	24	26	28	29	31	32	33
Canada	29	30	31	31	31	31	32	37	38	38	38	39	40	41	42	42	43	45	47	48	50	51	53
China	15	16	15	15	16	13	16	18	16	14	14	14	14	14	14	14	16	17	17	21	21	22	23
EU27	23	24	25	25	26	25	26	30	31	31	31	32	32	33	33	34	35	36	37	38	40	40	42
France	29	30	31	31	33	32	34	39	40	41	41	42	43	44	45	46	47	48	50	51	53	54	56
Germany	28	28	29	30	31	30	33	37	38	38	39	40	40	42	42	43	44	45	46	47	48	49	51
India	14	14	15	14	15	14	15	17	18	18	18	18	17	17	17	16	16	16	16	16	16	17	18
Italy	24	26	28	28	28	28	29	33	34	35	35	36	36	37	38	39	40	40	42	43	45	46	48
Japan	13	14	14	14	14	15	16	19	19	20	20	21	22	22	22	23	24	24	25	26	27	28	30
OECD	13	14	14	14	15	15	15	18	19	19	19	20	21	22	22	23	24	25	26	27	29	30	31
Russia	21	23	24	25	26	25	26	30	30	31	33	33	30	30	28	28	29	28	26	25	23	23	23
South Korea	24	22	23	21	21	20	23	25	25	26	25	25	25	25	25	26	26	26	26	26	27	27	29
United Kingdom	**24**	**25**	**26**	**26**	**26**	**27**	**28**	**33**	**35**	**35**	**35**	**36**	**38**	**39**	**40**	**41**	**42**	**44**	**47**	**49**	**51**	**52**	**55**
United States	15	16	17	17	18	18	18	22	22	22	23	24	25	25	26	26	28	29	31	32	33	34	36
World	10	11	11	11	12	11	12	14	14	14	14	15	15	15	16	16	16	17	18	19	20	20	21

[90] UK research and the European Union - The role of the EU in international research collaboration and researcher mobility. The Royal Society

4.5.4 Human Capital

A critical factor in determining a country's capacity to conduct research is the total number of researchers working in higher education, business, government or charity or other non-profit contexts. In 2014, the UK had 273,560 researchers according to OECD data (expressed as full-time equivalents rather than as headcount), equating to 4.1% of the global researcher population. Normalised per capita, the UK had 4.3 researchers per thousand population, ranking fifth among the comparators. South Korea and Japan had the highest number of researchers per thousand of the population at 6.9 and 5.4 respectively. China and Italy had the lowest at 1.1 and 2.0 respectively.

The pipeline of research talent is one that flows through higher education and into a research career, but which narrows as individuals pass through and siphon off into careers outside research. The culmination of formal training for researchers who hope to go on to play a leading role in the conception or creation of new knowledge is typically a higher research degree, which would be a PhD in most research fields. The number of PhD graduates produced from a national research system each year, therefore, may be used as an indicator of the volume of new talent generated within that country, irrespective of the national origin or destination of those graduates.

The UK's number of PhD graduates increased to 21,240 in 2014, according to the data from the Higher Education Statistics Agency (HESA). The UK growth of PhD graduates per thousand population was 2.4% per annum (2010-2014), which was in line with the US (2.2%), Canada (2.6%) and Germany (2.9%).

In the period 1996-2015, UK active researchers were highly mobile internationally, with over 72% of active researchers having published at least one article under a non-UK affiliation(s).[91]

Nearly half of the UK active researcher population is transitory. The Transitory group (i.e., those researchers who either stayed in the UK for less than two years or temporarily stayed outside it for a similar period, as indicated by the countries listed in their published articles) accounted for nearly half of all the active researchers. These researchers were, on average, the most productive, relatively higher in terms of seniority, and associated with high field-weighted citation impact.

Researchers in all four of the UK's constituent countries are highly mobile, with Wales having the lowest share of non-migratory researchers and the highest share in the transitory group. Each country has a net outflow of researchers, with Northern Ireland and Wales having the highest rates.[92]

[91] The measurement of international researcher mobility in the published literature is complicated by the difficulties involved in teasing out long-term mobility from short-term mobility (such as doctoral research visits, sabbaticals, secondments, etc.), which might be deemed instead to reflect a form of collaboration. In the comparative study, researchers who stayed overseas for 2 years or more were considered migratory, and were further subdivided into those where the researcher remained abroad or where they subsequently returned to their original country. Researchers who stayed overseas for less than 2 years were deemed transitory, and were also further subdivided into those who mostly published under a UK or a non-UK affiliation. Since author nationality is not captured in article or author data, authors are assumed to be from the country where they first published (for migratory mobility) or from the country where they published the majority of their articles (for transitory mobility). In individual cases, these criteria may result in authors being assigned migratory patterns that may not accurately reflect the real situation, but such errors are assumed to be evenly distributed across the groups and so the overall pattern remains valid. Researchers without any apparent mobility based on their published affiliations were considered non-migratory.

[92] Compared to the UK, the constituent countries have a lower proportion of non-migratory researchers and higher proportion in the outflow, inflow and net outflow categories,. This is because of migration of researchers across UK constituent countries.

Table 4.6: Share of active researchers in mobility groups for UK constituents, 1996-2015[93]					
UK constituent	**Non-migratory**	**Transitory**	**Outflow**	**Inflow**	**Net Outflow**
Wales	11.3%	59.7%	17.1%	11.9%	5.2%
Scotland	13.1%	57.3%	17.3%	12.3%	5.0%
England	22.1%	51.8%	15.5%	10.7%	4.8%
Northern Ireland	16.3%	54.7%	17.1%	11.8%	5.3%

4.5.5 Knowledge Exchange

The UK has a robust system of cross-sector knowledge exchange. The UK's income derived from intellectual property (IP) has grown as a percentage of total research resources since 2010, although the number of spin-off companies reduced significantly. UK academic and corporate users increasingly are downloading articles from each other's sectors, further strengthening an already robust cross-sector knowledge exchange within the country. Internationally, the UK's share of global patents has risen as a result of an increase in the number of its patents in force, and its share of global patents citing UK articles is similar to its global publication share. However, the UK's share of global patents in force ranked third lowest amongst the comparator countries.

4.5.6 Summary

The UK punches above its weight as a research nation, despite the pressures placed upon it and other research-intensive countries by emerging nations. In 2014, the UK represented just 0.9% of the global population, 2.7% of R&D expenditure and 4.1% of researchers, while accounting for 10.7% of citations and 15.2% of the world's most highly-cited articles.

The UK ranks first amongst its comparator countries by field-weighted citation impact (FWCI), an indicator of research impact and quality.

The UK's share of global patents has risen as a result of an increase in the number of its patents in force, and the share of global patents citing UK articles is similar to its global publication share.

The UK remains well-rounded across most fields of research and is a highly productive research nation concerning articles and citation outputs per researcher and unit of R&D expenditure. A sustained upward trend in UK research productivity may be correlated to its continued increase in international research collaboration, an activity that is generally associated with greater citation impact than research co-authored institutionally or nationally, while its national inputs are broadly stable in relative terms.

Table 4.7 provides a summary of the UK's research performance during the 5 years 2014-2018.

Table 4.7: UK 5-year summary					
	2014	**2015**	**2016**	**2017**	**2018**
Field-Weighted Citation Impact	1.58	1.58	1.61	1.58	1.56
Total publications	191,626	196,581	202,490	209,676	212,876
Share of total world publications (%)	7	7	7	7	7
Share of the world's most highly-cited publications (%)	14	15	16	15	14
Highly-cited articles as a share of domestic publications (%)	2	2	2	2	2
Total international publications	90,328	95,775	102,479	109,081	116,749
International Collaboration (%)	47	49	51	52	55

[93] International Comparative Performance of the UK Research Base 2016 - *A report prepared by Elsevier for the UK's Department for Business, Energy & Industrial Strategy (BEIS)*

However, while the UK leads in many worldwide rankings, the world is changing. There are growing indications that the UK is losing ground in the research leadership stakes and may not be able to sustain its position as a world-leading research nation in the long term. Despite punching above its weight in delivering increasingly high-quality research outputs on broadly stable or decreasing R&D expenditure and human capital inputs, the UK, along with other research-intensive nations, including the US, are seeing their global shares in key research indicators eroded by other countries.

Italy now has more articles per researcher than the UK and all other comparator countries; it has also increased its share of international collaboration and its field-weighted citation impact is set to rise above both the UK and Canada if current trends are maintained. However, the biggest pressure on the UK and others continues to be China. The quality of China's research in terms of field-weighted citation impact, alongside an increased share in the number of publications, has improved. As China and other emerging nations succeed in their desire to emulate and even surpass the research performance of countries like the US and the UK, their shares will naturally become larger while the erstwhile powerhouses see theirs shrink.

However, the Research Team considers that it is important to note that if over half of the UK's output is shared with other leading research economies, and if that half is the part of research output that attracts most citations, then metrics comparing research performance with other nations could be considered to be seriously compromised. That is, more than half the output used to profile the UK research base belongs, at least in part, to the countries with which the UK is compared. When we evaluate UK research publications, and particularly when we look at the most highly-cited research featured in UK government reports, then a large part of what we see is research produced by and in collaboration with the USA, Canada, European partners, Australia, China and others. Less than half the volume, and much less than half the citations, are attributable exclusively to the UK research base.

Bibliometric comparison (the analysis of publications and citations) can therefore no longer claim to measure differences between countries because the most frequently cited research comes out of a shared pot of networked projects. What applies to countries also applies equally to universities.[94]

Whilst universities such as Ulster University and Queen's University Belfast are unquestionably producing excellent research, much of their publication profile, and citation data that feeds into world university rankings is shared with other institutions in the UK or abroad. This means that such indicators are not capturing a distinct attribute of a single institution. Indeed, the more active, high profile and internationally engaged an institution is, the wider off the mark will be a quantitative assessment using limited bibliometric data alone.

[94] The Implications of International Research Collaboration for UK Universities, Digital Science/Universities UK, February 2016

4.6 The Research Excellence Framework

Within the UK, it is noted that the impact and excellence agenda has been developing rapidly with the introduction of the Research Excellence Framework (REF) in 2014.[95] The next exercise was conducted in 2021.[96] The REF is undertaken by the four UK higher education funding bodies: Research England, the Scottish Funding Council (SFC), the Higher Education Funding Council for Wales (HEFCW), and the Department for the Economy, Northern Ireland (DfE).

The REF is a process of expert review, carried out by expert panels for each of the 36 subject-based units of assessment (UOAs)[97], under the guidance of four main panels. Expert panels are made up of senior academics, international members, and research users.

The overall quality profile awarded to each submission is derived from a sub-profile for each of the three elements of the assessment, which are weighted as follows:

- The quality of research **outputs** (e.g. publications, performances, and exhibitions). This counts for 65 per cent of the assessment;
- The **impact** of the research beyond academia. This counts for 20 per cent of the assessment. The impact was a new feature in the REF 2014; and
- The research **environment** that supports research. This counts for 15 per cent of the overall results.

Impact was defined as *'an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia'*.[98]

4.7 The NI Universities

The Northern Ireland universities posted a very strong performance in the UK-wide Research Excellence Framework, with over 70% of the research activity submitted by Queen's University and Ulster University classed as 'world-leading' or 'internationally excellent'. Nonetheless, whilst the Department for the Economy, which has both policy and funding responsibility for the region's Higher Education sector, strongly welcomed this achievement as further vindication of its considerable investment in the local research base, it attaches at least as much importance to the successful exploitation of research - for the benefit of local businesses and the wider community, as well as for attracting inward investment.

However, it is important to recognise that the case studies submitted by universities as part of the REF assessment are subject to certain limitations as an analytical tool. Firstly, case studies are a skewed sample, intended by institutions to capture the best examples of impact from their research by disciplinary area. The level of impact certainly could not be extrapolated to the average research project. Other elements of the assessment process, such as the need to provide corroborating evidence for impact, may also have skewed the selection of case studies for inclusion in the dataset. The case studies are also produced with a particular disciplinary review panel in mind, and as such may be tailored for that audience. They are also limited by the data-collection capabilities of institutions. For example, where researchers have moved institutions, the impacts may have been more difficult to track and collect evidence on (since case studies remain with the institution, rather than travelling with the researcher).

[95] REF replaced the Research Assessment Exercise (RAE), a peer review based benchmarking exercise which measured the relative research strengths of university departments.
[96] NB While it will still be referred to as REF 2021, the results are not expected until April 2022 as an extension for submissions was provided due to the COVID-19 pandemic.
[97] Of the 36 UOAs, 11 were supported by Elsevier Scopus data. In addition to citation data, Scopus was required to provide the core UOAs with contextual information (i.e. average citations and centile citation thresholds) within each field. Of note, it is understood for example, that Queen's University used Scopus data to support its REF submission. In addition, the Research Team understands that researchers within QUB utilise Scopus data to update their CVs on an annual basis and also to produce reports and feedback on research grant projects. Source: Embracing the REF - Supporting research excellence in the UK and beyond, Elsevier Research Intelligence, 2014.
[98] https://re.ukri.org/research/ref-impact/

Finally, the case studies provide a snapshot in time, rather than evidence of impacts emerging over particular timelines.[99]

It is noted that the REF's consideration of impact is not solely on innovation and regional economic development but on broader socio-economic impact. Appendix VI provides further information on REF.

Of note, the benefits of international collaboration apply at all stages of research and innovation, from blue skies research to commercialisation.[100] Discussion with both NI universities indicates that they appear to be substantially engaged in international collaborative research activities. However, it is not clear what proportion of this activity is placed at the various points on the TRL scale:

TRL 1-3 = Fundamental Research;
TRL 4-6 = Industrial Research;
TRL 7-9 = Experimental Development.

This creates a risk that insufficient attention and focus may be being placed on addressing the so-called 'Valley of Death' (i.e. TRLs 4 through to 7, where neither academia nor the private sector typically prioritises investment). Although, it is noted that the US-Ireland R&D Partnership's Centre-to-Centre (C2C) mechanism seeks, in part, to address this risk by encouraging academia to work with industry partners.

As discussed in Section 1.3, it is widely recognised that many technologies, albeit promising, finish their maturity journey before deployment. To bridge the valley of death, collaborative efforts are often required. However, conflicts often emerge between academia and industry. Traditional collaborative conflicts between the two include confidentiality, publishing, IP rights and ownership. The mindsets and research foci of the two institutions can often be quite different. Consequently, if generating economic value from basic R&D efforts is a goal, sustained efforts to advance university innovations are needed. Building bridges between university researchers and businesses is critical for knowledge transfer.

4.8 Key Observations

Key observations arising from the review of information relating to NI's performance in international research collaboration include:

- In 2018, £794 million was spent on R&D by Businesses, Higher Education and Government in Northern Ireland. Of the £794m, 69.2% was spent by Businesses, 27.9% by the Higher Education sector and 2.9% by Government departments. As a whole, little information is available as to the extent to which the R&D that is undertaken is on an internationally collaborative basis. However, taken together, EU and other overseas funding accounted for 10% (£22.3m) of HERD funding in NI during 2018. This compares with 17.9% (£1,562m) of overall HERD activity in the UK during 2018. Whilst HERD represents only one part of overall R&D expenditure, this may indicate that R&D activity in NI is less internationally collaborative than (on average) other areas of the UK.
- Given the absence of specific information relating to NI's performance in international research collaboration, the Research Team has instead, for the most part, considered the overall UK performance, and relevant indicators therein.
- Traditionally, global scientific output has been measured through the analysis of published papers in peer-reviewed journals. Typically, individual articles are abstracted and collected onto databases which are then searchable by their users, usually through a subscription. These services provide access to information about titles, authors, abstracts, keywords and references for thousands of journal articles each year. These data are used to assess the quality of research and, through its use as measured by citations, its impact - recognition by an author's peers is considered to indicate that

[99] Evidence synthesis on measuring the distribution of benefits of research and innovation, RAND Europe on behalf of the Royal Society, 2018
[100] 'The Future of UK International Research and Innovation Collaboration' - Letter to the Prime Minister, the Council for Science and Technology, 30 October 2018.

the scientific community values the work that has been published. However, the use of bibliometric data is associated with a variety of complications. For example, of specific note concerning international research collaboration, in most scientific fields, a large majority of publications are co-authored by multiple researchers, often also affiliated to multiple research institutions and residing in multiple countries. This leads to the problem of credit allocation. When a publication is co-authored by multiple research units, how should the credits of the publication be allocated to the different research units?

- Of interest, in citation terms, research collaboration is beneficial. The inclusion of international co-authors on scientific papers has been observed to increase citation rates. Such observations are common across the globe, where the proportion of the world's most highly cited science for most countries is comprised mainly of internationally co-authored papers.
- However, it should be borne in mind that citation impact is not a direct measure of quality. A multi-authored piece may provide a 'network effect' in that it is seen by more people (perhaps as a result of having multiple international authors) and therefore becomes more cited. This does not necessarily mean it is of higher quality than one which is cited less. Nonetheless, citation is a commonly used indicator for quality and how well 'used' a piece of research may be.
- Ultimately, the Research Team considers that bibliometric data alone do not fully capture the dynamics of the changing scientific landscape and may not fully reflect its quality. However, such data presently offers the only recognised and most robust methodology for doing so on an international basis.
- Concerning such measurement, the annual European Innovation Scoreboard (EIS) provides a comparative assessment of the research and innovation performance of the EU Member States and selected 'Third Countries' and the relative strengths and weaknesses of their research and innovation systems. Using such data, over recent years, the UK Government has published several reports that compare the UK's research base with those from a range of countries and international benchmarks. This research has, to some extent, but not consistently, considered the comparative performance of each of the four UK jurisdictions. Points of note include:

    - The UK punches above its weight as a research nation, despite the pressures placed upon it and other research-intensive countries by emerging nations.
    - In 2018, the UK accounted for 7% of the world's publications. During that year, the UK published 212,876 publications, an 11% increase on the 191,626 produced in 2014 (representing a compound annual growth rate of 2.66%). This was the third-highest number of publications among comparator countries, behind China (606,219) and the US (686,263).
    - In 2018, the UK had a 14% share of the world's most highly-cited publications, which is double its overall article share. Highly-cited publications are classed as those in the top-cited 1% of all publications.
    - During the four year-period 2010-2014, the UK's four constituent countries broadly maintained their relative shares of publications and citations, albeit England and Scotland showed higher percentage shares of citations compared to shares of articles.
    - Field-weighted citation impact (FWCI) is considered to overcome the challenges in data analysis created by the accumulation of citations over time and fields of study that use different citation practices. In 2018, the UK's FWCI was the highest in the G7 and higher than the report's comparator countries.[101] This has remained the case since 2007 when the UK initially overtook the US to become the highest-ranked comparator. With a value of 1.56 in 2018, the UK's FWCI remains over 50% higher than the world average and 30% higher than the EU 27 average. Of note, within the UK, Northern Ireland's FWCI increased the most between 2010 and 2014, ending the reporting period just below that of Wales.
    - The UK is a key partner for global research collaboration and researcher mobility. International research collaboration and international researcher mobility are interrelated and interdependent and shaped by collaborative interactions that take place across multiple institutions, borders, continents and time zones. The UK's most prolific international partnerships are associated with

[101] However, many smaller countries, such as Denmark, Switzerland, the Netherlands, and Belgium, have much higher FWCI than the UK and the other comparators.

greater field-weighted citation impact (FWCI) per article, relative to the overall international collaborative output of either the UK or its partner countries.

- Research indicates that the US is the UK's top collaborative research partner. Of all the research published by UK researchers during the period 2005-2014, 12% was with a US co-author. However, the USA's total research output is much greater than that of the other countries. To account for this fact, the Royal Society undertook analysis applying Salton's cosine, a method that can be applied to normalise the data by the volume of output for both partners, giving a size-independent indicator of the strength of collaboration. Once this was applied, the strength of collaboration between the UK and Germany was shown to be greater than that between the UK and the USA.
- In 2018, 21% of the world's publications were internationally co-authored, compared with 11% in 1998. **Since 2016, the UK has seen over half its publications result from international collaboration each year**. In 2018, 55% of UK publications were the result of international collaboration. This makes the UK the second most internationally collaborative country in the G7, second to France (56%) and significantly higher than the OECD average (31%).
- However, **the Research Team considers that it is important to note that if over half of the UK's output is shared with other leading research economies, and if that half is the part of research output that attracts most citations, then metrics comparing research performance with other nations could be considered to be seriously compromised**. That is, more than half the output used to profile the UK research base belongs, at least in part, to the countries with which the UK is compared. When we evaluate UK research publications, and particularly when we look at the most highly-cited research featured in UK government reports, then a large part of what we see is research produced by and in collaboration with the USA, Canada, European partners, Australia, China and others. Less than half the volume, and much less than half the citations, are attributable exclusively to the UK research base.
- Bibliometric comparison (the analysis of publications and citations) can therefore no longer claim to measure differences between countries because the most frequently cited research comes out of a shared pot of networked projects. What applies to countries also applies equally to universities. Whilst universities such as Ulster University and Queen's University Belfast are unquestionably producing excellent research, much of their publication profile, and citation data that feeds into world university rankings is shared with other institutions in the UK or abroad. This means that such indicators are not capturing a distinct attribute of a single institution. Indeed, the more active, high profile and internationally engaged an institution is, the wider off the mark will be a quantitative assessment using limited bibliometric data alone.

- Also, concerning the universities, it is noted that the impact and excellence agenda has been developing rapidly with the introduction of the Research Excellence Framework (REF) in 2014. The REF is a process of expert review, carried out by expert panels for each of the 36 subject-based units of assessment (UOAs). Expert panels are made up of senior academics, international members and research users. Within the REF assessment, impact is defined as *'an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia'*. REF's consideration of impact is therefore not solely on innovation and regional economic development but on broader socio-economic impact.
- The Northern Ireland universities posted a very strong performance in the UK-wide REF, with over 70% of the research activity submitted by Queen's University and Ulster University classed as 'world-leading' or 'internationally excellent'. However, it is important to recognise that the case studies submitted by universities as part of the REF assessment are subject to certain limitations as an analytical tool. Firstly, case studies are a skewed sample, intended by institutions to capture the best examples of impact from their research by disciplinary area. The level of impact certainly could not be extrapolated to the average research project. Other elements of the assessment process, such as the need to provide corroborating evidence for impact, may also have skewed the selection of case studies for inclusion in the dataset. The case studies are also produced with a particular disciplinary review panel in mind, and as such may be tailored for that audience. The case studies also provide a snapshot in time, rather than evidence of impacts emerging over particular timelines.

- Ultimately, while the UK leads in many worldwide rankings, the world is changing. There are growing indications that the UK is losing ground in the research leadership stakes and may not be able to sustain its position as a world-leading research nation in the long term. Despite punching above its weight in delivering increasingly high-quality research outputs on broadly stable or decreasing R&D expenditure and human capital inputs, the UK, along with other research-intensive nations, including the US, are seeing their global shares in key research indicators eroded by other countries.

4.9 Summary Conclusions

Key conclusions arising from the review of information relating to NI's performance in international research collaboration include:

- There is a lack of specific information relating to NI's performance in international research collaboration, with most available information presented at a UK level;
- Nonetheless, there are indications that R&D activity in NI is less internationally collaborative than (on average) other areas of the UK.

5. DEFINING & MEASURING VALUE

5.1 Introduction

Previous sections have illustrated that international research collaboration is a key feature of the Northern Ireland research landscape, and is integral to its future. Increasing the international connectedness and depth of international engagement of research is fundamental to the long-term competitiveness of domestic research, and to ensure that research drives economic and social advancement.

At present, however, the mechanisms to understand and measure the benefits and values of international research collaboration are limited. This, however, is not unique to Northern Ireland and is a situation that is recognised across many countries.[102] For many countries, bibliometric data is the key mechanism used to capture the impact of international research collaboration undertaken at low TRLs. However, the Research Team notes that international research collaboration is constituted by a range of activities, often interrelated, which are not always amenable to quantitative evaluation, and which are likely to be realised in complex ways across the innovation system.

An important point to note, however, is that this complexity is not unique to international research collaboration, but more broadly to much of the activity involving academic research and development. This complexity and methods that might be addressed to capture the value of international research collaboration are discussed in this section.

5.2 Challenges in Measuring the Benefits of R&D

While there are many reasons for attempting to measure research's benefits to society, there are also several important challenges. One such challenge is the difficulty of establishing the link between R&I and the resulting benefits, which can be direct or indirect. This is often characterised in the literature in terms of attribution – in other words, whether a piece of research can be directly linked to the change observed, and the benefit apportioned in terms of the different studies from which it resulted. This is typically challenging since changes across many of these spheres will result from a wide range of RD&I and other social and economic factors, meaning that specifying the extent to which one stream or piece of research is responsible is often not feasible. To mitigate this, an approach that is often used is to consider instead the contribution of R&D to changes in society – i.e. whether it is plausible to demonstrate that the work made a meaningful contribution to that change. This links to **the 'pathway to impact' concept** – it is not necessary to prove exactly how much difference a particular piece of work made, but rather to demonstrate a plausible pathway through which it supported or contributed to a particular benefit.

In this context, the concept of absorptive capacity is relevant. Absorptive capacity is the ability to value, assimilate and apply knowledge. In the context of R&I, it is assumed that conducting research and innovation activities can facilitate the uptake of advances from elsewhere. The piece of research or innovation that leads directly to a benefit for society or the economy may come from another country, but the fact that research and innovation are happening within the UK/NI is considered to enable us to have the capacity – whether that be in terms of skills, mindset or access to knowledge – to capitalise on the benefits of that new thinking or evidence[103]. This is often less well captured in approaches to analysing the benefits of research. For example, many of the national-level frameworks, such as the Research Excellence Framework (REF), look to capture benefits to which research conducted by particular researchers made a material contribution. But benefits from RD&I in the UK also result from the ability to build and capitalise not only on the evidence produced in the UK but on wider learning from colleagues, collaborators and innovators on an international level.

[102] Measuring the Value of International Research Collaboration - Report Prepared for the Department of Industry and Science (Australian Academy of Humanities, May 2015)
[103] Evidence synthesis on measuring the distribution of benefits of research and innovation, RAND Europe on behalf of the Royal Society, 2018

Furthermore, it is generally understood that the benefits that come from R&I are not instantaneous. The time taken for benefits to accrue, known as 'time lags', can be a challenge in measuring the benefits of R&I. The time lags associated with a research or innovation activity and the associated benefits can span decades – one measure for biomedical and health sciences suggests that the typical pathway from bench to bedside could take around 17 years[104], and **it is likely that time lags will vary between sectors**. This can make conducting evaluations challenging. If conducted too early, the full benefits from R&I investments will likely not yet have emerged. If conducted too late, the challenges of recall, data collection and tracing the pathway from investment to outcomes become increasingly significant.

The complexity of pathways, along with the diversity of both outcomes and routes to those outcomes, also make measuring the benefits of R&I difficult both conceptually and practically. Evaluation frameworks and methods must balance the need to be both comprehensive and nuanced, and to collect meaningful, comparable data across contexts. Non-linearity makes modelling the R&I-to-impact process difficult, and **developing a set of metrics that is comprehensive and appropriate, yet comparable and feasible to collect, is extremely difficult**[105].

Linked to this is the challenge of burden. The burden of evaluation can fall on several different parties. There is the time required to plan and conduct an evaluation, which typically falls on research funders. There is also the burden on researchers themselves, who hold much of the information necessary for such evaluations and are often consulted through surveys or interviews. There may also be a burden on research users, who are a key source of information on how R&I is being employed and its contribution to changes in society. The balance of burden across these groups varies depending on the design of the evaluation and methods used.

As reflected above, there are significant challenges relating to measuring the benefits of academic R&D. This report does not try to address all of those challenges but instead seeks to focus on the best method to measure the benefit of international research collaboration (and within that, research focused on science and technology, as opposed to, for example, the Arts) that can be directly attributed to the investment made.

However, of note, research has identified that **few countries have developed a robust impact assessment and measurement system to evaluate whether international collaboration policies have desired effects**. Furthermore, there are considered to be large gaps in the data provided that could support these assessments.[106] The same research concluded that international science, technology and innovation (STI) collaboration policies and programmes that combine various policy drivers (e.g. research excellence with a diplomatic choice for the geography, scope and scale of research with improving competitiveness in specific thematic areas) *"usually have very fuzzy goals and the envisaged outcomes and impacts are not well defined. In such cases, setting up a coherent set of indicators to define its success on all fronts becomes difficult"*.

To date, much of the work that has sought to ascertain the value of academic research (collaborative or otherwise) has focused on macro-economic level analysis. However, whilst this approach has been widely used and is valuable in terms of providing an aggregated, macro-level analysis across the overall benefits of R&D in a quantified way, there are several limitations and methodological challenges, not least that **it does not give any information on the routes through which the returns are realised**, only the extent to which they are achieved. These challenges have been explored in detail by the (former) Department for Business, Innovation and Skills (BIS)[107].

[104] Morris et al. 2011 referenced in Evidence synthesis on measuring the distribution of benefits of research and innovation, RAND Europe on behalf of the Royal Society, 2018
[105] Morgan Jones, M., Manville, C., and Chataway, J. (2017). Learning from the UK's research impact assessment exercise: a case study of a retrospective impact assessment exercise and questions for the future. *The Journal of Technology Transfer*:1–27.
[106] Drivers of International collaboration in research, European Commission, 2009
[107] Rates of return to investment in science and innovation A Report Prepared for the Department for Business, Innovation And Skills (BIS), Frontier Economics Ltd, July 2014

Well known approaches that have sought to ascertain the benefits of academic research at the micro-level include:

1. The work of the STAR METRICS / Federal RePORTER project in the United States: STAR METRICS is a federal effort to create a repository of data and tools that will be useful to assess the impact of federal R&D investments. The National Institutes of Health (NIH) and the National Science Foundation (NSF), under the auspices of the Office of Science and Technology Policy (OSTP), are leading this project with funding provided by NIH, NSF, the U.S. Department of Agriculture (USDA) and the Environmental Protection Agency (US EPA). The programme was established in 2012 as it was recognised that no data infrastructure systematically coupled science funding with outcomes.

   The goal of the STAR METRICS project was to utilise existing administrative data from federal agencies and match them with existing research databases on economic, scientific and social outcomes.

   STAR METRICS seeks to leverage existing data that is available in the USA. It recognises that federal agencies already collect data on federal investments at the individual, award and institutional levels to manage awards, whilst academic researchers in the USA had collected large bodies of data on such scientific and innovation outcomes as citations, patents, business start-ups and initial public offerings (IPOs). To this end, a database was set up of all federally funded researchers and cleaned to ensure no confusions of people with the same or similar names etc. were made. This database was then used to match with other accessible databases such as public records of patents, institutional financial records, payroll data, as well as more traditional scientific output indicators such as scientific citations.

   Finally, there has been substantial investment in visualisation and other tools that convey complex information about science to a lay audience.

   As of 2016, the STAR METRICS consortium has decided to redirect STAR METRICS resources towards the ongoing development of Federal RePORTER (http://federalreporter.nih.gov).[108] Federal RePORTER is an initiative of STAR METRICS to create a searchable database of scientific awards from federal agencies and make this data available to the public. The Research Team's review of the materials on the Federal RePORTER website indicates that it does not appear to have the same focus on identifying outcomes as STAR METRICS originally had.[109]

2. The Industry and Academic Engagement project at Imperial College, London: This project aims to create a large database to link individual researchers and the outcomes of their work to economic impacts at a more granular level. This project was created in recognition that universities are increasingly called upon to conduct research that has a demonstrable impact. However, scholarly work investigating this topic had tended to focus on the most visible forms of commercialisation, such as licensing and spin-off companies. While these activities are important, the project recognised that less attention had been paid to other types of engagement, including collaborative research, consulting and contract research, even though they are relatively more common than the high-profile activities. Furthermore, it recognised that there was even less work on whether and how collaborative engagement between academics and industry functions as a seedbed for spin-offs and licences.

   With initial support from the EPSRC and European Commission, Imperial College has established a research project that will use Imperial College London as a site to explore the above issues. At the core of the project is the "TRansfer of knowledge at Imperial College" (TRIC) database that pools existing College records on the patenting and licensing of inventions, creation of spin-off businesses,

[108] https://www.starmetrics.nih.gov/Star/About
[109] https://federalreporter.nih.gov/

collaboration with industrial partners, research grants and consulting activity to generate a detailed picture of academic engagement at Imperial in recent years.[110] The Research Team has been unable to identify any published outworkings from this research project.

As noted, on an overall basis, economic analysis of the benefit of R&D (where it includes academic research) has tended to focus on a macro-economic analysis (which offers information on the outcomes, not the route through which these outcomes are achieved), with little available aggregated microeconomic analysis as to the outcomes of academic research (including that undertaken collaboratively). A factor influencing this is that **many of the benefits of R&D, particularly those which fall within the wider societal benefits, may not be easily quantifiable or monetisable**, so there is a risk that only those outputs that can be captured in this way are measured and thus valued.

Of note, the commercial impact of R&D is one of the traditional evaluation areas as it is often closely associated with much sought-after economic impacts. Most approaches in this area focus on intellectual property and revenue generation within the private sector. **The most widely used metrics for commercial impact are narrowly focused on a linear model of science and technology research feeding intellectual property into manufacturing industries. However, research and innovation can have a greater impact than this on the commercial sector, through improving processes, opening up new markets and other spillover effects**.[111]

Nonetheless, several commonly used metrics for commercial impact centre around intellectual property. Quantitative studies often employ figures on patent filings, grants and citations as metrics for commercial impact. As the filing or holding of a patent does not necessarily imply commercial impact, income from intellectual property or the formation of spin-out companies are often also considered.[112]

The UK's Research Excellence Framework records patent applications and grants as outputs. However, a key limitation of patent analysis is that many disciplines do not produce outcomes that generate intellectual property. Nonetheless, these disciplines may still have a significant commercial impact, for instance in the creative or digital economies. Appreciation of the relevance of intellectual property to specific fields is important if evaluators are to appropriately assess and compare commercial impact.

Ultimately, however, attempting to capture the commercialisation of research outputs is important, as it is often through this route that other impacts can be achieved on a wider scale (e.g. business or job creation).

As outlined in Section 4.3, **bibliometrics is the mechanism most often used to capture the impact of international research collaboration. This is where international co-authorship and citations are used as a proxy for measuring the level and impact of international collaboration. However, it provides a limited evidence base that cannot capture the many modes of collaboration outside co-authorships or outputs from across the research spectrum. Moreover, bibliometrics do not allow us to identify the value of international research collaboration and its system-wide effects**.

The constraints of bibliometric approaches are widely acknowledged, as is the need for more nuanced qualitative and quantitative measures to better understand the complex networks involved in international collaboration.

Additional quantitative approaches, such as counting numbers of international research exchanges, attendances at international conferences or the cost of shared research infrastructure, are often good ways of tracking the extent of internationalisation of the research sector but do not necessarily provide a way of understanding and evaluating the deep channels of mutual exchange that occur in international

[110] https://www.imperial.ac.uk/business-school/research/innovation-and-entrepreneurship/ie-research/research-initiatives-and-themes/university-industry-relations/academic-engagement/
[111] The Innovation Index: Measuring the UK's investment in innovation and its effects, NESTA, 2009.
[112] Evidence synthesis on measuring the distribution of benefits of research and innovation, RAND Europe on behalf of the Royal Society, 2018

collaboration and the many benefits that follow.[113] The rate of internationalisation of NI's research system could be relatively easy to track – for example, a simple count of the number of international partner investigators[114] on NI-funded research projects over time – albeit, this may be of limited use for policy development and programme evaluation.

However, at present, from an NI perspective, specific targets have not yet been established to measure the value of programmes such as the US-Ireland Programme, beyond the number and value of projects supported. However, per the analyses presented in Appendices IX and X, DfE (along with colleagues in SFI & NSF) seeks through its monitoring activities to capture information such as publications, presentations at conferences, leveraged awards etc. that have been generated as a result of each project as impacts or a proxy for longer term outcomes.

The overarching aim of this research report is t*o provide evidence-based advice to the Department on the policy, programmes, and funding to promote international research collaboration likely to maximise the return on its investment of resources.*

In answering this question, it is evident that a means to measure any 'return' on investment is required. However, the 'how to measure' question in NI's research performance has customarily been reduced to *post-facto* counting of outputs. Such an approach will not, in the Research Team's view, provide the basis to maximise the return on investment. Any sound measurement system for value should start with a *pre-facto* strategic question about what the activity is intended to achieve (beyond simply encouraging international collaboration) and a means of knowing it is achieving these objectives along the way and on completion of the activity. As reflected earlier in this report, achieving such a goal is not a simple task, given the (typically) low TRL levels that projects supported under the US-Ireland Programme are predominantly pitched at. As such, the remainder of this section considers good practice that is implemented elsewhere to achieve such a goal.

In the first instance, the Research Team considers that work should commence on the aggregation of individual benefits as these can translate into higher-order benefits. However, as this report contends, international collaboration is constituted by a range of activities, often interrelated, which are not always amenable to quantitative evaluation, and which are likely to be realised in complex ways across the innovation system.

[113] Measuring the Value of International Research Collaboration - Report Prepared for the Department of Industry and Science (Australian Academy of Humanities, May 2015)

[114] An international co-investigator is an individual from a research organisation outside the UK who otherwise fits the normal definition for a co-investigator on a research project. That is, they assist the grant holder in the management and leadership of a project. They would normally be expected to make a major intellectual contribution to the design and conduct of the project. Source: ESRC International Co-Investigators Policy Guidance on the inclusion of international co-investigators in ESRC proposals (August 2019)

5.3 International Principles and Best Practice

This section explores and examines international principles and, where available, best practices relating to the measurement of international research collaboration.

The rate of international research collaboration is growing rapidly on a global basis. However, approaches to identifying and measuring its value are in their early development, and the lack of suitable approaches is well known[115][116]. It is widely recognised that there is a growing need to design fit for purpose approaches to inform programme design and maximise policy effectiveness[117], and to do greater justice to the variety of outputs and activities of researchers.

The need to develop evaluation methods, that might include but should go beyond bibliometrics, is therefore important, for all countries, but particularly so for a small country such as Northern Ireland which has developed a dynamic regional network of research investment and output but has limited resources and thus should be assured that it is strategically investing its resources.

In the research sector, the growing demand for metrics has highlighted the need for international standards in research evaluation. Groups such as the Centre for Science and Technology Studies (CWTS) at Leiden University and Rand Europe are developing frameworks and instruments that specifically take account of different research methods, communication and publication processes, and collaborative practices across disciplines.

In April 2015, a group of academic and professional research evaluation experts released the 'Leiden Manifesto' best practice guidelines for metrics-based research evaluation[118]. The manifesto outlined that a problem was arising in the evaluation of research in that it was becoming led by data rather than by judgement. It stated that whilst metrics have proliferated (including the h-index which uses citation counting[119], metrics related to social usage and online comment) and were usually well-intentioned, they were not always well informed, and often ill applied. Thus, there was a risk of damaging the system with the very tools designed to improve it.

To address this perceived risk, the Manifesto offers a distillation of best practices in metrics-based research assessment, noting that **the best decisions are taken by combining robust statistics with sensitivity to the aim and nature of the research that is evaluated**. The Manifesto is summarised below:

1. **Quantitative evaluation should support qualitative, expert assessment**. Quantitative metrics can challenge bias tendencies in peer review and facilitate deliberation.
2. **Measure performance against the research missions of the institution, group or researcher**. Programme goals should be stated at the start, and the indicators used to evaluate performance should relate clearly to those goals. The choice of indicators, and how they are used, should take into account the wider socio-economic and cultural contexts. Scientists have diverse research missions. Research that advances the frontiers of academic knowledge differs from research that is focused on delivering solutions to societal problems. **A review may be based on merits relevant to policy, industry or the public rather than on academic ideas of excellence**. No single evaluation model applies to all contexts.

[115] Edlera, J., Fierb, H., and Grimpec, C. (2011), 'International Scientist Mobility and the Locus of Knowledge and Technology Transfer', Research Policy, 40(6), pp. 791–805.
[116] CREST Working Group (2007), Internationalisation of R&D – Facing the Challenge of Globalisation: Approaches to a Proactive International Policy in S&T.
[117] Measuring the Value of International Research Collaboration - Report Prepared for the Department of Industry and Science (Australian Academy of Humanities, May 2015)
[118] Hicks, D., Wouters, P., Waltman, L., de Rijcke, S., and Rafols, I. (2015), 'The Leiden Manifesto for Research Metrics', Nature, 520, pp. 429–431.
[119] The h-index is an author-level metric that attempts to measure both the productivity and citation impact of the publications of a scientist or scholar. The index is based on the set of the scientist's most cited papers and the number of citations that they have received in other publications

3. **Protect excellence in locally relevant research**. In many parts of the world, research excellence is equated with English language publication. Metrics built on high-quality non-English literature would serve to identify and reward excellence in locally relevant research.
4. **Keep data collection and analytical processes open, transparent, and simple**. The construction of the databases required for evaluation should follow clearly stated rules, set before the research has been completed. Simplicity is a virtue in an indicator because it enhances transparency. But simplistic metrics can distort the record (see principle 7). Evaluators must strive for balance — simple indicators true to the complexity of the research process.
5. **Allow those evaluated to verify data and analysis**. To ensure data quality, all researchers included in bibliometric studies should be able to check that their outputs have been correctly identified. Everyone directing and managing evaluation processes should assure data accuracy, through a self-verification or third-party audit. Universities could implement this in their research information systems, and it should be a guiding principle in the selection of providers of these systems. Accurate, high-quality data take time and money to collate and process. Budget for it.
6. **Account for variation by field in publication and citation practices**. Best practice is to select a suite of possible indicators and allow fields to choose among them. Citation rates vary by field: top-ranked journals in mathematics have impact factors of around 3; top-ranked journals in cell biology have impact factors of about 30. Normalised indicators are required, and the most robust normalisation method is based on percentiles: each paper is weighted based on the percentile to which it belongs in the citation distribution of its field (the top 1%, 10% or 20%, for example). A single highly cited publication slightly improves the position of a university in a ranking that is based on percentile indicators but may propel the university from the middle to the top of a ranking built on citation averages.
7. **Base assessment of individual researchers on a qualitative judgement of their portfolio**. The older you are, the higher your h-index, even in the absence of new papers. The h-index varies by field: life scientists top out at 200; physicists at 100 and social scientists at 20–30. It is also database dependent. Reading and judging a researcher's work is much more appropriate than relying on one number. Even when comparing large numbers of researchers, an approach that considers more information about an individual's expertise, experience, activities and influence is best.
8. **Avoid misplaced concreteness and false precision**. Science and technology indicators are prone to conceptual ambiguity and uncertainty and require strong assumptions that are not universally accepted. The meaning of citation counts, for example, has long been debated. **Thus, best practice uses multiple indicators to provide a more robust and pluralistic picture**. If uncertainty and error can be quantified, for instance using error bars, this information should accompany published indicator values. If this is not possible, indicator producers should at least avoid false precision. For example, the journal impact factor is published to three decimal places to avoid ties. However, given the conceptual ambiguity and random variability of citation counts, it makes no sense to distinguish between journals based on very small impact factor differences. Avoid false precision: only one decimal is warranted.
9. **Recognise the systemic effects of assessment and indicators**. **Indicators change the system through the incentives they establish. These effects should be anticipated**. **This means that a suite of indicators is always preferable** — a single one will invite gaming and goal displacement (in which the measurement becomes the goal). For example, in the 1990s, Australia funded university research using a formula based largely on the number of papers published by an institute. Universities could calculate the 'value' of a paper in a refereed journal; in 2000, it was Aus$800 (around US$480 in 2000) in research funding. Predictably, the number of papers published by Australian researchers went up, but they were in less-cited journals, suggesting that article quality fell. If metrics, such as citation counts, are all that is in the 'toolkit' there are ultimately implications for policy development and programme design.
10. **Scrutinise indicators regularly and update them**. Research missions and the goals of assessment shift and the research system itself co-evolves. Once-useful metrics become inadequate; new ones emerge. **Indicator systems have to be reviewed and perhaps modified**. Realising the effects of its simplistic formula, Australia in 2010 introduced its more complex Excellence in Research for Australia initiative, which emphasises quality.

The Research Team considers that there are several aspects (which will be returned to later) of the Leiden Manifesto that could be adopted by the Department as it seeks to identify the international research collaboration activity that is likely to maximise the return on its investment.

5.4 UKRI's Measurement

Researchfish is an online platform used by many research funders (including seven UKRI councils[120]) to assess the outputs, outcomes and impacts of the research they fund. The tool currently captures information on behalf of 79 research funders (74 registered in the UK, 5 overseas) and contains more than a decade's worth of output, outcome and impact data. Most of the information is collected through an annual survey of researchers where they enter information on the outputs, outcomes and impacts of their research projects against standardised fields across a range of areas.

Researchers are expected to complete the survey for the lifetime of the project, and for some time after the project is completed (up to five years). Failure to submit a response can lead to consequences such as ineligibility for further funding; however, the completeness and accuracy of responses are more difficult to validate. Researchers are also invited to continue to add information over a longer timeframe, but there is no compulsion after the mandatory period set by the funder (this period varies – for example, it is five years for the MRC).

Researchfish is a rich data source that can support research evaluation and impact assessment initiatives. The data can be analysed in several ways, including by single research funders, in aggregate form or comparatively across research funders (or research institutions). Research funders will often extract narratives that describe impact from Researchfish data.[121] Of note, the Research Team's discussions with both NI universities indicate that they are familiar with UKRI's (and by turn, Researchfish's) requirements and regularly complete returns using it.

Researchfish is a unique resource in that it provides consistent (and real-time) longitudinal data on the impacts of a large proportion of UK academic research. The level of coverage of the dataset could not be readily generated after a project has already been implemented through surveys or other data collection mechanisms, and **the comparability across funders means that the dataset offers useful opportunities for comparisons and benchmarking as well as integrated, aggregate analysis**. There is also a significant amount of qualitative information in Researchfish which could offer opportunities for a more detailed and nuanced analysis of the data as better text mining tools emerge over time. Researchfish is reported to be extremely useful for providing an overview of the outputs and outcomes of portfolios of research, and for gaining an overall understanding of the key routes and areas of impact.

The information captured also includes whether outputs are local/regional, national or international in scale. However, this does not facilitate regional analysis as, although the location of the institution may be provided, this does not necessarily mean that a 'local' impact is local to that institution.[122]

There are limitations to the Researchfish dataset. The first of these is the quality, integrity and completeness of the data. This is due to data being integrated from older data-collection systems (e.g. E-Val), and also compliance rates of individual researchers. Evidence suggests that Researchfish data under-reports impacts overall and, anecdotally, funders suggest that the most productive and impactful researchers may be least likely to submit complete data onto Researchfish. Completion practices may also vary between institutions. For example, in some institutions, the Researchfish return is delegated to administrative staff or a PA, while at other institutions researchers complete it for themselves.

Nonetheless, the nature of the question set and consistency between funders is valuable in terms of enabling aggregate analysis, but research indicates that this is also a challenge in that it does not effectively capture all relevant outcomes for every research programme (indeed, this would be close to impossible). In particular, it was suggested by respondents in several interviews (per RAND Europe

[120] Seven UKRI councils have adopted a harmonised approach to collecting the outcomes, outputs and impacts of the research they fund. This process moves away from previous final reporting based approaches by asking UKRI councils funded award holders to provide information throughout the duration of their funding, and for a period of time after that has ended.
[121] Evidence synthesis on measuring the distribution of benefits of research and innovation, RAND Europe on behalf of the Royal Society, 2018
[122] Ibid

research[123]) that the question set could be updated to shift away from the initial medical focus to reflect the diversity of funders that now use the tool. The tool is already intended to cover all disciplines, but there is evidence that this has not been adequately addressed.[124]

A common question set has been agreed upon across all the Researchfish funders which give detailed information on the 16 common outcomes including all of the sub-type options that can be chosen from.

A summary of the key types of outcomes captured is featured overleaf:[125]

1. Publications	Almost every research grant is anticipated to result in publications. Of note, the PI need not be a named author to list a publication as an outcome of a grant. It is enough for there to be a direct link between the publication and the work supported by the grant.
2. Engagement Activities	Relates to the communication of the research to audiences beyond the researcher's normal peer group. For example, through: • Participation in a formal working group or expert panel? • A talk or presentation? • Hosting or participating in other kinds of events (e.g. workshops or open days)? • A magazine or newsletter article (print or online)? • A broadcast e.g. TV/radio/film/podcast? • Other interactions with the media (e.g. interview, press release, press conference, responding to media enquiries)? • An engagement focused website, blog or social media channel? Researchers are also asked to think about and try to summarise any consequences of their engagement.
3. Collaborations and partnerships	Researchers are asked to provide information about any external collaborators they may have worked with (or be working with) to further the funded research, including: • those listed in the original application; • any who have agreed to work with the researcher and supported their research after it started.
4. Software and Technical Products	Researchers are asked to identify whether the work has resulted in new/improved software, for example: • web-tools; • applications; • middleware; • business platforms. Researchers are encouraged to identify the research domains that have benefitted from the software and how.
5. Awards and Recognition	Recognition of outstanding work comes in many forms, for example: • A National honour e.g. Order of Chivalry, OBE, etc. • A Research prize or Medal or other award recognising research excellence; • An honorary degree or election to honorary membership/fellowship of a learned society; • Appointment to a prestigious honorary/advisory position by an external body; • Winning a Poster/abstract prize awarded at a prestigious conference; • Outstanding success in attracting visiting staff or users to your research group; • A personal invitation as keynote (or other named) speaker to a conference.

[123] RAND Europe is a not-for-profit organisation whose mission is to help improve policy and decision making through research and analysis.
[124] Ibid
[125] https://epsrc.ukri.org/funding/managing/ros/

6. Impact	Researchers are asked to identify the wider 'Impact' of the research findings - beyond their immediate peer group. This can take many different forms. For example, new insights/products/processes can lead to changes in behaviour, or policy, or patterns of production/consumption; all of which can have discernible and sometimes far-reaching consequences. Researchers are asked to use the 'Impact Narrative' to summarise how the research has contributed to any such changes. It is recognised that impacts can take time - years - to evolve and be recognised, so it is understood there may be little to say for at least the first year after funding ended. It is for this reason, that researchers are asked to provide details for projects for up to five years after a project has been completed.
7. Spin-out Companies	It is recognised that new businesses, jobs and wealth creation are among the more compelling reasons to invest public funds in research. Researchers are therefore asked to record whether the research has directly or indirectly led to a new spin-out company (include a joint venture with a collaborating partner organisation).
8. Research Tools and Methods	Researchers are asked to identify whether, in the course of the funded project, they have developed new or better ways to conduct research investigations.
9. Leveraged (Further) Funding	Researchers are asked to identify whether they have on their own or as a member of a consortium received 'Further Funding' from any source specifically to allow them to: • continue their funded research; • extend their funded research ideas into new areas; • help exploit the findings of their funded research.
10. Influence on Policy and/or practice	It is recognised that research can have a wide impact in indirect ways. Researchers are therefore asked to identify whether their funded work has: • been used to influence, or been cited in official policy; • led to changes in how specialist services are delivered to specific groups or the general public; • led significant numbers or specific groups of people to change the way they think or behave; • been especially relevant to specific industry sectors.
11. Next destinations (trained researchers)	When people have moved on from a funded project, funders using Researchfish want to know: • Which organisation/sector/country do they take their skills to; • Whether they remain actively engaged in research, or put their experience to use in another way. This helps inform funders' understanding of how the wider economy benefits from the skills people gain while supported through their funding.
12. New Products and Processes	Researchers are asked to identify whether their work has resulted in any kind of new/improved product or process, for example: • materials • technique / technology • systems • instruments / devices • physical models
13. Use by Industry	Researchers are asked to identify whether any discoveries/insights are being put to practical use in a non-academic context: • by industry; • by government; • by any others; • in the UK or overseas.

14. Intellectual Property	Researchers are asked to identify whether the funded research led to the filing of a patent application, or a granted patent, or whether intellectual property arising from the work is being exploited under licence.
15. Shared Data	Many funders expect datasets from funded research to become available for sharing (unless legitimate constraints apply). It is anticipated that research will likely result in datasets that: • should normally be open to scrutiny if they underpin published results; • are likely to be useful to others, even if they do not underpin published results.
16. Use of Research Facilities	Researchers are asked to identify whether they have used a shared research facility or another resource, located in the UK or overseas, to help carry out their funded research. If so, they are asked to identify the difference that it made to their research.

It is noted that in many of the areas cited above, researchers are encouraged to answer the 'so what' question i.e. what difference has the result cited made, what has changed etc.

Furthermore, it should be noted that the UKRI councils ask several mandatory additional questions which relate directly to each funded award. Some of these are funder specific, and others are award specific (see Appendix XII for full details).

5.5 Use of Case Studies

Case studies are also a useful means to capture the outworking of an R&D project. Case studies are a qualitative, descriptive research technique, and provide detailed information about a limited topic or context to produce a rich and detailed understanding of that particular area, rather than widely generalisable conclusions. The objective of a case study is to explore, explain or describe an activity. The topics of case studies can be varied, and in this respect, they are almost completely flexible. However, groups of case studies together can say more about a broader context if they are carefully selected.

Case studies are widely used in the context of research evaluation and research impact assessment. However, the detail and quality of case studies vary substantially, and in some cases, they are little more than anecdotes. The nature and content of case studies vary depending on their purpose. Case studies are often used for advocacy purposes, to describe excellent examples of impact to showcase the quality and impact of a portfolio of work. This is illustrated in their widespread use in reporting by the Research Councils. They can also be used to help 'bring to life' examples of impact in wider portfolio reviews. 'Stories' or narratives are naturally appealing and can often carry more weight than statistics or data since they are more memorable and create a more personal connection.

Case studies can also be extremely useful from an analytical perspective as they set out how outcomes and impacts came about, not just what they are. With careful sampling (not just selecting for the 'best' examples) and analysis, this can provide useful insights beyond the specific examples investigated. Generally speaking, case studies have a distinct advantage over other methods when a 'how' or 'why' question is asked. The case study methodology can access detail and context. When used correctly, case studies can provide rich and deep contextual information, building a full understanding of a particular situation. Case studies can deal with heterogeneous and non-routine behaviour or circumstances better than many other techniques, and provide a useful way to capture diverse impacts, including those that are not easily quantified, and can address the non-linear nature of R&I. Overall, the case study approach is flexible and wide-ranging, meaning that it can be usefully applied to diverse contexts. [126]

[126] Evidence synthesis on measuring the distribution of benefits of research and innovation, RAND Europe on behalf of the Royal Society, 2018

However, one of the key limitations of case studies is that they are very specific to the context in which they take place. This means it can be difficult to generalise any findings as they may be specific to that context. This issue can be addressed somewhat by careful selection of case studies for analytical purposes. Equally, in some situations, this may not be important – for example, when trying to showcase examples of great impact. Case studies also have an inherently subjective element. Although they can draw on factual data, in many cases much of the most interesting output of a case study relies on personal interpretation and inferences, and it can be difficult to test the validity of findings. Finally, case studies require a relatively high level of investment per subject or topic, meaning that they are not a useful way to gain insights across the whole of a portfolio or field of research. They are more useful to provide detailed information and examples to supplement rather than replace wider portfolio analysis.

5.6 OECD Measures

The OECD Science, Technology and Industry Scoreboard draws on the latest internationally comparable data to uncover the strengths of the OECD and other leading economies. It aims to help governments design more effective science, innovation and industry policies.[127] One of five thematic areas of policy interest featured in the report is 'research excellence and collaboration'. It is intended to help to inform the policy debate with a set of metrics on the variety and nature of mechanisms for knowledge diffusion in the age of digitalisation. It points to the research performance of countries that follow different paths of scientific specialisation, the international mobility of highly skilled individuals, innovation across borders and collaboration among firms in innovation processes.

However, it should be noted that the OECD cautions that indicators are pointers; they do not address causal relationships. Moreover, the validity of a set of indicators depends on its use. The selected indicators have been developed with the following criteria in mind:

- Indicators should be based on high-quality statistics and robust analytical principles and be measurable internationally, over time and with prospects of improvement.
- Indicators should be relevant, particularly for decision-makers.

Concerning its suggested 'research excellence and collaboration' indicators, the following is noted:

Theme	Suggested Indicators
Research excellence and specialisation	• Scientific publications provide **a measure of scientific production activity** based on the number of documents published in peer-reviewed journals and indexed by data providers. Estimates of scientific publication output are based on counts of citable documents (articles, reviews and conference proceedings), indexed within Elsevier's Scopus database, by authors with affiliations in each country. Documents are assigned on a fractional basis, according to the number of authors and their respective affiliations in that particular country. • The indicator of top-cited publications is considered to provide **a "quality-adjusted" measure of research output.** The indicator of scientific excellence (top-cited publications) shows the percentage of a country's scientific output that is included in the group of the 10% most-cited publications in their respective scientific fields. • Countries exhibit specialisation in different scientific domains. A specialisation index provides evidence of the fields in which a given country accounts for a relatively high share of scientific production, compared to the global distribution of scientific output across fields. The relationship between specialisation and citation impact is analysed in four selected domains: Biochemistry, Computer science, Materials science and Neuroscience. The specialisation indicator is calculated by dividing a field's share of documents within a given country by the global share of that particular field. Economies that have field distributions very similar to that of the entire world exhibit specialisation values very close to 1. • For smaller countries, pockets of excellence can be found in specific areas.

[127] OECD (2017), OECD Science, Technology and Industry Scoreboard 2017: The digital transformation, OECD Publishing, Paris

Theme	Suggested Indicators
Excellence in scientific collaboration	• *International collaboration* is defined as the number of domestically authored publications incorporating institutional affiliations of other countries or economies, as a percentage of all citable publications (articles, reviews and conference proceedings) attributed to authors with an affiliation in the reference economy. • International collaboration can apply to documents where the leading author has as first affiliation the reference economy and those where the lead author's first reported affiliation is abroad. The *leading author* is identified from the identity of the designated *corresponding author*. • The *normalised citation impact* measure is the ratio between the average number of citations received by documents published by authors affiliated to an institution in a given economy and the world average of citations, over the same period, by document type and subject area. • *Scientific excellence* indicates the amount (in percentage) of a unit's scientific output that is included in the global set of the *10% most cited* papers in their respective scientific fields. This indicator can be used in combination with data on the affiliation of the corresponding author – to better describe the role of international collaboration as a driver of scientific excellence. Of note, according to the OECD, measures of scientific research collaboration and citation impact (a quality measure of scientific publishing) at the country level are positively correlated, especially for economies with lower levels of scientific production. These smaller economies attempt to overcome their limited scale by participating more intensively in global networks. Furthermore, joint analysis of excellence and leading authorship (i.e. affiliation of the leading author) provides further insight into the source of a country's top-cited publications, as many are underpinned by international collaborations, often led by authors with foreign affiliations. Indeed, some countries have high overall excellence rates thanks to the contribution of collaborative articles led by authors abroad.
Scientists on the move[128]	Scientist mobility facilitates the circulation of scientific knowledge. One way to track the mobility of scientists is to trace changes in institutional affiliation over their list of publications in scholarly journals. This approach shows that brain circulation (churn) is far more important than brain gain/drain (net flows). The nine largest international bilateral flows of scientists over the period 2006-2016 involved exchanges with the United States. Of the top 40 connections, this country (i.e. the US) was a net beneficiary in 14 cases, followed by the United Kingdom with 6 and China with 5. Scientists who undertake research abroad and return to the economy in which they first published contribute to raising the overall quality of domestic research by 20% on average. With few exceptions, individuals not changing economic affiliations (stayers) are more likely to publish in journals of lower "prestige". In terms of measurability: • Scientific authors are listed in the Scopus database of peer-reviewed scientific publications and identified by a unique author ID assigned by Elsevier. • International mobility is inferred from authors with at least two publications over the reference period and is based on changes in institutional affiliation and sequence of publications. The open researcher and contributor ID (ORCID) promotes the use of unique identifiers linkable to an individual's research output.

[128] Of note, the Royal Society has stated that the focus of discussion has moved from preventing 'brain drain' to making the most of 'brain circulation', with it argued that old patterns of one-way flows of technology and capital from the core to the periphery are slowly breaking down, creating far more complex and decentralised two-way flows of skills, capital and technology, with scientists following the best science and the best resources. Knowledge, Networks and Nations: Global scientific collaboration in the 21st century. Royal Society Policy document 03/11. Issued: March 2011

5.7 Other Data Used to Measure International Collaboration

In recent years, some research evaluation methodologies have moved away from relying solely on the traditional channels of scholarly communication, and have begun to focus on 'grey' literature (scholarly work communicated through media, social media and policy reporting) and forms of social impact. So-called 'Altmetrics' have recently been developed to capture the diverse 'impacts' that academic publishing through alternate channels of scholarly communication is having.

Altmetrics are non-traditional bibliometrics proposed as an alternative or complement to more traditional citation impact metrics, such as impact factor and h-index. The term altmetrics was proposed in 2010, as a generalisation of article-level metrics, and has its roots in the #altmetrics hashtag. Although altmetrics are often thought of as metrics about articles, they can be applied to people, journals, books, data sets, presentations, videos, source code repositories, web pages, etc.[129]

However, the usefulness of altmetrics for estimating scientific impact is controversial.[130] Some limitations affect the usefulness due to technique problems and systematic bias of construct, such as data quality, heterogeneity and particular dependencies. In terms of systematic bias, like other metrics, altmetrics are prone to self-citation, gaming and other mechanisms to boost one's apparent impact. For example, likes and mentions can be bought. Also, altmetrics can be more difficult to standardise than citations.

For these reasons, the Research Team would not advocate the use of altmetrics in any formal capacity at this juncture.

5.8 Summary Conclusions

The higher education sector is becoming increasingly globalised with international research collaboration considered to be key to the UK and NI's economic and social future. It is broadly anticipated that harnessing the potential opportunities it presents will have benefits that extend far into the future.

Governments around the world are recognising the value of international collaboration through new policies, including around science and research diplomacy, and designing programmes that aim to foster international cooperation. The European Union's Horizon 2020 programme is an exemplar in this regard and in recent years has focused on building reciprocal arrangements and multinational collaborations.

At present, however, the mechanisms to understand and measure the benefits and values that flow from international collaboration are limited. The constraints of bibliometric approaches are widely acknowledged, as is the need for more nuanced qualitative and quantitative measures to better understand the complex networks involved in international collaboration.

This research project aims to inform the development of a more comprehensive approach to measuring the impact and value of international research collaboration. As part of this work, the Research Team has considered both existing and new and emerging approaches to measuring the values that flow from international collaboration in the research sector. The Research Team considers a broader repertoire of evidence is needed in NI for defining, identifying and measuring the value of international collaboration, and proposes a strategic evaluative approach.

From this perspective, evaluation should be viewed as an integral part of planning collaborative ventures and involves steps such as identifying the aims and intended outcomes of collaboration, developing agreed indicators for measuring progress towards achieving pre-set goals, and introducing a feedback

[129] https://en.wikipedia.org/wiki/Altmetrics
[130] "Altmetrics: An Overview and Evaluation", Williams, A. Online Information Review 41(3). June 2017

loop for learning and adjustments into research design and programme implementation.[131] Evaluation is not something that should be developed *post hoc* but should be tailored to the aims and outcomes of each project as it is being designed.[132]

At the highest level, the intention should be to allow stakeholders to see the links between government policy goals, the Department's expenditure, the international research collaboration activities and their outcomes more clearly than is presently the case. Much of this process should be informed by procedures and guidance already in place such as NIGEAE.

This would require activities such as:

- Identify the anticipated benefits of a collaboration programme at the system, institutional and researcher levels;
- Identify a range of values and data that might point to those benefits being achieved;
- Asking the NI partners to set out what the international research collaboration is intended to achieve at institutional, programme, and project levels;
- Directly link their proposed activities with the objectives, deliverables and KPIs of a programme;
- Define specific and measurable (quantifiable) KPIs, using wording that is not open to interpretation;
- Plan to measure KPIs from the start of a collaboration.

The potential strategic importance and growth of international research collaboration suggest a need to develop fit for purpose frameworks and measures that reflect the diverse values and the system-wide effects that collaboration can have. Evaluation frameworks also need to take account of a broader range of data to complement the planning approach proposed in this report. Where appropriate, the Research Team considers that existing collections of data should be usefully repurposed into an appropriate evaluation framework. This section provides an outline of some of the existing data. Not all of these are currently formally collected, however, they are all currently accessible (some to researchers, others to institutions and government).

The Research Team further considers that it will be important to strike a balance between the traditional research imperatives (i.e. advancing scientific knowledge measured via traditional research indicators) with policy and programme goals that may not be realised until well into the future.

However, this can be mitigated by linking any anticipated longer-term outcomes to short term programme outcomes. This work should include tangible short term reporting outcomes, given that it is likely the anticipated longer-term policy outcomes may be difficult to identify (in terms of causality) when they *are* finally realised, and difficult to measure.

Nonetheless, the Research Team considers that capturing the value of international research collaboration will not be a simple task. In terms of identifying the value of international collaboration, as well as measuring and evaluating it, it is clear that a variety of approaches would ideally be required. Indeed, whilst the Research Team considers that quantifiable metrics are of considerable importance, we consider that elements of the Leiden Manifesto best practice guidelines for metrics-based research evaluation (outlined earlier) should be borne in mind. Chief among these is that 'quantitative evaluation should support qualitative, expert assessment'.

[131] This should not be conflated with, for example, the types of strategic objectives that have been established for the US-Ireland Research & Development (R&D) Partnership programme and which are presented in Section 2.4.1 of this report, and should relate more so to establishing a set of agreed indicators that might be reflective, for example, of those set out within the Researchfish framework.

[132] Whilst it is recognised that the application form/process utilised for the NI aspect of programmes such as US-Ireland Research & Development (R&D) Partnership programme asks projects to identify project aims and objectives and completion reports also require PIs to outline the research work carried out as part of the project including its achievements against any 'outcomes and targets' that might have been cited in the original proposal, they do not do so within a framework such as that used by UKRI/Researchfish, resulting in a lack of consistency, which creates difficulty when attempting to aggregate or collate indicators.

6. LINKS TO INDUSTRY

6.1 Introduction

Much of this report has focused on university-university collaboration. However, the benefits of research collaboration have also long been recognised by those working in the public and private sectors as reducing transaction costs and delivering economies of scope and scale by pooling risks and exploiting synergies across partners.

University business collaboration (UBC) encompasses the processes through which the knowledge developed and maintained in universities becomes the knowledge used by business in current operation and/or future strategy. As such UBC is neither an end nor a collection of outputs but many different ways of using and reusing knowledge, and this knowledge can take many forms.

To some extent, UBC underpins all drivers of economic prosperity: innovation, foreign direct investment, human capital, scientific infrastructure, intangible assets, knowledge transfer, intellectual property and firm creation, to name but a few.

It does not matter whether university-held knowledge comes from an external commission or internal curiosity-driven research; what is important is that the knowledge can be developed for use in business operations. UBC is a two-way concept that captures multiple routes for universities and businesses to impact on each other, not just in terms of monetary revenues, but also in terms of making a difference beyond their organisation and sector.

6.2 The Functions of Universities in Innovation Systems

How universities contribute to innovation is increasingly well recognised, stretching well beyond their roles in expanding the stock of codified knowledge, translating fundamental research into inventions that can be commercialised, and their roles as educators. Through their increasingly direct linkages with universities, firms can develop and enhance the capabilities and competencies that feed into their innovation processes (e.g., tacit and codified knowledge, know-how, practices and processes, tools and techniques), and do so at different stages of the value chain, from early-stage technology development to scale-up, production, logistics, marketing and sales. These linkages touch many sectors of the economy, stretching well beyond manufacturing and technology-product driven firms, to include those within the services and public sectors, and often well beyond the regional boundaries of universities.

Increasing attention is also being given to the proactive and strategic initiatives and activities within universities aimed at strengthening the system-wide conditions in which innovation takes place. While these roles are often framed in a regional context, these ‘system development’ roles are evident in sectoral and technological systems. Examples include building the underpinning skills and infrastructure critical to the functioning of the system; informing system-specific strategies; working alongside key firms and stakeholders to provide system leadership; and developing standards and the wider institutional framework shaping the system’s innovation processes.

Table 6.1 brings these many functions together. Albeit it should be recognised that inevitably, different universities will specialise in different combinations of functions, drawing on their internal capabilities and competencies, and their specific context. Some will provide a broad range while others will focus their strengths such as developing human capital in particular areas or providing applied research solutions to industrial challenges.

Table 6.1: Diversity of functions performed by universities in the innovation system[133]	
Category	**Function**
Developing talent and human capital	• Developing skilled labour (both generic/domain-specific skills) • Developing entrepreneurial/enterprise skills • Workforce development and training (generic, advanced)
Developing and deploying knowledge/technologies for innovation & problem solving	• Knowledge generation through user funded research/co-produced research • Adding to the stock of codified knowledge e.g. through publications, patents, prototypes • Transferring existing knowledge/know-how e.g. through consultancy, informal linkages • Investing in and enabling access to, specialised infrastructure, instrumentation and equipment • Providing technical assistance • Commercialising new technologies through new venture creation and licensing.
Strengthening system and spatial conditions for innovation	• Providing leadership and expertise to inform policy/system development • Strengthening local/system capabilities and capacity for entrepreneurship and innovation • Supporting internationalisation activities of firms & attracting talent, investment, resources • Developing infrastructure supporting innovation and economic growth • Providing business assistance/support • Strengthening other competitiveness conditions (e.g. regional quality of life) • Facilitating access to finance for R&D and innovation
Providing spaces for open-ended conversations and entrepreneurial experimentation	• Convening academics/industry researchers/innovators networks • Supporting the creation of industry identity • Developing industry-responsive curricula • Bridging disconnected actors in the system • Hosting and participating in standards-setting forums • Providing forums for potential investors • Understanding industrial development pathways and market opportunities • Providing spaces with necessary support encouraging entrepreneurial experimentation

These university-based activities are known to have important spillover effects on regional economies.[134] For example:

- Spin-off and start-up companies emerging out of universities locating nearby, creating and supporting local jobs and attracting investment to the area;
- Education activities have a very real effect on the availability of skilled labour in the local economy;
- Supporting the emergence and evolution of local knowledge-intensive and high technology clusters;
- Attracting revenues to the area through academics' knowledge exchange activities;
- Playing very real and important civic and community roles in their localities;
- Generating powerful (global) reputational effects for the region, particularly where it has a widely recognised reputation for excellence in areas of research, education and knowledge exchange (KE).

Also, there is strong evidence that universities play an important role in attracting R&D-related investments to the area.[135] The excellence of the science base, the availability of expertise, and the ability of universities to work with industry are all important factors in R&D location decisions. Geographic proximity can make it easier for firms to keep up-to-date with scientific advances; facilitate the formation of personal connections and exchanges, and ease the flow of tacit and embodied knowledge.

[133] Revisiting the innovation and economic development engines of universities: building strategic multi-focus knowledge hubs Article by Tomas Coates Ulrichsen, University of Cambridge. Featured in State of the Relationship report 2015. National Centre for Universities and Business

[134] See e.g. Jaffe, A.B. (1989) "Real Effects of Academic Research", The American Economic Review, vol. 79; Anselin et al. (2000)

[135] "University Research and the Location of Business R&D", The Economic Journal, vol. 117; Varga (2002).

Therefore, becoming a national or global centre of excellence in a particular domain of strategic importance may generate powerful forces for attracting high-value investments, talent and innovation-related activity to the area.

6.3 Policies for Collaboration

Through collaboration, academics seek to access industrial capabilities and resources, to commercialise research ideas or test their commercial potential, to develop 'real world' links or to develop potential career pathways for students. Firms seek to access leading-edge research knowledge, research infrastructures or research services, to develop in-house capabilities or to identify potential future employees, and so on.

However, a recurring challenge, encountered in even the most advanced and innovative economies, is that the outcomes of publicly-supported research often fail to be effectively translated into new products, processes and services for the benefit of the private sector and society more broadly. Consequently, there is a long tradition of implementing measures to foster longer-term cooperation between science and industrial actors and these now represent a significant part of the portfolio of innovation policies in many countries.

An extensive array of measures to support collaboration has been developed by governments and, over time, there has been a shift in their primary rationale, from addressing barriers to 'technology transfer' to enabling 'knowledge transfer'. This shift in policy objectives aims to optimise a broader range of innovation modes that build on a systemic view of innovation, involving less tangible interactions and feedback loops between parties.

Common forms of government support for such collaboration include[136]:

- Project-based approaches – grants and subsidies conditional upon collaboration.
- People-based approaches – industrial secondments or studentships.
- Multi-actor networks either co-located (Science Parks, Collaborative Research Centres) or facilitated by technology (virtual networks) or approaches such as Innovate UK's network of Catapult Centres.

Higher Education Institutions also undertake collaboration independently of any formal support mechanism:

- Knowledge-based approaches – licensing and IP, generally at the level of individual institutions; spin-outs.
- Informal contacts and advice provision.
- Contract and collaborative research performed for industry.
- Property-led initiatives in the form of science parks.

However, despite a plethora of governmental support complemented by universities' initiatives, evidence from a range of studies indicates that significant barriers to science-industry cooperation persist. For example, despite its headline finding that *"Since the Lambert Review[137] there has been a huge change in both the quantum and the quality of [UK] business–university collaboration"*, the Wilson review of university-business collaboration cites research conducted by Imperial College which points to several reasons why university-business collaborations may not progress beyond the stage of initial discussions.[138] These are:

[136] Policies for science-industry collaboration. Article By Paul Cunningham, Manchester Institute of Innovation Research. Featured in State of the Relationship report 2014. National Centre for Universities and Business.
[137] Lambert, R. Lambert Review of Business-University Collaboration. HM Treasury, London, 2003.
[138] Wilson, T. A Review of Business–University Collaboration. BIS, London, 2012.

- The needs of business do not align with the mission and strategy of the university and expectations of outcomes may differ.
- Universities operate on longer-term commitments than the timescales required by businesses. Sometimes this is down to the bidding cycle for external funding.
- Universities may lack the skill set or the facilities to meet the needs of business.
- The two parties may not agree on a suitable price for the service. This is particularly the case in the context of full economic costing in research collaboration.
- Failure to agree ownership of the intellectual property that may be generated: despite significant progress since the publication of the Lambert (Intellectual Property) Agreements, this is still reported as a significant issue in some negotiations.
- Contrasting views on the management of indemnities and liabilities between prospective partners; viewed as being an increasing problem.

As noted by Wilson (2012), university-business cooperation operates within a rich ecology of interrelationships (often involving a diversity of intermediaries) and the motives underlying such cooperation are diverse. The success of any government interventions will be highly dependent on the ecology within which they operate.[139]

Policy interventions, therefore, have the potential to support the generation and diffusion of innovation by fostering an effective translation system. However, in general, the effectiveness of policy interventions to facilitate research translation is not measured particularly well, as a result of lack of evaluation in some sectors and limited metrics in those that do undertake evaluation.[140]

6.4 The Role of Intermediaries

There are many interacting conditions needed to enable research and innovation, and these are common for publicly and privately funded research. For research to be developed into innovations that can deliver benefits to society, there needs to be an effective translation and innovation system in place. Translation is the process by which ideas and discoveries are developed into new and improved products, services and approaches.

However, not all research is translated into innovation. While the UK has a strong research base through its world-leading university sector, the same success is not seen in translation and innovation. Stimulating innovation is a key policy aim for government to ensure that public services can be delivered more efficiently and effectively, to help create the conditions for improved productivity and growth in the UK economy, and also to improve health and well-being, as well as cultural and social enrichment. While increases in government investment in R&D are important to increase the stock of new ideas and discoveries, for this investment to result in benefits to society, there needs to be an effective translation and innovation system in place. Ensuring that research, where there is a potential for innovation, delivers benefits to society requires a better understanding of the conditions needed to enable translation and innovation, the contexts in which innovation is more or less likely to emerge, and the systems which support it.

Several conditions, and their interaction, are deemed critical to the translation and innovation process across sectors.[141] These include: (i) drivers; (ii) input resources; (iii) enabling resources; (iv) institutional factors; and (v) absorptive capacity.

i. Drivers are the motivations that spur innovation to occur and are, therefore, a key condition for innovation.

[139] Wilson, T. A Review of Business–University Collaboration. BIS, London, 2012.
[140] Evidence synthesis on the conditions needed to translate research and drive innovation. RAND on behalf of the National Academies (the Academy of Medical Sciences, the British Academy the Royal Academy of Engineering and the Royal Society), 2018
[141] Evidence synthesis on the conditions needed to translate research and drive innovation. RAND on behalf of the National Academies (the Academy of Medical Sciences, the British Academy the Royal Academy of Engineering and the Royal Society), 2018

ii. Input resources, including knowledge, talent and capital, are the primary resources needed for an actor, organisation or sector to undertake innovation.
iii. Enabling factors, including infrastructure and the formation of networks, facilitate the collaboration of multidisciplinary teams, which are increasingly needed for successful translation and innovation.
iv. Institutional factors, including structures (e.g. regulation, standards) and culture, shape the environment in which translation and innovation take place. Regulation is necessary to ensure safety and fairness, but outdated or maladapted regulatory approaches can often represent a barrier to entry into the market for smaller organisations, and so can act to constrain innovation. Culture encourages and incentivises innovation when it is open, trusting, and conducive to risk-taking and learning from failure rather than avoiding it.
v. Absorptive capacity is an important aspect of innovation systems. In some sectors, a lack of systemic readiness and an emerging skills gap suggests that there could be constraints on the absorptive capacity of the UK innovation system.

Effective translation across all sectors requires the interaction of all of the conditions across the different stages of the translation pathway (from ideation and research through to uptake and diffusion).

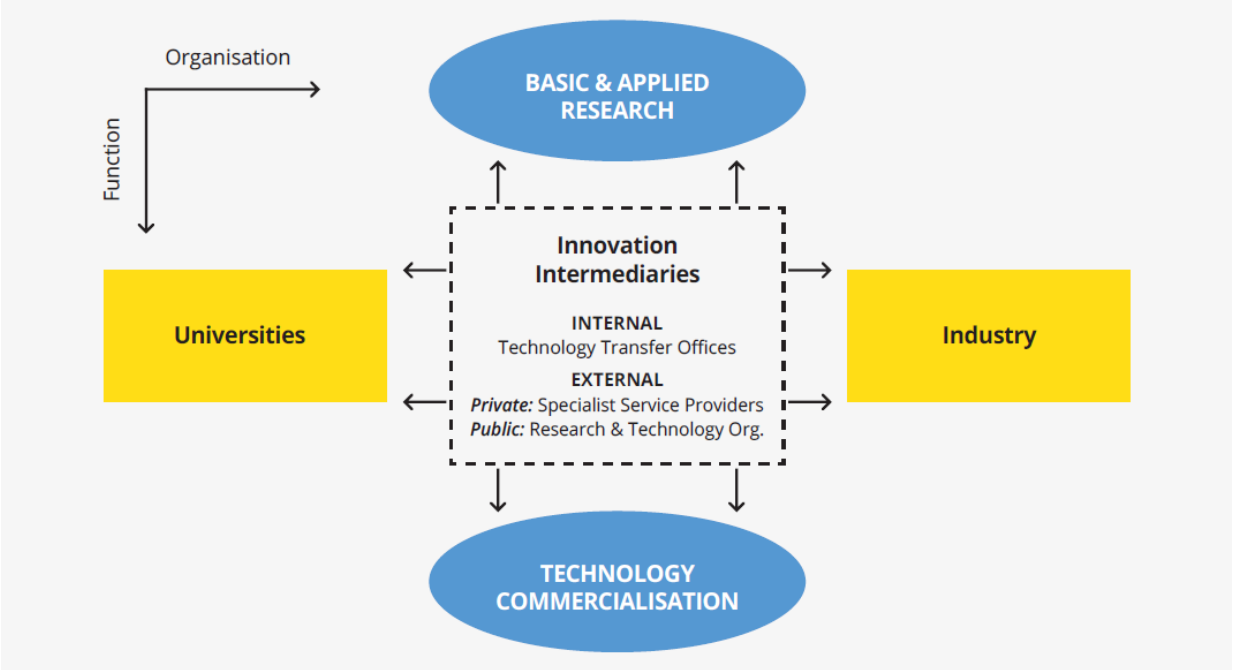
However, while knowledge, talent and capital are necessary at all stages of translation, it is their interaction through enablers, such as networks and infrastructure, which is particularly important. Successful translation in all the sectors relies on extensive networks between a range of actors (e.g. government, academia and industry). However, such intermediaries are often crucial in the context of academic research.

The need to coordinate decentralised processes of knowledge generation and diffusion has brought to the fore the role of institutional interfaces and specialist firms whose main objective is the transfer of scientific and technological knowledge[142]. These organisations facilitate the diffusion of knowledge and directly manage or support the translation of research into commercially-viable knowledge suited to the solution of specific industry needs. They act as 'knowledge brokers' – or 'intermediaries' – in the process of innovation.

Innovation intermediaries can bridge the gap between universities and industry, and connect the domains of basic and applied research with the market (Figure 6.1). They can be either internal or external to the university system. University technology transfer offices are typical 'internal' intermediaries, while research and technology organisations that may work with but are independent of, higher education institutions (HEIs), can be defined as 'external' intermediaries. These can be private businesses, such as specialist service providers, or publicly-funded organisations, for example, national labs or intermediaries such as the Fraunhofer Society in Germany, the VTT Technical Research Centre of Finland or the TNO Organisation for Applied Scientific Research in the Netherlands.

[142] Bozeman, B. (2000) Technology transfer and public policy: a review of research and theory, Research Policy 29; Debackere and Veugelers. (2005). The role of academic technology transfer organisations in improving industry science links, Research Policy, 34(3); D'Este and Patel (2007).

Figure 6.1: Innovation Intermediaries



The content and mode of knowledge exchange with or through any intermediary will vary with the nature of the knowledge base, the applicability of intellectual property rights, and the expected value, scope and objective of the transaction[143]. Some research suggests that external intermediaries can be especially important in conducting activities at the exploratory – or experimental – technology development phases.[144] The rationale is that these activities may be hard to finance through alternative funding sources (including venture capital) and can only be managed with difficulty in a university environment, where the incentives of science predominate over commercial imperatives, and where the costly process of scaling up operations to meet market targets may be difficult to achieve.

External intermediaries, however, operate in a mission-driven or market-driven environment designed to address specific societal or industry needs. They have to combine enough 'absorptive capacity' in basic science with strong applied skills. These pre-conditions are associated with investments in infrastructure and training for the development of emergent technologies and for solving technical problems that client firms may not be able to address on their own. In so doing, intermediaries often seek to attract in their local contexts of operation key and otherwise missing elements of industry value chains and to create a focal space for the exchange of knowledge. Part of this knowledge will need to be retained locally if such institutions are to contribute directly (through the creation of skilled jobs) and indirectly (by boosting the innovative capacity of local clients) to regional economic growth.[145]

However, it should be recognised that over the past decade UK universities have intensified their engagement with business, albeit great unevenness remains across industries and between large and small firms in the likelihood and volume of collaborative activities.[146] Also, concerning the activities of internal intermediaries, the performance of UK universities is considered to be very strong on a

[143] Schmoch (1999) Interaction of Universities and Industrial Enterprises in Germany and the United States: A Comparison, Industry and Innovation 6(1); Bekkers and Bodas-Freitas (2008)
[144] Bridging the gap: innovation intermediaries. Andrea Mina, Cambridge Judge Business School. Article featured in State of the Relationship report 2014. National Centre for Universities and Business.
[145] Bridging the gap: innovation intermediaries. Andrea Mina, Cambridge Judge Business School. Article featured in State of the Relationship report 2014. National Centre for Universities and Business.
[146] Of note, during 2020, Queen's University Belfast claimed the top position (and maintaining it from 2019) in an Entrepreneurial Impact report published by Octopus Ventures. The ranking measures UK universities' effectiveness in terms of their production of intellectual property, creation of spinout companies, and successful exits from such spinout companies, relative to their total funding.

comparative international basis for a range of metrics that include the number of licenses executed, licensing income and number of spin-offs[147]. However, the returns from these market-facing activities were found to be extremely skewed and are highly concentrated among a minority of institutions.[148]

In part to address some of these weaknesses, in 2010 and 2011, the UK government coordinated a process of consultation that led to the establishment of the Catapult Centres, a set of innovation centres designed to operate at the close to the market interface while being strongly connected with the research base in the development of selected technology platforms. The programme is overseen by Innovate UK.

6.5 Building Collaboration Capacity in Universities

The circulation of knowledge in and out of universities is a critical element in the chain of activities that turn research into wellbeing. However, formal recognition of – and a funding policy for – knowledge exchange (KE) as a core activity in universities is a relatively new idea that raises both challenges and opportunities.

In the last ten years, the UK has made significant progress in developing this paradigm to include activity beyond technology transfer and this progress has been recognised by both the European Commission[149] and the National Academies in the US.

One of the hindering elements in the application of this new paradigm across countries is the lack of common structures for assessing KE beyond specific outputs such as patents or licenses. However, such countable outputs are partial. The UK has sought to tackle this challenge by focussing on tracking the progress of its KE funding by using cost-benefit evaluation to demonstrate the social returns on public investment in KE (around 6:1 on average). However, it was expected that, as KE matured within the sector, robust metrics would emerge to monitor progress, justify and allocate public investment in these activities. What maturity has shown is that forms of, and benefits from, KE activities are so diverse that a thorough evaluation would incur a disproportionate cost.[150]

Nonetheless, some researchers have suggested that some indicators may be suitable to monitor the progress/growth of KE activities over time and are more suitable for comparison, and in doing so purge away short-lived events such as, for example, a bumper year in income from IP sale. Such indicators include income from:

- Consultancy;
- Contract Research;
- Continued Professional Development (CPD); and
- (Accessing) Facilities & Equipment.

These four components were selected in principle because they were suggested to be less volatile than others such as licensing.

[147] European Commission (2009), Metrics for Knowledge Transfer from Public Research Organisations in Europe: Report from the European Commission's Expert Group on Knowledge Transfer Metrics, Brussels. Praxis Unico (2012)
[148] Hughes et al. (2013), The Dual Funding Structure for Research in the UK: Research Council and Funding Council Allocation Methods and the Pathways to Impact of UK Academics, A Report from the Centre for Business Research and the UK~IRC for the Department for Business, Innovation and Skills.
[149] http://ec.europa.eu/research/innovation-union/pdf/kti-report-final.pdf
[150] Using trend growth in knowledge exchange income to track collaboration across UK HEIs. Article by Adrian Day, HEFCE & Rosa Fernandez, NCUB. Featured in State of the Relationship report 2014. National Centre for Universities and Business.

6.6 Monitoring University-Business Collaboration

A key point to note about the nature of international research collaboration is that if key papers are shared then so is their intellectual content and so is any IP arising. Institutions should therefore be wary about the agreements they sign over ownership and rights to exploitation of research outcomes. However, some researchers have suggested that for institutions and countries, IP ownership and holding knowledge assets is a thing of the past. This is part of a shift to open research. They argue that from this point forwards the key will be how agile and competent you are to use assets that you cannot prevent others from accessing.[151] This places a great deal of importance upon the role that universities place on commercialising their research and their engagement with business.

Given its importance, the National Centre for Universities and Business (NCUB) has developed a monitoring framework (the University-Business Collaboration Monitoring tool) that aims to establish appropriate indicators that capture two-way connections between universities and businesses over time. Nonetheless, NCUB cautions that these are inevitably a subset of the wider activities and operations that make UBC and should not be regarded as the whole story, but by being time-consistent, they provide a view of progress and serve as an early warning of changes in UBC.

The monitor uses 15 metrics (drawn from publicly available data released annually[152]) across four dimensions: resources for collaboration, knowledge flows between universities and business, partnerships, and commercialisation activity, as summarised below:

Indicator	Definition	5 Year Average
Collaboration	Industry income from KE (excluding licencing)	Income received by universities from large and small businesses as a share of total external income.
	Business funds in HE	R&D funded by business and performed by HE as a share of all R&D performed in HE.
	Foreign funds in HE	R&D funded by foreign sources and performed by HE as a share of all R&D performed in HE.
Knowledge Flows	Graduate employment	Share of employed (full-time) first degree leavers that are employed in innovation active sectors (as defined in the UK Innovation Survey).
	Postgraduate employment	Share of postgraduates in work, or a combination of work and study.
Partnerships	HEI deals with SMEs	The number of deals with SMEs reported by UK universities.
	£ per deal with SMEs	The average size of the deal with SMEs.
	HEI deals with large businesses	The number of deals with large businesses reported by UK universities.
	£ per deal with large businesses	The average size of the deal with large businesses.
	Innovate UK academic grants	The number of grants with academic partners awarded by Innovate UK.
	£ per Innovate UK academic grant	The average size of grants with academic partners awarded by Innovate UK.
Commercialisation	Licenses granted	The number of non-software and software licenses issued by UK universities.
	Income from licencing (£m)	University income from licencing.
	Patents granted	The number of patents granted to UK universities.
	Spin-offs	The number of spin-offs still active after three years of their creation by UK universities.

[151] The Implications of International Research Collaboration for UK Universities, Digital Science/ Universities UK, February 2016

[152] Data sources include Higher Education-Business and Community Interaction (HE-BCI) Survey; (ONS) UK Gross Domestic Expenditure on Research and Development (GERD); Destinations of Leavers in the United Kingdom (DLHE); gov.uk database on Innovate UK funded projects.

The UBC monitor, therefore, considers factors such as the sources of funds for collaboration, flows of people between academia and industry, knowledge shared in documents such as articles and patents, partnerships between universities and businesses, commercial outputs and the creation of business by universities etc.

Of note, the UBC monitor includes investment in HE performed R&D from both UK business and businesses abroad. This reflects several factors, including the fact that the investment from abroad has increased dramatically over recent years. This broad category of funding includes overseas governments as well as private investors and it reflects increasing efforts and the increasing attractiveness of UK universities to foreign direct investment (FDI). However, whilst the increasing funding from FDI demonstrates success for British UBC, it imposes risks too, as the UK does not have control over these foreign funds for universities' R&D activities.

The monitor reflects that UBC covers a portfolio of activities that are not only connected but can also be adjusted independently of each other to match specific need and demand. For example, increasing engagement with smaller enterprises may reduce the size of the average collaboration deal. Due to these internal connections between the parts, keeping the collaboration base in balance while expanding it is critical, as a disproportionate focus in one area can have direct unintended and equally disproportionate impacts elsewhere.

Following common movements in different but connected parts of UBC illustrates compensation mechanics between these activities, for example, exchanging researchers between universities and business moves together with co-authored publications between academia and industry. [153]

The UBC monitor combines indicators of cumulative (total) changes but also organisational changes within the total so that co-movements in sets of indicators can be used to make connections between parts. For example, it follows quantity and quality of outputs or deals so it is clear that increasing one may come at the expense of another.

Albeit, NCUB cautions that because of uncertainty and multiple influences in the journey of ideas to market, it is difficult to separate what collaboration leads to which application, or which policy is responsible for holding up or improving performance. [154] Nonetheless, it does not preclude monitoring progress and early warnings, without having to attribute impact.

For example, R&D funding by businesses could decline, but this would not necessarily mean they are not using the knowledge created and maintained in universities through multiple other channels, including the knowledge exchanged through the mobility of students and researchers, but also knowledge codified in written documents such as articles or patents.

A direct approximation to the use of university-developed knowledge in business operation is the destinations of graduates, with it noted that the destinations of all qualifiers 6 months after graduation are recorded in official statistics. Ideally one would like to be able to reflect similar indicators for the use of more experienced researchers for business operations and strategies but comparable data over time is not available. However, a means to assess cross-sector collaboration in knowledge sharing over time is the incidence and citation impact of joint academic-corporate publications.

Other forms of documental knowledge generated in universities and used readily by businesses include patents and licenses. Industrial partners (large and SME) consistently account for the majority of this income (90%) amongst UK universities confirming the fact that near market applications provide a better fit for business operation than other types of UBC.

The role of UBC in firm strategy is difficult to observe using indicators external to the firm, but the breadth and depth of partnerships between universities and businesses are deemed as the most important

[153] University Business Collaboration Monitoring Tool - Article by Rosa Fernandez, NCUB. Featured in State of the Relationship report 2015. National Centre for Universities and Business.
[154] Hughes, A and Martin B (2012) Enhancing Impact: The Value of Public Sector R&D. www.ncub.co.uk/impact

factor for collaboration success by practitioners and experts.[155] Partnerships reflect more involved commitments, often for longer-term, and shared governance of the relationship.

It is well known that UBC is not as widespread among businesses as it is among universities; a small percentage of 6% of UK businesses report to have collaboration deals with universities, although this share has been improving for all sectors except the utilities. A larger proportion of firms (nearly a quarter) report universities as highly important sources of information for innovation, which represents the relevance of UBC for innovation strategy.[156] The number and value of deals between universities and businesses can therefore be informative of the level of commitment. Potentially, higher-value deals among the smaller businesses could indicate deeper or longer-term engagement. On the other hand, an effort to target deals with smaller industry partners will inevitably reduce the value of the average deal. To capture these separately, the monitor tracks the number of interactions with larger and smaller businesses and their value as reported by universities, as well as the value of academic grants reported by Innovate UK.

The most direct indication of the use of enterprising university knowledge is the creation of new businesses as captured by spin-off activity (whether university-owned or otherwise).

By combining different aspects of the same collaboration activity, such as different types of investment, or volume and quality of publications and partnerships, NCUB's monitor enables users to assess organisational changes, such as the composition of investment or the concentration of resources in fewer but higher quality outputs or partnerships. These organisational changes provide context when using the monitor as an early warning tool, as the selected indicators are related to one another and do not change autonomously.

The NCUB produces a 'Devolved monitor' which displays 12 of the 15 indicators tracking collaboration in England, Scotland, Wales and Northern Ireland. The most recent results (for the 2016-17 academic year) are summarised below:[157]

Table 6.2: NCUB Devolved Monitor

Indicator	England		Northern Ireland		Scotland		Wales	
	2017 4 Yr Average	2017	2017 4 Yr Average	2017	2017 4 Yr Average	2017	2017 4 Yr Average	2017
Industry income for KE (excluding licencing)	38.2%	36.7%	28.6%	26.8%	51.0%	45.8%	27.8%	26.1%
Graduate employment in innovative sector	38.1%	37.6%	42.5%	34.3%	38.1%	37.5%	33.4%	34.3%
HEI deals with SMEs	62,705	54,332	1,419	1,349	12,698	19,433	1,277	1,061
£ per deal with SME	£2,561	£3,165	£3,221	£3,141	£1,951	£1,811	£4,498	£5,480
HEI deals with large business	19,426	19,895	574	430	4,044	4,992	1,115	894
£ per deal with large business	£27,010	£26,770	£13,115	£16,886	£20,570	£14,743	£10,674	£11,931
Innovate UK academic grants	516	607	28	25	65	66	32	34
£ per Innovate UK academic grant	£385,950	£234,322	£162,194	£140,801	£282,370	£240,667	£139,092	£126,879
Licences granted	5045	7487	82	87	443	538	357	405
Income from licencing (£m)	£83.3	£81.3	£8.6	£9.2	£7.5	£9.1	£1.6	£2.1
Patents granted	967	1179	40	46	113	171	22	20
Spin-offs	698	732	53	53	178	189	94	98

[155] University Business Collaboration Monitoring Tool - Article by Rosa Fernandez, NCUB. Featured in State of the Relationship report 2015. National Centre for Universities and Business
[156] University Business Collaboration Monitoring Tool - Article by Rosa Fernandez, NCUB. Featured in State of the Relationship report 2015. National Centre for Universities and Business
[157] https://www.ncub.co.uk/what-we-do/collaboration-progress-monitor-2019#fn1

In specific relation to the Northern Irish universities:

- They saw a decrease in both industry income from knowledge exchange activities (1.3%) and graduate employment in innovative sectors (8.3%) from 2016.
- A significant increase of 62.1% in the number of deals with SMEs was reported by Northern Irish universities. However, the size of the average deal fell by 31.8%. The reverse was true with regards to large businesses, with a decrease reported in terms of the number of deals (20.2%) and an increase reported in terms of the size of the average deal (30.3%).
- Northern Irish universities observed a decrease in both the number and the average grant size of Innovate UK grants from 2016 (19.4% and a striking 51.4% respectively).
- The number of licenses granted as well as the income from licencing activity both increased (42.6% and 14.7% respectively), while the number of patents granted more than doubled. The number of spin-offs active for at least 3 years remained unchanged from 2016 at 53.

6.7 Returns to Research Investment

A fairly large evidence base is emerging on the role of links between research and business communities in driving the returns to research investment. In general, it might be expected that collaboration between research and business communities acts as a channel for knowledge exchange which could help the link between knowledge stocks and innovation, and thus increase the returns to R&D investments (or at least reduce lag times).

A 2014 report produced for the former UK Department for Business, Innovation and Skills (BIS) looked at available evidence relating to the returns derived from business and research sector collaboration.[158] The report describes how the topic has been treated both from a macroeconomic perspective, using variables indicating engagement in traditional production function models, and a microeconomic perspective looking at individual academics and examples of collaboration at the individual firm and university level. A summary of the report's findings is featured below:

6.7.1 Private and public collaboration from a macroeconomic perspective

Berman (1990) analyses the role of direct industry funding for research conducted in universities. He finds that industry funding is associated with additional industry-level R&D funding, and leads to marketable returns with a much shorter time lag (about 5 years) than for university research financed in other ways (about 12 years), though this could just reflect industry funding "nearer to market" research. Medda et al. (2003) use a sample of 1,008 Italian firms from 1992 to 1995 to analyse the effects of collaborations on productivity outcomes. They find that collaboration between firms was highly effective, resulting in more rapid productivity growth. However, research conducted as collaborations between firms and universities had no impact on firm productivity. The authors caution that this may not be due to university research being unproductive; rather it could be that the types of projects conducted in collaboration between firms and universities may be further from the market or otherwise less likely to generate commercial returns.

6.7.2 Private and public collaboration from a microeconomic perspective

Micro-level analysis of individual firms and academics has focused on two main types of university-industry relationships:

- Commercialisation (or technology transfer); and
- Academic engagement.

'Commercialisation' refers to the exploitation by businesses of an academic idea to generate financial rewards. Lockett and Wright (2005) find a positive correlation between the business development

[158] Rates of return to investment in science and innovation A Report Prepared For The Department For Business, Innovation And Skills (BIS), Frontier Economics Ltd, July 2014

capabilities of UK Technology Transfer Offices (TTOs) and start-up formation, though Chapple et al. (2005) find TTOs at UK universities have low levels of absolute efficiency compared to US TTOs.

'Academic engagement' involves collaboration between the university and business sectors, often based on personal relations. D'Este and Perkmann (2011) identify three main forms of collaboration:

- Collaborative Research: arrangements aimed at cooperation on R&D projects that are not directly commercially relevant;
- Contract Research: referring to research that is directly commercially relevant, often explicitly commissioned by firms; and
- Consulting: research or advisory services generally provided by individual academic researchers.

The report found that whilst research literature has provided a considerable degree of evidence on whether and why academic researchers engage with business, rather less is said about the success or otherwise of such interactions in terms of outcomes and economic returns. The report's case study findings make it clear that academic partnerships with key strategic industries like aerospace and life sciences are highly valued by businesses, recognising the key need to absorb scientific knowledge produced in academic institutions as a way to drive innovation, but also point to the conceptual difficulties of disentangling the returns to this collaboration from the returns to other investments needed to innovate.

6.7.3 The geographic closeness between firms and researchers

There is a body of literature that suggests that the proximity of firms to research centres influences the returns to research investments. This complements the report's case study evidence which suggests that physical proximity remains a key driver of collaboration, allowing for trusted relationships between academics and business partners to emerge over time, and for easier interaction to solve commercial problems drawing on academic and scientific expertise.[159]

6.7.4 Conclusions featured in the Report

The BIS commissioned report considered the rates of return to investment of all types (both private and public) in science and innovation. Relevant conclusions drawn included:

- The overwhelming majority of available evidence relates to private returns to private sector R&D investments by firms and social returns generated through spillover effects at the industry, national and international levels. By contrast, there is relatively little evidence on the returns to non-R&D intangible investments, both private and social.

- In terms of public investment, there is a large body of evidence on comparing returns to private and public R&D spending, though this focuses primarily on R&D conducted by the private sector, but which may be funded publicly or privately. Much less is known about the returns to publicly funded R&D of different types, including:

  - The returns to public R&D investments delivered by different funding bodies (e.g. through universities, research councils or higher education);
  - The returns to public investment in basic or applied research.

- There is quite a large literature on links between business and researchers exploring motivations for collaboration. At the moment the evidence is rather thin on whether such collaboration yields higher returns to investment.

[159] Rates of return to investment in science and innovation A Report Prepared For The Department For Business, Innovation And Skills (BIS), Frontier Economics Ltd, July 2014

- The best recent evidence suggests that publicly-funded R&D investments in the UK generate significant social rates of return of around 20%.[160] This figure is based on relating private sector productivity growth to public R&D investments, similar to how returns to private R&D investment are typically estimated. There is some evidence that the returns measured in this way vary according to the source of funding. **R&D channelled through research councils, and particularly science-based and more applied research council investments, appear to have the greatest impact on private sector productivity growth.**

- A focus on how publicly-funded R&D affects the private sector is likely to underestimate the social returns to this investment. For example, public R&D investments may generate improvements in public health, national security and an intrinsic 'value of knowledge' which are not captured in a traditional knowledge spillover framework. Quantifying these benefits is much more difficult. There is also good evidence that public incentives for R&D crowd in additional private sector investments, which again would suggest larger overall returns. The evidence for crowding in is strongest for fiscal incentives and public subsidies for private sector R&D. There is less clear evidence regarding the impact of R&D conducted directly by the public sector (including that channelled through higher education), though the literature on this issue is somewhat thin.

- There is **clear evidence of an interrelationship between public and private sectors in driving innovation.** Links to academia are increasingly seen as an important complement to the in-house knowledge of industry, and a significant amount of private-sector output and innovation is thought to depend critically on public funding of academic research. **Engagement with academia and the science base is also seen to be a key driver of where firms locate private R&D investments**.

6.8 The Connected Programme

Whilst NI's universities are considered to be successful in securing investment from engagement with companies and other organisations through a wide range of Knowledge Exchange activities, ranging from collaborative research to consultancy, from access to facilities and equipment to licensing of intellectual property, from bespoke training to continuing professional development, annual NI R&D Surveys published by the Northern Ireland Statistics and Research Agency (NISRA) consistently show that the vast majority of registered companies in Northern Ireland are not fully engaged with the Higher and Further Education sectors.

It is for this reason that DfE supports a unique Northern Ireland programme called 'Connected'. Connected is the first and only Knowledge Exchange programme in the UK to be delivered across both Higher and Further Education. It enables businesses of all sizes to have coordinated access to the full range of services available from the universities and colleges including research, product development, knowledge exchange, innovation and training.

As a ground-breaking initiative involving Queen's, Ulster, the Open University in Northern Ireland and Northern Ireland's six further education colleges, Connected enables these institutions to come together to provide a highly effective 'one-stop-shop', taking companies through the entire process from problem definition through to solution identification and implementation. Connected's specialist staff are also well placed to advise companies on possible sources of funding, including the highly successful Innovation Voucher and Knowledge Transfer Partnership (KTP) programmes administered by Invest NI.

The success of the programme has further underlined both the need and growing appetite from companies for HE and FE collaboration.

[160] Conceptually, returns on science and innovation investments can accrue privately to those making the investments, or socially to others. Social returns encompass both increases in profits for firms who can make use of the innovations created by other firms or in the public sector, as well as harder-to-measure returns to wider society such as gains to health, well-being, security and efficiency in the policy making process and the delivery of public services.

Nonetheless, it is recognised (per the Innovation Strategy for Northern Ireland) that **if Northern Ireland is to compete in the global marketplace, there is a crucial need to significantly increase Knowledge Exchange activities and the breadth of stakeholder collaboration.**

6.9 Summary Conclusions

Undoubtedly, the local universities play an important role in NI's regional innovation and economic growth. Much of this can be demonstrated through their contribution to the supply of skilled labour or their direct engagement with local businesses. However, their role in generating spillovers from their wider research, education and KE activities, and from their wider asset base should not be overlooked. This includes the benefits of becoming more strongly and deeply embedded into global sectoral and technological systems and the implied effects on the location of high-value activities within these global systems.

Nonetheless, this should not negate the necessity to seek to maximise the potential to anchor those spillovers locally.

Whilst the Research Team recognises that university missions are multi-dimensional addressing multiple objectives, spanning research excellence, education and supporting innovation and economic development, we consider that international programmes such as the US-Ireland R&D Partnership offer the potential to anchor the universities' activities even more strongly in NI (whilst having international ambition) and to ensure that international research collaboration efforts are responsive to regional needs. To achieve this, the Research Team considers that such programmes should feature, at the local level (i.e. specific to NI) 'system-embedding' objectives to embed the research activities undertaken into Northern Ireland's specific innovation system(s) i.e. they should aim to achieve specific regional, technological, sectoral and socio-economic objectives.

This should not curtail the universities, for the most part, in terms of the type of research undertaken, but instead, place the question as to how the activities and linkages created best capture value for the region in the consideration of any application received.

For example, it raises issues relating to the important interdependencies between demand and supply conditions within the NI innovation system, not least the capabilities of firms to absorb and exploit the resources, knowledge and expertise generated within universities. This will condition the nature and scale of value realised by firms from their knowledge-based interactions with universities.

Analysis of demand opportunities and an understanding of where universities can contribute most effectively should be an important factor in shaping the pattern of international research collaboration activity.

7. REVIEW OF DFE SUPPORTED INTERNATIONAL RESEARCH COLLABORATION

7.1 Introduction

As discussed in Section 2, the Department for the Economy (DfE) manages the NI element of two programmes focused on promoting international research collaboration (outside of promoting EU Framework / Horizon Programme collaborations through its Collaborative Research Support Fund):

1. The US-Ireland Research & Development (R&D) Partnership; and
2. Pilot rounds of the SFI-DfE Investigators Programme.

Appendices IX and X provides the Research Team's detailed summaries and analysis of available project materials relating to each initiative respectively, whilst this section summarises key aspects of the activities undertaken, and impacts realised, through these two initiatives.

Also, this section provides a summary of the Research Team's consultations with 27 of the 45 NI Principal Investigators (PIs) that have been involved in a research project(s) delivered under one and/or other of the two initiatives.

The Research Team was provided with contact details for 45 PIs that were involved in 54 projects undertaken through either the US-Ireland Research & Development (R&D) Partnership or the pilot rounds of the SFI-DfE Investigators Programme. Some of the PIs had been involved in projects delivered under both schemes. 27 (or 69%) of the 45 PIs engaged in the primary research.

Table 7.1: Summary of PI Consultations

	US-Ireland	SFI-DfE	Total
No. of projects	40	14	**54**
No. of unique PIs	34	14	**45**[161]
No. of PIs unable to contact	3	3	**6**
No. of PIs able to contact ('X')	31	11	**39**
No. of Consultations Completed ('Y')	**20**	**7**	**27**
% complete (Y/X x100%)	**65%**	**64%**	**69%**

7.2 Activity Summary

7.2.1 Number of Projects Supported through the US-Ireland Research & Development (R&D) Partnership

The following is an analysis of the full portfolio of proposals submitted, as of 10th March 2020 (up to project reference USI 146), for merit review under the US-Ireland Research & Development (R&D) Partnership.[162]

Table 7.2: Portfolio of Proposals Submitted

Proposal Status	NIH	NSF (incl. C2C)	NIFA	Total
Approved	13 (incl. 1 DfE funded project USI 035)	40 (incl. 7 C2C)	5	**58**
Declined	59	94	28	**181**
Sub-Total – Approved/Declined	**72**	**134**	**33**	**239**
% Approved	18%	30%	15%	24%
% Declined	82%	70%	85%	76%
Pending decision	10	7	4	**21**
Withdrawn	4	1	1	**6**
Total no. of applications	**86**	**142**	**38**	**266**

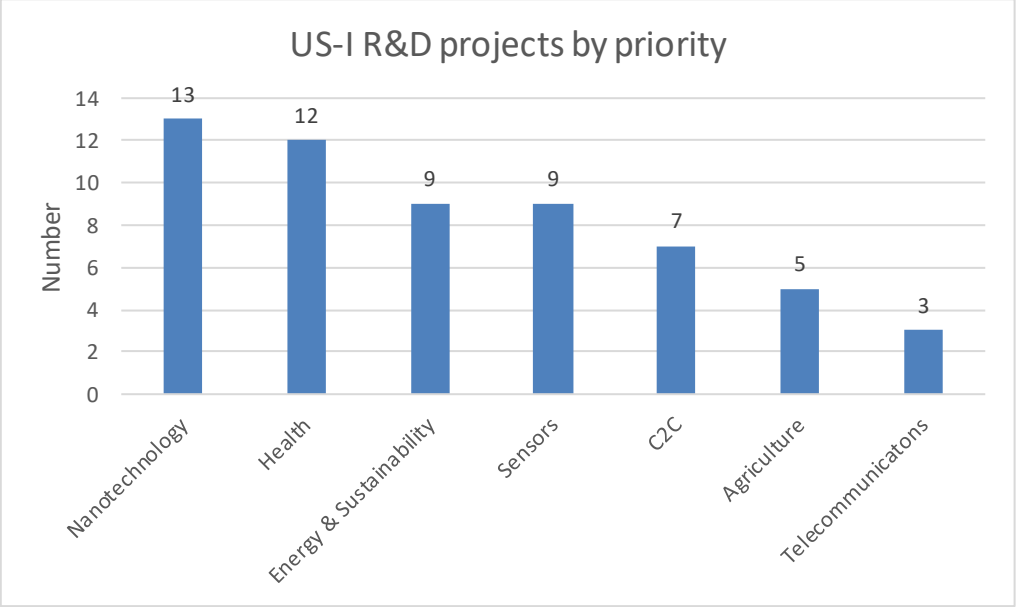
[161] NB: 3 PIs were involved in both a US-Ireland R&D project and an SFI-DfE project.
[162] Review of Partnership Progress - Prepared by InterTradeIreland, Secretariat, 10th March 2020 / Reviewed by DfE and Agreed with InterTradeIreland, 13th January 2021.

Points to note include:

- On an overall basis, 266 applications have been submitted to the US-Ireland Research & Development (R&D) Partnership up to March 2020. At that time, 239 had undergone full peer review by the relevant US agency.
- Close to one quarter (24% or 58 projects) of the applications that have been fully reviewed have been approved for funding.
- It is understood that the cumulative value of the 58 approved projects is c£79m.

It is understood that at a recent meeting of the US-Ireland R&D Partnership Steering Group, an NSF representative noted that the approval rating (30%) for US-Ireland proposals was 'almost unheard of in NSF' for standard US-only proposals.

The following chart illustrates (for the period to March 2020) the profile of approved US-Ireland R&D Partnership projects by priority area.



7.2.2 Number & Value of DfE Supported Projects

The table below provides a high-level overview of activity supported by DfE under the US-Ireland Research & Development (R&D) Partnership and the pilot rounds of the SFI-DfE Investigators Programme to March 2020. NB for the US-Ireland Research & Development (R&D) Partnership, the table features details for the 40 (of 41) projects for which information was provided to the Research Team. One project (USI 150) that features in Section 7.2.1 was approved following the Research Team commencing its analysis, so is not included in this table.

Table 7.3: Number & Value of DfE Supported Projects

		US-Ireland	SFI-DfE
No. of projects		40	14
University Involved:	QUB	33	13
	UU	7	1
Approximate Total Project Value		£35.4m	£17.8m
Approximate NI Project Value		£12.1m	£8.5m
Approximate C2C Project Value (included in Total Project Value above)		£9.4m	-
Approximate NI C2C Project Value (included in NI Project Value above)		£2.1m	-

As reflected above:

- 40 projects have been supported under the US-Ireland Research & Development (R&D) Partnership and 14 under the pilot rounds of the SFI-DfE Investigators Programme. 7 of the USI projects are Centre-to-Centre projects;
- Of the 54 projects, 46 have involved QUB and 8 have involved Ulster University.
- Allowing for currency exchange values, the total anticipated value of the 40 USI projects is c£35.4m, of which 34% (£12.1m) is the direct NI project value. Of this total, the 7 Centre-to-Centre projects have an anticipated total project value of c£9.4m, of which 27% (£2.1m) is the direct NI project value.
- Again, allowing for currency exchange values, the total anticipated value of the 14 SFI-DfE Investigators Programme projects is c£17.8m, of which £8.5m (48%) is the NI project value.

7.2.3 Staff Supported under DfE Projects

The table below provides a summary (per the project completion reports and/or annual report on impacts) of the number of university staff/personnel supported under the projects supported under both programmes. Data from USI 150 are not included in this table.

Table 7.4: Staff Supported under DfE Projects

NI Staff supported	US-Ireland	SFI-DfE
PDRAs	47	20
PhDs	28	7
Postgraduate Masters Students	1	-
Engineers	2	-
Technicians	2	-
Undergraduates	10	-

The Research Team notes that the information provided with some of the earlier monitoring reports does not provide a clear indication of the staff and personnel involved in projects, with the number of academics involved, in particular, appearing to be understated. Consequently, it is understood that DfE revised the quarterly progress report template in April 2018 to be more succinct and requiring the Principal Investigator to specifically state the personnel involved in projects during the claim period.

7.2.4 Sectors Supported under DfE Projects

Under the US-Ireland Research & Development (R&D) Partnership, 15 (37.5%) of the supported projects include the area of nanotechnology, whilst 13 include the area of energy & sustainability. As illustrated below, some projects straddle two research areas. Data from USI 150 (a nanotechnology project) are not included in this table (full analysis of the 40 projects is set out at Appendix IX, Section 2. This analysis includes the seven C2C projects, now designated per sector/research area).

Table 7.5: Sectors Supported - US-Ireland

Sector/Research Area	No. of Projects
Nanotechnology	13
Energy / Sustainability	11
Sensors	9
Telecommunications	4
Nanotechnology & Energy / Sustainability	1
Nanotechnology & Telecommunications	1
Sensors & Energy / Sustainability	1
Total	**40**

Under the pilot rounds of the SFI-DfE Investigators Programme, 5 of the 14 projects were in the area of sustainable food production and processing.

Table 7.6: Sectors Supported – SFI-DfE	
Sector/Research Area	**No. of Projects**
Sustainable Food Production and Processing	5
Diagnostics	3
Therapeutics: Synthesis, Formulation, Processing and Drug Delivery	2
Digital Platforms, Content & Applications	1
Future Networks & Communications	1
Processing Technologies and Novel Materials	1
Smart Grids & Smart Cities	1
Total	**14**

7.2.5 Technology Readiness Levels (TRLs)

Whilst the specific Technology Readiness Levels of the projects supported under the US-Ireland Research & Development (R&D) Partnership have not been recorded in the materials received, it is understood that all of the USI projects would represent basic research (i.e. TRL 1-3), and this is borne out by our reading of the proposals.

Concerning the pilot rounds of the SFI-DfE Investigators Programme, 13 of the 14 projects supported commenced at a TRL between 1 and 3:

Table 7.7 – TRLs – SFI-DfE	
Technology Readiness Level	**No. of Projects**
TRL 1	2
TRL 2	7
TRL 3	4
TRL 4	1

7.3 Outputs Achieved

For the remaining analyses, all data in respect of US-Ireland projects have been based on the 40 projects supported by DEL/DfE to March 2020 (but excluding USI 150 as explained at 7.2.2 above).

It is also important to note that the US-Ireland data may underestimate the actual position as DfE's Quarterly Progress Reports were revised in April 2018 to explicitly capture many of the metrics discussed in this section. Before that date, PIs had not been required to provide this specific data.

7.3.1 Journal Publications

The Research Team has reviewed the list of publications featured in the project monitoring materials. From September 2018, the PIs of US-Ireland projects have been required to provide details of *'referred journal publications supported by the DfE award'* and so it is reasonable to assume that any listed journal publication recorded in these progress reports relates to, or at least involves the NI institution. In some instances, however, it was difficult to identify what institutions were involved in the development of journal publications, and as such the Research Team and DfE have sought, where possible, to align the named authors with academic institutions. On that basis, the following analysis should be considered as indicative:

Table 7.8: Journal Publications		
	US-Ireland	SFI-DfE
Total Journal Publications	174	179
Of which the Research Team was unable to identify whether the publication was undertaken on a collaborative basis	2	8
Of which the Research Team was unable to identify whether the publication was undertaken on a collaborative basis but was able to identify that a NI academic was involved	13	1
Of which were NI in collaboration with RoI and US	42	-
Of which were NI in collaboration with RoI	22	28
Of which were NI in collaboration with the US	17	-
Of which were NI only	14	17
Of which were NI in collaboration with RoI or US from outside the project	13	5
Of which were NI in collaboration with other International	25	16
Of which were NI in collaboration with other UK HEIs	24	7
Of which were the USA only	2	-
Of which were RoI only i.e. with no NI involvement (but sometimes with other partners including international)	-	97

The analysis of the project materials indicates that:

- The 40 USI projects have generated 174 journal publications. Of the 174 publications:
  - It was not possible to identify whether 2 were undertaken on a collaborative basis or whether an NI academic was involved;
  - It was not possible to identify whether 13 were undertaken on a collaborative basis but it was possible to identify the involvement of an NI academic;
  - 42 were collaborative on a tri-partite basis (involving the USI partners);
  - 22 were in collaboration on a NI/RoI basis (involving the RoI partner in the project);
  - 17 were in collaboration on a NI/USA basis (involving the US partner in the project);
  - 14 were publications featuring only NI-based academics;
  - 13 were in collaboration with RoI or US institutions from outside the USI project;
  - 25 were in collaboration with other international institutions/organisations;
  - 24 were in collaboration with other UK institutions/organisations;
  - 2 were publications featuring only USA-based academics.

- The 14 SFI-DfE projects have generated 179 journal publications. Albeit it should be noted that the monitoring materials indicate that only 40% (72) could be *'primarily attributable'* to the SFI-DFE project. As such, it is unclear what role the SFI-DfE projects played in the development of the majority of publications recorded in the monitoring materials. Nonetheless, of the 179 publications:
  - It was not possible to identify whether 8 were undertaken on a collaborative basis or whether an NI academic was involved;
  - It was not possible to identify whether 1 was undertaken on a collaborative basis but it was possible to identify the involvement of an NI academic;
  - 28 were in collaboration on a NI/RoI basis;
  - 17 were publications that featured only NI-based academics;
  - 5 were in collaboration with RoI institutions from outside the SFI-DfE project;
  - 16 were in collaboration with other international institutions/organisations;
  - 7 were in collaboration with other UK institutions/organisations;
  - 97 were RoI publications without any NI involvement (either with or without other partners, sometimes including international).

  Discussion with DfE indicates that the findings relating to the 14 SFI-DfE projects may be influenced by the fact that monitoring of SFI-DfE projects was completed by SFI based on reports submitted by RoI PIs rather than joint reports.

7.3.2 Conference Publications

The Research Team has reviewed the list of conference publications featured in the project monitoring materials. Similar to Journal Publications, from September 2018, the PIs of US-Ireland projects have been required to provide details of *'referred conference publications supported by the DfE award'* and so it is reasonable to assume that any listed journal publication recorded in these progress reports relates to, or at least involves the NI institution. In some instances, however, it was difficult to identify what institutions were involved in the development of journal publications, and as such the Research Team and DfE have sought, where possible, to align the named authors with academic institutions. On that basis, the following analysis should be considered as indicative:

Table 7.9: Conference Publications

	US-Ireland	SFI-DfE
Total Conference Publications	88	16
Of which the Research Team was unable to identify whether the publication was undertaken on a collaborative basis	6	-
Of which the Research Team was unable to identify whether the publication was undertaken on a collaborative basis but was able to identify that a NI academic was involved	57	-
Of which were NI in collaboration with RoI and US	6	-
Of which were NI in collaboration with RoI	1	2
Of which were NI in collaboration with the US	5	-
Of which were NI only	12	1
Of which were RoI in collaboration with the US	1	-
Of which were RoI only i.e. with no NI involvement (but sometimes with other partners including international)	-	13

Similar to Journal Publications, discussion with DfE indicates that the findings relating to the 14 SFI-DfE projects may be influenced by the fact that monitoring of SFI-DfE projects was completed by SFI based on reports submitted by RoI PIs rather than joint reports.

Nonetheless, the analysis of the project materials indicates that:

- The 40 USI projects have generated 88 conference publications. Of the 88:
  - It was not possible to identify whether 6 were undertaken on a collaborative basis or whether an NI academic was involved;
  - It was not possible to identify whether 57 were undertaken on a collaborative basis but it was possible to identify the involvement of an NI academic;
  - 6 were collaborative on a tri-partite (NI/RoI/USA) basis;
  - 1 was in collaboration on a NI/RoI basis;
  - 5 were in collaboration on a NI/USA basis;
  - 12 were publications featuring only NI-based academics; and
  - 1 was in collaboration on an RoI/USA basis.

- The 14 SFI-DfE projects have generated 16 conference publications. Albeit it should be noted that the monitoring materials indicate that only 44% (7) could be 'primarily attributable' to the SFI-DFE project. Of the 16 conference publications:
  - 2 were in collaboration on a NI/RoI basis (i.e. involving both project partner institutions);
  - 1 involved only the NI partner; and
  - 13 involved only the RoI partner (sometimes alone and sometimes with other international partners).

7.3.3 International Presentations

The Research Team has reviewed the international presentations featured in the project monitoring materials. Similar to other aspects of reporting, from September 2018, the PIs of US-Ireland projects have been required to provide details of *'international presentations directly supported by DfE award'*. Nonetheless, in some instances, it was difficult, in some cases, to identify whether an NI partner was involved in the delivery of the presentations cited. On that basis, the following analysis should be considered indicative.

The Review Team's and DfE's review of the project monitoring materials indicates that there were 177 international presentations associated with the 40 USI projects. However, the Research Team was only able to identify 63 instances where an NI partner was involved in the delivery of the presentation.

Table 7.10: International Presentations		
	US-Ireland	**SFI-DfE**
Total International Presentation	177	305
Of which involved NI partners in the delivery of the presentation	63	28
Of which are not known (or RoI only)	114	277

It should be noted that discussion with DfE indicates the view that if a QUB/UU PI has cited an international presentation in their reporting that it may be reasonable to assume that they or a colleague was involved in the delivery of the presentation. Going forward, such ambiguity can be addressed by requiring the PI to specifically identify who delivered an international presentation. DfE further notes that if the presentation was based on the work of a joint project, then, by definition, it must reference the NI involvement and include work performed by the NI partner.

The 14 SFI-DfE projects generated 305 conference publications, of which the Research Team was only able to identify 28 instances where an NI partner was involved in the presentation. Similar to other aspects of the SFI-DfE project reporting, the results identified are likely to be influenced by the RoI partner being responsible for preparing and submitting the progress reports to SFI (on behalf of both partners).

7.3.4 NI Industry Involvement

Of the 40 US-Ireland Research & Development (R&D) Partnership projects, 10 (25%) had some involvement with NI industry. DFE advises that PIs are not required to report on this in the revised Quarterly Progress reports, however, they are required to provide information relating to any industry engagement in the revised Project Completion Reports.

Table 7.11: NI Industry Involvement		
	US-Ireland	**SFI-DfE**
No. of Projects that involved NI industry	10	4

A similar proportion (c29%) of the 14 SFI-DfE projects involved, to some extent, NI industry.

The Research Team considers that across both programmes and allowing for the low TRLs of the research involved, the proportion of projects that have involved NI industry to some extent should be considered positively. This may particularly be the case, when one considers the nature of the industrial base in NI which is dominated by small companies tending to have low absorptive capacities and of which only a very low proportion are themselves R&D active.

7.3.5 Follow-On Funding Achieved

The NI partner on 12 of the 40 USI projects secured follow-on funding from various local/national/international funding bodies that they attribute in some way to the USI project. In three cases, this included further USI funding. The total value to the NI partner of the follow-on funding achieved by those projects is c£9.7m.

Table 7.12: Follow-On Funding Secured		
	US-Ireland	**SFI-DfE**
No. of Projects that Received Follow-on Funding	12	12
Approximate Total Follow-on Funding Associated with Projects (where known)	£14.9m	£203.7m
Approximate Follow-on Funding awarded to NI Partners	£9.7m	

12 of the 14 SFI-DfE projects received follow-on funding totalling c.£203,652,463 (allowing for conversion to Sterling) of which £31,476,915 (15%) was listed as being 'primarily attributable' to the SFI-DFE project. The c£203m was associated with 104 further projects, of which 21 (20%) were noted as having an NI partner involved. The value of follow-on funding awarded to NI partners could not be discerned.

7.4 Economic, Commercial or Industrial Outcomes

The following section provides an overview of economic, commercial or industrial impacts that have been reported under both of the programmes and can be related to Northern Ireland.

Again, it should be noted that the US-Ireland data may underestimate the actual position as DfE's Quarterly Progress Reports were revised in April 2018 to explicitly capture many of the metrics discussed in this section. Before this point, PIs had not been required to provide this specific data.

7.4.1 The US-Ireland Research & Development (R&D) Partnership

Across the 40 US-Ireland Research & Development (R&D) Partnership projects, two-thirds (N=26 or 65%) have not yet (in May 2020) reported any substantive economic, commercial or industrial impacts, although, as noted above, this may not be unexpected given the low TRLs of the projects supported. A summary of the impacts reported by the remaining 14 projects is provided below (further detail is provided in Appendix IX). Please note that none of the 14 projects reported a monetary value associated with the reported impact, albeit some of the impacts would appear to lend themselves to such impacts being able to be more fully monetised.

Table 7.13: US-Ireland R&D Partnership Economic, commercial or industrial impacts Reported	
Project	**Economic, commercial or industrial impacts Reported**
USI 001	A contract is in place with industry (in the USA) to supply antibodies for diagnostic kits.
USI 002	Aspects of the research were included in a training course that was delivered at Schrader Electronics in 2015.
USI 013	Several Invention Disclosure submissions were made to the Office of Innovation at UU and were investigated for IP protection.
USI 023	The sensor technology developed under this research was introduced into a NI-based SME under a Knowledge Transfer Partnership between QUB and McFarland Associates.
USI 033	Some of the work was investigated for IP protection and was deemed to be patentable, although it was not pursued on advice from the University's Research and Innovation Office.
USI 035	A facility for producing screen-printed electrode arrays that would serve as the foundation for the sensors was established at UU.

Table 7.13: US-Ireland R&D Partnership Economic, commercial or industrial impacts Reported	
Project	**Economic, commercial or industrial impacts Reported**
USI 039	The project completion report noted that it was envisaged that the recombinant baculovirus stocks generated through this project might have the potential for commercial exploitation and the feasibility for this was to be discussed with the QUB Research and Innovation Office. It was also noted that the Enfer Group had expressed interest in utilising recombinant proteins produced by QUB for in-house disease surveillance testing and some exploratory discussions on exploitation via this route had been undertaken. The project completion report further noted that there were possible commercialisation opportunities relating to the application of several proteins produced which had the potential to improve the diagnostic surveillance of bovine respiratory disease (BRD) with associated economic benefits due to reduced mortality, morbidity and antibiotic misuse and improved performance of livestock.
USI 041	The QUB team had successfully developed a model bi-wing anchor (an optimised shape based on the investigations) and tested it to demonstrate its application. The project completion report highlighted that a key contribution made by the QUB team was the proof of concept of the flying wing anchor, confirmed by the real-time filming of the events. Another significant contribution to the project was the possible application of alternative anchoring methods in granular soils. It was envisaged that this would need further investigation for potential field application. The report noted that local industry was keen to see this particular anchoring method in action and it was envisaged that the research team at QUB would have a demonstration model. It was anticipated that the additional work could lead to a Knowledge Transfer Partnership with an industry partner.
USI 044	The work completed in this project strengthened the existing data which enabled the QUB Principal Investigator, Helen McCarthy, to spin out the RALA (Radioactive Lanthanum) technology into pHion Therapeutics in May 2017. Since then pHion has won several awards and worked with commercial partners across the world. pHion now employs 10 people and has secured £2M of non-dilutive Innovate UK funding. (See https://www.phiontx.co.uk/).
USI 049	The project completion report indicated that this project provided the framework for a subsequent project (USI 132 - EMERALD) that was anticipated to have much more commercial significance and societal benefit, especially in the developing world, in the form of an inexpensive solar-powered brine-splitting cell for the production of fuel (H2) and disinfectant (Cl2 or bleach).
USI 057	The project completion report notes that there was potential for the application of 2D materials to biosensors of strategic interest to local companies such as Randox.
USI 067	The project completion report noted that the project had developed the world's first method for synchronising vision sensors for monitoring civil infrastructure in real-time. It was noted that the system has been named 'QUBdisp'. According to the report, the research went beyond its initial plan in that, the full system was used to monitor the Peace Bridge in Derry at the time of the Halloween event. This came about due to some concerns of bridge safety under crowd loading during the previous year. It was noted that NI's Department for Infrastructure is unique in Europe and the USA in that it has overall responsibility for all Civil Infrastructure (in Northern Ireland) which includes the strategic maintenance of our road, rail and water network and the bridges that connect them. This enabled field trials on real bridges under live loading to prove the QUBdisp system. According to the report, several SMEs (for example McFarland's and Amphora Technologies) had incorporated vision-based monitoring into their businesses based on demonstrations from this project, with it suggested that the low cost and highly accurate solutions developed were highly beneficial to their clients.
USI 096	The AMASS project exclusively used local NI companies (Walter Watson Ltd, Lagan Valley Steel Ltd, Kennedy & Morrison Ltd, M. Hasson & Sons Ltd, Hutchinson Engineering Ltd, Foxcut Waterjet Cutting Services) for the supply and fabrication of all steel assemblies

Table 7.13: US-Ireland R&D Partnership Economic, commercial or industrial impacts Reported	
Project	**Economic, commercial or industrial impacts Reported**
	tested. Smyth Steel Ltd was also engaged in discussions on multi-axis CNC fabrication of steel sections. The project completion report stated that the research had validated the performance of a new connection type, with it suggesting that its adoption could provide a market opportunity to the benefit of the aforementioned local companies offering CNC cutting and fabrication services for structural steel.
C2C	
USI 085	The project completion report noted that the project had developed new networking hardware for data centres that has the potential to improve performance and reduce power consumption.
USI 090	Part of the novel nanoparticle process platform was filed in a patent application. It was anticipated that the Patent Cooperation Treaty (PCT) (ie the international stage of the patent application) would be filed by 11th Jan. 2020.
USI 110	Synchrophasor technology developed during the CREDENCE project (Collaborative REsearch of Decentralisation ElectrificatioN Communications and Economics) is directly benefiting the NI economy via the spin-out company, Phasora Ltd. (See https://www.phasora.net/).

7.4.2 Pilot rounds of the SFI-DfE Investigators Programme

Across the 14 SFI-DfE Investigators Programme projects, two-thirds (N=9 or 64%) have not yet (in May 2020) reported any substantive economic, commercial or industrial impacts. Again, this is perhaps not to be unexpected given the low TRL nature of the research projects supported under this programme. A summary of the impacts reported by the remaining 5 projects is provided below (further detail is provided in Appendix X). Please note that none of the 5 projects reported a monetary value associated with the impact, albeit some of the impacts would appear to lend themselves to such impacts being able to be reported.

Table 7.14: SFI-DfE Investigators Programme Economic, commercial or industrial impacts Reported	
Project	**Economic, commercial or industrial impacts Reported**
14/1A/2304	The project's latest annual report states that *"based on work conducted at UCD a patent has been filed which is expected to result in both additional funding from and a licence agreement with Zoetis, the world's leading Animal Health company"*. It is not clear whether any aspect of the patent or any downstream revenues will be attributable to QUB.
14/1A/2371	The project trialled both the anaerobic digestion (AD) and nutrient capture technologies with several NI/RoI and international companies e.g. Eli Lilly, Moy Park, Devenish Nutrition, Kerry Group, Glanbia, Dale Farm, Ostara, NI Water and Irish Water. QUB licensed one product from the research and it was anticipated that they would develop a spin-out company to commercialise others.
14/1A/2559	QUB engaged with several international and NI businesses including Shin-Etsu, Maag, Almac and Amgen to explore possible future collaborations and further funding opportunities associated with the single and co-extrusion platforms.
14/1A/2582	QUB worked with Astex Pharmaceuticals to develop a clinical trial of IAPantagonists in combination with chemotherapy in advanced colorectal cancer. This was scheduled to be reviewed by Cancer Research UK (CRUK) in Q1 2020.
15/1A/3058	Engagement with industry – EirGrid, Glen Dimplex, B9 Energy, Enelytix

7.5 Employment Outcomes - The US-Ireland Research & Development (R&D) Partnership

As before, it should be noted that the US-Ireland data may underestimate the actual position as DfE's Quarterly Progress Reports were revised in April 2018 to explicitly capture many of the metrics discussed in this section. Before this point, PIs had not been required to provide this specific data.

Across the 40 US-Ireland Research & Development (R&D) Partnership projects, just over one-third (N=15 or 38%) indicated that there had been some form of positive employment impact as a result of

the research project, as summarised below. Of note, whilst many of the employment positions were in academia, some are in NI-based businesses, indicating strong potential for knowledge transfer.

Table 7.15: Employment Outcomes

Project Ref	Role in Project	Employment following project involvement[163]	Did working on the project assist in gaining employment[164]
USI 001	PDRA	Research Fellow @ QUB	Yes
USI 021	PDRA	Academia	Yes
	PhD	Academia	Yes
	PhD	Industry	Yes
USI 035	PDRA	Postdoc in Japan	Not stated
	Undergraduate	Industry (Biomedical Engineer in Randox)	Not stated
	Undergraduate	Industry (Biomedical Engineer in Randox)	Not stated
USI 039	PDRA	Industry (Almac Group)	Yes
USI 043	PDRA	Industry (Seagate Technology)	Yes
	PDRA	Industry (AquaQ Analytics)	Yes
USI 049	PDRA	Industry	Yes
	PDRA	Industry	Yes
	PDRA	Academia	No
	PDRA	Academia	Yes
	Other	Academia	Yes
USI 058	PDRA	Academia – Experimental Officer at University of Exeter	Yes
USI 065	PDRA	Academia – Research Fellow @ UU	Yes
	PhD	Academia – Research Associate @ UU	Yes
USI 067	PDRA	Academia – Research Fellow @ QUB	Yes
	PhD	Academia – Royal Academy of Engineering Fellowship @ QUB	Yes
USI 073	PDRA	Industry (UK based company)	Not stated
USI 082	PDRA	Academia – Research Fellow @ University of St. Andrews	Yes
	PhD	Academia – PDRA @ UCD	Yes
	PhD	Academia – Further Education (PGCE) @ QUB	Yes
	PhD	Academia – Research Assistant @ QUB	Yes
C2C			
USI 085	PDRA	Academia - Research Fellow @ UU	Yes
	PDRA	Academia - Research Fellow @ Bristol University	Yes
	PDRA	Academia - Research Fellow @ UU	Yes
	PDRA	Academia	Not stated
USI 090	PhD	Industry (Almac)	Not stated
	PhD	Industry (Amgen Ireland)	Not stated
	PhD	Not Known	Not stated
USI 108	PDRA	Academia – in Spain	Not stated
	PDRA	Academia – Research position @ QUB	Not stated
	Postgraduate Masters	Further Education – PhD @ QUB	Not stated
USI 111	PDRA	Academia – Lectureship @ UU	Yes

[163] Source: The most recently provided Project Completion or Impact Report. This differs for each project.
[164] Source: Impact Report question "Did working on this DfE award assist in gaining this employment (Yes or No)?". The response is the PI's view and information on how the DfE award assisted in gaining this employment was not asked for or provided.

7.6 Student & Educational Impacts

As before, it should be noted that the US-Ireland data may underestimate the actual position as DfE's Quarterly Progress Reports were revised in April 2018 to explicitly capture many of the metrics discussed in this section. Before this point, PIs had not been required to provide this specific data.

7.6.1 The US-Ireland Research & Development (R&D) Partnership

22 of the 40 US-Ireland Research & Development (R&D) Partnership projects report specific 'student and/or educational' impacts as a result of the project. These included the following types of impacts:

- Student exchanges;
- Exposure to 'cutting-edge technology and applications';
- Training opportunities;
- One PhD student successfully secured a 5 Year Royal Academy of Engineering Fellowship at QUB with a value of £620k. Two undergraduate projects were related to this work and one MSc project. The MSc project went on to win the best project and was awarded £800 prize money from the civil engineering industry sponsor; and
- Supply of skilled individuals to labour in areas where there had been skills gaps;

The Research Team notes that the available information relating to 'student and/or educational' impacts was quite limited in several situations, with little information as to the number of students to benefit, where the student exchanges occurred (e.g. in RoI or the US) etc.

7.6.2 Pilot rounds of the SFI-DfE Investigators Programme

Six of the 14 SFI-DfE Investigators Programme projects report specific 'student and/or educational' impacts as a result of the project, as follows:

Table 7.16: Student and/or educational impacts

Project Ref	Details
14/1A/2304	• The Impact Report states that several additional students benefited from the DfE award including 5 PhD students at QUB and a further 7 MSc projects and BSc projects on microbial phosphorus cycling.
14/1A/2371	• The PI noted that the project not only provided training for the directly funded team members but also supported undergraduate and taught MSc projects for 16 students in the first 2 years. 10 of these students have gone on to take employment in industry, while the remaining 6 are undertaking post-graduate courses.
14/1A/2474	• Project staff were trained in GDPR awareness, freedom of information, anti-fraud awareness and health and safety essentials (also some UK legal requirements on anti-discrimination etc.).
14/1A/2559	• The project's Impact Report states that several students benefited from the DfE award including 2 MSc projects, 2 BSc projects and 3 Erasmus students. • The QUB team hosted two Secondary School students for 4 weeks as part of the Nuffield Research Placement Programme. • QUB staff undertook a range of training including training on Rondol extruder, creating infographics and visual content and advantages of characterising pharmaceuticals using differential scanning calorimetry (DSC) & thermogravimetric analysis (TGA).
14/1A/2582	• QUB hosted several lab tours for members of the public and external funding bodies, during which the research team explained the translational impact of their work. Open days at QUB allowed a much more interactive learning experience and wider outreach, with the research team demonstrating techniques and how they can be applied to address our research interests.
15/1A/2864	• QUB PI awarded Royal Society Wolfson Foundation Fellowship 2019.

7.7 Scientific & Other Impacts Recorded

It should be noted that the US-Ireland data may underestimate the actual position as DfE's Quarterly Progress Reports were revised in April 2018 to explicitly capture many of the metrics discussed in this section. Before this point, PIs had not been required to provide this specific data.

7.7.1 The US-Ireland Research & Development (R&D) Partnership

The Research Team has identified the following key scientific and other types of impact reported by US-Ireland Research & Development (R&D) Partnership projects. NB this summary should not be interpreted that those projects that are not featured did not achieve scientific and other types of impact. Instead, it reflects the presentation and/or reporting of information and whether such key impacts could be readily identified by a non-scientific reader.

Table 7.17: USI Scientific and Other Impacts Reported

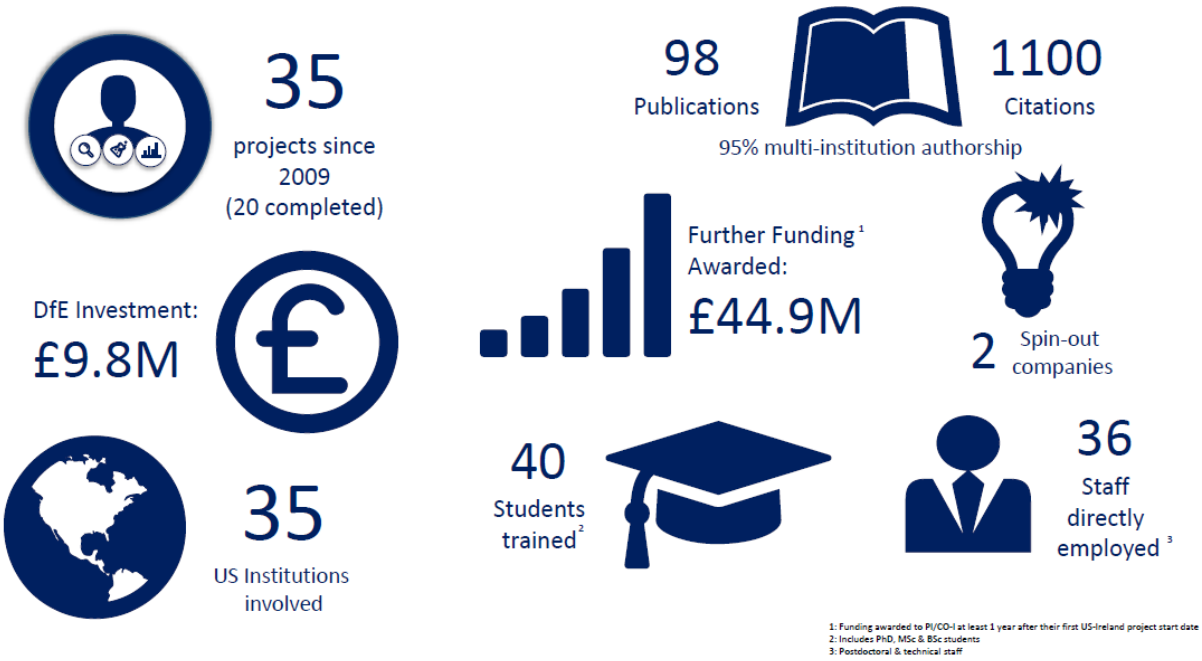
Project Ref	Details of Other Benefits
USI 009	• The QUB research identified a novel and successful way of growing high-quality germanium dioxide insulating layers on germanium. This was achieved by using a dilute oxidising ambient at the normal growth temperature of 550°C, as opposed to carrying out oxide growth at reduced temperature. This breakthrough has enabled high-quality metal-oxide-semiconductor (MOS) gate stacks to be produced on germanium. • QUB also reported for the first time the use of atomic layer deposited thin dielectric interfacial layers to enhance the quality of contacts between aluminium and n-type germanium. Both aluminium oxide and hafnium dioxide have been successfully characterised.
USI 021	• QUB project partners were active in STEM outreach including participating annually in the Sentinus schools R&D programme. • The work impacted the photocatalysis community through the contribution of knowledge relating to the mechanism of visible light photocatalytic activity.
USI 023	• A sensor system developed as part of the project was used on NI roads e.g. Dee Street Bridge. • The sensor system was used to extend the safe working life of the chimney stacks at Ballylumford Power station which enabled an additional 12 months of use with an estimated saving of £2m. • During this research project the PhD acted as coordinator for a 'bridge to schools' programme. • QUB was selected to host the International workshop for Civil Structural Health Monitoring. This event was hosted in May 2016 and 60 attendees, from 13 different countries were welcomed to Queen's, including academic representatives from the USA, China, Mexico and Malaysia, and industry representatives from CERN (the European Organization for Nuclear Research).
USI 033	• The PI noted the success of the project research as the technology developed continues to be used in QUB. • During the project, the team used the technology to create WiFiEar, a radical alternative to the induction coil hearing, a new form of assisted listening. The team developed a pitch for the Invent 2014 competition and won the Electronics category of the competition. The Windows Advanced Rasterization Platform (WARP) hardware (a hardware platform for efficient multi-modal sensing with adaptive approximation) was used to prototype an initial solution. It was able to show how the technology could be used to enhance or indeed in this case, radically change the listening environment for disabled people.
USI 035	• Development of a screen-printed sensor fabrication facility at Ulster.
USI 049	• The project completion report noted that the partnership between Stanford and QUB developed to such a level that Stanford routinely sent QUB their anodes and photoanodes for testing. • The project completion report indicated that this project provided the framework for a subsequent project (USI 132 - EMERALD) that was to be of much more commercial significance and societal benefit, especially in the developing world, in the form of an inexpensive solar-powered brine-splitting cell for the production of fuel (H2) and disinfectant (Cl2 or bleach).

Table 7.17: USI Scientific and Other Impacts Reported	
Project Ref	**Details of Other Benefits**
USI 057	• The project noted that there was considerable potential for the development of 2D biosensors using devices similar to those studied in this project and that this might be of interest to companies such as Randox, who already fund an engineering centre of excellence, partly based at the Queen's Advanced Micro-Engineering Centre which hosted this research project.
USI 067	• The value of enhanced Structural Health Monitoring (SHM) using a contactless sensor which was developed in this project were demonstrated to the Department of Infrastructure (DfI) and led to further collaboration with the PDRA on a 5 year Royal Academy fellowship, which was leading the area of network-level systems for Intelligent Infrastructure. DfI funded two part-time PhD studentships and set up a dedicated department for Smart Infrastructure monitoring. • DfI has provided data evidence and support for a REF 2021 Impact Case Study on Structural Health Monitoring (SHM) for Intelligent Infrastructure which demonstrates the economic, environmental and societal impact of a bridge failure/closure and how the use of SHM can prove safety without closure. • PI awarded Aftab Mufti Medal for the Best Journal Paper of 2017 in the International Journal of Civil and Structural Health Monitoring (the Official Journal of the International Society for Structural Health Monitoring of Intelligent Infrastructure (ISHMII) and top journal in this field).
USI 073	• Participation in the Science NI Festival in 2018 and 2019. As part of the Roadshow event (touching several locations in NI), the basic concepts behind chemical bonds and atomistic simulations were presented in the form of a videogame to young children.
USI 080	• On June 11th, 2019, QUB hosted a visit by a delegation from the Royal Academy of Engineering where they learnt about the millimetre work undertaken at ECIT including NEMO. • On June 13th, 2019, QUB hosted a visit by the Secretary of State for Northern Ireland, The Rt Hon Karen Bradley MP. Again, millimetre work undertaken in the NEMO project was highlighted.
USI 134	• The PI noted that this project substantially contributed to the development of the Centre for Wireless Innovation (CWI), which at the time, comprised of around 60 people (academics, PhDs, PDRAs, industry experienced engineers and commercial staff) and was the largest centre in the UK (and one of the largest in Europe) in the field of communications technologies. As a testament to this, the Centre was ranked 28th in the world (5th in Europe) in telecommunications engineering according to the 2019 Shanghai Ranking's Global Ranking of Academic Subjects.
USI 137	• The UrbanARK project was included in the Northern Ireland Climate Change Adaptation Programme 2021 – 2024 as a strategic project under the Key Priority Area 'NC' – Natural Capital – NC2.1 • The details of the UrbanARK project were submitted as evidence under the 3rd UK Climate Change Risk Assessment (CCRA3) Submission of Evidence Process (December 2019). • The UrbanARK project conducted a project workshop with colleagues from Belfast City Council and Dublin City Council in March 2019 to support the Councils in developing knowledge and understanding concerning Coastal Flood Risks and possible engineering and technological solutions to mitigate identified risks.
C2C	
USI 085	• The project's completion report noted that the project was (at the time of submission, Nov 2019) at the leading edge of global data centre networking technology and was not expected to yield direct value in the short term. However, the PI noted that the project helped to expand Ulster's expertise in the field of Software Defined Networks (SDN) and to establish new expertise in the UU team that included knowledge of network modelling and 5G mobile systems. This expertise was being used to forge new strategic research avenues within the BT Ireland Innovation Centre at Ulster to build long term relationships with the cellular research group at BT's research facilities in Martlesham, England. It was envisaged (in January 2020) that the work with BT has the potential to generate patents and technology transfer activities with BT's research team in the coming years.

Table 7.17: USI Scientific and Other Impacts Reported	
Project Ref	**Details of Other Benefits**
USI 111	• The USI 111 Centre-to-Centre work served to further enhance the research on hydroxyapatite coatings taking place at NIBEC, Ulster University. A key example of this was the development of a collaboration between Dr Adrian Boyd and researchers in Riga Technical University, Latvia which was a direct result of mutual interests in substituted hydroxyapatites. • The original PDRA at NIBEC has taken up a full Lectureship (Assistant Professorship) at Ulster University with the experience gained on the USI 111 C2C project considered to have been highly beneficial in this regard. The project has also provided training opportunities for 10 undergraduate Black and Minority Ethnic (BME) students, one of whom is a named author on a paper presented at the 10th Biometal Symposium on Biodegradable Metals for Biomedical Applications. • It is considered that the outputs of this project (publications, presentations, etc.) are leading to the design and development of better medical devices, which will ultimately lead to improved outcomes for patients. That is, the current generation of bone fracture fixation solutions are far from optimal and the C2C project, in partnership with industrial collaborators, has moved the development of a new generation of devices forward. The project reports that the outcomes from this work are changing the clinical pathway with the potential for significant benefits to be gained by removing the need for multiple surgeries. "*This exciting international collaboration provides a critical mass of research expertise capable of realising the potential of a new generation of orthopaedic implant devices that require a single surgical intervention. By enhancing key properties of magnesium alloy implant devices, we will be able to control their resorption in a way that provides for improved clinical outcomes in previously difficult to manage factures*" NI Principal Investigator

Of note, QUB provided (26 July 2020) the following summary of impacts relating to US-Ireland Research & Development (R&D) Partnership projects that it has been involved in:

Figure 7.1: QUB-related US-Ireland Research & Development (R&D) Partnership Project Impacts



Of note, in terms of funding alone, the summary information provided by QUB suggests a return on DfE investment of over 4.5 concerning leveraging further investment in the research base. It also suggests a publication rate of nearly three, and a citation rate of over 31, per project. More than one PhD, MSc or

BSc student has also been trained per project. These key metrics suggest a strong performance in terms of value for money.

7.7.2 Pilot rounds of the SFI-DfE Investigators Programme

The Research Team has identified the following key scientific and other types of impact reported by SFI-DfE Investigators Programme projects. NB this summary should not be interpreted that the projects that are not featured did not achieve scientific and other types of impact. Instead, it reflects the presentation and/or reporting of information and whether such key impacts could be readily identified by a non-scientific reader.

Table 7.18: SFI-DfE Scientific and Other Impacts Reported

Project Ref	Details of Other Benefits
15/1A/3152	• This award enabled Northern Ireland to participate in multiple international consortia, including the GIANT, GLGC, LIFEPATH, and CKDGen projects. • Progress reports noted that the research directly resulting from this project had been invited for oral presentation at multiple international conferences and the QUB PI had been invited to two centres in the USA to help them maximise their developing kidney disease research and to the National Institute of Ageing for a working group on harmonising epigenetics. • Within the UK, the QUB PI joined a clinical study group for kidney disease and was invited to participate in several meetings about developing a UKRI Infrastructure Roadmap.

7.8 Response to COVID-19

Of note, at the time of writing, during the COVID-19 pandemic, Science Foundation Ireland (SFI) launched an 'SFI Covid-19 Rapid Response Research & Innovation Funding Call' during March 2020, that aimed to address many of the challenges that had emerged during the crisis in the Republic of Ireland. However, on 30 June 2020, SFI re-launched the call to include specific "all-island" themes in a bilateral approach with DfE which, in turn, had secured the involvement of both DAERA and the HSC R&D Office. The original approach from SFI to DfE was a direct result of DfE's existing relationship with SFI (in particular through the US-Ireland R&D Partnership and the pilot rounds of the SFI-DfE Investigators Programme).

DfE pledged funding of up to £2.6m to the end of March 2021 to allow Northern Ireland universities to collaborate with colleagues in the Republic of Ireland where they made a successful joint bid to the re-launched SFI call. This decision reflected DfE's recognition that the SFI call represented an important opportunity for local researchers to make a significant and immediate contribution to tackling the hugely demanding and unique range of medical-related, societal and economic challenges posed by this latest strain of Coronavirus. The Department considered that it would also provide NI researchers with an important opportunity to engage with counterparts in RoI and potentially elsewhere to increase their potential to make significant and impactful breakthroughs that would address the manifold challenges posed in the UK, Ireland and beyond by the COVID-19 virus.

Under the terms of the re-launched call, projects (whether RoI-only or RoI/NI) were only approved if they were deemed to have the clear potential to develop solutions that could be operational and fully deployed within 6-12 months of project start (typically late October / November 2020). RoI partners could receive funding from SFI up to the end of 2021.

Subsequently, twenty-one joint RoI/NI proposals were submitted for consideration by SFI's international peer-review panels, of which nine joint proposals were successful. Seven of the successful projects are being funded by DfE (5 QUB and 2 UU) and two by DAERA (1 QUB and 1 QUB/AFBI). HSC follow-on funding has also been agreed for one of the DfE-funded UU projects, commencing April 2021.

This represented a strong approval ratio of over 1 in 2.3 (the ratio in the original RoI-only call was between 1 in 3 and 1 in 4). SFI described this as *"a very positive outcome for the partnership"*.

Of particular relevance at the time of writing (mid-COVID-19 pandemic), the potential relevance and importance of international research collaboration are evident from the very earliest phases of the US-Ireland Research & Development (R&D) Partnership. That is, at a meeting of the Steering Group on the 14th March 2006, the 'Emerging Respiratory Infections/Avian Influenza Working Group' reported that the focus of the group had expanded from avian influenza and pandemic influenza preparedness to include the broader threat of emerging viral infections. At that time, five research themes were identified within the broad area of emerging respiratory infections based on expertise within each jurisdiction and potential for collaboration. These included:

- Mechanisms of cross-species transmission and host adaptation;
- Basic immunology of respiratory viral infections;
- Vaccine and adjuvant design and optimisation;
- Antiviral target identification and therapeutics design and optimisation; and,
- Diagnostics design, optimisation and development.

Whilst not the focus of the projects supported by DfE, such a focus on the cross-species transmission of viral infections and human health now appears particularly prescient, and given the UK's recent experience, it is reasonable to consider that success in such research areas has the potential for substantial societal and economic benefit, and also the potential to prevent or alleviate considerable damage caused by situations such as viral pandemics.

7.9 Principal Investigators - Consultation Summary

The Research Team was provided with contact details for 45 PIs that were involved in 54 projects undertaken through either the US-Ireland Research & Development (R&D) Partnership or the pilot rounds of the SFI-DfE Investigators Programme. Some of the PIs had been involved in projects delivered under both schemes. 27 (or 69%) of the 45 PIs engaged in the primary research.

Table 7.19: Summary of PI Consultations			
	USI	**SFI-DfE**	**Total**
No. of projects	40	14	54
No. of unique PIs	34	14	45[165]
No. of PIs unable to contact	3	3	6
No. of PIs able to contact	31	11	39
No. of Consultations Completed	**20**	**7**	**27**
% complete	**65%**	**64%**	**69%**

The following sub-sections provide a summary of pertinent details emerging from those consultations.

7.9.1 Factors that had Influenced Researchers to Engage in International Research Collaboration

The Principal Investigators identified a range of factors that influence them to engage in international research collaboration. These included:

- To access complementary expertise not necessarily available elsewhere in Northern Ireland;
- To expand the individual's or their university's capability;
- To continue to and/or to further develop international relationships;
- To gain access to state-of-the-art equipment;
- To ensure NI research is represented globally; and
- To engage in larger-scale projects than would be possible otherwise.

[165] 3 PIs (all QUB) were involved in both a US-Ireland R&D project and an SFI-DfE project - Chris Elliott, Gavin Andrews and Jorge Kohanoff.

"The best scientific research is collaborative, interdisciplinary and transcends national boundaries. We have sought international partners with overlapping interests in healthcare and with a particular focus on diabetic kidney disease".

NI Principal Investigator

7.9.2 Sources of Support for International Research Collaboration Activities

Aside from the Universities' QR funds and specific DfE support (i.e. the US-Ireland R&D Partnership and the Pilot rounds of the SFI-DfE Investigators Programme), the following sources of support (financial or otherwise) were identified by the PIs as being available to take forward international research collaboration activities:

- UKRI and its Research Councils (e.g. EPSRC – Engineering and Physical Sciences Research Council, MRC – Medical Research Council);
- EU funds e.g. Horizon 2020, Interreg;
- The Royal Society;
- Global Challenges Research Fund;
- Leverhulme Trust;
- Newton Fund; and
- Wellcome Trust.

However, of note, a number of the PIs advised that apart from DfE's support there are very few support mechanisms available to support collaborative activity with researchers in the USA. The direct access which DfE and its predecessor Departments have been able to secure, along with SFI and the other NI/RoI partners, allowing universities here to participate in NSF programs, is highly unusual and not something which many other funders, either nationally or globally, have been able to secure. The Good Friday Agreement (GFA), and the key role of the then US President and his Special Envoy played in securing that international Agreement, created a unique window of opportunity and policy prerogative to pursue greater trans-Atlantic cooperation in the context of encouraging increased collaboration on the island of Ireland. The US-Ireland R&D Partnership flowed directly from this and so remains an enduring legacy of the GFA, representing a small but nonetheless significant element of the 'peace dividend' on the island of Ireland.

7.9.3 Methods Used to Evaluate International Research Collaboration Activities

The PIs outlined a range of methods and/or metrics that are currently used to evaluate the impact of the international research collaboration activities that they are involved in. These included:

- Bibliometric data including:
  - Number of publications, specifically the number of publications in high impact journals;
  - Number of citations; and
  - Impact factor / h-index.

  Concerning this, both universities noted that they use Elsevier's Pure Portal which collates all evidence of impact including citations (Source: Scopus) and h-index (Source: Pure – number of publications and Scopus – number of citations).

  NB The h-index is defined as the maximum value of h such that the given author/journal has published h papers that have each been cited at least h times. The index is designed to improve upon simpler measures such as the total number of citations or publications. The index is considered to work best when comparing scholars working in the same field; citation conventions differ widely among different fields.

- Success in attracting further research funding relating to the original project;
- Impact on their individual, or the university's, international reputation;

- The number of invitations to international conferences;
- The success of PhDs involved (i.e. in achieving their qualification);
- The level of stakeholder involvement including industry engagement or dissemination through scientific fora and public engagement;
- The level of economic or commercial impact including the number of patents/IP/technology/products developed or spin-out companies created; and
- The level of political or social impact including influence on policy, impact on clinical practice/treatment of patients.

Whilst it is noted that since April 2018, DfE has sought to capture many of these metrics through revising the structure of its reporting templates – both for quarterly reports and completion reports – while also introducing new annual impact reports to capture outcomes achieved not only through 'live' projects but also for the five years following the completion of the DfE-funded activities, the PIs considered that such metrics might be more readily and uniformly applied to projects undertaken through the US-Ireland R&D Partnership or the SFI-DfE Investigators Programme e.g. through the use of tools such as Researchfish.

Also, one PI noted that a common method of assessing the quality of a larger funded programme is an international site review. That is, a panel of independent international experts are assembled by a funder to conduct a site visit. The expert reviewers then assess written evidence, hear presentations from the PIs and associated staff and then question the PIs directly. This PI noted that during December 2019, SFI had organised a site visit to review progress in an SFI-DfE funded project. Discussion with DfE indicates that SFI routinely organises such visits for its Investigator Programme projects and DfE is invited to attend as an observer for any joint SFI-DfE projects and is subsequently provided with the SFI report on the visit.

7.9.4 Challenges encountered in Developing/Implementing International Research Collaboration Activities

Only a small number (N=6) of the PIs considered that they have encountered any challenges in developing or implementing international research collaboration projects. The challenges that were identified by this cohort of PIs included:

- Identifying appropriate funding mechanisms for each of the prospective project partners (N=3);
- Identifying potential collaborators with the necessary complementary skills (N=2); and
- Identifying the right partners at the right time (i.e. at a time when each of the prospective project partners has available research capacity) (N=1).

> *"Developing and implementing international research collaborations involves time-dependent networking at national and international conferences. It is important to establish rapport with researchers who may not be well acquainted with the strengths and opportunities offered by PIs and their institutions in Northern Ireland (and RoI). Having time to travel and meet researchers in other countries has been vital in building relationships. This can be helped by short-term secondments to work in another group/laboratory/university/hospital."*
>
> NI Principal Investigator

7.9.5 How International Collaborative Research has Enhanced the University's Research

As noted, to date, the Department's support for international research collaboration activities has focused on the US-Ireland R&D Partnership and the two Pilot rounds of the SFI-DfE Investigators Programme. All (i.e. 100%) of the Principal Investigators were of the view that both initiatives had enhanced the research activity that was taken forward in their university, including through the following means:

- It was emphasised by almost all the PIs that the US-Ireland R&D Partnership provides the opportunity for NI PIs to formally collaborate with researchers in the USA and Republic of Ireland, and in its absence, it is very unlikely that this would have occurred in a tripartite manner, or to a large extent with US researchers at all. The PIs noted that few funding mechanisms exist to take

forward collaborative projects with US researchers. This suggests the programme has a high degree of 'activity additionality'.

- Indeed, as a consequence of the limited opportunities to partner with US researchers beyond the mechanisms afforded through the US-Ireland R&D Partnership, none of the PIs was able to comment on whether their success ratio (relating to international research collaborations with US researchers) compared favourably or otherwise with other funding mechanisms. However, the PIs report that on average, their success ratio with US-Ireland R&D Partnership proposals has been between 10%-20% (which anecdotally, the Research Team has been advised is a very strong success ratio for typical US-only research applications to the NSF)[166].
- Several PIs noted that the US-Ireland R&D Partnership had been the catalyst for several long-term and successful collaborations between their University and researchers in both the Republic of Ireland and the USA, often going beyond the initial focus of a singular research project. Examples include:

  - A PI stated that as a result of the US-Ireland support, they had forged effective working arrangements to share research strategy, exchange technical expertise, equipment, bioinformatic data and materials, and co-train personnel. This PI stated that the University's QR funds would have been insufficient to pump prime such a major collaboration and would not have been able to sustain the longer-term commitment.
  - Another PI that received SFI-DfE Investigators Programme support stated that the project had acted as a catalyst for further research collaboration between the partners, noting that *"the two institutes' labs essentially now work as one – we share a lot of staff and resources, and we would not be in this position without SFI-DfE support."*

- Several PIs noted that the longevity of the US-Ireland R&D Partnership programme had provided underlying stability to the PIs' endeavours to seek to identify and build partnerships with their US peers.
- Several PIs noted the significance of being awarded either the US-Ireland R&D Partnership or the SFI-DfE Investigators Programme funding, as both the NSF and the SFI are regarded as being prestigious organisations. In the PIs' views, approval by these organisations, and in particularly NSF, provided a 'rubber stamp' of quality reflecting the strong reputation of their rigorous systems of international peer review. Many PIs emphasised that receiving these types of awards support them in leveraging funding from other sources.
- Both initiatives were cited as having given more junior researchers (PhD students and PDRAs) experience that would not have been available otherwise e.g. via moving between sites and laboratories and working with other PIs, some of whom are world-leaders in their field of expertise.
- Related to this, a small number of PIs noted that success in achieving a US-Ireland R&D Partnership project funding award had enabled the university to attract highly skilled PDRAs to NI.

Some specific examples of impacts highlighted by individual PIs are provided below:

Project Ref.	Key Impacts
USI 001 & SFI 14/1A/2646	• Engagement with industry and commercialisation of the prototype developed through the project (USI 001) with a US-based company. The relationship with this company has continued to develop and at the time of consultation (circa June 2020), the business was in discussions with QUB for it to become its main supplier of reagents. • A PhD student exchange programme was established between the University of Maine and QUB to allow the transfer of key skills and knowledge. It was noted that both undergraduate and postgraduate students have benefited from this programme of activity including being given opportunities to see how the technology and developed assays have been used in daily life. • Elements of the content and research undertaken within both projects have been incorporated into the university's curriculum.

[166] NB For reasons of confidentiality, the NSF did not wish to confirm its typical project approval ratios.

Project Ref.	Key Impacts
USI 023 & USI 067	• During the first project (USI 023), a sensor system was developed and used on NI roads (e.g. Dee Street Bridge) and also to extend the safe working life of the chimney stacks at Ballylumford Power station which enabled an additional 12 months of use with an estimated saving of £2m. • QUB was selected to host an international workshop for Civil Structural Health Monitoring, This event was hosted in May 2016 and 60 attendees, from 13 different countries were welcomed to Queen's, including academic representatives from the USA, China, Mexico and Malaysia, and industry representatives from CERN. • The sensor technology developed under this research has been utilised by a NI-based SME (McFarland Associates) under a Knowledge Transfer Partnership with QUB. • A three-week exchange visit was carried out in July-August 2018 where researchers from Queen's visited the University of Central Florida and a bridge site in Orlando for an extensive period of laboratory and field testing of the developed system. • A PhD student involved in the second project was the successful applicant for a 5-year Post-Doctoral Research Fellow post at QUB on an EPSRC funded Prosperity Partnership Project - Roadmaps to Zero Net Emissions in Urban Public Transport (StreetZero) in collaboration with Wrightbus (~£4m total project fund) following the completion of the USI project. • The value of using contactless sensors (which were developed under USI 067) to enhance Structural Health Monitoring (SHM) was demonstrated to the Department of Infrastructure (DfI), which has led to further collaboration with the PDRA through a 5 year Royal Academy fellowship, relating to network-level systems for Intelligent Infrastructure. DfI now funds two part-time PhD studentships and has established a dedicated unit for Smart Infrastructure monitoring. • DfI has since provided data evidence and support for a REF 2021 Impact Case Study on SHM for Intelligent infrastructure which is demonstrating the economic, environmental and societal impact of a bridge failure/closure and how the use of SHM can prove safety without closure.
USI 049	• The partnership between Stanford and QUB has developed to such a level that Stanford routinely sends QUB their anodes and photoanodes for testing. It was noted that the high quality of the work was reflected by the high quality of the published articles. Collaborative research activity has continued through a further US-Ireland project (USI 132).
USI 085	• The PI advised that this project is at the leading edge of global data centre networking technology, and as such was not expected to yield direct monetary value in the short term. It has, however, helped to expand Ulster's expertise in the field of Software Defined Networks (SDN) and to establish new expertise in the UU team that includes knowledge of network modelling and 5G mobile systems. The expertise developed has since been used to forge new strategic research avenues within the BT Ireland Innovation Centre at Ulster and to build long term relationships with the cellular research group at BT's research facilities in Martlesham, England.
SFI 15/1A/3152	• The research on diabetic kidney disease has greatly improved the understanding of the inherited risk of kidney disease and genetic susceptibility to the progression of chronic kidney disease. QUB has explored the influence of environmental factors and the interplay of genetic risk with gender, obesity, smoking etc. Some fundamental discoveries have been made using multi-omics tools to explore genetic, epigenomic, transcriptomic and metabolomic factors that determine kidney health. QUB now has a very sophisticated understanding of the interactions between genes and the environment in this area of public health. Improvements in technology e.g. substantially reduced costs and higher efficiency in DNA sequencing help to drive the rate of discovery and enhance the applicability to human health. • The research has identified an important mechanism that links the poor control of diabetes in an individual with long-term changes to the expression of genes in the kidney of persons who have inherited certain genetic risk factors. This interaction between high blood glucose and the genetic background will cause damage to the filtering apparatus within the kidney and leads to kidney failure. This has shifted the researchers' understanding of the cause of kidney disease and gives fresh impetus to developing effective treatments. • This award is cited as having enabled QUB to participate in multiple international consortia projects, including the GIANT, GLGC, LIFEPATH, and CKDGen projects.

Project Ref.	Key Impacts
	• QUB has been invited for oral presentation at multiple international conferences to discuss the research undertaken within this project. • Also, the QUB PI has been invited to two research centres in the USA to help them maximise their developing kidney disease research, and to the National Institute of Ageing for a working group on harmonising epigenetics.

An example of how a US-Ireland R&D Partnership project progressed to research taken forward through the Pilot rounds of the SFI-DfE Investigators Programme and subsequently to involve NI-based SMEs is illustrated below:

*"The US-Ireland R&D Partnership has proved to be the catalyst to a very long-term and successful collaboration between my group at Queen's University & Belfast City Hospital and researchers in the Conway Institute, University College Dublin and the Broad Institute (MIT / Harvard) Cambridge, MA, USA. We formed the GENIE consortium (**GE**netics of **N**ephropathy: an **I**nternational **E**ffort) in 2009 and have secured sequential NIDDK RO1 5-year programme grants in 2009 and 2015 and will submit a grant for a third round of funding in early July 2020. We have also secured partner funding from multiple other agencies over the last ten years. The synergy between the research groups (allied with other international partners) has allowed us to undertake cutting edge translational research for diabetic kidney disease.*

We have forged effective working arrangements to share research strategy, exchange technical expertise, equipment, bioinformatic data and material resources, and co-train personnel. We have built this capacity through multiple face-to-face meetings, regular teleconferences, and frequent communication. This organisational structure provides tremendous synergy from the integration of various levels of expertise at each of the sites and leverages substantial co-funding (e.g. JDRF DNCRI).

The substantial body of work accomplished by the GENIE consortium has also allowed us to tackle (at scale) a more commercially orientated programme of work under the auspices of the SFI-DfE Investigators Programme. In this work, we are seeking to develop and validate (with partner SMEs) diagnostic tools that can help identify persons with chronic kidney disease and then predict which individuals are at highest risk for progression to end-stage kidney failure that typically requires chronic dialysis and/or renal transplantation. This has immediate potential for translation into healthcare diagnostics and clinical algorithms."

NI Principal Investigator

7.9.6 Impacts on the Careers of Early-Stage Scientists

Each of the PIs agreed that they were able to recruit promising PhD students and post-doctoral research assistants (PDRA) to work on the research projects taken forward under the two programmes.

"We have been able to recruit promising doctoral (PhD) students and post-doctoral research fellows to work with us in these research programmes. Early-stage scientists have successfully competed for prestigious external (to NI or RoI) awards to support their salaries and career development. This has enhanced the mobility of some of the individuals (working in centres of excellence outside of Ireland) and improved the conversion of early-stage scientists to tenured career tracks in universities or to secure posts in biotech or pharma companies or careers as NHS scientists."

NI Principal Investigator

The PIs advised that the international experience and exposure was advantageous for the PhDs' and PDRAs' development and helped them to define their career path and build on expertise and knowledge in their specific area.

Several PIs noted that some of the early-stage scientists had successfully competed for prestigious awards (e.g. a 5-year Royal Academy fellowship) to support their salaries and career development.

Furthermore, the PIs were of the view that the international experience had enhanced the mobility of some of the individuals and improved the conversion of early-stage scientists to tenured careers in universities or had helped them to secure posts in industry (both in NI and in some cases further afield).

One PI secured the following statements from PDRAs who had worked on a US-Ireland R&D Partnership project. Both subsequently went on to work in businesses in Northern Ireland:

PDRA 1	*"My post-doctoral project in QUB involved the design and characterization of photonic devices with nanoscale confinement. I used different numerical methods such as finite-difference time-domain and finite element methods to design a hybrid plasmonic structure that offered significant energy density squeezed in a sub-10nm scale. I had a chance to use several characterisation methods. Scanning near-field optical microscopy was one of the methods I used to study the near-field optical properties of different structures.* *My experiences in QUB matched well with the requirement of an R&D role for the Heat-assisted magnetic recording (HAMR) technology development in Seagate Technology. As a result, I was able to fit in immediately and started with a project as one of the first few assigned to it. My works eventually helped it to become a top priority project leading to nearly £60million investment and employment of many people recently in Seagate's Springtown site in Northern Ireland. In my current role, I work as the lead design engineer and provide solutions for active and passive photonic components that eventually trigger a plasmonic transducer to generate a sub-50 nm heat spot. I have several intellectual properties filed as patents and trade secrets in recent years, and some of the inventions are in various stages of the filing process."*
PDRA 2	*"During my time as a post-doctoral researcher on the US-Ireland project, I learned many valuable skills, from the advanced problem solving and collaborative work approach inherent in post-doctoral research to computational skills developing and performing simulations. While there is no direct application of physics in my career today, my time on this project led me to my current role as a software engineer at AquaQ Analytics in Belfast through the development of these skills. I am currently contracting through AquaQ to a major international investment bank which has direct investment in Belfast, bringing international money into the NI economy."*

7.9.7 Wider Effects

Some PIs were of the view that the US-Ireland R&D Partnership and/or the SFI-DfE Investigators Programme have promoted a much greater awareness and positive understanding of NI's research expertise and also of other aspects of life in general in Northern Ireland.

According to the PIs, their involvement in the research projects has demonstrated to partners and potential partners that Northern Ireland can deliver high-quality collaborative research on time, within budget and at scale and this has helped improve the visibility of Northern Ireland as a potential partner in research and as an attractive location for teaching, education and commerce.

In particular, it was noted that the longevity of the US-Ireland R&D Partnership has helped strengthen links with researchers both in the Republic of Ireland and in the USA, leading to long-lasting relationships as well as long term collaborations.

The importance of both programmes in providing a pool of skilled researchers/scientists in NI was also noted.

> *"One of the most important outcomes of these research collaborations is the generation of a much larger pool of well trained, motivated and interconnected researchers with the capacity to translate research into societal, economic and/or commercial impacts in NI and beyond. For example, supported researchers now work in many fields including biotech companies (Randox, Almac), NHS workforce (consultant physicians and laboratory scientists) and university academics in NI, RoI, Scotland and USA. Innovation from a research-trained workforce can be unexpected e.g. transformation of the renal transplant service in Northern Ireland resulting in the highest living donor kidney transplant rate in Europe with a commensurate improvement in life expectancy of persons with end-stage kidney failure and reduced healthcare costs (because of reduction in the number of persons on dialysis)."*
>
> NI Principal Investigator

7.9.8 International Best Practice

Few of the PIs were able to identify policies, programmes or activities relating to international research collaboration that is implemented elsewhere in the World (including other areas of the UK) that might have merit in the Northern Ireland context. Indeed, many suggested that the US-Ireland R&D Partnership represented best practice.

A small number of the PIs did, however, suggest that there should be a greater focus on developing and training PhD students and other early-stage scientists in NI to ensure that NI had a pool of skilled individuals that could serve to attract FDI. Two examples of suggested activities were provided:

- The Irish Clinical Academic Training (ICAT) programme - This is an integrated clinical academic training programme on the island of Ireland (NI and RoI) funded by the Wellcome Trust. The ICAT Programme is a strategic partnership of six Irish universities (Trinity College Dublin, Queens University Belfast, NUI Galway, University College Cork, Royal College of Surgeons of Ireland and University College Dublin) and mentors clinical academic trainees for up to six years to the point of independence as an early-stage clinical researcher. This programme has been supported by the Health Research Board (RoI), Public Health Agency R&D Division (NI), Health Service Executive (RoI) and the postgraduate clinical training bodies in NI and RoI. The ICAT programme has secured over €15 million from Wellcome and partner funders. The PI suggested that a similar programme could be developed for other early-stage scientists.
- Centres for Doctoral Training - Centres for Doctoral Training (CDTs) are formed by a group of research organisations (universities and industry partners) combining research and expertise to support and train PhD students. One PI suggested that there is a need to increase the number of Centres for Doctoral Training across various disciplines in NI.

7.9.9 Methods to Maximise the Impact of International Research Collaboration

The PIs were of the view that the outputs of international research collaboration could be maximised to create societal, economic or commercial impacts within NI through greater engagement with industry, local government and the general public to highlight the potential of the research outputs. It was noted that this could be achieved through exchange visits, lectures, conferences and communication via social media, radio, newspapers etc.

A number of the PIs also suggested that there was a need for more follow-on funding to allow PIs to take forward successful research projects with industry, with many suggesting that there was not a clear 'translation pathway' for the international research projects that they were involved in. However, a number stated that there was a 'translation pathway' for their research including:

- Informing public health policy and healthcare transformation through stakeholder fora;
- Discovering new knowledge with commercial therapeutic or diagnostic potential and linking to business;
- Securing industry involvement in the research through KTP partnerships.

Where there might be commercial potential benefits that could accrue from more applied follow-on funding, this is something on which the universities' Commercialisation Offices would be well placed to advise. As some PIs mentioned above, the KTP route is a possibility (administered in Northern Ireland by Invest NI) and both universities have KTP teams who could advise. Invest NI's 'Grant for R&D' is another possible avenue.

7.9.10Support Required from the Department

The PIs suggested a variety of support or activity that the Department should consider to inter alia increase the quantity, quality and impact of international research collaboration activity, including:

- Encouraging the universities to promote both research programmes;
- Allowing PIs to have more than one active project at a time (note – following discussions between DfE and the universities, this has now been increased to two in NI only from October 2020 for the US-Ireland R&D Partnership);
- Helping the universities to showcase research outputs/outcomes through dissemination networking events (perhaps held every 2-3 years). It was suggested that such events would provide researchers with opportunities to network and learn about the benefits of these programmes. It was also suggested that it would be beneficial if Invest NI could be in attendance to help the researchers build links with industry. (Note - Showcasing and dissemination are both eligible activities under both the US-Ireland R&D Partnership and the SFI-DfE Investigators Programme);
- Enhancing the level of monitoring and evaluation associated with the research projects. A number of the PIs were of the view that more scrutiny is required from DfE to ensure that they are supporting worthwhile projects with it suggested that processes similar to those employed by UKRI should be used. It is acknowledged, however, that there is a tension here with the 'single proposal – single review' principle on which both the US-Ireland R&D Partnership and the SFI-DfE Investigators programmes are based.
- It was also stated that DfE should ask projects to be explicit at the time of application what the anticipated impact of the project is and subsequently apply monitoring and evaluation techniques to establish whether projects have delivered what they set out to do. Discussion with DfE indicates that for the US-Ireland R&D Partnership, it does request this information at the pre-proposal stage (i.e. before the proposal is submitted to the NSF), but, given the low TRL nature of these projects, commercial outcomes are not usually attained during the lifetime of the project. Given this, DfE has put in place a system of Annual Impact Reports for at least 5 years after projects are completed in an attempt to capture these aspects. This is in addition to the required Quarterly Progress Reports and Project Completion Reports.
- Increase DfE's level of engagement with projects, through attending project conferences/events, engaging in SFI reviews etc. Concerning this, DfE notes that for the SFI-DfE Investigators Programme, it routinely receives copies of all SFI reviews which are in turn reviewed by the DfE Programme Manager/deputy Programme Manager and the progress reported to the Head of HE Research & Knowledge Exchange. DfE is also invited to attend the SFI site reviews in person.
- Providing follow-on funding or 'impact delivery' funds to support the best projects to then help deliver economic impacts.

All of the PIs were of the view that DfE should continue to support international research collaboration with researchers in the USA and the Republic of Ireland, with the following noted:

- A focus on developing research partnerships with the Republic of Ireland was even more important than might previously have been the case (in light of the UK's exit from the EU). It was suggested that developing such relationships might facilitate NI's continued involvement in EU programmes, which were considered to be very important to both universities' research activities and also that from a practical perspective there was substantial merit in undertaking some research on an 'all-island' basis;
- Developing relationships with US researchers often provided NI researchers with access to world-leading expertise and specialist equipment that is not available on the island of Ireland.

Whilst the PIs were uniformly of the view that a focus should be maintained on developing relationships with the USA and Republic of Ireland, many suggested that DfE should consider expanding the support to other countries, albeit without diluting the support currently available, to give NI PIs more opportunities to engage with international expertise. The PIs suggested a range of countries including Canada, China, Japan, New Zealand, Singapore to complement the continuing access to European research following the UK's recent Trade Deal with the EU (the 'EU-UK Trade and Cooperation

Agreement' of December 2020, which confirmed that the UK will have 'associated status' allowing it to access Horizon Europe going forwards).

7.10 HEI Management & Strategic Stakeholders - Consultation Summary

This section summarises the key findings drawn from consultations with representatives from NI's two universities and a variety of strategic stakeholders including representatives from:

- Department for the Economy (DfE);
- Department of Agriculture, Environment and Rural Affairs (DAERA) - Chief Scientific Adviser's Office, Science, Evidence and Innovation Policy Division (SEIPD);
- HSC Research & Development Division, Public Health Agency;
- Invest NI;
- InterTradeIreland;
- Members of the US-Ireland R&D Partnership Steering Group;
- Science Foundation Ireland;
- US Consulate-General: Belfast;
- US State Department.

7.10.1 Programme Impact

In specific relation to the US-Ireland R&D Partnership, stakeholders noted that developing international research collaboration is complex and time-consuming. However, such complexity is increased in a tri-partite situation. For this reason, amongst others, the consultees considered that the US-Ireland R&D Partnership has been a considerable success. Consultees noted both its longevity and the comparatively high approval ratio of its projects, indicative of the 'good science' that has been taken forward through shared expertise. There was a common view that collaborations have been taken forward in a spirit of 'genuine partnership'. Furthermore, stakeholders, including those from the US noted how the US-Ireland R&D Partnership is held in very high regard, and for the most part, represents best practice concerning international research collaboration. Indeed, it was noted that it is the model that the US science partners are largely seeking to develop with other countries.

The robustness of the NSF/NIH/NIFA project approval processes was commented upon by several stakeholders, including the level of challenge that applications are given to ensure that they are genuinely collaborative and build on the individual expertise of each named partner. Indeed, several stakeholders were of the view that if the NSF approved a project, that in itself was an indicator that the research was 'world-class'.

A key impact that was attributed to the US-Ireland R&D Partnership was that it *"legitimises universities on the Island in the eyes of US businesses"* and many have begun to contract research directly with universities on the island of Ireland as a result.

Key impacts attributed to both programmes included:

- Leverage – of finances, know-how and resources. The view that the '*sum of the parts was greater than the whole*' was reflected by several consultees, with it suggested that the partnerships presented opportunities to maximise the potential of complementary skills and expertise, and to undertake larger-scale research projects (e.g. through access to larger patient databases) than the individual partners might be able to alone;
- Providing early-stage career scientists with development opportunities that could not be provided otherwise – exposure to world-leading scientists, different methods of working, different equipment etc.
- Attracting talented early-stage scientists to work in NI;
- Strengthening NI's Foreign Direct Investment (FDI) promotional messaging.

However, whilst stakeholders acknowledged that the recently introduced US-Ireland R&D Partnership Centre-to-Centre projects offer greater opportunities for industrial engagement, there was a view that greater emphasis could be placed on this across all projects supported. From an NI perspective, it was suggested that some PIs may require training on the commercialisation of R&D (and that completion of such training should be a pre-requisite before the receipt of funding), and further that the universities' Technology Transfer Offices may not be sufficiently linked into the various projects that are delivered under both international research collaboration programmes. Furthermore, it was suggested that all projects supported by DfE should set out clearly at the outset what the market potential of the prospective research is, and project monitoring and evaluation should contain a focus on the market opportunity and commercialisation.[167] Albeit one consultee noted that NI might not have a sufficient pool of businesses to fully maximise some of the research outworkings.

Of note, discussion with DfE concerning the findings outlined above indicated its own note of caution as to how firmly the commercial outcomes of the projects supported under both the US-Ireland R&D Partnership or the SFI-DfE Investigators Programme could be anticipated at the proposal stage given the type of very low TRL research supported which is often focused on basic, investigative research which is, by definition, very far from the market place, but which, in the longer term, may result in commercial applications (although sometimes in areas not envisaged at the outset of the research collaboration).

Positively, one consultee from outside NI noted that whilst the NI partner often had the least budget and smallest pool of researchers, it was often an NI PI that *"was driving the partnership project"*.

Indeed, one of the NI universities noted that whilst the US-Ireland R&D Partnership programme represented only a small portion of its research activity, it was disproportionately important due to the quality of research undertaken and the associated prestige offered by the programme.

7.10.2 Wider Effects

Both the university and strategic stakeholders considered that the US-Ireland R&D Partnership and the SFI-DfE Investigators Programme have had wider socio-political impacts, albeit most suggested that such impacts are difficult to explicitly define. Nonetheless, the types of impacts attributed to the two programmes included:

- Facilitating a deeper understanding of not just the expertise that is available on the Island, but of its people and its culture;
- Developing a spirit of collaboration and sharing of knowledge to achieve goals and address challenges of mutual interest;
- Providing reassurance to prospective Foreign Direct Investment businesses that relevant expertise and a pipeline of skilled personnel is available;
- Supporting projects that go beyond purely commercial interests and that consider the welfare of the whole population (perhaps best reflected by the joint actions taken forward to address challenges emerging from the COVID-19 pandemic);
- Contributing to the achievement of foreign policy objectives, strengthening alliances on a transatlantic basis (with it noted that the US-Ireland R&D Partnership has provided, since its inception, the platform for several NI politicians to meet US politicians and dignitaries);
- Strengthening national security interests (e.g. through a shared focus on cybersecurity).

[167] In relation to this feedback, DfE notes that its proposal template requires the PI to comment on a project's commercial impact potential.

7.10.3Monitoring and Measuring Impact

Discussion with Science Foundation Ireland indicates that it requests a copy of each full US-Ireland R&D Partnership project proposal at the outset and uses this as the starting point of its project monitoring activities.

Key barriers, cited by several stakeholders, in monitoring the impact of US-Ireland R&D Partnership projects and its reporting at a programme-level are differences in the reporting timelines and requirements that are requested of the researchers involved across the three jurisdictions. For example:

- DfE asks PIs for quarterly reports;
- SFI asks for an annual report to cover the period 1st February to 31st January; whilst
- NSF requires an annual report during the month following the project's initial start date.

Also, each of the three partners asks the projects to report on different aspects of the project relevant to the activities funded in their respective jurisdiction or its impact.

Of note in the NI context was feedback from DAERA that it has a business case for its international research collaboration projects, wherein it has established a series of Key Performance Indicators that included metrics such as:

- The number of projects supported;
- The value of research funding levered;
- The number of scientific papers produced;
- Employment created.

The DAERA consultee noted that measuring the impact of R&D is a relatively new area for the Department (i.e. DAERA). However, it was noted that DAERA is developing new metrics (which were with its Minister for consideration) for all areas of its research and development activities, and in the future, there may be a greater focus on measuring outcomes, as opposed to outputs.

The HSC Research & Development Division consultee noted that alongside the projects' reporting, it uses Researchfish to monitor the outworkings of projects that it supports (although it was noted that it can be difficult to attribute some publications to a specific project). However, HSC noted that it often turns researchers away if their previous project reporting has not been strong or is missing. HSC further noted that across any collaborative projects that it supports, they ask the NI researchers to bring out in their reporting the specific impacts on Northern Ireland.

One of the two NI universities suggested that publications are losing their importance as an indicator of impact, albeit it was acknowledged that they continue to be an important means of *"telling the world about the strength of research being undertaken"*. It was suggested that changes in scientific understanding, new technologies developed, or new coding represent better indicators of a project's impact. Of note, the view, relating to the diminishing importance of publications as a means of measuring impact, was shared by SFI.

An NI university noted that where a project is truly collaborative, any research output relating to publications should be co-authored.

In terms of reporting, both NI universities considered that the current reporting requirements are too frequent, noting that the outworkings of R&D may not move materially quarterly. However, discussion with DAERA indicated that it also uses the reports to process claims as well as track a project's progress, as does DfE.

Both universities suggested that there should be less frequent reporting, but that the quality of reporting should be improved, with a greater focus on impact, similar to the requirements of UKRI (who it was suggested only requires annual reporting on impact), which both universities and their PIs are very

familiar with. Discussion with DFE notes that it only asks for reporting on impact annually, which is entirely separate from, and additional to, the quarterly progress reporting it requires.

One of the NI universities notes that alongside an annual impact report, a final follow-up report, circa three years following a project's completion should be required. However, the Research Team is aware that, since 2018, DfE has required annual follow-on reports for completed projects. It intends to continue to request these for at least five years after a project has been completed.

Similar to DfE, SFI noted that it monitors the impact of each project that it supports on an annual basis (see Section 8.2 for details) and for up to 5 years following the project's completion. Furthermore, SFI applies sanctions if a PI does not comply with its reporting requirements. That is, a PI will accumulate penalty points if they fail to report accordingly, until such a point where they might pass a threshold that will prohibit them from accessing further funding from SFI. For DfE, claims will not be paid if reports are not forthcoming, per DfE's Letter of Offer requirements.

Of note, one stakeholder noted that it is often the case that researchers do not understand what a project's impact might be in its fullest sense, and that many researchers need training on measuring impact.

From the universities' perspectives, it was noted that their respective REF scores would continue to be the most important indicator for them, albeit they both recognised that it was important to capture information of importance to funders.

7.10.4Views on Programme Features

Both NI universities were of the view that outside of the US-Ireland R&D Partnership, opportunities to partner with US universities were limited, primarily due to funding eligibility criteria applied to different programmes and access to funding. The fact that the funding bodies from the three jurisdictions were working together in partnership (as well as the research institutes in the three countries) was considered to have considerably simplified processes relating to funding and was particularly welcomed.

SFI noted that it undertakes a preliminary review of each application before its full submission to the US-Ireland R&D Partnership programme, and whilst it considers that most are fully collaborative, it noted that some applications have reflected *"grantsmanship"* and as such have not been passed for approval. DfE also reviews the draft proposals in respect of eligibility of PIs and that proposals fall within one of the agreed priority areas, but is not in a position to review proposals from a technical perspective in the way which SFI does (having dedicated scientific desk officers) to address the '*grantmanship'* issue.

Whilst the universities considered that both a larger available funding pot and a higher level of award per project would be welcome, it was acknowledged that the average project value of c£300,000 is equivalent to a *"decent-sized UKRI research grant"*, and did not present a particular barrier to the quality of research that could be undertaken. It was noted that such a sum of money could broadly cover the employment cost of a PDRA and a PhD student for 3 years and allowed £50k-£60k for overhead costs. Indeed, it was noted that some other research funds do not allow the costs associated with PhD students to be covered, so this was considered to be a *"hugely beneficial"* aspect of the US-Ireland R&D Partnership. It was noted that ideally there would be parity with the level of support that is provided to the RoI partner.

However, it was noted by some stakeholders that the £300,000 budget for Centre-to-Centre projects was restrictive in trying to involve businesses or other organisations.

The universities noted that DfE strongly encouraged meaningful engagement between the partners including travel to support face-to-face meetings, and welcomed this as it was considered that this greatly facilitated the process of developing relationships (which was key to collaboration) and sharing knowledge.

However, as referenced earlier, both universities were of the view that the frequency of reporting (i.e. quarterly) was overly onerous. It was suggested by both that there should be less frequent reporting, but that the format of the reporting templates could be developed, with a greater focus on impact, similar to the requirements of UKRI, which both universities and their PIs are very familiar with.

7.10.5Future Direction

In the context of risks associated with the Brexit process, all consultees were of the view that NI needed to maintain a focus on developing international research collaboration. Indeed, both NI universities noted the continuing importance of maintaining access to Horizon Europe, noting that it takes years to fully develop international relationships and highlighting the risk that existing relationships with research bodies in the EU could be lost. It is a positive development, therefore, that continuing access to European research has been secured in the EU-UK Trade and Cooperation Agreement of December 2020 (which confirmed that the UK will have 'associated status' allowing it to access Horizon Europe going forwards).

All stakeholders that were consulted recognised the strategic importance of the US-Ireland R&D Partnership and were of the view that all opportunities should be taken to develop it further, including new areas of focus (e.g. Advanced Manufacturing) and brokering relationships with other US Departments, including DARPA, with it noted that the newest priority area of cybersecurity could form an initial area of exploration in this respect. Of note, QUB identifies the US as a 'priority country' and has developed a 'USA Strategy Group' to explore and develop opportunities there.

One consultee noted the increasing importance of interdisciplinary research and teams and suggested that this should be a feature of future R&D programmes supported by DfE.

Both universities considered that further developing collaborative relationships with their RoI peers was key to their future strategies, and indicted that they would strongly welcome DfE's continued support in that area. Indeed, several stakeholders noted the importance of developing research relationships with the Republic of Ireland as recognised in the New Decade, New Approach document.[168] It notes that *"the Government [of Ireland] would be interested in jointly exploring the feasibility of an all-island research hub, in cooperation with relevant agencies and stakeholders, North and South"*.

It was noted that relationships with RoI researchers develop very organically, unlike with researchers in other jurisdictions, as, for example, some of the NI/RoI researchers have previously studied or worked together.

Concerning whether DfE's support should focus on developing a relationship with other countries, there was mixed feedback with:

- On one hand, a view that DfE might not have the resources to achieve this effectively and should instead seek to maximise the opportunities presented by UK-wide initiatives and support structures; whilst on the other
- A view that DfE should help the universities to broker new bi-lateral relationships in other leading research-oriented countries, including with the Horizon 2020 "big hitters" (i.e. France, Germany, Belgium and Israel).

It was noted that Invest NI had previously supported researchers to visit the US to identify potential research partners through Planning Grants (originally supported via its RTD Networking Programme), but has since withdrawn this support (due to the low uptake). Both NI universities indicated that they would welcome the reintroduction of this support as it was very useful in supporting the development of research relationships.

[168] New Decade, New Approach, January 2020

Of importance, several NI stakeholders advised that NI needs a research strategy, and within that, a strategy for international research collaboration, which would allow for longer-term planning and that would provide assurances as to the level of available funding.

7.11 Summary Conclusions

The Department for the Economy (DfE) manages the NI element of two programmes focused on promoting international research collaboration (outside of promoting EU Framework / Horizon Programme collaborations through its Collaborative Research Support Fund):

1. The US-Ireland Research & Development (R&D) Partnership; and
2. Pilot rounds of the SFI-DfE Investigators Programme.

The Research Team has considered activity undertaken and feedback from both PIs that have been involved and stakeholders relating to both programmes. Key conclusions arising include:

- From the time of its launch in 2006 to 10th March 2020 (up to project reference USI 146), 58 projects, with a cumulative value c£79m had been supported under the US-Ireland Research & Development (R&D) Partnership. 40 of the 58 projects were supported by DEL/DfE, with 7 of the projects being Centre-to-Centre projects.
- 14 projects have been supported under the pilot rounds of the SFI-DfE Investigators Programme.
- The thematic or sectoral areas within which projects have been supported under both programmes provide a high degree of complementarity with NI's recently published '*10x Economy'* document and include areas such as nanotechnology, telecommunications, energy and sustainable food production and processing.
- The majority of projects supported under both programmes have started at low TRLs (typically 1-3, which represent basic research).
- The Research Team's review of materials dating back to the launch of the US-Ireland Research & Development (R&D) Partnership indicates that a variety of outputs have been achieved. However, it should be noted that the outputs identified may underestimate the actual numbers achieved, as DfE's Quarterly Progress Reports were revised only in April 2018 to explicitly capture many of the metrics that the Research Team sought to quantify. Before that date, PIs had not been explicitly required to provide such data. Nonetheless, outputs identified include:

  The 40 DfE-supported USI projects had generated:

  - 174 journal publications, albeit some may not have been published on a collaborative basis (which also applies to some of the other outputs identified for the 40 DfE-supported USI projects);
  - 88 conference publications;
  - 177 international presentations (albeit the NI PI may not have been involved in the delivery of some of the presentations cited);
  - The NI partner on 12 of the 40 USI projects secured follow-on funding, amounting to just under £9.7m, that they attribute in some way to the USI project.
  - Across the 40 US-Ireland Research & Development (R&D) Partnership, two-thirds (N=26 or 65%) have not yet (in May 2020) reported any substantive economic, commercial or industrial impacts, although, as noted above, this may not be unexpected given the low TRLs of the projects supported. None of the 14 remaining projects reported a monetary value associated with the reported impact, albeit some of the impacts would appear to lend themselves to such impacts being able to be more fully monetised.
  - 22 of the 40 US-Ireland Research & Development (R&D) Partnership projects report specific 'student and/or educational' impacts as a result of the project. These included the following types of impacts:
    - Student exchanges;
    - Exposure to 'cutting-edge technology and applications';
    - Training opportunities;
    - One PhD student successfully secured a 5 Year Royal Academy of Engineering Fellowship at QUB with a value of £620k. Two undergraduate projects were related to this work and one MSc

project. The MSc project went on to win the best project and was awarded £800 prize money from the civil engineering industry sponsor; and
  - Supply of skilled individuals to labour in areas where there had been skills gaps.

The 14 SFI-DfE projects had generated:

- 179 journal publications. Albeit it should be noted that the monitoring materials indicate that only 40% (72) could be 'primarily attributable' to the SFI-DFE project. As such, and also true of other outputs identified for the SFI-DfE projects, it is unclear what role the SFI-DfE projects played in the development of the majority of publications recorded in the monitoring materials.
- 16 conference publications;
- 305 conference publications, of which the Research Team was only able to identify 28 instances where an NI partner was involved in the presentation. Similar to other aspects of the SFI-DfE project reporting, the results identified are likely to be influenced by the RoI partner being responsible for preparing and submitting the progress reports to SFI (on behalf of both partners).
- 12 of the 14 SFI-DfE projects received follow-on funding totalling c.£203,652,463 (allowing for conversion to Sterling) of which £31,476,915 (15%) was listed as being 'primarily attributable' to the SFI-DFE project. The c£203m was associated with 104 further projects, of which 21 (20%) were noted as having an NI partner involved. The value of follow-on funding awarded to NI partners could not be discerned.
- Across the 14 SFI-DfE Investigators Programme projects, two-thirds (N=9 or 64%) have not yet (in May 2020) reported any substantive economic, commercial or industrial impacts. Again, this is perhaps not to be unexpected given the low TRL nature of the research projects supported under this programme. None of the 5 remaining projects reported a monetary value associated with the impact, albeit some of the impacts would appear to lend themselves to such impacts being able to be reported.
- Six of the 14 SFI-DfE Investigators Programme projects report specific 'student and/or educational' impacts as a result of the project, including awards and further training provided.

Amongst both the 54 PIs, HEI management and strategic stakeholders that the Research Team consulted with, the feedback received relating to both the US-Ireland Research & Development (R&D) Partnership and the pilot rounds of the SFI-DfE Investigators Programme was very positive, with the Research Team noting the following key conclusions:

- The complexity of identifying opportunities for and developing international research collaboration projects was outlined by most consultees. For this reason, amongst others, the consultees considered that both the US-Ireland R&D Partnership programme and the pilot rounds of the SFI-DfE Investigators Programme had been considerably successful.
- Indeed, in specific relation to the US-Ireland R&D Partnership programme, stakeholders, including those from the US noted that it was held in very high regard, and for the most part, represents best practice concerning international research collaboration. Indeed, it was noted that it is the model that the US science partners are largely seeking to develop with other countries.
- Indeed, the strength of the collaborative projects is reflected by feedback from the US National Science Foundation who reported at a meeting of the US-Ireland R&D Partnership Steering Group that the approval rating (30%) for US-Ireland proposals was 'almost unheard of in NSF' for standard US-only proposals.
- A key impact that was attributed to the US-Ireland R&D Partnership was that it *"legitimises universities on the Island in the eyes of US businesses"* and many have begun to contract research directly with universities on the island of Ireland as a result.
- Indeed, one of the NI universities noted that whilst the US-Ireland R&D Partnership programme represented only a small portion of its research activity, it was disproportionately important due to the quality of research undertaken and the associated prestige offered by the programme.

- Both the university and strategic stakeholders considered that the US-Ireland R&D Partnership and the SFI-DfE Investigators Programme have had wider socio-political social impacts, albeit most suggested that such impacts are difficult to explicitly define. Nonetheless, the types of impacts attributed to the two programmes included:

  - Facilitating a deeper understanding of not just the expertise that is available on the Island, but of its people and its culture;
  - Developing a spirit of collaboration and sharing of knowledge to achieve goals and address challenges of mutual interest;
  - Providing reassurance to prospective Foreign Direct Investment businesses that relevant expertise and a pipeline of skilled personnel is available;
  - Supporting projects that go beyond purely commercial interests and that consider the welfare of the whole population (perhaps best reflected by the joint actions taken forward to address challenges emerging from the COVID-19 pandemic);
  - Contributing to the achievement of foreign policy objectives, strengthening alliances on a transatlantic basis (with it noted that the US-Ireland R&D Partnership has provided, since its inception, the platform for several NI politicians to meet US politicians and dignitaries);
  - Strengthening national security interests (e.g. through a shared focus on cybersecurity).

- Apart from DfE's support, there are very few support mechanisms available to NI PIs to support collaborative activity with researchers in the USA. The direct access which DfE and its predecessor Departments have been able to secure, along with SFI and the other NI/RoI partners, allowing universities here to participate in NSF programmes, is highly unusual and not something which many other funders, either nationally or globally, have been able to secure. The Good Friday Agreement (GFA), and the key role of the then US President and his Special Envoy played in securing that international Agreement, created a unique window of opportunity and policy prerogative to pursue greater trans-Atlantic cooperation in the context of encouraging increased collaboration on the island of Ireland. The US-Ireland R&D Partnership flowed directly from this and so remains an enduring legacy of the GFA.
- The US-Ireland R&D Partnership has been the catalyst for several long-term and successful collaborations between their University and researchers in both the Republic of Ireland and the USA, often going beyond the initial focus of a singular research project.
- The longevity of the US-Ireland R&D Partnership programme had provided underlying stability to the PIs' endeavours to seek to identify and build partnerships with their US peers.
- Indeed, all of the Principal Investigators that were consulted with were of the view that both initiatives had enhanced the research activity that was taken forward in their university, with it indicated that in the absence of both initiatives opportunities to undertake similar collaborations would be highly curtailed (or in the case of US-Ireland R&D Partnership projects, potentially not feasible at all), indicating a high degree of 'activity additionality' associated with both;
- Of note, few of the PIs were able to identify policies, programmes or activities relating to international research collaboration that are implemented elsewhere in the World (including other areas of the UK) that might have merit in the Northern Ireland context. Indeed, many suggested that the US-Ireland R&D Partnership represented best practice.
- However, whilst it is noted that since April 2018, DfE has sought to capture a variety of project impacts through the revision of the structure of its reporting templates – both for quarterly reports and completion reports – while also introducing new annual impact reports to capture outcomes achieved not only through 'live' projects, but also for the five years following the completion of the DfE-funded activities, both the PIs and other representatives from the two universities considered that such metrics might be more readily and uniformly applied to projects undertaken through the US-Ireland R&D Partnership or the SFI-DfE Investigators Programme e.g. through the use of tools such as Researchfish.
- Furthermore, whilst stakeholders acknowledged that the recently introduced US-Ireland R&D Partnership Centre-to-Centre projects offer greater opportunities for industrial engagement, there was a view that greater emphasis could be placed on this across all projects supported. From an NI perspective, it was suggested that some PIs may require training on the commercialisation of R&D (and that completion of such training should be a pre-requisite before the receipt of funding), and

further that the universities' Technology Transfer Offices may not be sufficiently linked into the various projects that are delivered under both international research collaboration programmes.

- Whilst the universities considered that both a larger available funding pot and a higher level of award per project would be welcome, it was acknowledged that the average project value of c£300,000 is equivalent to a *"decent-sized UKRI research grant"*, and did not present a particular barrier to the quality of research that could be undertaken. It was noted that such a sum of money could broadly cover the employment cost of a PDRA and a PhD student for 3 years and allowed £50k-£60k for overhead costs. Indeed, it was noted that some other research funds do not allow the costs associated with PhD students to be covered, so this was considered to be a *"hugely beneficial"* aspect of the US-Ireland R&D Partnership. It was noted that ideally there would be parity with the level of support that is provided to the RoI partner. However, it was noted by some stakeholders that the £300,000 budget for Centre-to-Centre projects was restrictive in trying to involve businesses or other organisations.
- In the context of risks associated with the Brexit process, all consultees were of the view that NI needed to maintain a focus on developing international research collaboration. Indeed, both NI universities noted the continuing importance of maintaining access to Horizon Europe, noting that it takes years to fully develop international relationships and highlighting the risk that existing relationships with research bodies in the EU could be lost. It is a positive development, therefore, that continuing access to European research has been secured in the EU-UK Trade and Cooperation Agreement of December 2020 (which confirmed that the UK will have 'associated status' allowing it to access Horizon Europe going forwards).
- Of importance, several NI stakeholders advised that NI needs a research strategy, and within that, a strategy for international research collaboration, which would allow for longer-term planning and that would provide assurances as to the level of available funding.

8. BENCHMARKING

Section 8 considers elements of good practice, identified through the research and consultations process, that are implemented elsewhere.

8.1 Israel

During the consultation phase of this project, one of the key stakeholders identified Israel as a good practice example relating to its efforts to build international research collaborations.

Fuelled by a vibrant entrepreneurial culture, robust technological infrastructure and highly skilled human workforce that produces the most substantial number of start-ups per capita in the world, innovation is considered to be one of Israel's most valuable resources. At the same time, Israel is today home to over 350 R&D centres of multinational corporations, many of them Fortune 500 companies, illustrating Israel's profound and disproportionate impact on the advancement of global innovation as well.

According to the World Economic Forum's 2016-2017 Global Competitiveness Report, Israel is the second most innovative country in the world. The study ranked 138 countries in terms of competitiveness, and Israel moved up three steps this year, to hold a place in the top 25. When it comes to academia, Israel is ranked fourth in the world for research personnel, with the highest number of PhDs per capita anywhere else globally. This ecosystem provides a fertile ground for research and innovation alike.

The Israel Innovation Authority, an independent publicly funded agency, was thus created to provide a variety of practical tools and funding platforms aimed at effectively addressing the dynamic and changing needs of the local and international innovation ecosystems. This includes early-stage entrepreneurs, mature companies developing new products or manufacturing processes, academic groups seeking to transfer their ideas to the market, global corporations interested in collaborating with Israeli technology, Israeli companies seeking new markets abroad and traditional factories and plants seeking to incorporate innovative and advanced manufacturing into their businesses.

To meet the various needs of its wide range of clients, the Israel Innovation Authority has developed a new internal structure focused on six primary innovation divisions. Each division offers a unique "toolbox" of customised and comprehensive incentive programmes. These divisions thus serve as a launchpad for successful innovative projects, providing entrepreneurs and companies with the most relevant plan for them to realize and implement their ideas, develop their products and mobilise private investment.

One of those divisions, the International Collaboration Division, is responsible for coordinating international collaboration in innovative R&D knowledge and technology between Israeli companies and research entities and counterpart organisations abroad, thus offering various competitive advantages for the Israeli industry in the global market.

Operated by the Europe, Americas and Asia Pacific Desks, as well as the desk for multinational corporations, support for such strategic alliances are made possible through an array of bilateral cooperation agreements and bi-national funds, as well as through the EU Framework Programme for Research and Innovation. The Israel Innovation Authority can provide matching between partners abroad and in Israel to help find the right collaboration opportunities for each individual or business. The Division's programmes include:

- Bilateral Programmes for Parallel Support;
- R&D Cooperation with Multinational Corporations;
- EU Framework Agreements - Horizon 2020;
- Programme for Boosting Participation of Israeli Companies in the European Frameworks Programme - Horizon 2020;

- European Programmes for Parallel Support;
- Incentive Programme for Adapting Products for Emerging Markets;
- Bi-national Funds.

Whilst most of the programmes noted above have a more overt focus on industry and applied research, bar the activity under the EU Framework Agreements - Horizon 2020, which also has a focus on Israel's academic sector, it is noted that Israel also places considerable focus on developing academic international research collaborations. For example, in August 2019, a research collaboration between Israel and the US received a US$56 million boost from Israel's Council for Higher Education (CHE). The approved plan is to create a special budget to be allocated to the National Science Foundation (NSF) and the United States-Israel Binational Science Foundation joint programme, with the funding financing research programmes over five years.[169]

The NSF-BSF programme awards grants for joint research programmes in a variety of research fields. For the Israeli higher education system, it is considered to be a valuable instrument to strengthen internationalisation. In addition, in late 2019, CHE had another two initiatives in the pipeline to reinforce collaborations with US institutions:

- The Council has increased the number of postdoctoral scholarships for inbound internationals, with a focus on US and Canadian researchers. The total budget, administered by CHE and the Zuckerman Institute, was anticipated to amount to approximately $11m over four years.
- Funding for postdoctoral scholarships for Israeli and US researchers within the Fulbright Israel United States-Israel Education Fund was also given a boost.

Beyond projects focused on North America, CHE is funding several bilateral research with Germany, India, China and Singapore, in addition to its participation in the EU's Horizon 2020 programmes.

In addition, in early 2019, Israel announced an investment of $120m to double international student numbers in support of its ambition to become an international study destination.

8.2 Republic of Ireland

8.2.1 Strategy

The Republic of Ireland published its National Research and Innovation Strategy 2021-27 Consultation Paper on 11 June 2021. The development of a new national strategy for research and innovation (R&I) was a key commitment in the Government's Economic Recovery Plan 2021, which sets out the *"dual ambition of placing research, development and innovation at the heart of addressing Ireland's economic and societal challenges, and building capacity and capability across the research and innovation system to move R&I up the value chain."*

The Department of Further and Higher Education, Research, Innovation and Science (DFHERIS) is leading the development of this new national strategy, in consultation with key Government Departments, agencies and stakeholders. This new Department has been established with a clear mandate to work with all stakeholders to strengthen Ireland's R&I ecosystem, drive reform and collaboration, and enhance outcomes that contribute to meeting societal, economic and global challenges.

[169] https://thepienews.com/news/56m-boost-for-israel-us-collaboration/

The following themes are identified in the Consultation Paper:

1. Role of R&I as a key enabler of the transition to a green, digital and sustainable knowledge-based economy and society;
2. Importance of R&I for economic recovery and sustainable growth;
3. Value of human capital from the research system in meeting high-end skills needs;
4. Value of R&I for knowledge;
5. Strengthening the role of research for policy;
6. Importance of R&I in supporting balanced regional growth, including in the context of driving research performance in the Technological Universities;
7. Role of the R&I system in **driving connectivity and collaboration on an all-island, EU and global level**.

The Consultation Paper notes that the importance of strengthening relationships and engagement beyond the Republic of Ireland's national R&I system cannot be underestimated as such relationships have been a key asset in enabling Ireland to take its place among the top performers globally and excel in key areas of R&I. It notes that the next Strategy will need to prioritise RoI's engagement at many levels, including supporting all-island R&I activity, aligning national priorities with European Research Area (ERA) priorities, optimising participation in the Horizon Europe Framework Programme, strengthening the east-west relationship and looking to foster relationships with key global partners. The aim is two-fold: firstly, to deepen existing cooperation and, secondly, to develop more cross-border research cooperation between public research performers, enterprises and other stakeholders.

DFHERIS accounts for approximately 54% of the Government's research and development budget, which is disbursed through three key research funding bodies, one of which is Science Foundation Ireland.[170]

8.2.2 Project Monitoring

Discussion with Science Foundation Ireland (SFI) indicates that it monitors the outworking of each project that it supports. By way of example, SFI provided details of its monitoring of the 14 projects that were supported as part of the pilot rounds of the SFI-DfE Investigators Programme. This information is presented in full in Appendix XI. The Research Team notes that activities, outputs and outcomes featured in the monitoring report provided cannot be considered to be equivalent for Northern Ireland as it is considered from the perspective of the Republic of Ireland. Also, a caveat applies insofar as SFI's monitoring report notes that all of the information *captured "may not be primarily attributed to the award in question"*.

The report indicates that SFI routinely monitors (for all R&D projects supported, and not just those under the SFI-DFE Investigators Programme Partnership) activity, output and outcomes indicators including the following:

1. Research Team composition in terms of grade/level of experience/level of qualification. For example, the number of SFI-approved funded investigators, co-principal investigators, PhD students, Masters students etc.
2. Research Team composition by nationality and gender;
3. The destination of departing team members e.g. industry, further education, an academic role within the HEI etc.
4. The primary objective of the academic collaboration including options such as:
    - Joint publication/Research;
    - Access to/provision of material, equipment, software, data;
    - Building networks & relationships; and
    - Training and Career & Professional Development (CPD).
5. The location of the 'primary academic collaborator';

[170] The other two are the Irish Research Council and the Higher Education Authority through the core grant to HEIs.

6. The objective of any non-academic activity, including options such as:

    - To learn about and/or test the potential of, and explore, ideas and options for possible new directions of future R&D;
    - To provide a flexible and cost-effective extension of the R&D resources (expertise, equipment, facilities) available to the organisation;
    - To develop networks with academics and access the global academic network;
    - To identify possible recruits and/or support and influence the supply of relevant skills;
    - To leverage activity and funding through collaborative programmes, for example, those supported by the European Framework Programme;
    - To save costs, by making comparatively short-term, arm's-length use (e.g. consultancy) of skills, knowledge and expertise which would be expensive to bring in-house by recruitment of full-time staff.

7. The location of the 'primary non-academic collaborator';
8. The type of 'non-academic collaborator' involved e.g. SME, Multi-National Corporation, Government Department etc.
9. The level and source of any follow-on funding achieved, including whether the funding came from outside the Irish Exchequer;
10. The number of scholarly outputs (i.e. publications) by type, with options including:

    - Refereed Original Articles
    - Refereed Review Articles
    - Refereed Conference Proceedings
    - Book Chapters
    - Books
    - Edited Conference Proceedings

11. The number of scholarly outputs with an industry co-author;
12. The number of scholarly outputs with an international co-author;
13. The number and type of education and public engagement (EPE) activities undertaken, with options including:

    - Broadcast/Film
    - Careers Experience Programme
    - In-Class Activities
    - Informal Learning
    - Public Event
    - Student Work Placement/Career Activities.

14. The number of conferences, seminars and workshops by type and role of the researcher, with options including:

    - Convenor
    - Co-organiser
    - Member Organising and Programme committee
    - Member Organising and Scientific committee
    - Member Organising committee
    - Member Scientific committee

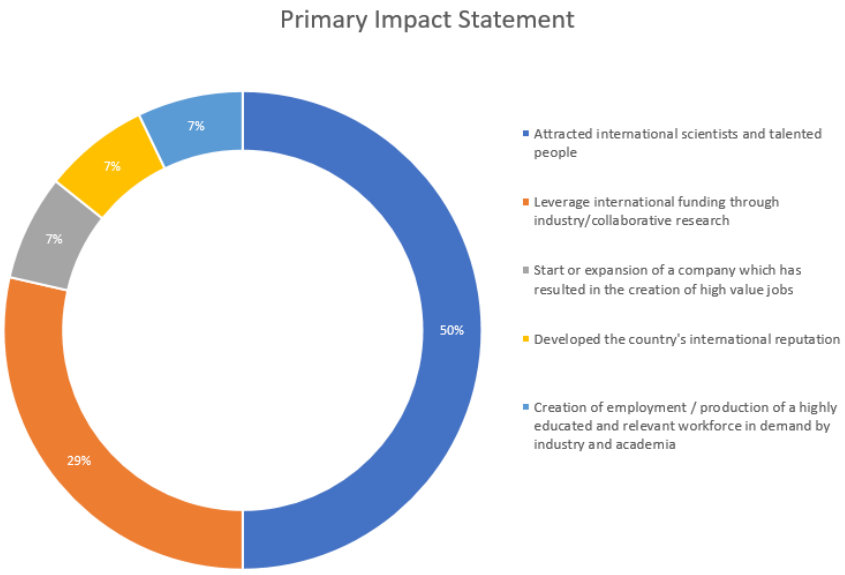
15. The number of 'commercial activities' by type, with options including:

- Assignments
- Invention Disclosures
- Licensed Technology
- Patent Filed and Pending
- Spin-Out Companies
- Start-up Companies

Of interest, the RoI partners have recorded the following 'commercial activities' as a result of the 14 projects supported under the pilot rounds of the SFI-DfE Investigators Programme:

Table 8.1: Commercial activity by type (SFI reporting)	
Type of activity	**No.**
Assignments	1
Invention Disclosures	1
Licensed Technology	1
Patents Filed and Pending	4
Spin-Out Companies	1
Start-up Companies	2
Grand Total	**10**

16. The capture of an 'Impact Statement' to reflect the 'Primary Impact' of the research, with the following options and results captured for the14 projects supported under the pilot rounds of the SFI-DfE Investigators Programme.



Of note, during February 2019, SFI became a signatory to the San Francisco Declaration of Research Assessment (DORA), making a formal commitment to assessing the quality and impact of research through means other than journal impact factors.

DORA comprises a set of recommendations that respond to the pressing need to improve how the output of scientific research is evaluated by funding agencies, academic institutions and other parties. SFI has been supporting DORA principles for several years by asking applicants to describe the wider impact of their research. The recently launched SFI Frontiers for the Future Programme values diverse types of research outputs in both the application and review process and, in particular, places importance on the content of publications rather than the publication venue. Discussion with SFI indicates that it will continue to implement these, and other changes, to align its review and evaluation processes with DORA principles.

By supporting the statement as a signatory, Science Foundation Ireland is supporting the efforts to shift the culture of research assessment away from journal-based metrics and recognising the need to improve how the outputs of scientific research are evaluated.

8.3 DORA

The Declaration on Research Assessment (DORA) was developed in 2012 during the Annual Meeting of the American Society for Cell Biology in San Francisco. It has become a worldwide initiative covering all scholarly disciplines and all key stakeholders including funders, publishers, professional societies, institutions and researchers.[171]

DORA's ultimate aim is to promote *real* change in research assessment. It considers that one of the keys to this is the development of robust and time-efficient ways of evaluating research and researchers that do not rely on journal impact factors. DORA's stated objectives include:

- **Raise awareness -** To call attention to new tools and processes in research assessment and the responsible use of metrics that align with core academic values and promote consistency and transparency in decision-making
- **Facilitate implementation -** To aid the development of new policies and practices for hiring, promotion and funding decisions;
- **Catalyse change -** To spread research assessment reform broadly by working across scholarly disciplines and globally;
- **Improve equity -** To call for broader representation of researchers in the design of research assessment practices that directly address the structural inequalities in academia.

DORA is developing a toolkit of resources to help academic institutions improve their policies and practices. So far, it includes two briefing documents that offer principles to guide institutional change and strategies to address the infrastructural implications of common cognitive biases to increase equity:

- 'Ideas for Action 'outlines five common myths about research evaluation to help universities better understand barriers to change and provides analogous examples to illustrate how these myths exist inside and outside of academia. It also offers five design principles to help institutions experiment with and develop better research assessment practices.
- 'Unintended Cognitive and Systems Biases' identifies seven personal biases that can influence hiring, promotion, and tenure decisions. It also reveals four institutional and infrastructural implications of these biases and provides strategies to develop new institutional conditions that reduce bias.

Discussion with both Ulster University and QUB indicates that they have signed up to DORA.

8.4 The UK - The Newton Fund and Global Challenges Research Fund

One of the strategic stakeholders that were consulted highlighted the Newton Fund as representing good or best practices in developing international research collaborations. The Newton Fund and Global Challenges Research Fund (GCRF) form part of the UK's Official Development Assistance (sometimes known as UK Aid).

The Newton Fund builds research and innovation partnerships with countries in Africa, Asia and Latin America to support economic development and social welfare, tackle global challenges and develop talent and careers. It does this through:

[171] https://sfdora.org/

- Equitable partnerships with middle-income countries;
- Multidisciplinary research based on agreed national strategies;
- Nurturing talent and careers with capacity development.

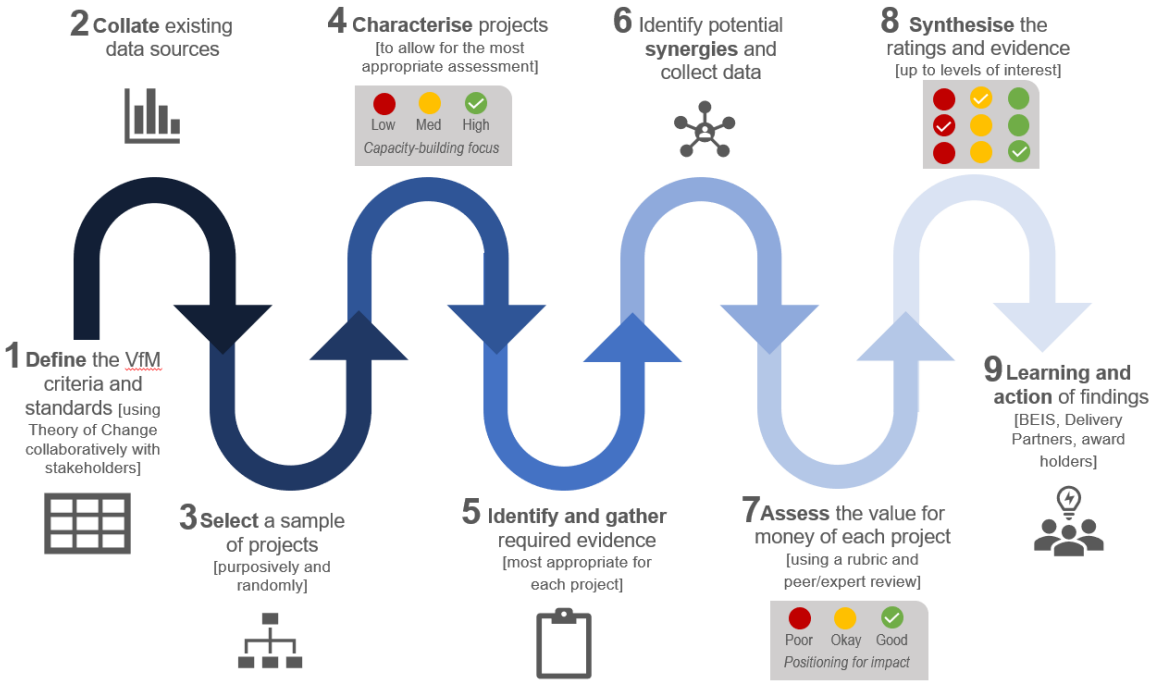
Each Newton Fund partnership is unique. The UK and international partners work together to devise and deliver Newton Fund programmes. Resources provided by the UK are matched by partners, building in collaboration from the very beginning.

The Newton Fund is managed by the UK's Department for Business, Energy and Industrial Strategy (BEIS). The fund is delivered through UK partners who offer tailored research and innovation programmes in partnership with governments and organisations in each Newton Fund partner country (of which there are currently 17 in total).

Under the Newton Fund, UK researchers work in partnership with researchers from these partner countries on tailored research themes including health and neglected diseases, low carbon energy, environmental resilience and research commercialisation.

BEIS considers that ensuring and demonstrating the value for money (VfM) of public investments such as the Newton Fund and GCRF is extremely important as it involves spending taxpayers' money to benefit developing countries. However, it also acknowledges that it is quite difficult to determine this due to the complexities of research and innovation. BEIS advises that some difficulties for assessing VfM include the long timeframe to achieving impact, attributing a benefit to a particular research project and that many benefits of research are impossible to quantify in simple monetary terms.

Nonetheless, BEIS, its funding partners and other stakeholders have been working together to find the most appropriate way to conceptualise and assess the value for money of the funds. Its approach is summarised in the diagram below: [172]



BEIS' approach draws on the International Development Research Centre's Research Quality Plus framework, and King and Oxford Policy Management's (OPM) Approach to Assessing Value for Money in International Development Programmes.

[172] Our approach to assessing Value for Money, BEIS, 25 November 2020

The approach essentially takes a sample of projects and programmes (multiple projects under a given theme) through a peer/expert assessment based on specific criteria. This allows for different research and innovation projects to go through the same process transparently and fairly with the use of a rubric. The rubric, collaboratively developed with GCRF and Newton Fund stakeholders, considers the following areas:

Panel members score projects/programmes on the above criteria using four levels: poor, acceptable, good and excellent. BEIS advises that it is important that its approach can take a portfolio approach to assessing VfM, as some research attempts may fail, and others may be highly successful. That is, BEIS did not want a VfM approach to risk prioritising short-term, easily demonstrable results at the expense of transformational research and innovation. Therefore, once the projects/programmes have been assessed by a panel and receive an overall VfM score, the evidence can be synthesised at different levels, from the programme through to the fund level.

During 2018-19, the Newton Fund recorded (for the year):

- 161 instances of Intellectual Property protection; and
- 35 instances of spin-out companies.

8.5 Case Study - Australia

Australia undertakes world-class research across the full spectrum of research activity, from Science, Technology, Engineering and Mathematics (STEM), through to the Humanities, Arts and Social Sciences (HASS). This is achieved through universities and other publicly funded research organisations, such as the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Australian Nuclear Science and Technology Organisation *(*ANSTO) and the Australian Institute of Marine Science (AIMS).

Much of Australia's success in research has been built upon financial and esteem-based incentives that encourage researchers to produce academic papers. In the university sector, there has been strong evidence that this focus has led to dramatic increases in research production.[173]

However, more recently, Australian policy has focussed on delivering benefits or impacts from publicly funded research. For example, the CSIRO Impact Framework attempts to account for the social,

[173] Measuring the Value of International Research Collaboration - Report Prepared for the Department of Industry and Science (Australian Academy of Humanities, May 2015)

environmental and economic impacts of its research. This has been driven in large part by national fiscal management that demands evidence of the return on investment of public funds. As a response, much attention in the higher education sector has focussed on measuring the broad societal benefits that flow from publicly-funded research – for example, the Excellence in Impact for Australia (EIA) trial (2012) which sought to evaluate research impact through case studies. This reflected a growing international trend towards broadened research evaluation metrics combined with expert judgement (e.g. the role of case studies in the UK Research Excellence Framework 2014).

Research excellence and impact are both important aspects of the Australian innovation system, and policies that quantify the returns on the public investment into research are considered to be fundamental to ensure the confidence of the public in the value of investing in research. However, the Australian system considers that it is not enough for policy to simply measure research quality and research impact – it is imperative that public policy drives (and supports) the kinds of behaviours that will maximise the quality and impact of research in the long term. Such an approach must not only focus on retrospective performance measures alone but must also form an integral part of the planning of research agendas at all levels – for the research system as a whole, institutions and researchers.

Importantly, Australia recognises that a significant contribution to this can be made through an increased focus on international collaboration**. However, they further recognise that this requires a shift from traditional frameworks that focus on simple measurements of incidence, to broader frameworks that are capable of tracking the complex systems and changes that are involved in international collaboration, and the benefits that flow.**

Appendix V provides an overview of the CSIRO Impact Framework.

8.6 Summary Conclusions

The Research Team's consideration of good practice relating to international research collaboration, identified through the research and consultations process, that is implemented elsewhere has identified the following:

- Countries that lead the way in innovation place great emphasis on developing international collaborative research. For example, Israel ranks as one of the World's most innovative countries. The Israel Innovation Authority is an independent publicly funded agency, created to provide a variety of practical tools and funding platforms aimed at effectively addressing the dynamic and changing needs of the local and international innovation ecosystems. To meet the various needs of its wide range of clients, the Israel Innovation Authority has developed a new internal structure focused on six primary innovation divisions. Reflecting the importance of international collaborative research to Israel's overall innovation performance one of those divisions is the International Collaboration Division. This division is responsible for coordinating international collaboration in innovative R&D knowledge and technology transfer between Israeli companies and research entities and counterpart organisations abroad. It has supported the creation of an array of bilateral cooperation agreements and bi-national research funds; some of which place considerable focus on developing academic international research collaborations.
- Neighbouring (and to some extent competing) countries such as the Republic of Ireland have developed specific National Research and Innovation Strategies. Within such strategies, emphasis is placed on supporting international connectivity and collaboration. In the case of the Republic of Ireland, the aim is two-fold: firstly, to deepen existing cooperation and, secondly, to develop more cross-border research cooperation between public research performers, enterprise and other stakeholders.
- Robust project monitoring is considered an essential mechanism for supporting the implementation and assessment of such strategies;
- Mechanisms to monitor research projects are evolving and being adopted both elsewhere and within NI (by the two universities), with the introduction of approaches such as DORA (The Declaration on Research Assessment), which aims to promote *real* change in research assessment. It considers

that one of the keys to this is the development of robust and time-efficient ways of evaluating research and researchers that do not rely on journal impact factors.

- The UK's Official Development Assistance's Newton Fund was identified by stakeholders as representing good or best practice in developing international research collaborations. It is managed by the UK's Department for Business, Energy and Industrial Strategy (BEIS), which acknowledges that it is quite difficult to determine its value for money due to the complexities of research and innovation. Nonetheless, BEIS, its funding partners and other stakeholders have been working together to find the most appropriate way to conceptualise and assess the value for money of the funds. Its approach includes defining prospective value for money indicators at the outset and then following a Theory of Change model to assess impact.
- Similar models were identified as being used in other countries, such as in Australia, whose Commonwealth Scientific and Industrial Research Organisation (CSIRO) has adopted a distinct focus on delivering benefits or impacts from publicly funded research and uses its CSIRO Impact Framework to account for the social, environmental and economic impacts of its research. This framework recognises that the measurement of value relating to international research collaboration must extend beyond traditional frameworks that focus on simple measurements of incidence, to broader frameworks that are capable of tracking the complex systems and changes that are involved in international collaboration, and the benefits that flow.

9. CONCLUSIONS & RECOMMENDATIONS

Section 9 presents the Research Team's conclusions and recommendations relating to the Department's policy, programmes, and funding used to promote international research collaboration likely to maximise the return on its investment of resources.

9.1 Conclusions

9.1.1 International Research Collaboration's Importance

The persistent focus on excellence in the funding of research and innovation in the UK has paid huge dividends. Excellent research delivers high levels of economic and social impact across the country. It is a magnet for foreign direct investment in R&D which is vital to increasing overall investment in the UK and it attracts talented researchers from around the world who go on to deliver further excellent work[174]. There is therefore a compelling case for that focus remaining in future.

The '10x Economy' (Economic Vision) document (2021) seeks to optimise Northern Ireland's comparative advantages across a range of sectors. In the international research collaboration arena, this means playing to strengths, building capacity in areas of research priority, and working on shared research challenges.

International research collaboration is a key feature of the Northern Ireland research landscape and is integral to its future. Increasing the international connectedness and depth of international engagement of research are both fundamental to the long-term competitiveness of domestic research, and to ensure that research drives economic and social advancement. The prioritisation of spending in this area is recognised both by the UK Government and the NI Executive.

International collaboration fundamentally enhances and transforms scientific research; it is driven by three main factors:

- Quality: The added value gained by bringing together different skills, knowledge and perspectives (manifested in the increased citations of papers with international collaborators). Scientists search out suitable collaborators in their field wherever they are located, to progress their research, bringing together a range of relevant and complementary skills and resources.
- Efficiency and effectiveness: The drive to combine intellectual, financial and infrastructural resources, to achieve more than one nation could manage alone.
- Necessity: To address high-level global challenges such as climate change and pandemics which do not recognise national boundaries, and which require large-scale cooperation and the mobilisation of resources to tackle them, as well as the application of global knowledge to local manifestations of these problems.

However, the challenge for governments, scientists, civil society and others, is how to reap the maximum benefit from international research collaboration.

Northern Ireland's participation in both the US-Ireland R&D Partnership and the pilot rounds of the SFI-DfE Investigators Programme have undoubtedly benefited its science, research and innovation landscape. However, there are some aspects of the systems currently utilised which prohibit the Research Team from determining the full extent to which resources have been maximised.

Given the current economic context, in which the global economy has been severely impacted by the Covid-19 pandemic and there remains a degree of economic uncertainty following the EU-UK Trade and Cooperation Agreement (albeit that continuing access to Horizon Europe has been secured as part of this agreement), the Research Team considers that it is important to stabilise the NI research

[174] Changes and Choices - Advice on future frameworks for international collaboration on research and innovation, commissioned by the Minister of State for Universities, Science, Research and Innovation (Professor Sir Adrian Smith and Professor Graeme Reid, July 2019).

environment, as much as is possible, and build on the capability that has been established through the DfE supported international partnerships to date.

Although an association with Horizon Europe has been confirmed in the EU-UK Trade and Cooperation Agreement of December 2020, leaving the EU has other significant potential impacts on the UK's research and innovation ecosystem, not least in regions such as Northern Ireland where strands of EU structural funds and regional development support have been combined with research and innovation funding to play a vital role in developing the local economy. This creates a need to explore how the Government's new UK Shared Prosperity Fund (UKSPF) can be developed to support further integration of research and innovation into regional economic development[175].

9.1.2 Why we should Engage?

How universities contribute to innovation is increasingly well recognised, stretching well beyond their roles in expanding the stock of codified knowledge, translating fundamental research into inventions that can be commercialised, and their roles as educators. Through their increasingly direct linkages with universities, firms can develop and enhance the capabilities and competencies that feed into their innovation processes (e.g. tacit and codified knowledge, know-how, practices and processes, tools and techniques), and do so at different stages of the value chain, from early-stage technology development to scale-up, production, logistics, marketing and sales. These linkages touch many sectors of the economy, stretching well beyond manufacturing and technology-product driven firms, to include those within the services and public sectors, and often well beyond the regional boundaries of universities.

Increasing attention is also being given to the proactive and strategic initiatives and activities within universities aimed at strengthening the system-wide conditions in which innovation takes place. Indeed, as evident by proposals under NI's City Deals, the two NI universities are increasingly seeking to become knowledge hubs in the economy, to become even more deeply embedded in innovation systems, and to actively foster interactions and spillovers to link research with application and commercialisation, and taking on roles of catalysing and animating economic and social development. While these roles are often framed in a regional context, these 'system development' roles are evident in sectoral and technological systems.

Developing the universities' research capability and capacity is therefore of importance for NI's further prosperity and growth. However, such an opportunity will not be maximised without international collaboration.

Engaging in international collaborative research also indicates to the rest of the World that Northern Ireland is a global, outward-looking nation. It helps to demonstrate that we have a world-leading research and enterprise environment that can attract collaboration from across the globe.

To attract and retain the most highly skilled individuals, NI must provide a competitive landscape and offer to researchers, innovators and investors. One where it is recognised that ideas can be turned into new global businesses.

[175] The UKSPF is "specifically designed to reduce inequalities between communities" and to "help deliver sustainable, inclusive growth". However, at the time of writing there remains great uncertainty about the exact nature of any successor fund: how much it will be, its purpose and structure.

9.1.3 How we should Engage?

To 'maximise the positive impact of DfE Policy, Programmes and Funding in support of International Research Collaboration', DfE must adopt a new coherence and sharper focus to its international research and innovation effort.

As the UK redefines its relationship with the European Union in the wake of the December 2020 EU-UK Trade and Cooperation Agreement, it is recognised that the UK Government is committed to pursuing a far-reaching relationship with the EU, and with individual member states, on science, research and innovation as an integral part of its approach. NI must be ready to maximise the opportunities that this new relationship will present.

The UK has secured association with Horizon Europe as part of the EU-UK Trade and Cooperation Agreement and is continuing to actively shape the development of that programme. However, it would be prudent for NI to continue to explore credible and ambitious alternative collaborations and partnerships internationally to deliver positive outcomes for science, research and innovation.

The Research Team, therefore, considers that the Department and NI's two universities should jointly develop a strategy that will establish a roadmap as to how it is anticipated NI will maximise the opportunities that are available to engage in international research collaboration through, amongst other means:

1. UK-wide support structures (as outlined in Section 2);
2. Island of Ireland structures;
3. The US-Ireland R&D Partnership Programme; and
4. Other mechanisms including the Executive's international engagements and the universities' international networks.

Strategic planning of international research collaboration should allow the Department to make informed decisions about when, where and how to invest to maximise the range of values that come from international research collaboration.

Collaborations undertaken through such an approach should reflect the capabilities, ambitions and longer-term vision of Northern Ireland.

Of note concerning the development of such a strategy, it may be of limited benefit to develop overly complex strategic analyses of 'who Northern Ireland's best research partners' would be. For example, a good link for engineers may not be a good link for clinicians.

9.1.4 How do we measure success?

The concept of research excellence is ubiquitous, but its meaning depends on context, and often the meaning attributed to the notion of excellence differs markedly among both academics and policymakers alike.

In addition, many reports argue that there are substantial shortcomings in the existing mechanisms for science's quality control system, which undermine trust in assessment practices around scientific excellence. Nonetheless, whilst considering the robustness of the peer review system is beyond the scope of this research, the research team notes that **the peer-reviewed system employed by the NSF is widely regarded as being amongst the most robust employed globally.** This provides comfort that the science proposed under the US-Ireland R&D Partnership, in particular, is likely to be of a very high standard. Indeed, the National Science Foundation employs two criteria in the merit review of proposals:

- What is the intellectual merit of the proposed activity?
- What are the broader impacts of the proposed activity? (This considers factors such as the promotion of teaching and learning, the inclusion of under-represented groups and other benefits to society.)

However, these criteria do not provide guidance as to the types of research outcomes that might be considered as being excellent from a Northern Ireland perspective. On that basis, the Research Team's first recommendation is that the Department examine whether research excellence can be 'institutionalised' in the form of a range of stable research excellence indicators that it can use to assess the merits of basic and applied research projects/programmes, including those with an international collaborative aspect, and as such broaden the notion of research excellence beyond the internal academic value system to include wider socio-economic impacts as well. This would see the creation of a set of indicators, which would coexist with expert reviews as measures of quality.

We recommend that a 'range' of indicators be selected as there is a risk, in stripping away some aspects (and focusing on others), that a distorted view on the phenomenon of interest might arise, with potentially severe consequences for policy decisions derived from them. This recognises that basic research cannot often be defined in a single-best, fixed and objective way from the outset.

Although the existing evidence (in terms of macro-economic rates of return and evidence that public sector investment in R&D 'crowds in' private sector R&D investment) provides a compelling case for the benefits that R&D can deliver, particularly to the economy, there are many benefits that come from investment in R&D that are not well measured or, in many cases, well understood.

Indeed, notwithstanding the recognised importance of international research collaboration, the mechanisms to understand and measure the benefits and values of international research collaboration are, at present, limited. This, however, is not unique to Northern Ireland and is a situation that is recognised across many countries. International research collaboration is constituted by a range of activities, often interrelated, which are not always amenable to quantitative evaluation, and which are likely to be realised in complex ways across the innovation system.

However, whilst case study examples exist (for example those created as part of the REF assessment) that seek to demonstrate the myriad ways in which R&D enriches our society, improves our quality of life through improved social cohesion, through broader and deeper cultural experiences, through improved safety and security, and richer and more engaging education, often the evidence for the role international research collaboration plays in helping to realise these has not been fully articulated or measured.

There are many metrics and indicators that might feasibly be used to demonstrate and evidence the benefits of international research activity, knowledge exchange and impact. The decision about which of these to use should be informed by consideration of what it is a programme/project is trying to achieve and which qualitative or quantitative measures provide meaningful evidence of progress against that goal. However, it should be recognised that in some cases, it may only be possible to find proxy indicators for the impacts of a programme/project, but these should nevertheless be as relevant and as robust as possible.

Bibliometrics is the mechanism most often used to capture the impact of international research collaboration. However, in the Research Team's view, it provides a limited evidence base that cannot capture the many modes of collaboration outside co-authorships or outputs from across the research spectrum. Moreover, bibliometrics do not allow us to identify the value of international research collaboration and its system-wide effects.

Taking the position that NI cannot maximise the return from international research collaboration until it can adequately measure its impact, an aim of this report is to inform the development of a more comprehensive approach to measuring the impact and value of international research collaboration across the publicly-funded research sector, one that is responsive to different disciplinary practices across the research system, and to the range of different activities and levels of engagement.

The Research Team considers that this will require moving beyond frameworks that focus on simple counts of incidence, to frameworks capable of tracking the complex systems and changes that are

involved in international collaboration and the broad range of values that flow – in other words, a shift from focussing on questions of 'what' happened and to 'whom', to questions of 'why' and 'how'.

Measuring value will require utilising approaches that encompass quantitative and qualitative methods. Evaluation should be seen as an integral part of planning, and involve steps such as identifying the aims and intended outcomes of collaboration, developing agreed indicators for measuring progress towards achieving pre-set goals, and introducing a feedback loop for learning and adjustments into research design and programme implementation.

Evaluation frameworks that take account of the diverse values that flow from international research collaboration and the deep and complex networks that are involved must also take account of a broader range of data to complement measurement and evaluation processes. There are currently significant collections of data that could be usefully repurposed into an appropriate evaluation framework, and indeed discussion with both universities indicates that they would be open to their use in the context of DfE supported research.

The research team acknowledges that the construction/selection of appropriate indicators is in itself a complex process, as might be the process of agreeing on a shared meaning of research excellence in the context of Departmental funded projects and programmes. For that reason, we consider that to the extent possible, the Department should seek to work within frameworks that the universities are already familiar with, albeit recognising that any chosen indicators/definition of research excellence and its implications for quantification should be positioned against the background of the specific goals and interests that a project/programme is anticipated to serve.

The Research Team has explored many different mechanisms that are used to measure the impact of university R&D and international research collaboration and are of the view that there is considerable scope to make full use of Researchfish for analysis of the impact of university research that is supported by the Department (be that of an internationally collaborative basis or otherwise). As a unique and relatively comprehensive longitudinal dataset, there is scope for particularly informative analysis to be undertaken. Researchfish collects data throughout the lifetime of a research grant and after completion, allowing for long-term follow up on the way that outcomes and impacts develop. The Research Team, therefore, recommends that the indicators captured by Researchfish are used as the basis for the selections of the aforementioned recommended 'range' of indicators to be selected.

Importantly, the Research Team recommends that a strong focus is not placed on 'citations' or 'publications' over other potential indicators, albeit recognising that they should be considered, given their continuing importance to the university sector.

Furthermore, the Department should always use more than one research metric as the quantitative input. This reduces opportunities to 'game the system' and drives desirable outcomes. Bibliometric information should be seen as representing only one element within a broader range of information sources available to support decision making in a research management context.

A key benefit of this approach is its ability to provide a longitudinal analysis of impacts, rather than a 'snapshot' end of project report which only evidences time-limited impact, rather than looking at changes in impacts over a long period. However, R&D impacts may be short- or long-term, and so the time window covered by data collection is critical.

We further recognise that capturing the outcomes and impacts of (internationally collaborative) research is complex, and the indicators that might be selected (if our previous recommendations are adopted) will seek to put into numbers phenomena that are hard to measure. However, indicators necessarily de-contextualise information. For this reason, the indicators should be accompanied (at the application and evaluation stage) by sufficient narrative to help ensure that research impact is fully captured and not lost through over-simplification.

Combining such information with a case study approach would, in the Research Team's view, allow for more nuanced and cross-disciplinary analysis and provide for a more comprehensive picture of the range and nature of benefits from R&D, whilst minimising the level of additional burden on researchers or research users through additional data collection.

Because several (potential) impacts can only be captured with qualitative information, the proposed approach encompasses the strengths of both the metrics and narrative approaches to present illustrative case studies of the impact of research projects on the regional innovation ecosystem. The narrative case study should be supported by indicators to identify, categorise and explain the (potential) impact that the project will have/has had on the regional innovation ecosystem. This 'multi-method, multi-sources' approach allows for a greater degree of objectivity, comparability and tracking of progress over time.

Our suggested approach would help ensure that there is a focus on understanding the process of creating research impact, including critical events and their linkages.

Our recommended approach, therefore, has the advantage of blending two of the key types of approach to assessing R&D project portfolios[176]:

- Aggregations of project-level metrics - typically derived by summing up data collected from individual projects or studies; and
- Narrative portfolio assessments which utilise primarily qualitative approaches to take stock of a given portfolio and its results.

Each form of assessment has its advantages and disadvantages, so a blended approach may offer the best potential to capture all the benefits that result from a project or programme.

The adoption of such an approach should ensure that supported projects report on their (anticipated) impact to NI specifically, beyond their contributions to academia (albeit these should also be ascertained) i.e. the anticipated research impact should also be considered from the perspective of its demonstrable contribution to the economy, society, culture, national security, public policy or services, health, the environment, or quality of life etc.

Given the variables involved, such considerations must be incorporated into the planning of projects, programmes or policies. To this end, to fully develop the framework and methodology proposed, the Department should develop a set of standard guidelines for evaluating international research collaboration in policy, programme and project settings.

In specific relation to post-project evaluation, consideration could be given to creating expert review panels. Such panels should be sufficiently broad and diverse to consider projects in various sectors and should as a minimum encompass both scientific and economic appraisal/evaluation understanding (i.e. the appropriate skill set to assess the proposed 'impact pathway' or 'logic model'). The latter is recommended as scientific peers have been found to be not necessarily good at judging socio-economic impacts.[177] The notion of 'innovation impact' is not as well understood as 'scientific impact'. The fact that key concepts and notions are still in flux, and may not be understood the same by all experts, suggests the application of expert panel reviews, which would allow for contesting and conflicting opinions that can be played out and negotiated for consensus-seeking.

Concerning the monitoring of projects supported by *'single proposal – single review'* programmes, such as the US-Ireland R&D Partnership, the lead agency which conducts the original scientific review of the proposals, might be particularly well placed to develop core metrics in consultation with the other international funders (including DfE) for use at both the in-project monitoring and post-project evaluation stages. Indeed, for such projects, the lead agency which conducted the original scientific

[176] Research-Portfolio Performance Metrics, RAND 2019
[177] Debackere, K., Arnold, E., Sivertsen, G., Spaapen, J., Sturn, D., and Mahieu, B., Performance-Based Funding of University Research, MLE on Performance-based Research Funding Systems (PRFS), Horizon 2020 Policy Support Facility, 2018.

review at the proposal stage, and has the appropriately scientifically qualified desk officers, would be best placed to lead on the scientific evaluation of projects, post-completion. We would recommend, though, that DfE seeks to augment these with NI-specific metrics to ensure that local impact can be captured.

9.1.5 Support Required

Internationally collaborative science should continue to be encouraged, supported and facilitated. Even in difficult economic times, governments need to maintain investment in their science base to secure economic prosperity, tap into new sources of innovation and growth, and sustain vital connections across the global research landscape. Sustained investment builds a nation's capacity to assimilate excellent science, wherever it may have been conducted, for that country's benefit.

Well-structured and flexible funding mechanisms should therefore be in place to support collaboration. It is important that NI-based researchers have the ability, support and resources to collaborate with the best partners – wherever they may be.

NI's universities already collaborate with partners in a range of countries, both EU and non-EU. The emphasis is on working with the best partners, those that are most appropriate for the specific research being undertaken. However, the importance of collaboration with EU partners should not be underestimated. Even with the securing of associate status with respect to Horizon Europe under the EU-UK Trade and Cooperation Agreement, it will still be important that NI has as much flexibility as possible to create effective international collaborations (with the potential for impact) wherever appropriate partners are found – and this must include both EU and non-EU partners.

The importance of both policy and funding stability in nurturing effective research partnerships should be recognised.

Of note, high-quality research partnerships may be enabled by international agreements, but they are implemented via the willing and mutually beneficial agreement of Principal Investigators (PIs) and their research groups. This aspect is of key importance, and steps should be in place to ensure that researchers receive the support to enable them to both identify and take forward appropriate collaboration projects. To this end, there may be merit in the Department reintroducing its support for PIs to explore research relationships with PIs in other countries.

Careful design of international research collaboration programmes, preferably with evaluations, could help improve the conditions for the translation of research and to drive innovation. Interventions should, where possible, ensure that all pertinent enabling and institutional factors interact (for example HEIs' TTOs) to enable the effective translation of research to occur.

To ensure that collaborations are 'win-win', an underlying principle should be that all partners must derive a benefit that is commensurate with their contributions. Concerning this, risk mitigation measures should be clearly articulated such as how ownership of background and foreground knowledge/IP will be managed.

In relation to the quantum of monies/funding required, the Research Team considers that the 'market' for international collaborative research is in a considerable state of flux, but given its aforementioned importance, the sum available should be no less than that that is currently available. However, if possible, and allowing for what might be constrained public sector funding in coming years, efforts should be made to increase the total sum available to NI HEIs and businesses.

9.2 Recommendations

The Research Team considers that the implementations of the following recommendations will improve the effectiveness and efficiency of international research collaboration activity in Northern Ireland:

1) Develop an International Research Collaboration Strategy - A strategy is required to align activities that will grow Northern Ireland's international research connectivity and enhance its reputation as a hub for international research talent. The development and implementation of such a strategy will require not only the Department, but also the two universities, and other economic development and research/innovation ecosystem stakeholders to cultivate a coordinated approach that delivers identifiable results. Such a strategy should anchor the focus of international research collaboration to local needs.
2) If establishing an international research collaboration programme with other international funders, ensure to set out from the outset:

- The intent of the Department's involvement in the collaboration activity e.g. curiosity-driven science, foreign policy concerns, industrial competitiveness, a specific mission of the government, or another factor;
- A clear rationale for government involvement that sets the activity apart from activity taken forward by the universities otherwise (i.e. additionality and added value);
- Clear aims and objectives of the fund/programme;
- Articulate the purpose, objectives, strategies and associated priorities, and performance indicators of a programme through clearer linkages between strategic plans, programme documentation and available budget;
- The application assessment process and eligibility criteria from a Northern Ireland perspective;
- A plan as to how collaboration activity will be facilitated e.g. how will the prospective partners in both NI and the other country become aware of each other's knowledge and experience;
- An appropriate monitoring framework to ensure that the original intent is being carried forth into actual planning and execution;
- A clear plan as to how collaborations will be both monitored and evaluated, especially given the difficulty of quantifying basic research outcomes. Ideally, the evaluation criteria should be built into the project and monitored accordingly.

3) DfE should consider the reintroduction of support for activities such as travel that might be necessary to develop international research collaboration networks.
4) Maintaining a stable source of funding should be considered a baseline requirement for any international programme. This should provide the necessary confidence to allow researchers to explore research collaboration opportunities.
5) A logic model approach should be used to help design both formative assessments and summative evaluations (after a project's completion).
6) Work with the universities and other funders to agree on a comprehensive list of performance indicators and on a minimum set of 'key performance indicators' drawn from those captured by Researchfish and also additional quality criteria for monitoring/evaluating international research collaboration projects.
7) The selection of metrics for outcome and impact measurement needs to consider the trade-offs associated with their use and balance the efforts needed to collect data to inform these metrics with their utility to key stakeholders, as well as their intended use. This recommendation reflects lessons learned from the literature and our judgment that, in a world of research constraints and performance-measurement demands, there is an opportunity to make explicit choices about the metrics used at each stage represented by the logic model.
8) Consider developing outcome and impact tracking and measurement in an incremental fashion. It might not be feasible to simultaneously introduce a broad suite of outcome and impact metrics. Instead, their gradual implementation, focusing initially on a small number of selected metrics, might be more realistic.

9) At the application stage, the universities could be asked to also describe "how" the proposed collaborative research is anticipated to have a positive impact on the NI regional innovation ecosystem, potentially beyond what is captured by the available performance indicators. For example, this could relate to the project's anticipated contribution to[178]:

   - Technological development, knowledge transfer and commercialisation;
   - Entrepreneurship and support for enterprise development;
   - Education and human capital development;
   - Regional orientation, strategic development and knowledge infrastructure.

10) Subsequently, the project's monitoring should be informed by a 'narrative with numbers', in which indicators of the innovation performance of the project are contextualised and supported qualitatively. This evidence base could be supplemented with information on observed impacts or descriptions of specific impact pathways.[179]
11) The Department should consider the resourcing, in terms of staffing across an appropriate range of background/qualifications, to ensure that such programmes can be delivered/monitored as envisaged by the above recommendations.
12) The Department should consider setting aside at least the same level of funding per annum, but preferably a greater sum, dedicated to university-based international research collaboration. This recommendation is made based on the importance placed on international research collaboration elsewhere and the potential which programmes, such as the US-Ireland R&D Partnership programme or the SFI-DfE Investigators Programme, could play in linking with and maximising research activity in NI, such as that proposed under the City Deals, and particularly through mechanisms such as the Centre-to-Centre activity.
13) Related to the previous recommendation, NI funding for Centre-to-Centre project activity should be set at an equivalent level to our US and RoI partners, so as to not disadvantage the NI partner.

[178] Example output or impact indicators for each of these elements of a regional innovation system are outlined in Appendix VIII. Source: A Regional Innovation Impact Assessment Framework for universities, a Science for Policy report by the Joint Research Centre (JRC), the European Commission's science and knowledge service, January 2018
[179] The concept of 'impact pathway' refers to narrative stories of how a university's activities (e.g. research) led or could lead to a specific impact.