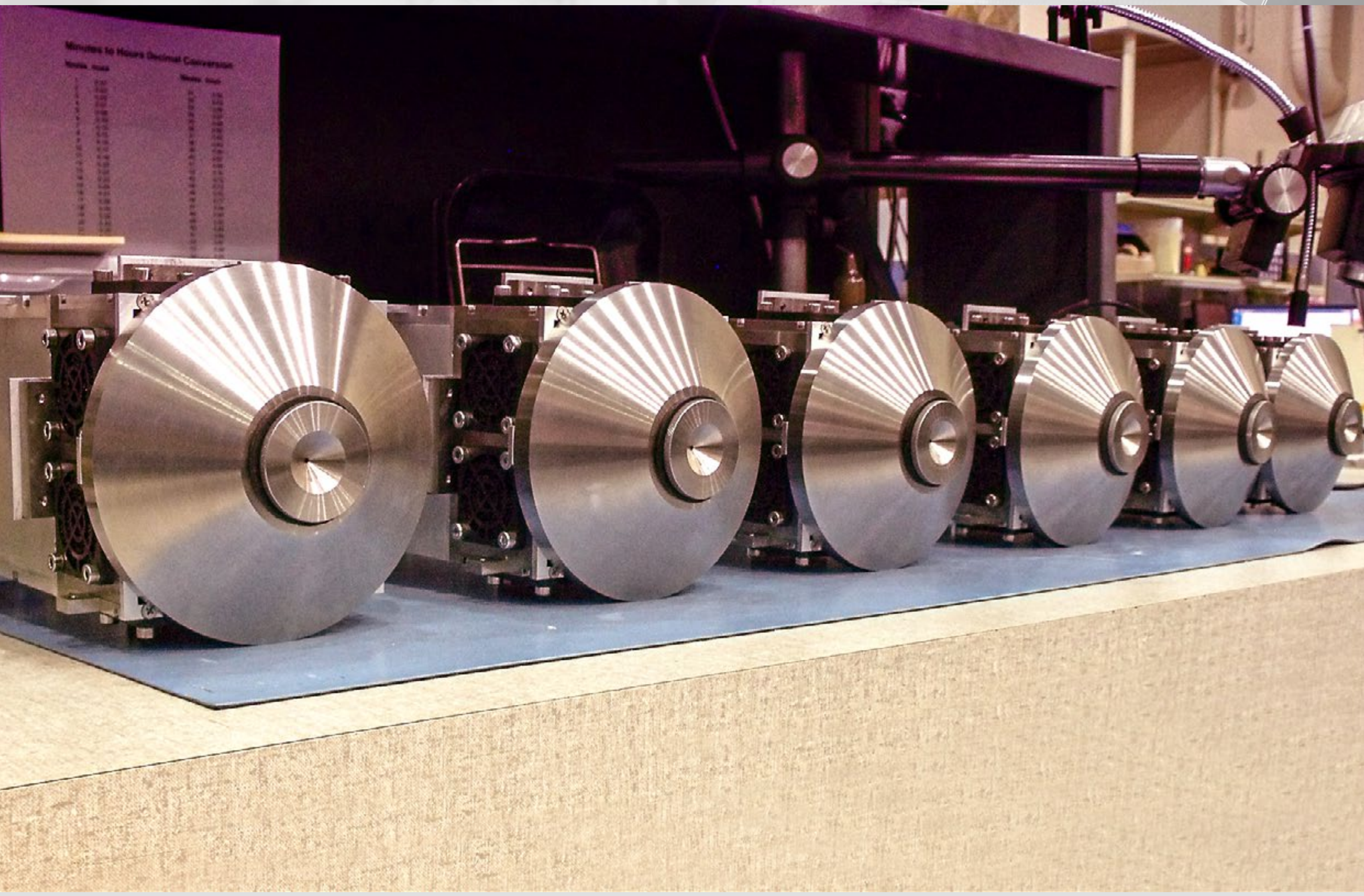
CBI Economics



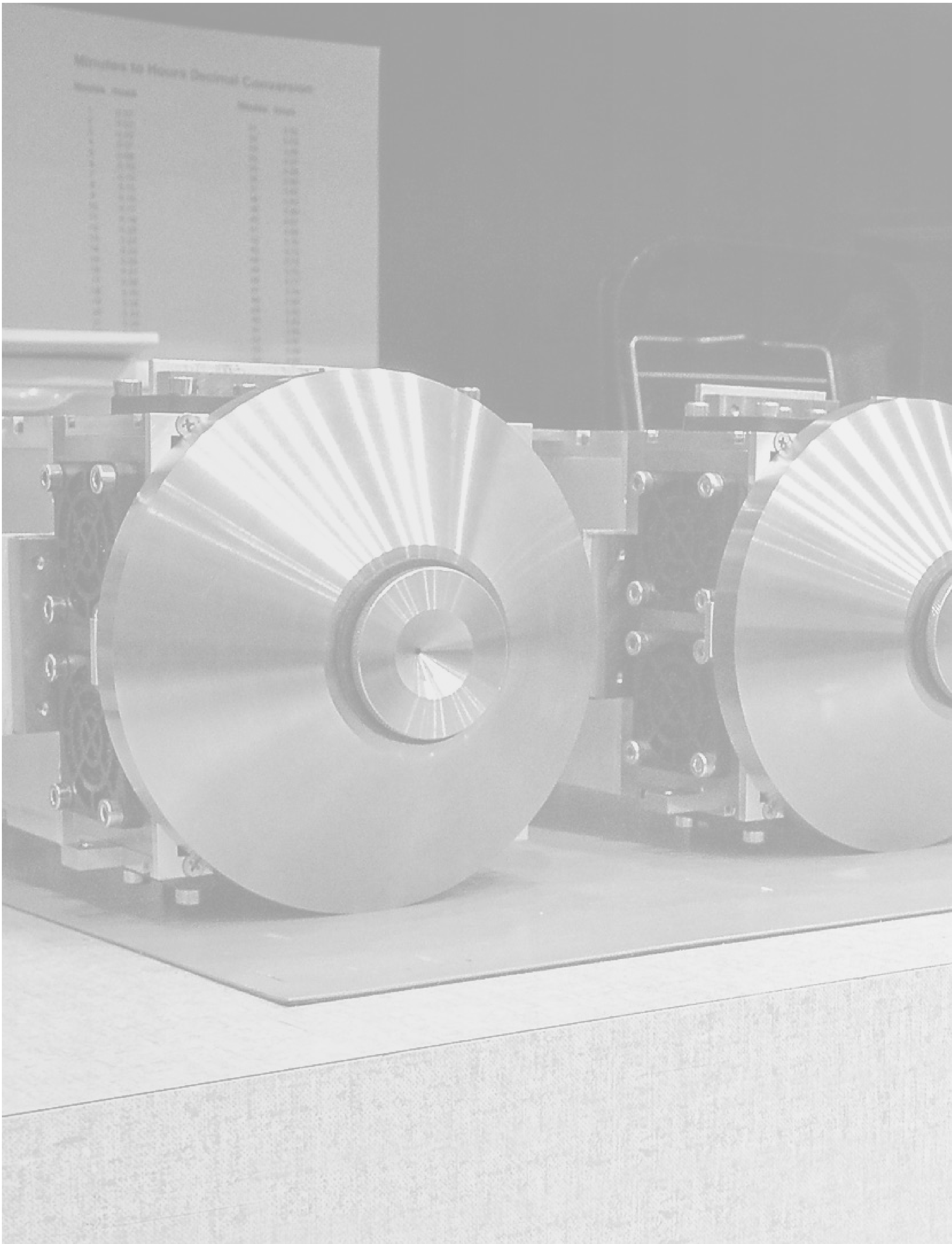
Paradigm shift

Unlocking the power of physics innovation for a new industrial era

October 2021

Commissioned by

IOP Institute of Physics


Minutes to Hours Decimal Conversion

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Foreword Institute of Physics

Throughout the history of industrialisation, physics has driven innovation. From Newton's laws of motion, through to electrification after Faraday and the nuclear age during the last century, breakthroughs in physics have played an essential role in enabling new technologies to emerge, creating industries and shaping our lives. Today, on the cusp of the 'fourth industrial revolution' of big data and artificial intelligence, physics is once again underpinning progress.

For the UK and Ireland, the relationship between physics and innovation has never been more important. At the Institute of Physics (IOP), our role is to help create the conditions for physics to thrive. If we can do this, physicists, and those working with physics in the UK and Ireland, can continue to lead the way in developing new technology and processes that enable competitiveness and prosperity. This creates solutions to the great challenges facing the world, from clean energy and climate change to healthcare and food security.

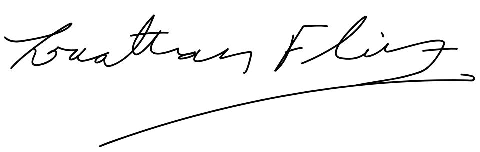
To make this happen, the IOP's strategy for 2020-24, 'Unlocking the Future', identifies some key challenges and some aspirations for the changes we hope to see. One of our aspirations is to achieve increases in public and private R&D spending to 2.4% of GDP in the UK, and 2.5% of GNP in Ireland. We want to support the UK and Ireland to become the science and innovation superpowers that we know they can be.

We build this work on evidence. Earlier in 2021 we commissioned CBI Economics to undertake the largest survey of its kind, to find out about the innovation activity of those businesses using physics in their work. This report presents the findings of that research: a wide array of data that examine the extent of innovation among these businesses, their propensity to innovate, and the challenges they face.

There is much in this report to celebrate. Activities that we identify as built on physics skills and expertise are associated with high levels of innovation. Put simply, of those companies that are doing physics, most are innovating, and those that are doing the most high-intensity physics, tend to be innovating more. Physics is continuing to play its historic role in innovation.

However, the report also identifies challenges that innovating businesses face in securing investment, accessing skills, and collaboration. It identifies regional variations that show that not all parts of the UK and Ireland are benefitting equally. These are important findings that point to the need for ambitious R&D roadmaps in the UK and Ireland, so physics-based businesses can thrive and play their part in unlocking the benefits that physics can offer society and the economy.

The IOP is working to support members and the wider physics community to move beyond Covid and the challenges to innovation that the pandemic has caused for businesses, research and innovation organisations and universities. This report plays a vital role in giving us the detailed knowledge and insights we need to understand better the conditions in which innovation can flourish.



Jonathan Flint CBE FREng FInstP
President, Institute of Physics

Foreword CBI

As we slowly emerge from the COVID-19 pandemic, the UK has an opportunity to rebuild our economy to tackle climate change and renew our place in the world. As hosts of the G7 and COP26 this year, the UK is determined to lead the world in the transition to a net zero economy and raise standards of living around the UK. But for this ambition to be fulfilled, we need to foster an innovative economy and renew our competitive edge. The UK government's Plan for Growth has the right ambition, but much of the detail for business is yet to be filled in, and roadmaps to decarbonise our economy across sectors need to be set with investment in new technologies at their heart.

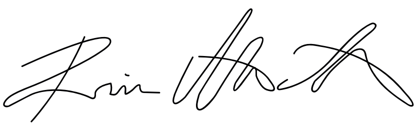
R&D and innovation have to be at the heart of any economic strategy. An innovative economy leads to breakthrough ideas and technologies, driving productivity growth, opening up new export opportunities and supporting high skilled jobs across the country. And with these economic opportunities comes an even bigger prize: the potential for new technologies and services to deliver significant improvements to our society's health, well-being and sustainability.

This report, undertaken by CBI Economics on behalf of the IOP, highlights some real success stories from the UK innovation ecosystem, companies that are doing truly amazing things. Whether it is designing satellites to monitor the impact of climate change, using nanotechnology to build ever more powerful computers, or breaking new boundaries in cancer diagnostics and treatments, the UK is already home to some of the world's most innovative and commercially successful businesses.

But we can do even better. The UK is a world-leader in research and idea generation, supported by globally renowned universities which attract the best talent from around the world. However, the UK simply does not do enough R&D and it lags behind on successful commercialisation of ideas.

This report provides new evidence on why this might be the case. It highlights that physics-based innovators have big ambitions, but with development times often stretching to many years they face a complex mixture of challenges related to funding, project risks and access to resource. Collaboration between businesses, and with the government, universities and other research institutes has been proven to be a key enabler of success, but many barriers remain. This report is a call to action for government, the research community and business to work together to overcome these challenges and unlock the investment that can deliver the success stories of the future.

On the topic of collaboration, I would like to thank Ibec, the Irish Business and Employers' Confederation, for their support with promoting the survey in the Republic of Ireland, and the IOP for being such fantastic partners. The expertise the IOP has gained from 100 years of supporting physics in the UK and Ireland has been invaluable during this project. Their insights, together with the Confederation of British Industry (CBI) unrivalled experience in business surveys and analysis, has resulted in this report, which provides clear steps to help the British and Irish governments meet their respective R&D ambitions.



Rain Newton-Smith
Chief Economist, CBI

At a glance: key findings from the survey

This report presents the findings from a survey of 304 innovative, physics-based firms across the UK and the Republic of Ireland (RoI). The survey was conducted by the Confederation of British Industry (CBI) during May 2021, with the (gratefully acknowledged) support of Ibec, the Irish Business and Employers' Confederation. The report was commissioned by the Institute of Physics (IOP), the professional body and learned society for physics in the UK and RoI, one of whose aims is to help unlock the powerful potential of physics, so that the UK and RoI can realise the full societal and economic benefits of the new industrial era.

To participate in the survey, businesses needed to be actively engaged with physics technologies or research areas, and to have undertaken research & development (R&D), product/service innovation or activities to directly improve production process within the previous five years (other forms of innovation, such as new business practices, were not considered). The survey and 10 accompanying case studies seek to understand the nature of physics-based R&D and innovation activity, as well as the challenges experienced and the opportunities to increase such activities in the years ahead. The data refer to the combined responses for the UK and RoI, unless otherwise specified. The key findings are as follows.

Physics-based firms are innovators by nature. Across the UK and RoI, physics-based firms are actively investing in scientific discovery and technology, driven by the goal of developing new products or services and growing their businesses.

- 91% of physics innovators agreed that R&D/innovation is a strategic priority that is incorporated into their business plans.
- 90% of physics innovators said their motivation was to develop new products or services, while 73% said such activities were undertaken to grow the company or achieve a higher market share.

The COVID-19 pandemic has disrupted R&D/innovation activity, but physics-based firms are looking to the future, with plans to increase investment in R&D/innovation in the five years ahead. The right support from governments can help unlock this investment and ensure that physics-based firms play their part in helping the UK and Irish governments achieve their R&D roadmap ambitions.

- 45% of physics innovators said that the COVID-19 pandemic had a negative impact on their R&D/innovation plans, though 26% said it had a positive impact.
- 65% of physics innovators expect their R&D/innovation spending to increase over the next five years relative to the previous five years (only 5% expected spending to fall).
- Physics innovators that have received public funding over the past five years were more optimistic than those that have received no public funding (71% expected to increase spending vs 57%, respectively), suggesting a critical role for government support.

Physics innovation is costly, risky and development times for physics-technologies are typically much longer than for other technology areas. This gives rise to complex financing needs that must be sustained over time. Costs and finance pressures are most acute at the manufacturing stage of the R&D/innovation journey.

- Half of physics innovators said the most significant challenges they face when undertaking R&D/innovation are the direct costs (50%) and potential costs/finance risks (48%).
- Physics innovators most commonly reported significant costs pressures during the large-scale prototyping (42% of physics innovators) and production/scaling up (42%) stages, the latter also reflecting the phase when it is most difficult to secure funding (40%).

Amid pressures on public finances and corporate cash balances following the COVID-19 pandemic, ensuring continued direct government funding for early-stage R&D will have a material impact on physics-based firms' innovation projects. A focus on long-term funding schemes and a more attractive tax environment can also help promote the commercialisation of new technologies, helping support manufacturing and exports in the UK and RoI.

- 67% of physics innovators in the UK and 65% in the RoI said greater access to direct funding for early-stage R&D could encourage more R&D/innovation activity in the next five years.
- 61% of physics innovators in the UK and 65% in the RoI said long-term funding schemes could encourage more R&D/innovation activity in the next five years.
- 59% of UK physics innovators believed that a more attractive tax rate for R&D would support greater activity in the UK. The share in the RoI was slightly lower (52%) and particularly so among foreign-owned firms (27% of foreign-owned firms in the RoI vs 58% in the UK).

Public funding for R&D/innovation projects helps attract private investment by accelerating the innovation process and providing a mark of quality for potential investors. Public investment generates a return for wider society through the development of new physics-based products and services that otherwise would not have been produced. Public investment also leaves a legacy of higher skills and technological capabilities. Improved access to support could spread these benefits among a wider range of businesses.

- 70% of physics innovators that had received public funding for R&D/innovation within the last 5 years said that it fills a financing gap without which the activity would not take place.
- 55% of physics innovators that had received public funding within the last 5 years said that it supported the development of products/services that otherwise may not have been produced. Physics innovators also pointed to a legacy of improvements to skills (55%) and equipment or infrastructure (37%).
- Among physics innovators that have not received any public funding, 35% in the UK and 23% in the RoI believed that improved navigation of support schemes could support more R&D/innovation in the next five years.

Skills shortages threaten to derail plans to increase investment in physics-based R&D/innovation, causing delays to projects, missed targets and missed opportunities. Skills shortages are particularly acute at the production/scaling up stage of the R&D/innovation pipeline. This points to a risk that technologies developed in the UK and RoI end up being manufactured abroad, deepening the loss of skills.

- 40% of physics innovators said that skills shortages were a significant challenge to undertaking R&D/innovation. Only 11% of physics innovators said they faced no difficulties recruiting.
- 66% of physics innovators reported suspending or delaying such activities in the past five years because of skills shortages. Almost one third said they had missed or scaled back production (30%) or sales goals (30%) or abandoned activity altogether (29%).
- 26% of physics innovators said they were either dissatisfied or very dissatisfied with their ability to attract and retain talent at the production/scaling up stage of their innovation journey.

Physics-innovators frequently rely on partnerships with other businesses or universities to access the facilities and equipment they need to undertake R&D/innovation. But for a significant minority of businesses, a lack of access to suitable facilities and equipment can be a barrier to R&D/innovation activity. There may be scope to increase collaboration further, particularly with public research institutions and public/private innovation partnerships, which can help support late-stage development activities such as testing and demonstration.

- 49% of physics innovators collaborate with partners/networks to gain access to facilities and equipment.
- 16% of physics innovators believe a lack of suitable facilities or equipment limits their ability to undertake R&D/innovation activity, with 26% pointing to a lack of suitable buildings or space and 20% citing a lack of physical testing equipment.
- As well as using their own equipment and facilities (87%), many physics innovators said they had relied on commercial partners (38%) and/or education providers (36%) for access. Only 17% had used a public research institution or public/private innovation partnership.

Given the highly specialised, technology-intensive nature of innovation at physics-based firms, collaboration is often the key to the successful integration of technologies and techniques into firms' own processes. The majority of physics innovators regularly collaborate with their suppliers and customers. They also have a meaningful connection with universities. But new forms of collaboration may be needed to realise the full potential of innovative supply chains and also to deepen business-university links.

- 84% of physics innovators said they collaborate to gain knowledge or information on opportunities or technical matters, while 70% do so to gain access to expertise or skills.
- 62% of physics innovators regularly collaborate with their customers, while 55% do so with their suppliers. Physics innovators also regularly collaborate with universities or other higher education institutes (42%, with a further 37% doing so occasionally).
- While six out of ten (60%) physics innovators work with their partners/network during basic research, collaboration tends to drop off during later stages of the innovation process, with only three in ten (28%) firms collaborating at the production/scaling up phase.

Introduction

Physics-based technologies hold the answer to many of societies' most pressing challenges

Physics plays a fundamental role in our society and the global economy. Since the dawn of modern physics in the early 20th century, the knowledge and ingenuity of physicists have helped to improve our prosperity, health and quality of life. Their influence is all around us. Say "physics technology" and many people might think of nuclear energy; or aviation, space and satellite technologies; or X-rays and a host of other medical imaging techniques used to diagnose and treat disease. Some may have heard of the wonder material, graphene. Far fewer will know of its already widespread uses—for example, providing slower wear in car tyres, clearer audio in earphones or lightweight strength in sports equipment. In fact, physics-based technologies are a fundamental part of our daily lives, from the electronic circuits powering our laptops, the WiFi that keeps us connected, the touch-screens on our phones, or the LEDs that light our homes. The list goes on.

Physics and physicists are also at the heart of tackling the big issues we face in the world today. In the years to come, we will depend more and more on knowledge and skills from physics and other disciplines to address the challenges facing us. The emerging potential of quantum technologies is just one example. Governments and businesses around the world are already investing billions in developing new quantum computers with the power to help solve some of society's most intractable problems, from developing advanced climate models to help combat climate change, or accelerating drug discovery to fight disease, or ensuring the data security that underpins our networked world. Whether by helping us live longer, more prosperously and sustainably, addressing our energy needs or protecting our biodiversity, physics has the potential to improve our lives.

Physics-based businesses already make a substantial contribution to the economies of both the UK and the RoI. Spanning a diverse range of sectors—including manufacturing, engineering, energy, construction, and services sectors—it is estimated that physics-based businesses contribute 10% and 16% of GDP in the UK and the RoI, respectively.[1] They also account for around 7% of employment in both countries, implying high value added per person employed (particularly in the RoI).[2] In other words, physics-based firms tend to be highly productive, a reflection of their technology- and knowledge-intensive nature. Given substantial evidence demonstrating the importance of business-led R&D and innovation for driving productivity and economic growth, physics-based firms will clearly have a significant part to play in driving the prosperity of the UK and Irish economies in the years ahead.[3]

This report was commissioned by the Institute of Physics to help unlock this potential. It presents new data from a survey of innovative, physics-based businesses across the UK and RoI that was conducted by the Confederation of British Industry, with support from Ibec, the Irish Business and Employers' representative body. The survey, which was carried out during May 2021, seeks to understand how targets for public and private investment in R&D (2.4% of GDP in the UK, 2.5% of GNP in the RoI) can be achieved through a focus on investment in ground-breaking physics research, cutting-edge innovation, and the development of the skills, facilities and infrastructure needed to make this happen.

Physics firms face a number of significant challenges in undertaking R&D/innovation

The survey sought to understand the conditions that physics-based businesses in the UK and RoI are currently operating in, what drives them to innovate and what inhibits them. To appropriately target the sample, a "physics-based business" was defined as a business that selected at least one option from a list of 42 physics-based technologies or research areas as being relevant to their operations. A "physics innovator" was defined as a physics-based firm that indicated they had undertaken some aspect of R&D or product/process innovation (full descriptions are in **Table 1.2** below) within the past five years (firms were also asked if they undertake business practice innovations, but this did not count towards being a physics innovator). Overall, 304 respondents to the survey were classified as physics innovators (see the Glossary for full definitions of the terms used throughout the report). A description of the methodology and breakdown of the sample is provided in Appendix 2.

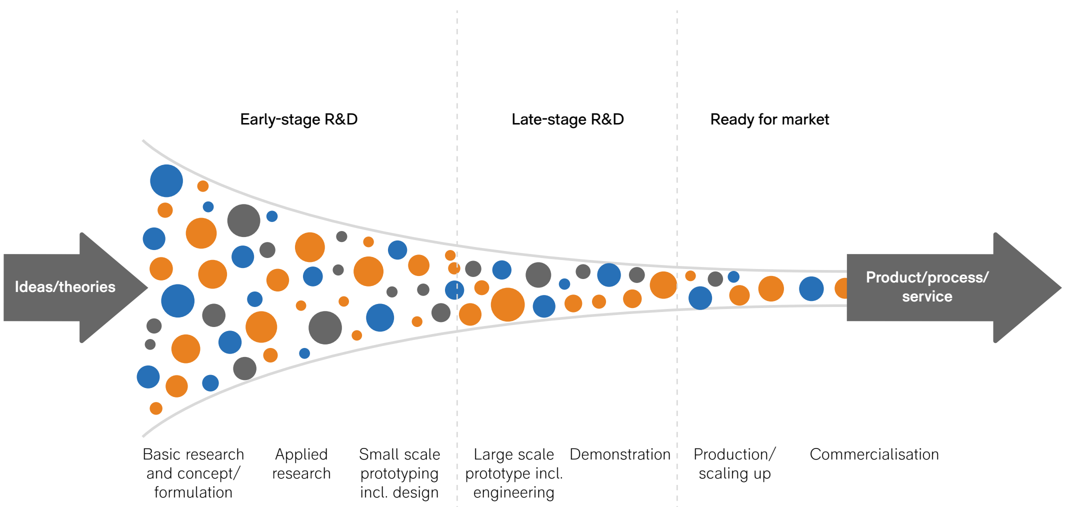
The survey finds that physics-based firms across the UK and RoI see scientific progress and R&D/innovation activity as central to their operations and growth plans. But physics innovators typically face a number of significant barriers. The biggest challenges are the high direct costs associated with undertaking R&D/innovation activity, along with the inherent risks of doing so in sectors that are by their nature capital intensive, with long-term financing needs. The survey provides evidence of the high value placed on public support for facilitating physics-based R&D/innovation activity, particularly during the early stages when future returns are hard to demonstrate. Public funding is also seen as delivering significant spill-over benefits, such as more collaboration, knowledge-sharing and access to equipment and facilities. However, the survey pinpoints particular vulnerabilities for the future, noticeably a lack of funding and sufficient talent at the manufacturing/commercialisation end of the R&D/innovation pipeline, which could mean missed opportunities for growth and exports for both the UK and the RoI.

The survey also asked how firms' R&D/innovation activities have been affected by Brexit and the COVID-19 pandemic. It finds that the disruption to businesses' operations since the start of the pandemic has had a negative effect on their R&D/innovation activity. However, there are encouraging signs of a potential recovery, with most physics innovators in both the UK and the RoI expecting to increase spending in this area over the next five years. This will involve tackling skills deficits that are already depressing R&D/innovation activity. It will require action from governments to broaden access to direct funding for R&D, as well as to provide more long-term certainty over funding for innovative physics-based businesses. And physics-based firms can seek more opportunities for collaboration with external partners/networks to access the facilities and equipment they need to succeed. The analysis can help inform discussion and allow businesses, universities and other research organisations, and policymakers to work together to unlock the potential of physics and ensure that the UK and RoI realise the full societal and economic benefits of the new industrial era.

Glossary of terms

- **Physics-based firm**: A respondent that selected at least one physics-based technology/research area out of a list of 42 as being relevant to their organisation.
- **Physics innovator**: A physics-based firm that undertook at least one aspect of R&D or product/process innovation during the past five years.
- **UK innovator**: A physics innovator carrying out R&D/innovation activity within the UK. This does not exclude them from also carrying out similar activity in the Republic of Ireland or elsewhere.
- **RoI innovator**: A physics innovator carrying out some R&D/innovation activity in the Republic of Ireland. This does not exclude them from carrying out similar activity in the UK or elsewhere.
- **Publicly funded innovator**: A physics innovator that has received funding from at least one public source in the past five years, such as central government, local or regional government or EU programmes. This does not exclude them from also using private funding.
- **Non-publicly funded innovator**: A physics innovator that has not received any funding from a public source in the past five years.

Illustration of the R&D/innovation pipeline



AAC Clyde Space

Pamela Anderson
Head of Institutional Engagement, AAC Clyde Space

AAC Clyde Space specialises in small satellite technologies and services that enable commercial, government and educational organisations to access high-quality, timely data from space. Our company has over 150 employees and more than 15 years of experience in subsystems, advanced sensors and data delivery and operates in Scotland, Sweden, the Netherlands, and USA.

At AAC Clyde Space, innovation is a core value. We are continuously moving forward, anticipating market needs and pioneering new ideas. In 2017, we won the Queen's Award for Enterprise in the Innovation Category. It's an exciting time in the industry, with fast innovation cycles and a rapidly expanding range of space applications. An unprecedented number of companies are eager to tap into this lucrative space-based data-driven market.

Through commercialisation of physics-based innovation, we are changing the way we use and benefit from space technology. We are fulfilling the promises of many years of small satellite development to ensure the services delivered from space work to improve our quality of life on Earth. We have 29 satellites designed and launched to-date, including for Earth Observation, for applications like ocean colour monitoring and wildfire detection, and Communications, for services such as ship tracking and Internet of Things (IoT).

We've learned a lot over the course of our innovation journey. Our top tips are: invest in R&D and innovation, it is hugely valuable; work collaboratively and with partners to fulfil any gaps in your own technical and business competencies; innovate to meet market demand, fully understand the benefits of the innovation, and listen carefully to customer needs.

But be ready to encounter some barriers. Access to skills and a diverse workforce is challenging: more must be done to attract greater diversity in the space industry in particular and in physics-based businesses in general. Another challenge is access to demonstration flight or validation opportunities to demonstrate new technical capability and gain in-orbit heritage, which is so critical to commercialisation of innovation in the space sector. Finally, the support for scaling-up and commercialising innovations can be limited. It is therefore important to maximise the utility of funding and support to deliver greatest impact.

For a longer version of this case study, please click **here**.

Physics-based innovation: opportunities and challenges

Physics-based firms are innovators at heart

Physics-based industries play a vital role in driving future growth across UK and RoI. Some of the most important challenges highlighted by governments in all developed countries in recent years directly involve physics – from improving health outcomes, to promoting the development of ultra-low-emission vehicles, to supporting industrial digitalisation and transforming the energy sector in the face of climate change. These trends make it absolutely imperative that physics-based businesses secure a position as global leaders in these sectors of the future.

Our survey highlights that physics innovators were actively engaged with a broad range of technologies and/or research areas. On average, respondents selected 7.5 out of the 42 physics technologies/research areas as being relevant for their business **(Table 1.1)**. The most common technology/research area among the sample was measurement and sensors (selected by 45% of respondents)—the focus of physics-based businesses like TRUEinvivo, a pioneering radiation measurement company, whose innovation journey is described in a case study on **page 32**. Other significant technology/research areas included materials science and technology (41%), electronics and electronic devices (39%), computer systems and architecture (33%), and control engineering (32%). Case studies describing the experiences of physics-based businesses in a range of sectors can be found throughout this report.

Unsurprisingly, larger firms in the sample engaged with more technology areas than smaller firms, which were more specialised. For UK-based innovators (those that indicated they carry out some R&D/innovation activity in the UK), large physics innovators selected an average of 12.2 physics technologies/research areas as being relevant for their business, compared with 7.3 for medium innovators and 6.5 for small firms. A broadly similar trend was evident among firms carrying out R&D innovation activity in the RoI (equivalent figures of 7.0, 4.8 and 4.9, respectively).

Table 1.1 'Which of the following technologies, research areas and/or techniques relate to your organisation?' (% of physics innovators)

Measurement & Sensors	45	Climate & Weather Technologies / Research	15
Materials Science & Technology	41	Display Technologies	15
Electronics (electronic devices)	39	Nanotechnology	14
Computer systems & architecture	33	Space & Satellites / Telescopes	13
Control Engineering	32	Vacuum Technology	13
Analytic Science	28	Microscopy	12
Lasers / Photonics / Optical Devices	27	Quantum Technologies	12
Digital signals/ signal processing	26	Medical Imaging / Equipment	12
Instrumentation engineering	26	Power Distribution	12
Energy Efficiency	25	Biophysics	11
Aerospace & defence	24	Combustion	11
Fluid Dynamics / Mechanics	23	Aerodynamics	9
Energy Storage / Batteries	22	Plasma technologies	9
Communication & signalling technologies	21	Geophysics / Earth Engineering	9
Energy Generation & Related Technologies	21	Tomography / Scanning Technologies	8
Physics-related AI / Robotics	18	Catalysis	8
Radio Frequency & Microwave Technology	18	Magnetism	8
Physical Science Research	17	Gas & Solution Phase Reactions	8
Semiconductors / Computer systems & architecture	17	Aerosols & Dispersion	6
Power Electronics	17	Extraction and drilling	6
Spectroscopy	16	Shock Waves	3

The respondents to the survey undertake a broad range of R&D/innovation activities and appear to strike a balance between research activities and product/process development. Around four fifths of physics innovators in the UK and RoI reported carrying out both research R&D (to gain or utilise knowledge) and development R&D to facilitate future product development. A similar share reported undertaking product/service innovation within the last year, with around three quarters undertaking process innovations **(Table 1.2)**. These figures compare to the 10%-20% undertaking internal R&D or product/process innovation among the wider business population, based on the results of the UK Innovation Survey (UKIS).[4] The sample also appears to be more R&D/innovation active than the "high physics" intensity group of respondents to the UKIS, which showed equivalent rates in the 20%-30% range[5] (this group is based on a classification of each industry developed by the IOP—see **Appendix 2**). Indeed, almost half of physics innovators (47%) in the survey had carried out all five types of activity over the past year, while only 7% had undertaken only one of the five activities.

Table 1.2 'Which of the following R&D or innovation activities has your organisation undertaken during the last five years?' (% of respondents)

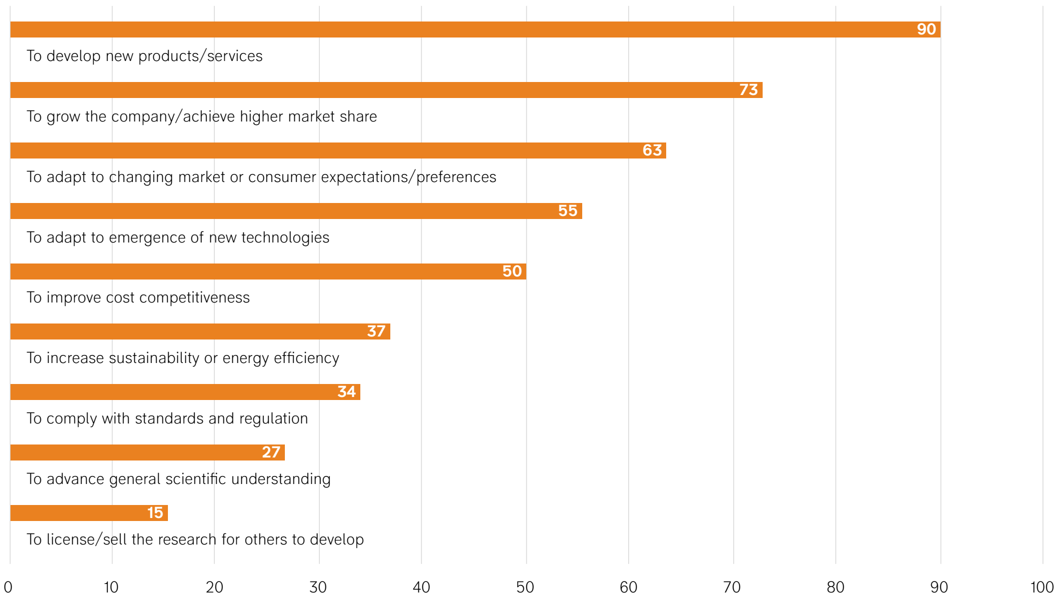
	Within last year	Not within the last year, but within the last five years	Not within last five years
Research R&D to gain new knowledge or utilise new knowledge for a practical purpose	81	14	5
Development R&D to facilitate future product development	83	11	6
Product/service innovations – to improve the commercial value of product/service (quality, design, usability etc)	82	12	6
Process innovations – to directly improve the production process of the product (efficiency, etc)	73	18	9
Business practice innovations – to indirectly improve the production process (supply chain management, quality management, knowledge management etc)	69	20	11

The vast majority of physics innovators reported that they undertake R&D/innovation for broadly commercial reasons. As **Exhibit 1.1** shows, nine out of ten (90%) firms said their motivation was "to develop new products or services", while seven out of ten firms (73%) said such activities were undertaken to grow the company or achieve a higher market share. Half of firms (50%) cited the need to improve cost competitiveness.

Notwithstanding these commercial motivations, a significant share of respondents indicated their firms are motivated by a desire to advance general scientific understanding—on average 27% selected this option, rising to 40% among large firms, suggesting these firms are better able to sustain more exploratory research that could lead to "disruptive" breakthroughs in future. Firms that indicated they were motivated by advancing general scientific understanding were almost equally as likely as others to be motivated by the aim of growing the firm (66%) or developing new products/services (83%), indicating they see no trade-off between carrying out discovery research and achieving commercial success. Across the sample, the importance of new technologies as a driving force for R&D/innovation is also clear, with more than half of firms (55%) selecting this option.

The significance of these motivations was generally consistent across the sample, but the survey revealed some variation across industries. A desire to increase sustainability or energy efficiency was a major driver of R&D/innovation activity in the energy (62%), water and gas (60%) and construction (50%) industries, for example, while the need to comply with standards and regulation was also an important consideration in water and gas (60%). A small number of firms in the sample (15%) carried out R&D/innovation to license/sell the outputs for others to develop, primarily in manufacturing (15%) and scientific and technical services (25%).

Exhibit 1.1 'Why does your organisation undertake R&D/innovation activity?' (% of physics innovators)



Further evidence of the importance of R&D/innovation is presented in Chapter 4, where it can be seen that the majority of firms (88%) reported R&D/innovation as a strategic priority for their firm **(see Exhibit 4.3)**, with a similar share (92%) identifying the strategic aim of the organisation in the next five years would be to target growth. All told, the survey suggests that the majority of physics innovators consider R&D/innovation activity as fundamental to their firm's operations, propelled by a desire to develop new products or services that will drive the growth of their organisation in the years ahead.

High costs, high risks and a lack of key innovation inputs are major challenges

As the case studies demonstrate ambition, leadership and a supportive internal culture can be vital elements of a successful innovation journey for individual businesses, and more often than not the barriers they face are external. Science and innovation systems are complex and composed of many complementary elements, and effective links between different organisations can play an important role in helping businesses to overcome the constraints they face in adopting new ideas and technologies. Previous research identifies the most critical elements in national innovation systems as the financing/funding environment, the availability of skills and talent, access to appropriate facilities and infrastructure, and a culture of collaboration to promote knowledge-sharing.[6]

Our survey suggests physics-innovators see deficiencies across of all these areas. This is not so surprising given the nature of innovation within physics-based business, which requires highly specialised skills and significant capital investment, which must be sustained over a prolonged period. **Table 1.3** reveals that the two most significant challenges facing physics innovators are the direct costs (50%) and the potential costs/risks (48%) of undertaking R&D/innovation activity. Two fifths of firms cited skills shortages as a significant challenge (40%), while one third pointed to difficulties accessing finance (33%). In general, firms undertaking R&D/innovation activity in the RoI appeared to face a greater number of challenges than those doing so in the UK (although they were less likely to cite a lack of, or improper equipment, machinery or space as a barrier).

Table 1.3 'What are the most significant challenges that your organisation faces in relation to undertaking R&D/innovation activity?' (% of respondents)

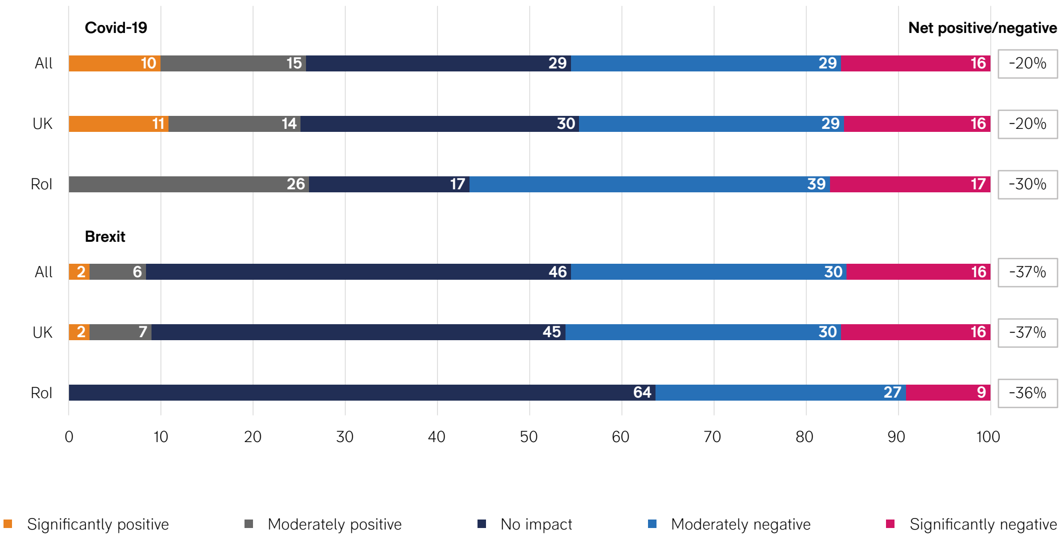
	All Physics innovators	UK innovators	RoI innovators
Access to finance	33	32	43
Direct costs of innovation	50	50	54
Uncertainties or risks related to undertaking R&D/innovation	48	46	61
Government policy and/or regulation	23	24	25
Skills shortages	40	39	46
A lack of equipment or improper equipment, machinery or space	16	17	7
Access to external expertise/insufficient collaboration	17	15	29
Organisational or cultural barriers	14	14	21

One addition to this list of challenges should be the broader economic environment, which has been characterised by unprecedented volatility in recent years. The onset of the COVID-19 pandemic in 2020 triggered the most severe shock to the global economy since the Second World War and has caused enormous disruption to business. And for many firms in the UK and RoI, this followed a prolonged period of uncertainty since the UK's vote in 2016 to leave the EU.

The survey found that both COVID-19 and Brexit have had a negative impact on R&D/innovation activity overall, but the impact of the pandemic was more mixed across individual firms. Overall, 45% of physics innovators responding to the survey said Brexit had a moderately (30%) or significantly (15%) negative impact on R&D/innovation plans in the past five-years, while 8% said it had a moderately (6%) or significantly positive (2%) impact. This gives a net balance[7] figure of -37% saying Brexit had a negative impact, with survey comments suggesting firms have missed out on projects to EU-based counterparts, seen reduced interest in collaboration from EU-based clients, experienced difficulties recruiting or retaining EU staff, faced legal restrictions on consulting activities, suffered border disruptions to supply chains and in some cases have missed out on EU funded innovation programmes. Interestingly, RoI-based innovators saw a similarly negative impact from Brexit (a net balance of -36%) as UK-based innovators (this may partly reflect the fact that some respondents have R&D/innovation operations in both countries). Northern Ireland innovators reported the most negative impact (-63%), although this is based on a small sample.

The picture was more varied with respect to the impact of COVID-19. Overall, physics innovators saw COVID-19 as having a net negative impact on R&D/innovation activity over the past year: 45% of physics innovators saw a moderately (29%) or significantly (16%) negative impact, but 26% of firms reported seeing a moderately (15%) or significantly (10%) positive impact. This gave a net balance of -20%, with a more negative impact in the RoI (net balance of -30%) than in the UK (-20%). The survey did not explore the reasons behind these trends, though comments pointed to a range of factors, including: weaker demand from clients; cash flow concerns leading to the diversion of research funds to protect core business; disruption to the supply of key equipment, components and materials; reduced laboratory access; as well as reduced contact with key technical staff, internal decision-makers or customers. As noted, however, some respondents also noted increased R&D/innovation activity in response to the pandemic, for example: to respond to increased demand for new diagnostic testing devices or greater interest in technologies to combat strategic risks (such as climate change); to focus on new market opportunities to compensate for weaker demand; or because weaker demand created the capacity to undertake such activities.

Exhibit 1.2 Impact of COVID-19 (Brexit) on R&D/innovation plans over the past one (five) year(s) (% of respondents, excl. N/As)



The decline in R&D/innovation activity over the past year is in keeping with the pattern of previous economic crises. For example, research by the OECD into the effects of the 2008-09 financial crisis suggests a reduction in activity in the immediate aftermath of the crisis, caused by rising uncertainties over market conditions, constraints on companies' internal resources, as well as reduced access to external finance.[8] This survey adds to the emerging body of evidence of the negative impact of the COVID-19 pandemic on R&D/innovation activity more generally. For example, a series of studies by the Enterprise Research Centre (ERC) has examined the effects on Innovate UK grant holders, finding that the financial pressures of the COVID-19 crisis, operational issues related to social distancing and lockdowns, and difficulties with collaboration has forced firms to revise their plans.[9]

However, the ERC report also finds that despite the disruption COVID-19 has inflicted on businesses, many continue to treat R&D as important.[10] This result is echoed in our survey, with the final chapter exploring the outlook for R&D/innovation activity, where we find an overwhelming majority of physics innovators plan to increase such activity in the years ahead **(see Chapter 5)**. The intervening chapters of this report focus on the specific challenges they face, providing more detail on the nature and consequences of the issues identified above, as well as possible mitigations and solutions.

Cotton Mouton Diagnostics (CMD)

Jenna Bowen
Senior Executive Officer, CMD

Cotton Mouton Diagnostics (CMD) is a Cardiff based diagnostics company. CMD's technology is based around an innovative and proprietary magneto-optical (MO) sensing system that exploits changes in the rotational behaviour of magnetic reporters that occur either as a natural marker of disease or as artificially introduced components of a MO assay.

Sensing platforms are often great in a lab setting, where everything is nice and controlled, and you have clean samples to work with, but once you get them out into the real-world, a lot of sensing technologies fall down because they aren't robust enough. This technology had been shown to work well during field testing in Africa and Asia, detecting malaria from whole blood samples.

A lot of our background work was done through relatively small pots of academic proof-of-concept funding, before spinning out the company. As the innovation journey progresses and you develop commercial prototypes, those costs increase. It's difficult when you're not generating a revenue stream to be able to support those things without that external grant support or external investor support for the company. Now we're in a position where we will be commercialising our first instruments within the first quarter of next year.

We embrace the concept of 'open innovation' at CMD, bringing together people from different backgrounds and sectors to collaboratively solve real-world problems. CMD is a multidisciplinary team by nature. We have physicists and engineers, but also, nanoparticle scientists and bioassay developers. Having that multidisciplinary team is really important, but also being a spin out, we're used to working with others, particularly with academics, to bring in new knowledge and expertise.

Over the last 12 months, we've been working with people that are more expert in the design of instrumentation for large scale manufacturing and scale-up, as well as consultants with regulatory and quality management backgrounds. Bringing such external expertise into our journey, has helped us push our innovation forward into a commercial pathway.

For a longer version of this case study, please click **here**.

Costs and financing

Physics innovators would benefit from more certainty over funding

Physics-based businesses are by their nature capital intensive, involving the use of cutting-edge technologies. Funding for R&D/innovation often needs to be sustained over a prolonged period, as the development of new products or services from the "ideation" stage, through prototyping, production and scaling up can take many years. This gives rise to complex financing requirements. As noted in **Table 1.3** above, the direct costs of R&D/innovation was the most commonly cited barrier to undertaking such activity, followed by the potential costs or risks/uncertainties of innovating. Comparisons with surveys of the wider business population suggest that these challenges are particularly acute among physics innovators. Analysis of the UKIS, for example, shows that the direct costs of innovation were more widely cited as a barrier by high physics-intensity firms (32%) than by medium (28%) and low (23%) physics-intensity firms, as were economic risks (25%, 24% and 20%, respectively). Both of these risks were also ranked more highly than other factors such as the availability and cost of finance, where differences between these groups were narrower.[11]

Table 2.1 'What are the most significant challenges that your organisation faces in relation to undertaking R&D/innovation activity?' (% of respondents)

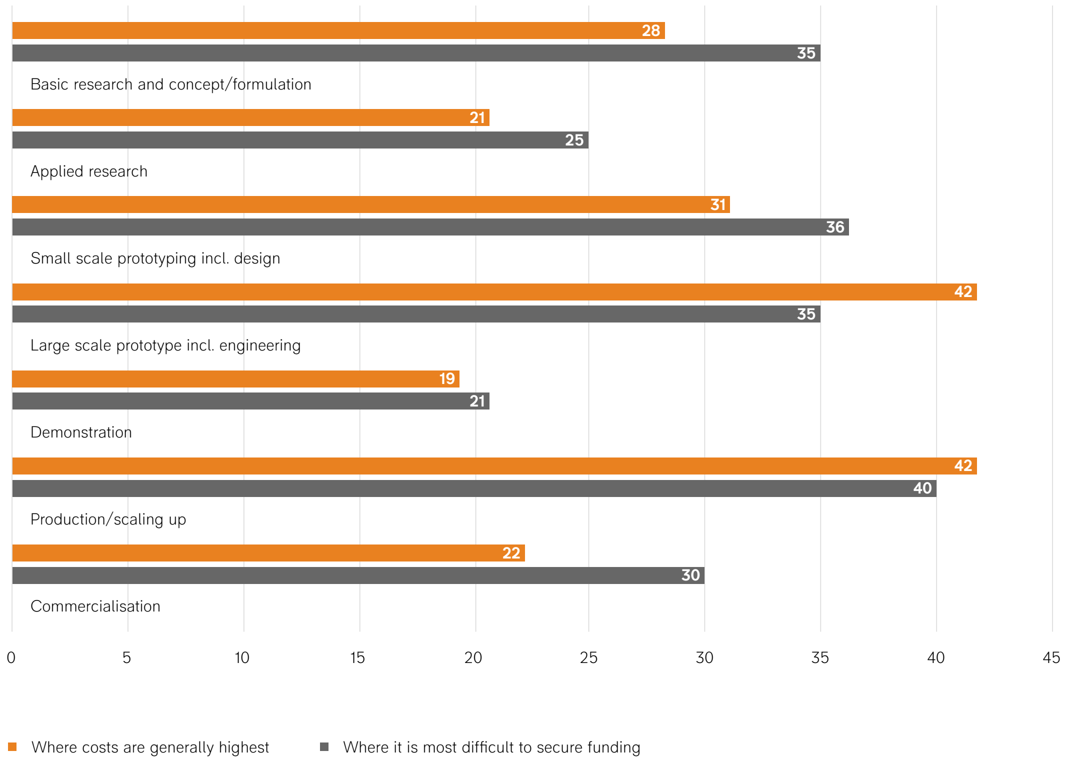
Significant direct costs	All physics innovators	UK innovators	RoI innovators
Labour costs	86	86	79
Capital costs	35	35	38
Overheads (e.g. finance, HR, offices, facilities, etc)	32	32	29
Materials costs	29	29	21
Sub-contractor costs	24	24	29
Laboratory/workshop costs	23	23	21
Technology licensing	12	13	4
Training costs	10	9	21
Significant potential costs or risks			
Costs of incorrect forecasts of market demand	49	50	42
Lower than expected returns due to increased competition	38	37	42
Uncertainty over future funding	36	36	33
Costs of multiple, simultaneous product innovations	25	26	17
Costs of organisational disruption	19	20	21
Costs of cascading, unintended product innovation	18	18	17
Risks of cannibalisation of demand from existing products	16	17	4

Given the importance of direct and perceived costs/risks as a barrier, **Table 2.1** breaks these two categories down further. The survey reveals that the most significant direct cost of undertaking R&D/innovation activity relates to the cost of labour (86%)—the wages and salaries of researchers, lab assistants and technicians, managers and so on. Capital costs (for new technology and equipment, labs, testing facilities, buildings, etc) were also seen as significant (35%), followed by general operating overheads (32%).

Among the potential costs or financial risks of undertaking R&D activity, market risks were seen as the most significant, with 49% citing the costs of incorrectly forecasting market demand as a significant risk and 38% pointing to the risk that competition erodes expected returns. Some respondents, particularly in the energy sector, shared concerns about the risks of "IP leakage" fuelling competition. A number of respondents also noted uncertainties over the commercial viability of R&D/innovation outputs, which can make it difficult to demonstrate a return on investment. In turn, this can generate uncertainty over future funding, which was selected as a potential risk by 36% of respondents. The responses also underlined the inherent uncertainties of undertaking R&D/innovation activity: a quarter of firms pointed to the costs of multiple, simultaneous product innovations (25%). And almost one in five (19%) cited the costs of organisational disruption and of costs from unintended product innovation (18%).

Given the high costs associated with undertaking R&D/innovation, having access to sufficient funding, as well as certainty over funding streams beyond the short-term, are critical for the innovation process. As **Table 1.3** above showed, one third of physics innovators identified access to finance as a significant challenge to innovation, with RoI-based innovators (43%) more likely to raise this concern than UK innovators (32%). **Exhibit 2.1** combines responses to two survey questions that shed light on how cost and finance pressures vary through different stages of the R&D/innovation process. It reveals that more physics innovators experience the highest costs during basic research (28% for UK and the RoI combined) than during the applied research phase (21%), with funding concurrently hardest to access during basic research (35% vs 25%). Cost pressures appear to be greatest during large-scale prototyping (42%) and production/scaling up (42%) stages, the latter also reflecting the phase when it is most difficult to secure funding (40%).

Exhibit 2.1 Stages of the R&D/innovation pipeline in which costs/difficulties in securing funding are highest (% of respondents)



Aerogen

Russell Greaney
Core Development Manager, Aerogen

Aerogen is the world leader in acute care aerosol drug delivery and is synonymous with the effective treatment of respiratory illness among patient groups of all ages, playing a critical role in emergency departments and intensive care units in over 75 countries worldwide. We are a global company with over 300 active and pending patents, headquartered in Galway, Ireland, with offices in seven other countries and over 350 employees.

Aerogen has an extensive knowledge around technologies that specialise in droplet formation. One area of current technological development is in aerosol droplet size. We are currently working on the development of a new breath synchronised device for delivery of medication to patients. The proposed Aerogen nasal drug delivery platform is a high efficiency, high consistency product for delivery of surfactant to pre-term babies. Current clinical practice for surfactant drug delivery to the infant lung requires invasive intubation which is associated with significant clinical side-effects including airway occlusions and brain bleeds. The aim of this project is to enhance knowledge and capability to develop a product to deliver clinically useful surfactant therapy reliably, reproducibly, and safely to new-borns (with the potential for use with other drug types).

Designing this type of product comes at a cost, and this project was no different. A major internal capital investment was provided, along with some government grants that helped create innovation collaborations with local universities. State of the art equipment (if not in house) was purchased, including a full scanning electron microscope with energy-dispersive X-ray spectroscopy, which was required to inspect, measure, and analyse prototypes during the development phase of the project. The device cost increased through each phase, but significant costs were approved at the early concept stage to ensure a good design for manufacture.

Aerogen in its infancy saw the necessity for research and innovation. Amongst many of our labs is a development lab where metrology and resonance physics is utilised at the highest level. The development lab is quickly becoming an innovation centre where pioneering methods of measurement and analysis are used to help resolve scientific or technological uncertainty. Training and innovation partnerships are provided when required and continued improvement is ever present at Aerogen.

For a longer version of this case study, please click **here**.

A majority of physics innovators sought diverse sources of funding for R&D/innovation

In the UK and RoI, as in all developed economies, the innovation system relies on both public and private funding. According to OECD data, although private funding accounts for the majority of R&D, government financed spending on R&D accounted for around 25% of total R&D spending in both the UK and RoI, much of it channelled through the higher education sector or spent by government agencies. However, direct public support for business expenditure on R&D is also substantial, accounting for 5% and 3% of total R&D spending in the UK and the RoI respectively, and continuing to rise in the UK, with increased spending via Innovate UK (though spending in the RoI has been relatively stable).

Analysis of our survey sample suggests that respondents were much more likely to have received public support than the wider business population. For example, data from the UKIS suggests that around 5% of all firms received public support from central government, with 3% saying they had received funding from local or regional authorities (equivalent figures for the RoI are unavailable). **Exhibit 2.2** shows the share of firms receiving different forms of public support for their R&D/innovation activity over the past five years. Overall, 59% of physics innovators in the survey reported financing R&D/innovation activity using some form of public funding over the past five years, with the remaining 41% using only non-public funding measures. The relatively high share of firms receiving public funding in the survey most likely results from the deliberate targeting of the sample towards R&D active and innovative firms, as well as physics firms specifically.

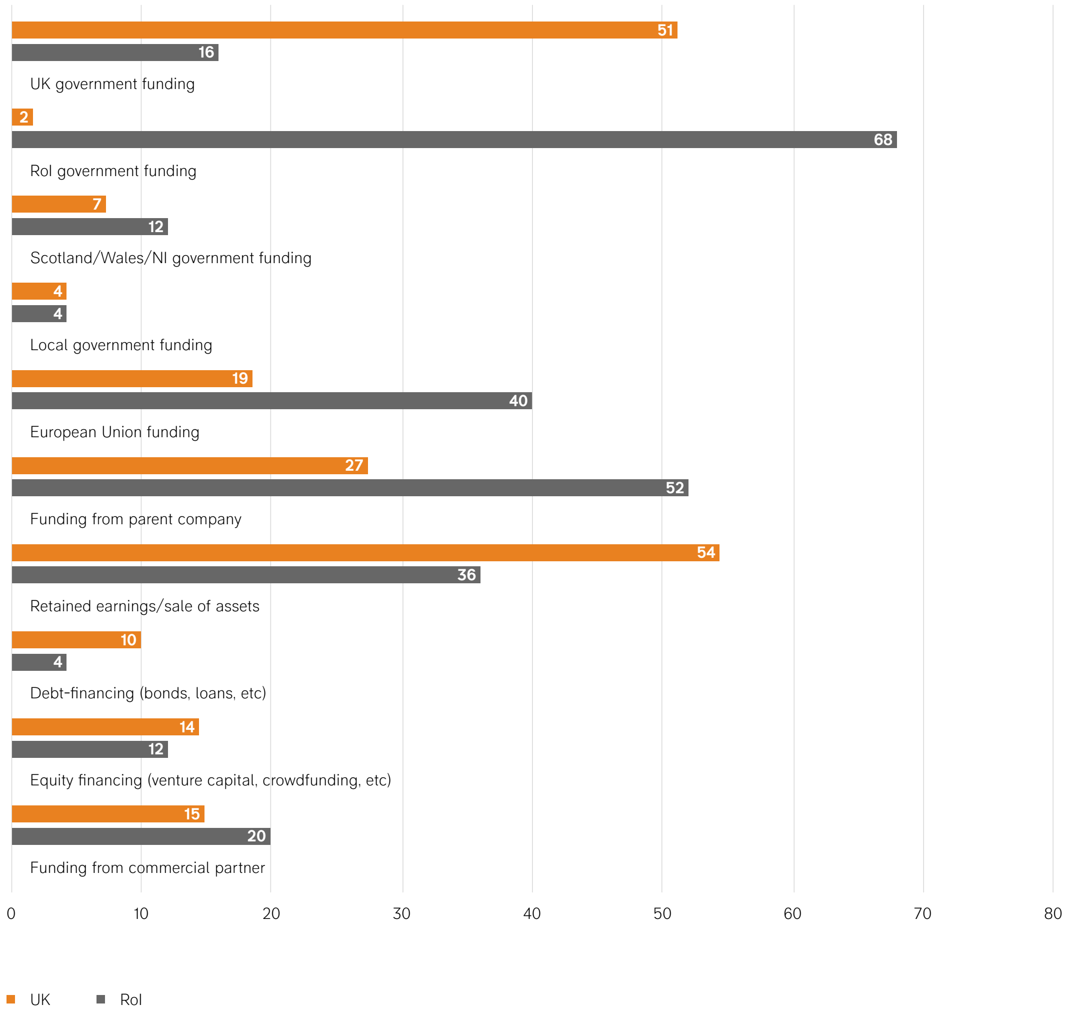
Central government was the most common source of public support overall. For UK-based firms, 51% had received R&D/innovation funding from the UK government in the past five years (56% in Scotland, 63% in Northern Ireland and 75% in Wales). EU innovation programmes were also significant, with 19% of physics innovators in the UK having received EU funding (25% in Northern Ireland, 38% in Scotland and 50% in Wales). For RoI-based physics innovators, 68% had received RoI government funding, with 40% receiving EU funding, suggesting a more prominent role for public funding than in the UK. Meanwhile, 26% of respondents with operations in Scotland and 25% with operations in Wales had received funding from devolved administrations (the figure was 50% in Northern Ireland, though again this was based on a small sample). The survey suggested that at least some of the firms in the sample have established R&D/innovation centres in a devolved UK nation specifically to gain access to public funding only available in those countries (for example, 16% of firms in Wales and 15% in Scotland).

It is also worth noting that large physics innovators in the survey were more likely to be recipients of public funding than smaller firms (in the UK, 67% of large UK physics innovators have received UK government funding vs 49% of medium-sized innovators and 50% of small innovators).

With respect to non-public funding sources, "internal" sources of funding were most commonly cited, with 53% of physics innovators financing R&D/innovation activity through retained earnings or sales of assets and 29% using funding from a parent company. The most common "external" sources were funding from commercial partners (15% of firms) and equity financing (15%), with debt-financing the least common source of non-public funding (9%).

Innovators in RoI were more likely to be funded through a parent than in the UK (52% in the RoI vs 27% in the UK) and, correspondingly, they were less likely to be funded through retained earnings or asset sales (36% in the RoI vs 54% in the UK). On average, respondents reported using 2.1 different sources of funding, with RoI-based innovators in the sample benefitting from a slightly greater diversity of sources (2.6 vs 2.0 in the UK). As **Table 1.3** showed, RoI-based innovators were more likely to be concerned about access to finance than UK innovators (43% vs 32%).

Exhibit 2.2 'How has your R&D/innovation activity been funded over the past five years?' (% of respondents)



TRUEinvivo

Shakardokht Jafari
CTO and founder, TRUEinvivo

TRUEinvivo is a radiation measurement company focused on reducing patient harm in radiotherapy and making treatment more effective. It is based at the Surrey Technology Centre.

To begin with I didn't have a budget for my innovation. When you have a purely new, unplanned idea, there is no budget for that. My supervisor had been quite concerned about how I was going to carry out the experiments I needed.

All I had was access to a radiation lab. I needed a lot of arrangement for my experiments, but when people saw the preliminary results, they were so excited and voluntarily conducted the experiments for me; Centres like the National Physical Laboratory (NPL), University of Surrey's Ion Beam Centre and 20 NHS hospitals across UK.

There are three key challenges that the industry faces, that you need to consider right from the beginning. One is to have the right team, who are like minded and who have faith in you and are not there just for the sake of doing a job and getting paid.

Two, if you are subcontracting a manufacturer for making the prototype, it is very important that those people understand the physics behind that technology, because it is so complex. If someone doesn't understand the knowledge behind it during the design, mistakes will be made during the manufacturing process that affect the physical performance of the equipment, serious delays happen, and prototype production costs hugely increase.

Third, and I think this is a challenge we have in the UK, I visited the Massachusetts Institute of Technology in 2017 and when I presented my technology to investors, I received two offers of $1m in investment in two weeks. I've been struggling a lot in the UK, so a lot needs to be done in terms of encouraging investors to invest in the development of physics and medical based technologies, because it takes so long. Investors want immediate reward, but medical technologies and physics-based technologies are very slow to get to the final stage of commercialisation. Right from the beginning, have a plan B and plan C for every financial route you're taking."

For a longer version of this case study, please click **here**.

Public funding provides vital support for physics-based R&D/innovation

Despite the relatively small share of business spending on R&D/innovation accounted for by public funds, it has long been recognised that public support has a vital role to play in stimulating private spending.[12] This is particularly the case where there is a high degree of uncertainty about the commercial potential of research, where the risks of copy-cat innovations are high, or where the timescales for investment returns are long (a particular issue for physics-based firms, which typically face longer development times than for other technology firms). There is also a substantial body of evidence that public support for business investment in R&D and innovation leverages additional private funding.[13]

We find strong support for these conclusions in our survey. Public funding was deemed "very important" for allowing R&D/innovation activity to take place by 71% of physics innovators that had received it, with only 4% saying it was unimportant. Indeed, for the majority of recipients this support was instrumental: 70% reported that public funding "fills a financing gap, without which the activity would not take place". A further third (34%) believed that funding attracts additional private funding, increasing overall resources towards a project. This is potentially because public support can help accelerate the innovation process and provide reassuring signals for potential investors. By contrast, only 19% believed public funding acts as an alternative to private funding.

Public funding is seen as yielding a significant social return in terms of both tangible "innovation outputs" as well as more intangible spill-over effects. For example, more than half of physics innovators (55%) said public funding supported the development of products/services that otherwise may not have been produced. A similar share (57%) believed that public funding encouraged more collaboration with external partners (a theme that is explored more in Chapter 4, below), which research suggests helps build so-called absorptive capacity—the ability of businesses to understand and exploit cutting-edge research.[14] Physics innovators also gave strong support to the notion that public support brings significant "legacy effects" that benefit future projects, including the development of skills and experiences (55%), improvements to equipment or infrastructure (37%) and organisational changes (30%).

Public funding appears to be reducing financing pressures during the early stages of the innovation pipeline, but the survey suggests there may be a need to direct more support towards later stages. Overall, publicly funded firms were more likely to see access to finance as a significant challenge (41% of publicly funded innovators cited this as a barrier vs 27% of non-publicly funded physics innovators). More specifically, publicly funded physics innovators were more likely to report difficulties securing funding at later stages in the innovation pipeline, such as demonstration (26% vs 15%) and production/scaling up (49% vs 28%), as well as struggling more at the applied research phase (28% vs 18%). On the other hand, non-publicly funded firms were more likely to struggle to access funding at the basic research or concept stage (44% vs 30% for publicly funded). This points to a substantial number of firms that are not accessing public support and facing high barriers to R&D (and as is discussed in Chapter 5, below, this may partly be related to difficulties navigating available support).

The race for skills, equipment and space

Skills shortages pose a significant challenge for physics-based R&D/innovation

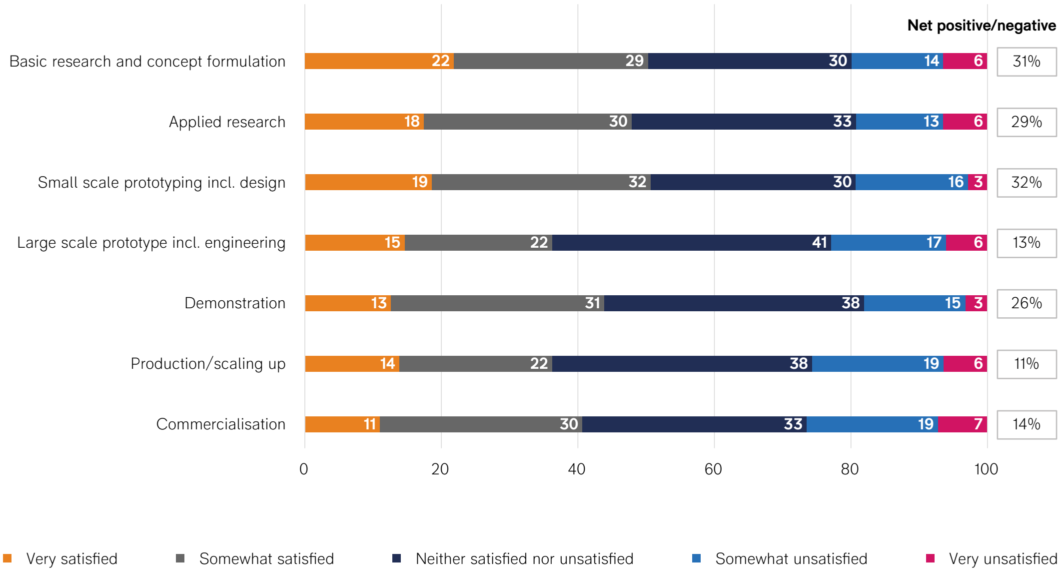
An adequate supply of skills, know-how and experience to develop new and existing scientific knowledge is a vital component of national innovation systems, but is seen as one of the most significant challenges to undertaking R&D/innovation activity across the UK and RoI. As **Table 1.3** highlights, skills shortages were the third most commonly cited barrier to R&D/innovation activity (after direct costs and potential costs/risks), selected by 40% of physics innovators. Concerns were more acute in the RoI than in the UK (46% vs 39% in the UK). Only one in ten (11%) physics innovators said that they do not experience any difficulties recruiting.

Table 3.1 provides more detail on the type of skills that physics innovators have experienced the greatest difficulties recruiting over the past five years. By far the most common problem for physics innovators was recruiting people with a combination of both commercial and specialist/technical skills (50%), though this was seen as a bigger concern in the UK (52%) than in the RoI (38%). People with this mix of skills were seen as harder to find than individuals with commercial skills (24%), specialist physics-related knowledge (29%) or STEM skills (22%) more generally. Among the firms that reported difficulties recruiting physicists, companies involved in quantum technologies (45%) appeared most concerned. All the above suggests a role for education providers and physics-based businesses to explore how to increase opportunities for researchers to gain more commercial experience, for example, through more business placements at early stages in their careers.

Table 3.1 'In the past five years has your organisation experienced difficulties recruiting staff for roles with the following competencies' (% of respondents)

	All physics innovators	UK	RoI
People with a combination of commercial and specialist/technical skills	50	52	38
People skilled in product or service design	38	40	24
People with production or manufacturing skills	29	28	33
People with specialist physics-related knowledge	29	30	24
People with data analytics skills	27	27	38
People with commercial skills (i.e. sales and marketing)	24	23	29
People without physics-related knowledge but with relevant STEM skills	22	21	33
People with basic digital skills	14	14	14
People with sourcing, procurement and supply-chain management skills	12	12	5
People with financial and risk management skills	8	8	5

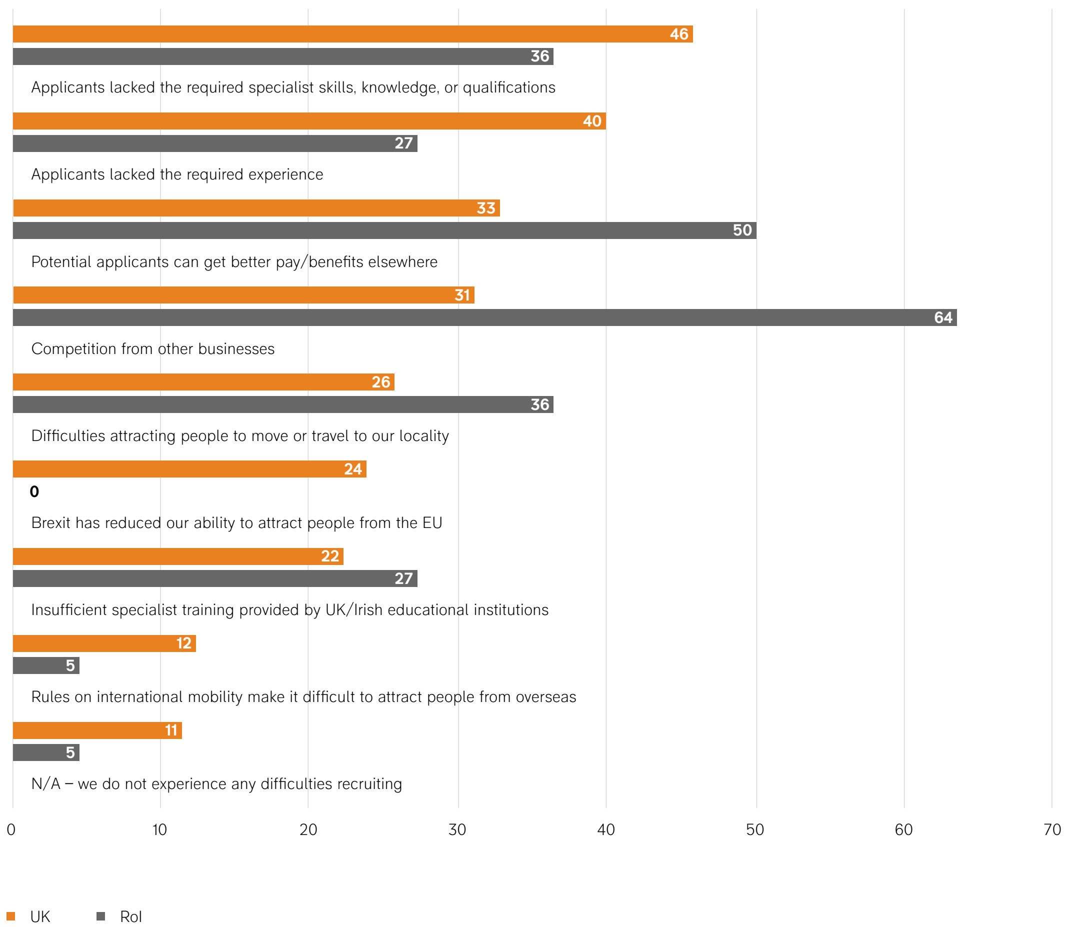
Exhibit 3.1 'How satisfied are you with your organisation's ability to attract and retain the talent you need at each stage of the R&D/innovation pipeline?' (% of respondents)



Physics innovators indicated that skills shortages become more acute at later stages of their R&D/innovation journey. **Exhibit 3.1** shows the net-balances between the share of respondents saying they are satisfied with their ability to attract and retain talent and those saying they are dissatisfied. It suggests that physics innovators are generally less satisfied with their ability to attract and retain staff at the large-scale prototype stage (net balance of +13%), production/scaling up stage (+11%) and commercialisation stages (+14%) than for other stages (+26% to +32%). These are perhaps the stages where a mixture of commercial and technical skills is utilised more. This pattern was consistent for both UK and RoI-based innovators.

Exhibit 3.2 sheds light on the causes of recruitment difficulties, revealing some variation between the UK and RoI. Among UK innovators, a lack of relevant skills (46%) and experience (40%) appears to be at the root of recruitment difficulties. By contrast in the RoI, competitive pressures appeared a more important explanation of recruitment difficulties, with two-thirds (64%) pointing to competition from other businesses and half pointing to the prospects of better pay/benefits for potential applicants elsewhere (50%). Only 11% of UK innovators and 5% of RoI innovators face no difficulties recruiting (an average of 11% among all physics innovators in the survey, as noted at the start of this chapter).

Exhibit 3.2 'What do you think are the reasons that explain your organisation's recruitment difficulties?' (% of respondents)



Orca Computing

Richard Murray
Co-founder and CEO, ORCA Computing

ORCA Computing is a spin off from the University of Oxford, and now based in West London. ORCA has developed a completely new quantum computing architecture for machine learning based on single photons, optical fibre, and proprietary quantum memory technology. ORCA has 14 full time employees across the UK, Poland, US and Canada.

ORCA was founded based on academic work funded by the EPSRC National Quantum Technologies Programme's investment in the networked quantum information technologies hub, bringing together quantum memory and quantum information science research activities, which identified an opportunity to use quantum memories for computing systems.

There is a limit to the number of PhD physicists, engineers, project managers, marketing, and salespeople we can find. We find it a challenge to find people with experience working with highly technical scientific and technology-based projects, who have also spent a lot of time working in fast paced start-up environments, bringing technical or highly scientific products to market.

We model ourselves on the structure of innovative digital companies. We define each individuals' overall objectives and then provide with ample space to allow them to be creative and find their own solutions. In this way, we empower employees to think for themselves and find solutions to the difficult challenges without too much top-down interference.

The challenge for any innovative business, however, is how to marry this freedom with a sense of focus and coordination. This is why we constantly discuss likely sources of distraction and what our priorities should be, which is then embedded in the objective setting. It takes constant attention to keep the ship pointing in the right direction and to keep everyone focused on the next big company milestone, such as delivering a demonstrator to show to a customer or investor.

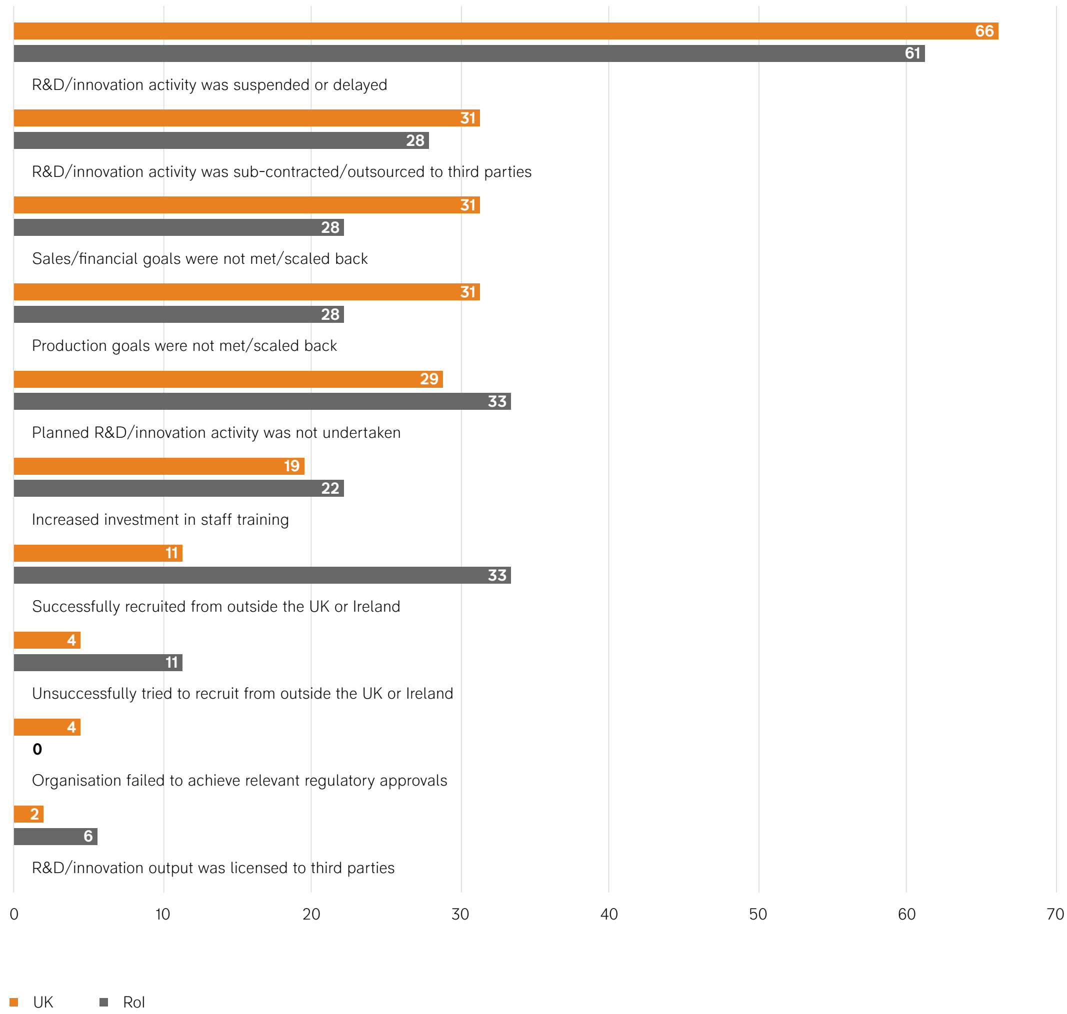
I believe that within an innovative company, the most critical skill is to be constantly hungry to learn. If the leadership want the employees to be curious and to learn, these learning traits must start with the leadership; they should be the ones who ask the most questions.

For a longer version of this case study, please click **here**.

The disruptive impact of skills shortages on R&D/innovation activity is felt in delays to projects, missed targets and missed opportunities. Overall, two-thirds of physics innovators (66%) reported suspending or delaying such activities in the past five years because of skills shortages. Almost one third of firms said they had missed or scaled back their R&D/innovation targets (30% for production goals and 30% for sales/ financial goals). A similar share (29%) reported that R&D/innovation activity was not undertaken due to skills shortages.

The survey also indicates some potential responses to these difficulties. Almost one third of physics innovators (30%) reported sub-contracting or outsourcing their R&D/ innovation activity. Only one in five firms (19%) sought to address skills shortages by raising investment in staff training, reflecting the highly specialised nature of R&D-intensive roles and the inherent difficulty of employees switching functions when skills are developed through academic study. **Exhibit 3.3** shows how these responses varied between the UK and RoI. Perhaps the most interesting difference was the higher share of RoI-based innovators saying that in response to skills shortages they had successfully recruited from outside the country (33% vs 11% in UK). This is possibly related to Brexit, and the fact that the RoI continues to benefit from access to skills from across the EU. While investment in physics (and STEM) education and steps to strengthen university-business links remain vital for skills development over the long-term, more could be done to plug skills gaps in the UK in the short-term, notably by examining rules around the mobility of international researchers.

Exhibit 3.3 'At any time in the past five years, have skills shortages had any of the following impacts?' (% of respondents)



One in six physics innovators struggle to access necessary equipment or facilities

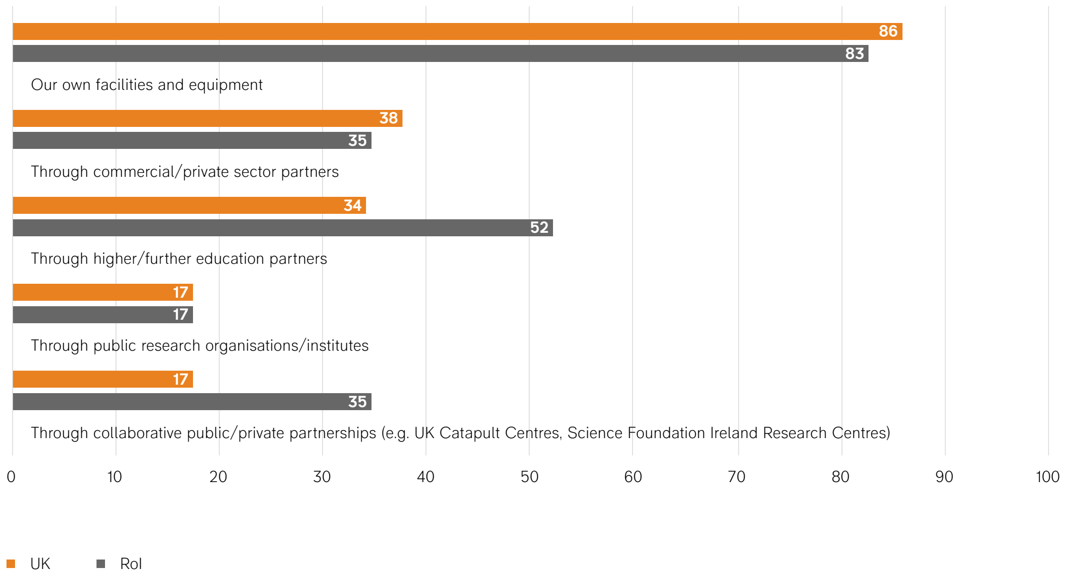
Along with the financing environment and a supply of necessary skills and talent, a third critical element of the innovation system is appropriate access to the physical assets to carry out such activities—the equipment, labs, testing facilities, etc. Although this is not seen as one of the most important challenges for undertaking R&D/innovation activity, a lack of (or improper) equipment, machinery or space was still seen as a significant barrier by as many as one in six physics innovators (16%—see **Table 1.3**). Exploring this in further detail, the survey found that one quarter of physics innovators (26%) believe a lack of suitable facilities limits their ability to undertake

R&D/innovation activity, with one in five (20%) highlighting access to physical testing equipment a limiting factor—UK innovators appeared more concerned by this (21%) than RoI-based innovators (9%).

The survey suggests that a sizeable share of physics innovators may be missing out on opportunities to advance their R&D/innovation projects by collaborating or utilising shared facilities and equipment. A large minority of physics innovators, 44%, reported accessing equipment and facilities through one source, 30% through two sources, with a further 26% relying on at least three sources. **Exhibit 3.4** shows that, while most of firms used their own equipment and facilities, over a third also accessed these resources through commercial partners (38%) and/or through education providers (36%). Almost one in five physics innovators (18%) accessed equipment and facilities through collaborative public/private partnerships such as UK Catapult centres or Science Foundation Ireland.

Publicly funded firms were more likely to collaborate over access to facilities and equipment. Thus half of publicly funded firms engaged with higher or further education providers (51% vs 14% for non-publicly funded firms), and around one quarter engaged through public research organisations (25% vs 5%) or collaborative public/private partnerships (23% vs 11%). This behaviour may reflect the particular circumstances or characteristics of publicly funded innovators, who were more likely to cite a lack of access (or improper) equipment, machinery or space as a key challenge to undertaking R&D/innovation activity (20% vs 12%).

Exhibit 3.4 'How does your organisation access the facilities and equipment needed to carry out R&D/innovation activity?' (% of respondents)



Kromek

Arnab Basu
Founding CEO, Kromek Group Plc

Kromek develops and manufactures advanced radiation detection technology for medical imaging, nuclear security, civil nuclear and security screening applications. From our manufacturing facilities in the UK and US, we provide radiation detection components and standalone devices to government, OEM and blue-chip customers worldwide.

Day one of Kromek consisted of a piece of paper and a second-hand computer in a room at Durham University; that is where our origins are. The journey begins at the customer end and understanding what solutions are needed to meet an existing demand. We use a process called design-led innovation, in which we understand the ecosystem, define the problem for which a solution is needed, interact with all the stakeholders and create a solution. The ecosystem includes the customer (needing a solution) and ourselves (providing a solution) but also all the other stakeholders, decision makers and user groups.

In our early days, we were fortunate to be in an environment in the Northeast of England where there was real desire among the local authorities and other regional bodies to support knowledge-based start-ups. From our origins in Durham University, we quickly moved to an incubation centre based in a brand-new science park, NETPark in County Durham. From the very early days, NETPark gave us the necessary infrastructure and support that helped us along that journey.

I have a people-centric and market driven approach to business. Having the market as a central guiding force is important along with the ability to go out and sell the vision of the solution you are creating. You follow the market; you find and analyse where the gaps are, and you respond to those gaps based on the technologies and organisational capabilities. Having the ability to react, to move fast, and to be agile in innovation is very important.

Additionally, we recruit the best people we can. In my senior management team, everyone is more experienced than I am and that is an intentional strategy that I have deployed from day one. You build a team with skilled people who shape your thinking.

For a longer version of this case study, please click **here**.

Collaboration and culture

A sizeable minority of firms eschew collaborating over their R&D/innovation

As discussed in the previous chapter, collaboration can play an important role in the innovation process by allowing firms to gain access to a bigger pool of knowledge and expertise, equipment or other resources. In addition, collaboration allows firms to share the time and effort involved in developing new products or processes, as well as the financial risks. While many physics innovators regularly do collaborate with other organisations, our survey suggests that a sizeable share do not. We explored the degree of collaboration across three key categories: knowledge infrastructure (such as universities or research institutions), business networks and other formal networks or organisations (such as learned societies or professional bodies, like the IOP). The results are shown in **Table 4.1**.

Analysing the firm-level data underpinning these results found that almost half (48%) of physics innovators did not regularly collaborate with any key bodies within the UK and/or RoI knowledge infrastructure (such as universities or research institutions). For those that did, the largest share engaged universities or further education providers. Thus 42% of firms regularly collaborated with universities or other higher education institutes, while a further 37% did so occasionally. Only 21% of physics innovators had not collaborated at all with a university or further education institute during the previous five years. This indicates that many physics innovators do have a meaningful connection with universities, even if this is not something that happens on a regular basis.

By contrast, far more firms had never collaborated with public research institutions (44%) or public/private innovation partnerships (53%). Although it is not clear whether this reflects a lack of suitable facilities/equipment or whether firms are unaware of the opportunities available, this does point to possible barriers to collaboration between different parts of the innovation ecosystem. There may therefore be untapped potential to promote access to the kind of facilities and equipment such institutions can offer, particularly for late-stage testing and demonstration activities, which rely on capital intensive facilities and are therefore often costly. Overall, however, it is worth noting that the share of physics innovators collaborating with "knowledge institutions" appears to be higher than among the general business population—OECD data suggests only 30% of all innovative UK firms collaborate with either higher education or government institutions.[15]

Physics innovators were more likely to collaborate with other businesses, with a majority saying they did so with customers and suppliers. This is in line with the trends seen in the wider business population (OECD data suggests a figure of 55% for both categories).[16] Business-to-business linkages can be particularly important where innovation relies on the integration of different technologies into firms' own processes. Nonetheless, the firm-level data suggests that one in five (21%) physics innovators does not collaborate with any other business on a regular basis, suggesting untapped potential to unlock the power of innovative supply chains. Respondents were least likely to collaborate regularly with other networks, associations or societies, with just over half (52%) reporting they did not collaborate regularly with peer networks, trade associations, professional bodies or learned societies. Those that did most commonly relied on peer networks.

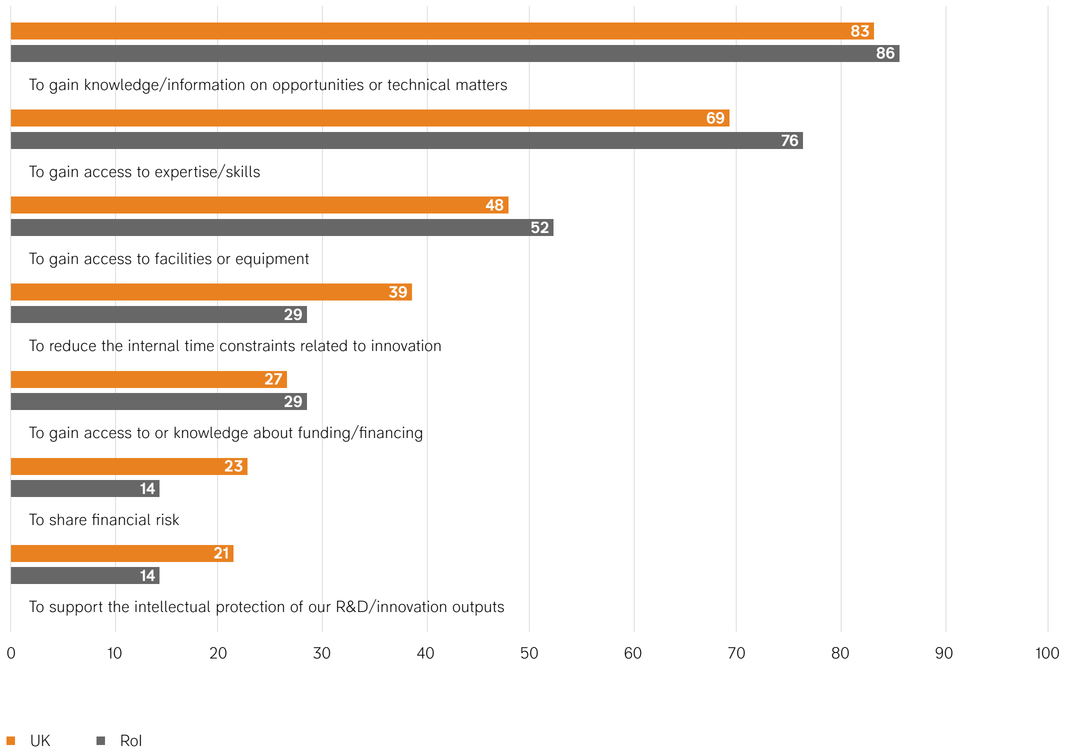
The firms that were most likely to collaborate were, on the whole, larger and more likely to have received some public funding. For example, both groups were more likely to engage regularly with knowledge institutions (such as universities, etc) and with other businesses. We also observed some variation between the UK and RoI. For example, while the shares regularly collaborating with universities (43% vs 46%, respectively) and public sector research bodies (27% vs 29%) were broadly similar, UK innovators were less likely than RoI-based innovators to collaborate regularly with both private research and technology organisations (30% vs 43%) and with public/private partnerships (17% vs 25%). UK innovators were somewhat more likely than RoI-based innovators to engage regularly with other businesses such as suppliers (55% vs 50%) and customers (64% vs 50%).

Table 4.1 'Has your organisation collaborated or engaged with any of the following networks/partners in the past five years for the purpose of R&D/innovation?' (% of respondents)

	Regularly	Occasionally	Never
UK/RoI Knowledge Infrastructure			
Universities or other higher/further education institutes	42	37	21
Public sector research organisations/institutes (incl. bodies sponsored by government departments)	27	29	44
Private research and technology organisations (incl. commercial and non-profit)	30	35	35
Collaborative public/private partnerships (e.g. UK Catapult Centres, Science Foundation Ireland Research Centres)	17	30	53
Business			
Suppliers	55	34	11
Customers	62	33	5
Cluster supply chains	13	23	64
Consultants	23	53	23
UK or RoI-based competitors or other businesses in your industry	13	36	51
Overseas-based competitors or other businesses in your industry	14	35	51
UK or RoI-based businesses outside your industry	12	39	50
Overseas-based businesses outside your industry	13	31	56
Networks, Associations and Societies			
Peer networks	40	33	27
Trade Associations	29	36	35
Professional Bodies	27	45	29
Learned Societies	15	32	53

Access to knowledge and talent are the most important drivers of collaboration. As **Exhibit 4.1** shows, 84% physics innovators said they collaborate to gain knowledge or information on opportunities or technical matters, while 70% do so to gain access to expertise or skills. As such, most physics innovators appear to collaborate early in the R&D/innovation process: the most common times for physics innovators to collaborate with their partners/network is during basic research (60%), applied research (51%) and small-scale prototyping (65%). Collaboration tends to drop off during later stages of the innovation process, with 37% of collaborating during large scale prototyping/engineering, 28% do so during the production/scaling up phase, and 22% during the commercialisation stage.

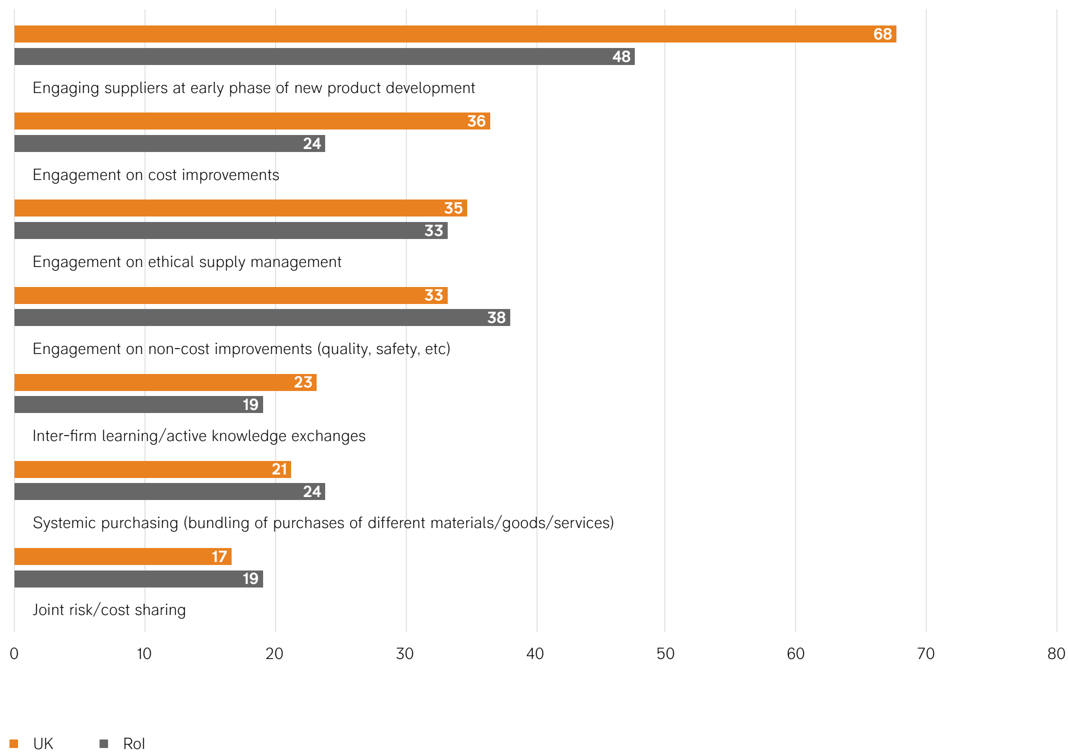
Exhibit 4.1 'Why does your organisation collaborate with partners/ networks?' (% of respondents)



As noted above, collaboration with suppliers is seen as particularly important, with more than half (55%) of physics innovators doing this regularly (55% in the UK and 50% in the RoI). **Exhibit 4.2** explores this in more detail. Two thirds (66%) of physics innovators engage suppliers at an early stage of new product development, though this was more likely in the UK (68%) than in the RoI (48%). A little over one third (36%) collaborated on cost improvements, which was again more likely among UK innovators (36% vs 24% in the RoI). Overall, a similar share (34%) engaged over non-cost improvements, such as quality or safety, but this was more commonly the focus of firms in the RoI (33% in the UK vs 38% in the RoI). Firms in the UK and RoI were equally likely to say they collaborated with suppliers over ethical issues (35% and 33%, giving an average 35% for all physics innovators).

Interestingly, despite the importance of knowledge sharing for collaboration in general **(see Exhibit 4.1)**, relatively few firms (23%) appear to collaborate with their suppliers to promote inter-firm learning or active knowledge sharing, possibly suggesting a desire to protect intellectual property. Exploring new ways for firms to collaborate within supply chains may be important for unlocking the potential for innovation within supply chains. Similarly, new initiatives could be considered to counter the tendency for collaboration to decline in later stages of the innovation pipeline—for example by expanding university "sandwich courses" or considering other ways to give doctoral students business experience during development stages.

Exhibit 4.2 'Which of the following aspects form part of your organisation's relationship with suppliers?' (% of respondents)



Elekta

Giulia Thompson
Head of System Physics, Elekta

Elekta is a leader in precision radiation medicine. The company is headquartered in Sweden, with UK operations based in Crawley. Our 4,000+ employees worldwide are committed to ensuring everyone in the world with cancer has access to – and benefits from – more precise, personalised radiotherapy treatments. Elekta has been pioneering the integration of imaging with the radiotherapy delivery system, Image-Guided Radiation Therapy (IGRT), to improve precision and accuracy of treatment.

Elekta's strong partnership with Philips, as well as having Philips staff seconded at Elekta, was key to the success of Magnetic Resonance/Radiotherapy technology (MR/RT) as our respective skills are complementary. To drive MR-guided radiotherapy, it was very important to work with a diagnostic leading company like Philips.

Our understanding of customer requirements was also greatly enhanced by having our physicists and engineers working closely with the research consortium scientists, with some Elekta staff even based on site. We recruited outside of our traditional radiotherapy domain and added MRI experts (physicists, radiographers and engineers) to our R&D teams, as well as to other areas of the organisation, e.g., operations and product management.

To date, 26 Elekta Unity systems are clinically operational around the world and more than 2,000 patients have been treated. The system has been used for the treatment of over 30 different anatomical sites. Over 360 scientific papers have been published. Unity has generated a whole new business line for Elekta, with a triple-figure growth of employees in the UK. The main competency centre for the new technology system is in Crawley, with new state-of-the-art facilities and teams covering the whole lifecycle, from research to supply, installation and maintenance.

Strong partnerships with technology, research, and clinical organisations, alongside team cross-functionality (e.g., physicists, engineers, radiographers, oncologists, regulatory experts), are key to success. External funding, e.g., from government or charities, is critical for initial de-risking of new technology and support of early users.

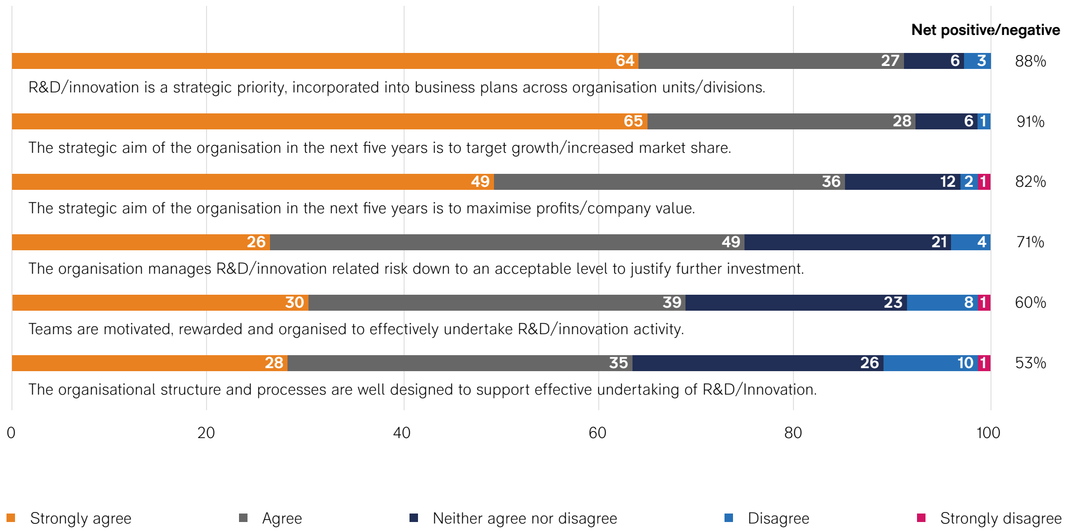
For a longer version of this case study, please click **here**.

Physics innovators are generally satisfied they have a pro-innovation culture

In complex, multi-faceted innovation systems, a successful journey from pure science to applied research to the creation of new products, processes and services requires a properly functioning set of relationships between various inter-dependent stakeholders. This chapter has already highlighted the value that many physics innovators place on collaboration with external partners, such as universities or other research institutions, or with their customers and suppliers. In the remaining section we consider the internal mechanisms that can help foster innovation, highlighting the importance of leadership and a pro-innovation culture.

On the whole, physics innovators are satisfied with their firms' approaches to and support for R&D/innovation activity. **Exhibit 4.3** provides the net balances of opinion of various statements regarding organisational culture—ie, it shows the share of those who either agree with the statement minus those who disagree. Nine out of ten (91%) physics innovators agreed that R&D/innovation is a strategic priority that is incorporated into business plans across organisation units/divisions (64% strongly agreed and 27% agreed), with only 3% disagreeing. This gave a net balance of 88%. UK innovators were slightly more likely to agree with this statement (89% vs 81% for RoI-based innovators). Innovators that had received some public funding were more likely to agree that R&D/innovation is a strategic priority than those that had not (93% vs 81%).

Exhibit 4.3 Net balance of physics innovators who agree with the statements on strategy and culture (%)



A slightly higher share of physics innovators see targeting growth or increased market share as the strategic aim of their firm over the next five years (a net balance of 91% agreeing), as opposed to maximising profits or company value (with a net balance agreeing of 82%), with two-thirds of innovators "strongly agreeing" that growth is the priority versus half "strongly agreeing" that the focus is on maximising value. These scores change little when comparing nations or funding sources.

A net balance of 71% of physics innovators agreed that their firm manages risk to an acceptable level, although only 4% disagreed. Publicly funded firms were less likely to agree with the statement than firms that had received no public funding (66% vs 77%). Publicly funded firms were also more likely to be concerned about uncertainty over future funding as a potential cost/financial risk (breaking down the responses in **Table 2.1** we found that 36% of firms saw future funding uncertainties as a risk overall, with 44% of publicly funded firms versus 25% for non-publicly funded firms).

Overall physics innovators appeared satisfied that their firms are supportive of R&D/innovation activity, but opinions towards people management and structures were more varied. A net balance of 60% of physics innovators agree that teams are motivated, rewarded and organised to effectively undertake R&D/innovation activity, while 53% agree that the organisational structure and processes are well designed to support effective undertaking of R&D/innovation. Publicly funded firms were more likely to agree with both statements (68% vs 50% and 58% vs 45% respectively). This was despite the fact that large firms (which are more likely to have received public funding), were actually less likely to agree with these statements than their micro, small and medium counterparts.

It is difficult to disentangle cause and effect here. It was noted above that 30% of publicly funded firms said that receiving public support encouraged organisational changes to support R&D/innovation activity. We have found that publicly funded firms collaborate more with knowledge institutions, their peers and industry bodies. And this collaboration is frequently done in order to gain knowledge and expertise, which could include knowledge about organising people and processes in order to do R&D/innovation most effectively. However, it is equally possible that companies with a more pro-innovation culture are more likely to collaborate and more likely to seek public funding.

Seagate

Brendan Lafferty
Sr Director, R&D, Seagate

Seagate is one of the largest hard disc drive data storage suppliers in the world, with more than 40,000 employees worldwide located across the US, Asia and EMEA. Seagate's facility in the UK, based in Northern Ireland, has had a cumulative investment of £1bn over 25 years to enable the manufacturing facility supplying the majority of Seagate's read-write transducers and extensive development capability.

As an organisation, we compete on a global stage. The facility that we have here is one of five in the world. By extension, you need to compete for people, skills, and talent on a global stage, and you need to have access to the best equipment. We've built up a very strong local government, academic and industry ecosystem where, over the years, we've established relationships specifically with Invest Northern Ireland and Queens University Belfast. Additionally, the government's investments have ensured that we continue to be an attractive investment location for both manufacturing and development of next generation read-write transducers.

There are two key considerations to enabling innovation. First is understanding the requirements and identifying the gaps to achieving those requirements. Second is understanding the physics to enable those requirements. From our perspective, we work very closely with our customers to understand what they need, while understanding what the physics and limitations with our current devices are. Then we define the technical requirements for all of the components.

We enable the right people and focus on the right projects, and they drive the solutions. At our facility in Northern Ireland, we have over 120 PhDs specialising in Physics, Chemistry and Material Science – this forms the foundational skills and knowledge required to enable innovation. We continue to invest heavily in our people for continuous learning and exposure to latest available technology globally. We also form strategic technical partnerships, particularly with academia and with our tooling and consumable suppliers. Frequently the specific technology required to enable our nanotechnology devices does not exist and therefore we work closely with partners to invent and develop new tooling, processes, or other capabilities to enable next generation of technology.

The result of this journey has been establishing one of the most advanced nanotechnology manufacturing and development facilities in Europe.

For a longer version of this case study, please click **here**.

Policy, regulation and the outlook for physics R&D/innovation

Firms expect to increase R&D/innovation activity in the years ahead

Since the onset of the COVID-19 pandemic in early 2020 businesses have been facing severe disruption to their operations, with COVID-19 restrictions prompting unprecedented temporary shut-downs of the economy. After over a year of intermittent demand, stop-start restrictions, pressure on cash reserves, and tough trading conditions, many businesses are less able to weather challenging economic conditions in the years ahead. The support of the UK and RoI governments has been a lifeline for many firms, but maintaining a supportive environment for business investment in the medium term will be vital to stimulate a lasting recovery of the UK and RoI economies.

With the successful roll-out of vaccines across much of the developed world at least, business confidence has improved during 2021 and so has the outlook for R&D/innovation activity across the UK and RoI. As **Exhibit 5.1** shows, two-thirds (65%) of physics innovators expected R&D/innovation spending to increase over the next five years in comparison with the previous five years, with 26% within that saying spending will increase significantly. Only 5% expected spending to fall, with the remaining 30% expecting no change. This gives a net balance of +60%, suggesting the prospects for a recovery are good.

RoI-based innovators appeared more optimistic than their UK counterparts, with net balances expecting R&D/innovation spending to increase of 74% compared with 59% for the UK. Among all physics innovators, firms that had received public funding were more optimistic than non-publicly funded innovators (67% vs 51%), which may reflect additional funding pressures experienced by those relying solely on private sources finance. Among different sectors, energy firms were the most likely to say that they will increase R&D/innovation spending (+76%).

Exhibit 5.1 'How do you expect your organisation's R&D/innovation spend in the UK/RoI to change in the next five years compared to the previous five years?' (% of respondents)

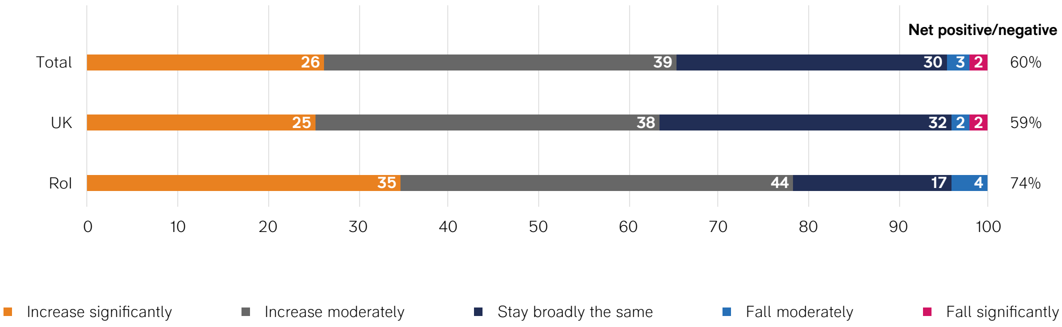


Table 5.1 provides explores the drivers of future growth. Among those expecting investment in R&D/innovation to increase, the most common reason given was to adapt to changing product and market demand (74%), closely followed by adapting to the emergence of new technologies (72%).

Table 5.1 Reasons to increase R&D/innovation spend (as % of those who said R&D/innovation will increase in next five years)

	All physics innovators	UK	RoI
To adapt to changing product/market demand	**74**	76	59
To adapt to the emergence of new technologies	**72**	71	77
To improve cost competitiveness	**56**	56	47
To increase sustainability or energy efficiency	**45**	46	41
To comply with standards and regulation	**37**	38	29
Reduction of macroeconomic uncertainty (e.g. Brexit, COVID-19 etc)	**35**	36	29
Improved opportunities for collaboration	**34**	35	24
Improvement in access to relevant people/skills	**28**	29	29
Improvement in availability of internal finance	**20**	20	29
Improvement in availability of external finance	**20**	19	24
Improvement in access to facilities/equipment	**17**	16	24
Improvement in cost of external finance	**7**	6	12

Teledyne e2v

Professor Trevor Cross
VP for Innovation, Teledyne e2v

Teledyne e2v makes enabling specialist electronic components for a range of high-end applications. Our space silicon image sensors have delivered images from every planet in our solar system, and our microwave power devices treat one patient every seven minutes through 90% of the world's radiotherapy systems. We employ over 1,600 people in countries across Europe, America and Asia, with UK operations in Chelmsford and Lincoln. This case study concerns the image sensor business.

Our approach is to stay aware of scientific research around the world, chart our product and technology roadmap and then secure company investment for short-term iterative product developments. Then we either implement these in-house, or for longer term emerging new technologies we work with third party companies and academia to enable us to do more and move faster, and in this area government investment can be a great accelerator. We've had a lot of support from the government, mostly through government spending, as a large proportion of our space imaging business comes from the publicly funded European Space Agency (ESA) programmes, though usually via space prime contractors.

Access to capital was not generally a barrier for us, but we did find it hard to access young engineers with the right background and skills. It was particularly challenging to bring in new skills for new technical disciplines too, especially those which are rare in Teledyne e2v (e.g., compound semiconductors). The tax environment was also a challenge, as our corporate holding company is international, and so has a choice about where to invest.

To see more effective translation of technology and the establishing of new elements/growth in this business the following would be beneficial in our view.

1. A fully funded National Space Innovation Programme where programmes are competed, and the outputs utilised for missions delivering data or a service.
2. The emergence of a mission-led National Space Programme with options for international (bilateral) cooperation. Here the missions would be procured by the agency in some way, and the supply would be competed for and fully funded.
3. And more broadly than just the space market, an ambitious programme to stimulate government as an early adopting customer of new capabilities. This would fit well as the next instrument to cement commercial success following developments in the world leading UK National Quantum Technology Programme (NQTP).

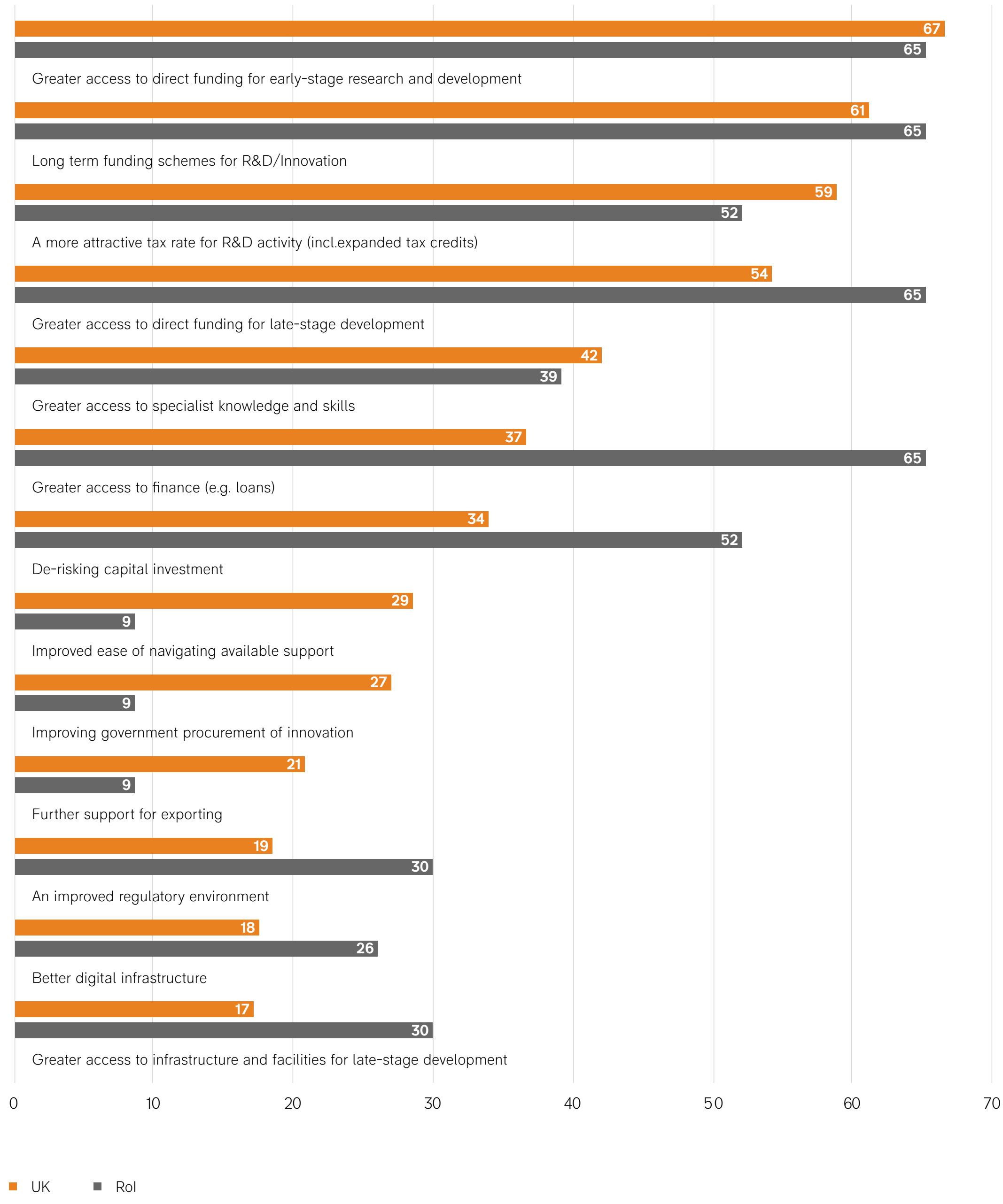
For a longer version of this case study, please click **here**.

Physics innovators see an important role for policy in supporting access to sufficient finance

Innovation policies can play an important role in supporting the post-COVID-19 recovery. To a degree the objective of innovation policy is likely to remain focussed on tackling long-term barriers that can hold R&D/innovation back and thus restrain productivity growth. But there is also an imperative to minimise any possible damage to innovation systems caused by the response to the pandemic itself, for example through its impact on the education and training of researchers, international mobility, collaboration, attitudes to risk, the availability of finance and the level of public support in the years to come.

The survey reveals particularly strong support for action to promote access to finance. **Exhibit 5.2** reveals that across both the UK and RoI, greater access to direct funding for early-stage R&D was the most commonly selected policy enhancement that could encourage more R&D/innovation activity in the next five years (67% and 65% of respondents respectively). Although there are no precise definitions of what counts as “early-stage R&D”, this is typically understood by businesses to cover activities from basic and applied R&D through to small-scale prototyping, with “late-stage R&D” capturing activities from large-scale prototyping through to demonstration and pre-production problem solving. Greater access to direct funding for late-stage development was also a popular policy action (54% in the UK and 65% in the RoI).

Exhibit 5.2 Policy enhancements that would allow physics innovators to undertake more R&D/innovation activity in the next five years (% of respondents).



Creo Medical

Liz Hayward
HR Manager, Creo Medical

Creo Medical, based in Chepstow (Wales), is focused on the development and commercialisation of technology and minimally invasive devices by bringing Advanced Energy to therapeutic endoscopy. Creo's first device, Speedboat Inject, is now in use worldwide, providing physicians with new treatment approaches and patients with life-changing outcomes.

Professor Chris Hancock founded Creo Medical in 2003, initially to target the treatment of cancers through use of high frequency microwave energy and dynamic matching techniques. Creo has harnessed the power of advanced bipolar radiofrequency and microwave energy to perform resection, dissection, haemostasis, and ablation. Our product range allows these energies to be utilised in the gastrointestinal tract, lungs, liver, and pancreas through miniature devices in minimally invasive treatments.

For founder and CTO Chris Hancock, the driving purpose behind Creo is to help people; to improve patient outcomes by leveraging, optimising, and controlling the right energy for the right reason. His original vision focused on a very R&D-led organisation, and the company was initially funded via a venture capital backed UK incubator. This allowed them to buy initial equipment, produce prototypes and begin to gain the company's first patents. However, he realised that a different approach would be required to take those prototypes to market and treat patients.

At this point, Craig Gulliford came on board as an angel investor and helped raise seed capital and additional funding through government grants, which allowed further advancement of the technology, including initial animal studies. In 2013, as Craig became Creo's CEO, Finance Wales offered funding and support. This was followed by additional investment by Pentax Hoya and the British Development Bank, which resulted in the first use of Speedboat Inject in a human case in 2015 and regulatory clearance from both the FDA and CE Mark in 2017, by which time, Richard Rees had joined in 2016 as CFO. We have subsequently developed our technology further with regulatory approval for a suite of innovative devices for use with our CROMA Advanced Energy platform. During 2020, David Woods also joined the Creo team as CCO, overseeing global commercial activities.

R&D inception to commercialisation has taken ten years, but we have now achieved an international customer base. We sell our technology directly via offices in the UK, USA and the Asia-Pacific region and also have routes to market through a channel of certified distributors globally.

For a longer version of this case study, please click **here**.

Across most categories, publicly funded physics innovators were more likely to see policy enhancements as more important than non-publicly funded innovators. Long-term funding schemes were a significant priority (70% for UK publicly funded innovators vs 48% for non-publicly funded; 50% vs 31% for RoI-based innovators). This, along with the fact that publicly funded innovators are also more likely to be concerned about future funding indicates that, currently, support is not being offered with enough certainty to allow innovators the confidence to continue with long-term projects. (As noted above, 44% of publicly funded firms selected uncertainty over future funding as a potential cost/risk vs 25% for non-publicly funded firms).

One notable exception to this trend concerned the importance of "improved navigation of available support", which was selected more by non-publicly funded innovators than by publicly-funded physics innovators (35% vs 23%). This indicates that there may be some firms that are not receiving support because they struggle to access it. Interestingly, this option was more likely to be selected by micro, small or medium sized firms than by large firms which, as has been noted, were more likely to have already received some public funding. UK innovators (29%) were also notably more likely to select this option than RoI-based innovators (9%).

More than half (59%) of UK firms (and 58% of foreign-owned firms) believed that a more attractive tax rate for R&D activity would support greater activity in the UK. The share in the RoI was slightly lower (52%) and particularly so among foreign-owned firms (only 27% of foreign-owned firms believed this was important for the RoI—see Appendix 1 for further discussion). In a recent consultation, IOP members outlined a number of ways in which the R&D tax relief system could be improved, particularly to expand the scope of activities that fall within the reliefs.[17]

It is interesting to note that the most popular policy enhancements are related to funding or financing R&D/innovation activity. However, this was only the fourth most commonly selected challenge in **Table 1.3**. This may indicate that physics innovators see a greater role for governments in tackling barriers to finance compared with other concerns, such as skills shortages. Nonetheless, around two out of every five physics innovators did see a role for policy in improving access to specialist skills and knowledge (42% in the UK and 39% in the RoI).

Improvements in the regulatory environment were seen as a priority for almost one in five UK innovators (18%) and almost one third of innovators in the RoI, particularly the administrative burdens of securing protection for intellectual property. **Table 5.2** explores attitudes towards various aspects of the regulatory environment, using net balances of the impact on firms' ability to undertake R&D/innovation activity—i.e., the share of those believing it had a positive effect minus the share believing it has a negative effect. Opinions were largely neutral regarding many aspects, with the exception of attitudes towards innovation protections (such as patents, design registration and copyright).

The rules governing IP protection were viewed positively—indeed, they were the most favourably viewed aspect of the regulatory environment for UK innovators, with a net balance of +27% of UK innovators seeing this as having a positive impact on R&D/innovation activity, and the second most favourable aspect in the RoI, where the net balance was +18%. (The impact of standards and certification rules was the most favourable among RoI-based innovators, with a balance of +30%, versus +4% in the UK). However, in both the UK and the RoI, physics innovators held largely negative views towards the administrative burden of securing and maintaining innovation protections. Overall, only 4% of physics innovators believed this has a positive effect on their ability to undertake R&D/innovation activity, while 39% said it had a negative impact, giving a net balance of -35%. This was broadly similar for UK innovators (-36%) and RoI-based innovators (-32%).

Table 5.2 Net % balance scores for the impact of the regulatory environment on R&D/innovation activity (ie, the difference between positive and negative opinions)

	Total	UK	RoI
Competition policies (e.g. anti-trust, product market regulation, state aid)	4	3	13
Merger and acquisition law/policy	2	1	13
Standards and certification rules	5	4	30
Price regulations	-5	-6	0
Regulation of public utilities	-4	-4	-14
Innovation protections (e.g. patents, design registration and copyright)	26	27	18
Administrative burdens of securing and maintaining protections	-35	-36	-32

Conclusion

This survey has found that physics-based firms across the UK and RoI see scientific progress and R&D/innovation activity as central to their business operations and growth plans. They engage with multiple physics-related areas and undertake a broad range of R&D/innovation activities. Most innovation activity is resolutely driven by commercial considerations, to create or improve products and services in order to grow the business and/or increase profitability. But for many firms, the COVID-19 pandemic has disrupted innovation projects, diverting financial resources and limiting access to key equipment, facilities and staff.

Getting projects such as these back on track is a necessary condition for a revival in business investment and ensuring balanced and sustainable recoveries of the UK and RoI economies. But simply reversing the damage of the pandemic alone will not be a sufficient condition for governments in both countries to achieve their ambitions to raise public and private spending in line with R&D roadmaps. This will require overcoming significant challenges related to the long-term financing of cutting-edge physics technologies, the talent needed to develop and commercialise them, and the equipment and facilities required along the way.

The survey and case studies underline that the biggest challenges physics innovators face in undertaking R&D/innovation activity are the costs and inherent risks of doing so. This is why public support is so vital, to help bridge the gap between the development of early prototypes and the point at which the promise of future revenues becomes more certain. Over half of the respondents to the survey said they had received public funding in the past five years, and the overwhelming majority of these believe that their R&D/innovation activity could not have taken place without this public investment. Physics innovators that had received public funding also pointed to a legacy of higher skills and technological capabilities that benefits future innovation projects. Following the disruption caused by the COVID-19 pandemic, and pressure on public finances and corporate cash balances, it is imperative to ensure continued direct government funding for R&D activity.

Currently, much of this public support is focussed on early-stage R&D. But the survey emphasises that costs tend to be highest in the later, most capital-intensive parts of the R&D/innovation process, such as large-scale prototyping and production. These stages also coincide with greatest difficulties in securing adequate funding. This is when physics innovators are also least satisfied with their ability to attract and retain talent. This suggests a real danger that physics innovators in the UK and RoI look beyond these shores as they move to the manufacturing/scaling up phase. This would represent a missed opportunity for encouraging growth and exports, and risk deepening the loss of vital skills in the UK and RoI. Physics innovators therefore see a role for long-term funding schemes to promote the commercialisation of new technologies, while a more attractive tax environment for R&D activity is seen as a particular priority.

Improved access to public support could spread these benefits more widely. Firms that have received public support are more optimistic about future increases in R&D/innovation spending. They tend to be larger, more varied in terms of the R&D/innovation activities they undertake and engaged with a broader range of physics-related areas. They tend to be more collaborative and see themselves as better organised internally in order to undertake this activity. One question the survey cannot answer, however, is the direction of causation. Are large firms better able to sustain the administrative burden of seeking public support and sustaining partnerships? This seems plausible, particularly as the need for improved ease of navigating support was a common complaint among smaller/medium sized companies, which could be better prepared for innovation/R&D earlier on in their journeys, particularly making the step from R&D to prototyping.

Given the highly specialised, technology-intensive nature of innovation at physics-based businesses, collaboration is often the key to the successful integration of technologies and techniques into firms' own processes. The majority of physics innovators regularly collaborate with their suppliers and customers. They also collaborate more frequently with universities than the wider business population. But there is clearly scope to encourage collaboration more widely, particularly to promote access to skills and know-how, and facilities and equipment. Why was it that publicly-funded firms were more likely to have concerns about access to facilities and equipment, despite also being more likely to collaborate to gain access? Does this point to inadequacies of the facilities they can access? Or does it reflect the challenges they have faced in accessing innovation infrastructure? Businesses often report that access to facilities can be quite fragmented, with a lack of a single portal that showcases all possible support available.

These are important findings that point to the need for a revitalised dialogue between governments, businesses and the physics research and innovation community over the opportunities and obstacles for achieving a paradigm shift in the environment for physics-based R&D/innovation across the UK and RoI. This is not only a question of filling funding gaps. Relatively small improvements such as improved navigation for existing support and opportunities can reap great rewards. And businesses also need to answer the question of why they don't collaborate more with other businesses, particularly given their difficulties with commercialisation, skills shortages and access to finance. This may be related to a desire to protect intellectual property, suggesting that new forms of business-to-business collaboration may be the key for unlocking more innovation within supply chains. Only by working together will the ambitious goals set out in R&D roadmaps in the UK and RoI be achieved, by allowing physics-based businesses to thrive and play their part in unlocking the benefits that physics can offer society and the economy.

Appendix 1 – The regional picture

This appendix presents the results of the survey based on the geographical location of R&D/innovation activity, covering data for the nations/regions of the UK and for the Republic of Ireland (RoI, for which there is no regional breakdown). It begins with an overview of the geographical distribution of the sample, drawing on research commissioned by the IOP that maps the weight of physics-based firms in the UK (data for RoI is not available). The second section explores the results for the UK in the context of the "levelling up" agenda, focussing on differences in access to key inputs for R&D/innovation activity across the English regions[18] and the devolved nations of the UK. The appendix concludes with four boxes that provide an overview of the main survey results for each of Scotland, Wales and Northern Ireland, and the RoI.

Innovation activity was spread across multiple sites

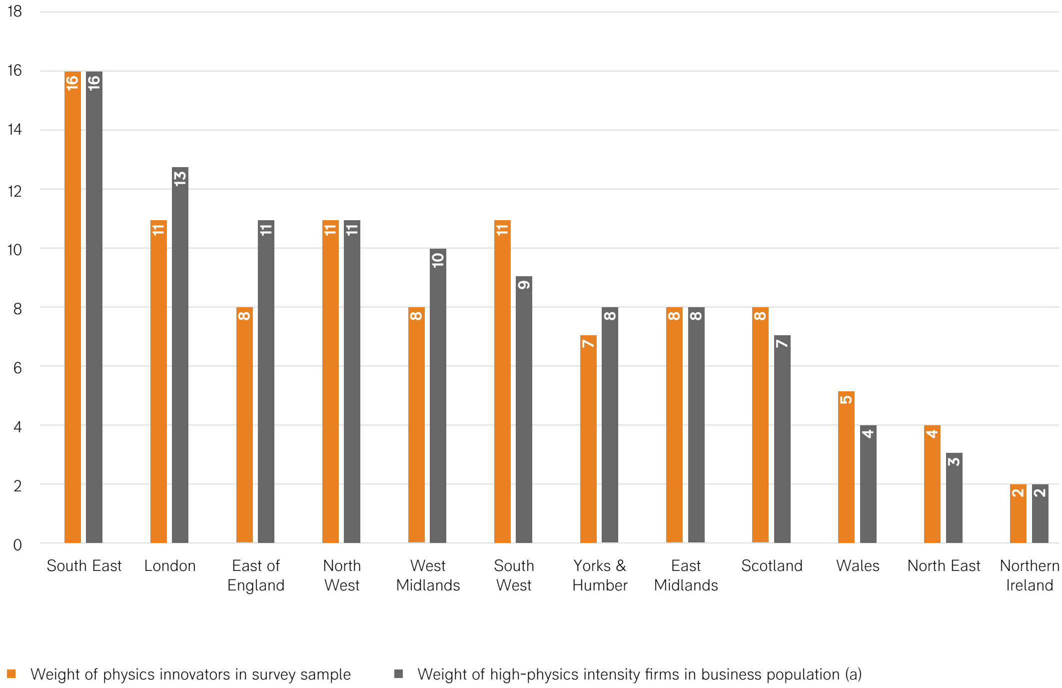
Physics-based firms operate in a broad range of sectors. IOP commissioned analysis of the geographical distribution of physics-based firms shows that they are relatively evenly distributed through the UK, ranging from around 8% of businesses in Northern Ireland to 14% in the West Midlands (unfortunately there is no equivalent data for the RoI).[19] **Exhibit A.1** shows the distribution of "high-physics" intensity firms in terms of absolute numbers, revealing that the greatest number are located in the South East.[20]

Respondents to our survey reported carrying out R&D/innovation activity in more than one location within the UK and the RoI (with an average of 1.7 regions/nations selected per respondent). Over one quarter (26%) of the respondents carried out R&D/innovation activity in the South East, for example, making this the region with the highest concentration of physics-innovators in the UK. Almost one in five (19%) had R&D/innovation in the North West, with London (18%), the South West (18%), also common locations. Overall, 10% of respondents undertook R&D/innovation activity within the RoI, with around one third of these also undertaking such activities in the UK). **Exhibit A.2** presents the relative weight of each UK region/nation in the sample, which largely mirror the distribution of high-physics firms across the regions/nations of the UK.

Exhibit A.1 High physics-intensive businesses per region/nation (% of total high physics-intensive business population)

In terms of absolute response rates, most regions/nations were sufficiently well represented in the survey to provide confidence in the results. There were at least 30 respondents reporting R&D/innovation in eight of the nine English regions, as well as in Scotland, and 29 responses for the RoI. However, the sample size for Northern Ireland (9 responses) was low in absolute terms, and results should be treated with caution. The North East (18) and Wales (24) also have relatively lower sample sizes, though to a lesser extent.

Exhibit A.2 Breakdown of IOP/CBI UK sample by region/nation compared to distribution of high-physics intensity firms (a) (%)



(a) Based on an IOP SIC-code classification of 'high physics intensity' businesses, with percentages derived using ONS's Business Struture Datbase for 2018.[25]

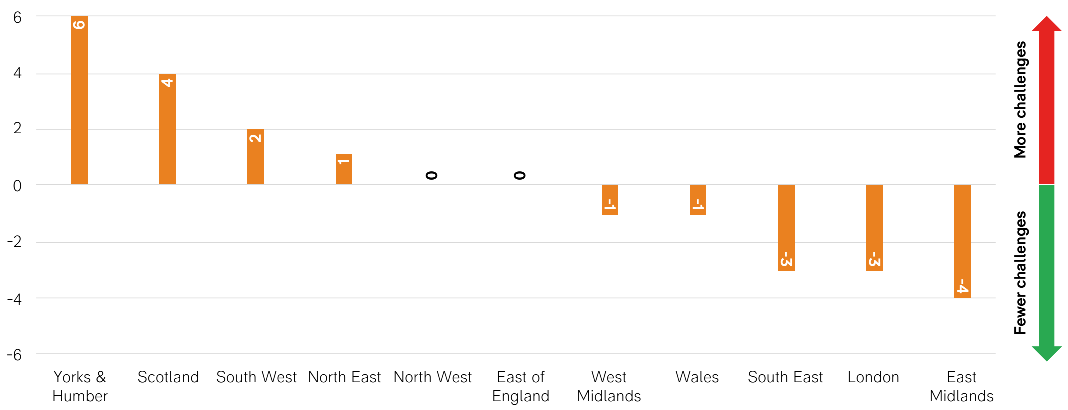
The survey asked respondents about the reasons that explain their firm's decisions to locate R&D/innovation activity in a particular region. The most common factors were having a historical presence in the area (46%) and proximity to headquarters (38%). But economic drivers were also significant, the most important being access to a skilled workforce (29%), followed by clustering effects (21%) and proximity to knowledge assets (20%), such as universities or research institutes. One in ten firms (12%) selected 'other', with several commenting that employees work from home or that location is unimportant. Other firms noted setting up where they/the firm's founder(s) were living at the time.

The UK's levelling up challenge

Recent years have seen a proliferation of studies examining regional and spatial economic disparities across Europe. The issue is particularly acute in the UK, where regional disparities are larger than in most other Western European countries. Regional differences typically have deep roots, but at least part of the explanation is the wide variation in the distribution of knowledge "assets"—skills and talent, R&D infrastructure, and thriving innovation networks.[21]

The survey adds to this evidence base, finding that physics innovators in some regions/nations were more likely to report experiencing challenges to undertaking R&D/innovation activity (ie, the eight challenges detailed in **Exhibit 1.4** in Chapter 1, such as direct costs, risks, access to finance, skills, etc). As **Exhibit A.3** shows, this was particularly the case for northern English regions (and especially Yorkshire & the Humber and the North East) and the South West. Firms in Scotland were also more likely than average to report facing challenges to undertaking R&D/innovation activity. By contrast, physics innovators in the Midlands and the Greater South East of England tended to identify fewer challenges.

Exhibit A.3 Prevalence of challenges to undertaking R&D/innovation in the UK (sum of standardised scores across all challenges)



Note: Standardised scores were calculated representing the deviation from the average for eight challenges to R&D/innovation. These were then summed to show how each region rated barriers overall. With zero representing the mean, a positive score indicates that respondents were more likely to experience challenges to R&D/innovation. Responses for Northern Ireland are excluded due to low sample size.

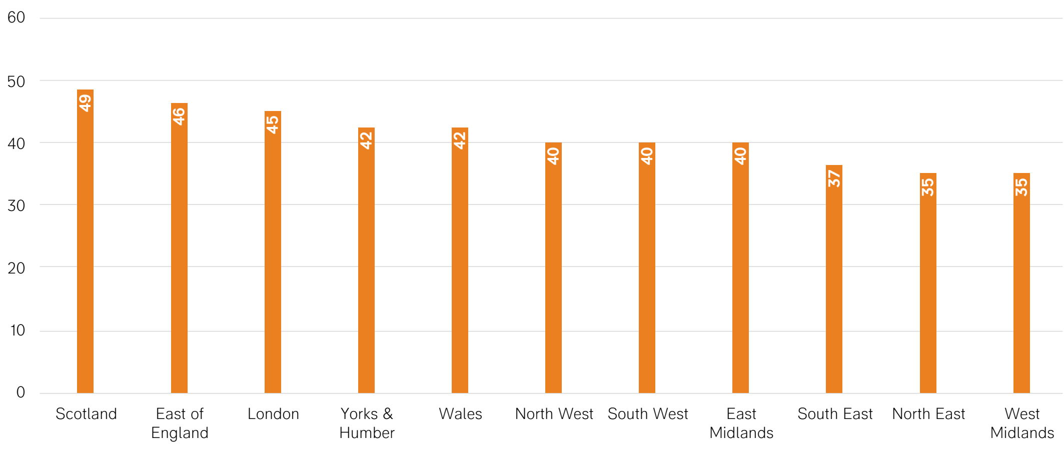
Most physics innovators face similar challenges, though skills shortages were particularly varied

We find that physics innovators' opinions about the relative significance of the challenges they face were broadly consistent across regions and nations. Thus the direct costs associated with undertaking R&D/innovation activity and potential costs/financial risks were seen as the top two concerns in all but one of the nine English regions.

In parts of the UK, however, physics innovators signalled that skills-shortages were a particularly pressing challenge (this category showed the greatest regional variation for this question). In the East of England, as well as in Scotland and Wales, skills shortages were ranked as the second most important challenge to undertaking R&D/innovation activity, while in Northern Ireland they were the leading concern. More than 40% physics innovators with R&D/innovation activity in these locations believed that skills shortages were a significant challenge to undertaking such activity.

In every region, finding people with a combination of commercial and specialist/technical knowledge has proved the most difficult challenge. But interestingly, one trend that the East of England, Scotland, Northern Ireland and Wales all had in common was that firms gave relatively high weightings to shortages of people with specialist physics-related knowledge (as did London and the South East).

Exhibit A.4 Physics innovators selecting skills shortages as a significant challenge to undertaking R&D/innovation activity (% of physics innovators with a presence in that region/nation)

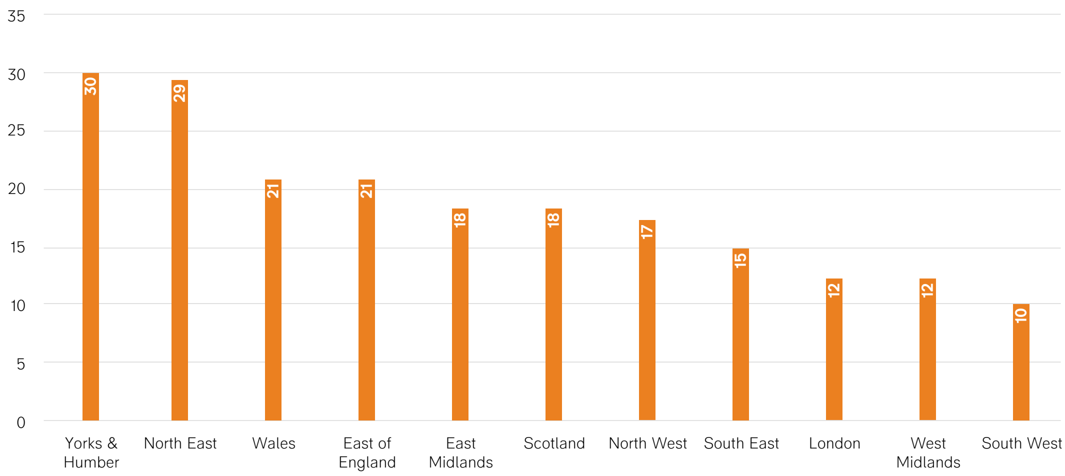


Note: Responses for Northern Ireland are excluded due to low sample size.

Around one in six physics innovators (16%) reported facing challenges from a lack of (or improper) equipment, machinery or space. These difficulties were particularly acute in Yorkshire & the Humber (30%) and the North East (29%), and to a lesser extent in the East of England (21%) and Wales (21%).

Physics innovators in the majority of regions/nations saw access to suitable facilities (buildings and space) as the most important constraint, but specific concerns were also evident in particular regions. In Yorkshire & the Humber and the North East, physics innovators were more than twice as likely to report difficulties accessing demonstration space/equipment—39% of physics innovators in the North East and 29% in Yorkshire & the Humber said that this was a constraint on their R&D/innovation activity, compared with just 14% among all UK physics innovators. In the East of England and in Wales, concerns over access to physics testing equipment were especially high, at 33% in both areas, compared with 20% among all physics innovators.

Exhibit A.5 Physics innovators selecting a lack of proper equipment, machinery or space as a significant challenge to undertaking R&D/innovation activity (% of physics innovators with a presence in that region/nation)



Note: Responses for Northern Ireland are excluded due to low sample size.

One interesting finding from the regional breakdown of the survey is that collaboration appears to be highest in the UK regions/nations that were most likely to report facing experiencing the greatest number of challenges. Thus, **Exhibit A.6** shows a measure of the extent of regular collaboration with "knowledge institutions", businesses and other networks (including trade associations, professional bodies & societies). It reveals that physics innovators in Wales, Scotland, the north of England, and the South West were more likely to collaborate regularly than were firms in the Midlands or Greater South East of England.

Exhibit A.6 Prevalence of regular collaboration over R&D/innovation activity (Sum of standardised scores across all partners/networks)

Note: Standardised scores were calculated representing the deviation from the average for eight challenges to R&D/innovation. These were then summed to show how each region rated barriers overall. With zero representing the mean, a positive score indicates that respondents were more likely to experience challenges to R&D/innovation. Responses for Northern Ireland are excluded due to low sample size.

Expanding on this further, **Exhibit A.7** explores collaboration over three aspects: skills, facilities & equipment, and finance. It plots the share of firms in each region of the UK reporting challenges with access to skills, finance and facilities & equipment, against the share of firms in the same region reporting that access to skills, finance and facilities & equipment were important drivers of their collaboration (data for Northern Ireland is excluded owing to its low sample size). Two things are immediately apparent. First, that physics innovators that experience the greatest difficulties accessing skills or facilities & equipment are more likely to seek collaboration with external partners as a means of overcoming these barriers. Second, despite acute difficulties accessing finance in some regions, physics innovators in these regions do not appear to collaborate in order to gain access to (or knowledge) about finance.

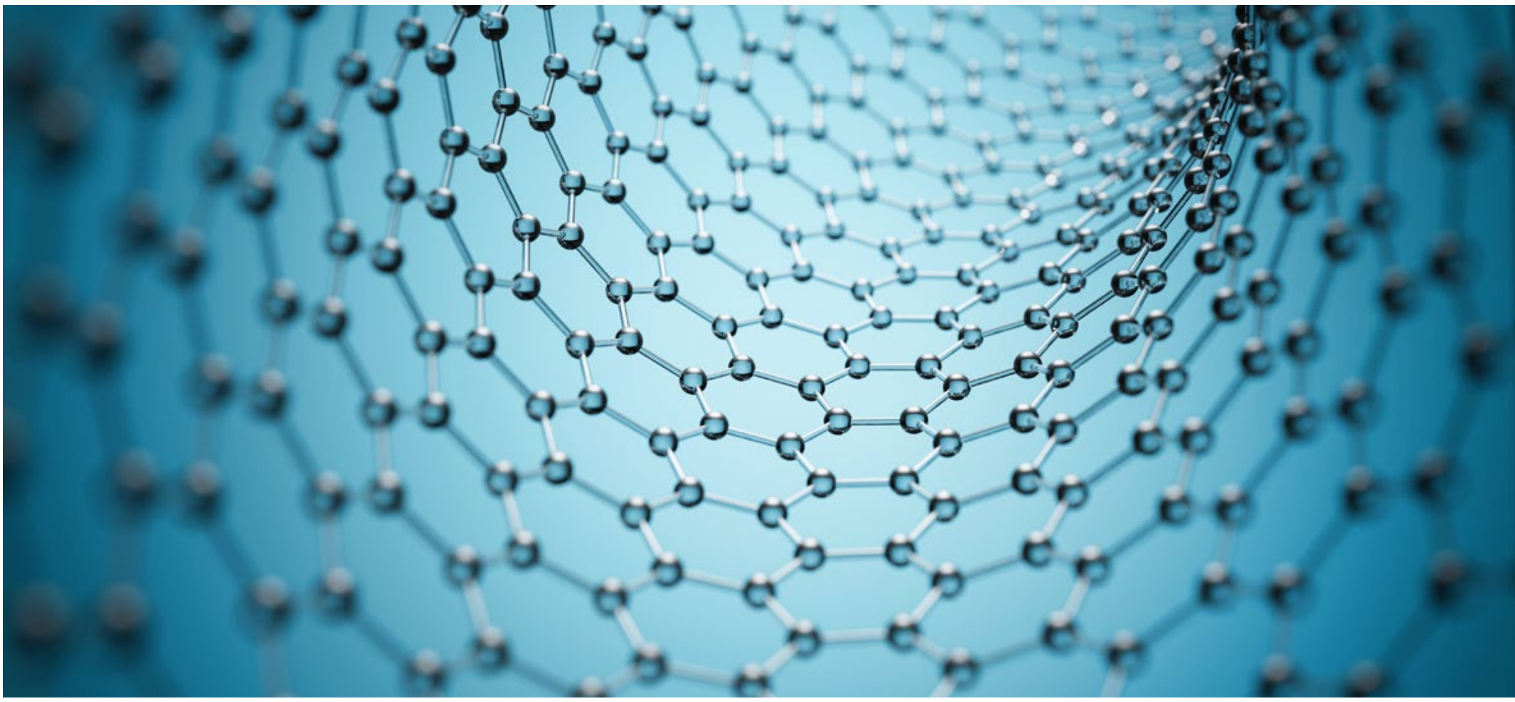
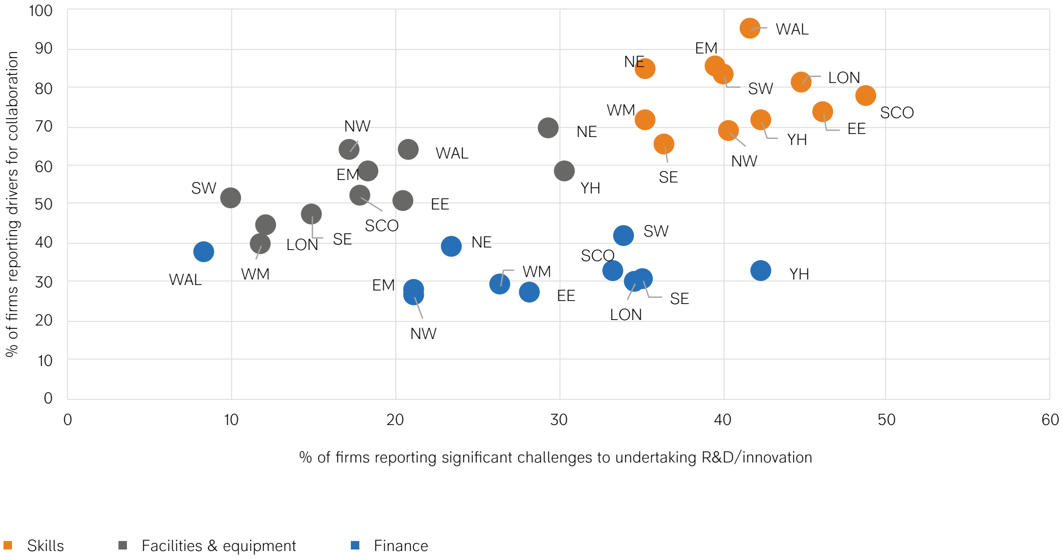


Exhibit A.7 Collaboration and access to skills, facilities & equipment, and finance, by UK nation/region



Note: Responses for Northern Ireland are excluded due to low sample size.

Scotland

The COVID-19 pandemic has disrupted physics-based R&D/innovation activity in Scotland, but a recovery is expected over the next five years. The survey included 39 physics firms with R&D/innovation centres in Scotland (henceforth referred to as Scotland innovators), with broad sectoral representation, but particular strengths in aerospace & defence (21%) and energy (18%). The survey found that 27% of Scotland innovators said COVID-19 had a positive impact on R&D/innovation, with 41% saying the impact was negative (giving a net balance of -15%). However, Scotland innovators are planning to raise spending on R&D/innovation in the next five years compared to the previous five (60% said spending would rise, with 10% saying it would fall, a net balance of +50%). With the right conditions in place, these businesses can play a key role in the ensuring that post-pandemic Scottish economy thrives.

Physics businesses undertaking R&D/innovation activity in Scotland see innovation as central to their business purpose, with 93% agreeing it is a strategic priority. Scotland innovators are motivated to invest for a multitude of reasons; to develop new products/services (90%), adapt to new technologies (72%) or changing preferences (72%). Scotland innovators are also motivated to innovate for societal benefits, with 51% looking to increase sustainability or energy efficiency and 36% motivated to advance general scientific understanding.

However, physics innovation is uniquely complex, with direct costs and risks representing significant challenges to undertaking R&D/innovation, according to 56% and 44% of Scotland innovators, respectively. Access to funding is also a key challenge for 33%, with a lack of funding most acute at the production/scale up (59%) and commercialisation (47%) end of the "innovation funnel". The production/scale up stage is also where direct costs tend to be highest (49%).

Public funding is vital for Scotland innovators, with 81% saying it is important for the activity being undertaken (compared to 70% for UK innovators). Scotland innovators received public funding from a number of sources in the past five years; 56% from the UK government (vs 51% for UK), 38% from the EU (vs 19%) and 27% receiving devolved nation funding. For 58%, this helps fill financing gaps that allow the activity to be undertaken, which is also evidenced by funding issues being cited less at the basic (29%) or applied (15%) research, where public finance tends to be most focused. Public funding has a net positive impact on attracting further private financing (33% say it attracts private financing, 8% say it acts as an alternative). Public funding also encourages more collaboration (63%), while allowing firms to improve skills (46%) and equipment (29%) which benefits future products.

Skills shortages threaten to impede plans to increase investment in physics-based R&D/innovation. Scotland innovators saw particular difficulties filling roles with specialist physics-related knowledge (45%) and a combination of technical and commercial skills (58%), with skills shortages particularly acute at the large-scale prototype and production/scaling up stages of the "innovation funnel". Around half of Scotland innovators (49%) said that skills shortages were a significant challenge to undertaking R&D/innovation. Only 7% of physics innovators said they faced no difficulties recruiting. A majority of Scotland innovators (70%) said that skills shortages led to R&D/innovation activity being suspended or delayed in the past five years, while 44% said activity was sub-contracted or outsourced. Interestingly, 44% also said that it led to increased investment in staff training, compared with only 19% for the UK overall.

Enhanced policy support could help unlock more R&D/innovation investment. A majority of Scotland innovators believe greater access to direct funding for both early-stage R&D (68%) and late-stage development (65%) could help increase spending in the next five years. Long term funding schemes were the most popular option (81%), stemming from the fact that 50% believed uncertainty over future funding to be a significant barrier to R&D/innovation. 42% also called for improved ease of navigating existing support. This is higher than for UK innovators generally (29%) which may reflect the greater variety of sources of public funding that Scotland innovators tend to receive support from.

Policy also has a role to play in supporting R&D/innovation activity in ways that go beyond addressing funding pressures. Scotland innovators were on average more likely to believe government policy and/or regulation were a significant barrier to innovation (44% vs 24% for UK). Over a third believed improved government procurement would support greater R&D/innovation activity, while around a quarter called for better digital infrastructure. Around a third also called for an improved regulatory environment, with the admin burdens of innovation protections the most negatively viewed aspect of the regulatory environment.

Wales

The COVID-19 pandemic had a more disruptive impact on physics-based R&D/innovation activity in Wales compared with the total UK. The survey included 24 physics firms with R&D/innovation centres in Wales, from a range of manufacturing (46%) and services (26%) sectors, as well as other broad sectors. It found that 60% of physics innovators with a presence in Wales (henceforth referred to as Wales innovators) said COVID-19 has had a negative impact on R&D/innovation, with 20% saying the impact was positive—the resulting net balance of -40% was weaker than in the UK as a whole (-20%). However, the survey, suggests that Wales innovators are optimistic that spending on R&D/innovation will increase in the next five years compared to the previous five years (68% saying spending would rise, with 11% saying it would fall, a net balance of +58%). Fulfilling these ambitions will mean ensuring that physics innovators can access the skills, capabilities and resources they need. In particular, tackling the barriers that can inhibit access to available public support will be vital for ensuring that physics innovators can play their part in advancing the levelling up agenda in Wales.

Their ambitions and intent are clear. Physics innovators undertaking R&D/innovation activity in Wales see innovation as central to their business purpose, with 95% agreeing it is a strategic priority. Across Wales, physics innovators are motivated to invest for a multitude of reasons; to develop new products/services (88%) and grow the company (83%), to adapt to new technologies (71%) or changing preferences (54%). Wales innovators are also motivated to innovate for societal benefits, with 48% looking to increase sustainability or energy efficiency and 33% motivated to advance general scientific understanding.

However, physics innovation is uniquely challenging, with direct costs representing the most significant challenge to undertaking R&D/innovation (58% of Wales innovators vs 50% for the UK as a whole). As in the rest of the UK, labour costs were seen as the most significant direct cost (86% for both), but Wales innovators were much more likely to cite lab or workshop costs as a significant direct cost (48% vs only 23% for the UK). Similarly, insufficient access to physical testing equipment (33% vs 21%), laboratories (22% vs 12%), and simulation or demonstration facilities (22% vs 14%) was also more likely to be seen as a potential limitation for undertaking R&D/innovation.

Skills shortages also present a significant obstacle to increasing investment in physics-based R&D/innovation in Wales (42%), as was the case elsewhere in the UK (40%). Roles with a combination of technical and commercial skills (61%) were hardest to fill, with shortages seen as particularly acute at the large-scale prototype stage of the “innovation pipeline”. Only 5% of physics innovators said they faced no difficulties recruiting. A majority of Wales innovators (79%) said that skills shortages led to R&D/innovation activity being suspended or delayed in the past five years, while 43% said activity was sub-contracted or outsourced.

Public support plays a vital role in supporting R&D/innovation. Of the 24 firms in the sample with R&D/innovation centres in Wales 75% had received funding from the UK government (vs 51% for the UK as a whole), 50% had received funds from the EU (vs 19%) with 25% receiving devolved administration funding. The vast majority (90%) of these firms described it is “very” or “moderately” important for the activity being undertaken (compared with 71% for the UK as a whole). For most, this helps fill financing gaps that allow the activity to be undertaken (56%), while also encouraging more collaboration (63%) and helping to develop relevant skills (56%), benefitting future projects. It was noteworthy that Wales innovators in the sample were much less likely to report that access to financing was a significant barrier than the UK as a whole (8% vs 32%).

Further policy enhancement could help unlock more R&D/innovation investment. In particular, 45% of Wales innovators saw easier navigation of existing support as a key enabler for R&D/innovation activity, which was significantly higher than in the rest of the UK (29%). A focus on long-term funding schemes was the most popular option (75%), while a majority of Wales innovators also believed greater access to direct funding for early-stage R&D (60%) and late-stage development (60%) could help increase spending in the next five years.

Wales innovators collaborate more regularly with key knowledge institutions (such as universities or research/innovation institutions), business partners and peer networks/associations than in the UK as a whole. Overwhelmingly (100%) they collaborate to gain knowledge/information on opportunities or technical matters, with 95% also saying they do so to gain access to expertise/skills and 63% to gain access to facilities and equipment. And with 54% of Wales innovators saying improved opportunities to collaborate were a key driver of their plans to increase investment (vs 35% in the UK as a whole), these partnerships may be central to realising R&D/innovation goals.

Republic of Ireland

For the majority of physics innovators in the Republic of Ireland (RoI), the COVID-19 pandemic was a source of disruption. The survey included 29 responses from physics innovators with R&D/innovation activities taking place in the RoI (henceforth known as RoI innovators), with broad representation across sectors, but a particular strength in computing & electronics (28%). It found that 26% saw a positive impact on R&D/innovation activity, but 57% saw a negative impact, giving a net balance of -30%, a little weaker than in the UK (-20%). Nonetheless, RoI innovators expect to increase investment in R&D/innovation in the five years ahead (a net balance of +74% vs 59% in the UK). These businesses can help the RoI government achieve its goals to raise R&D spending (a target of 2.5% of GNP was set under the 2015-20 innovation strategy, though this was not met). However, this may require ensuring greater access for smaller and medium-sized firms for R&D/innovation support, action to strengthen links between physics researchers and industry, and ensuring that the RoI remains an attractive location for highly skilled workers from abroad.

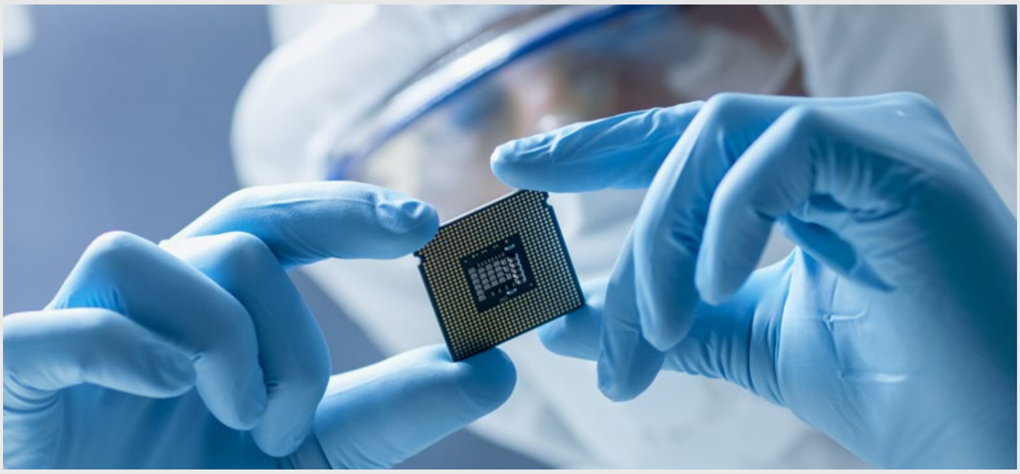
R&D/innovation activity is a strategic priority for the vast majority of RoI innovators (86%). As was the case in the UK, RoI innovators cite many motivations for undertaking R&D/innovation: to develop new products/services (86%) and grow the company (76%), or to adapt to new technologies (69%) or changing market/consumer preferences (66%).

Physics innovation is seen as costly and risky in the RoI (as well as in the UK). The direct costs (54%) and risks (61%) associated with R&D/innovation were seen as the two most significant challenges to undertaking such activity (vs 50% and 46% in the UK, respectively). Access to funding is also a key challenge (43% of vs 32% in the UK). Compared with the UK, RoI innovators appeared to experience fewer difficulties securing funding at the basic R&D stage (25% vs 36% in the UK). Funding pressures were most acute at later stages in the R&D/innovation pipeline, notably demonstration (46% vs 19% in the UK) and production/scaling up (42% vs 40% in the UK) stages.

This suggests that public funding for early stage R&D is helping RoI innovators, which were more likely than their UK counterparts to have benefitted from support over the past five years. For example, 68% of RoI innovators had received funding from the Irish government, compared to 51% of UK innovators receiving UK government funding. Support from EU funds was also more common in the RoI: 40% vs 19% in the UK. For 70% of RoI innovators, public funding helped fill financing gaps, without which the activity would not have been undertaken. A further 30% said that public funding helps attract private investment, increasing total resources for projects. Only 10% of RoI innovators said public funding acts as an alternative to private funding. Long-term benefits of public support include more collaboration (55%), the development of skills (60%) and improvements to equipment//infrastructure (45%) that benefit future products.

Although RoI innovators expect to raise spending on R&D/innovation in the five years ahead, policy intervention could increase this further. The overall level of policy support for R&D is below the OECD average and skewed more heavily towards tax credits than direct funding.[22] A majority of RoI innovators believe greater access to finance (ie loans), direct funding for early-stage R&D and direct funding for late-stage development (63% for all three options) could help increase spending in the next five years. Long term funding schemes were also a popular option (65%), while 52% called for support to de-risk capital investment.

Interestingly, although the RoI offers a relatively generous tax subsidy rate for R&D by OECD standards,[23] a majority of RoI innovators (52%) believed a more attractive tax rate for R&D would further increase R&D/innovation spend in Ireland in the next five years. This was particularly the case among Ireland-owned innovators, with only 27% of foreign-owned firms calling for an improved tax environment. The make-up of the sample for the RoI may help explain this: the survey included responses from a number of large, foreign-owned firms based in the RoI, which may already be benefiting from R&D tax credits.[24] This suggests that enhancing the tax environment for R&D could provide further benefits for small- and medium-sized innovators in particular.



As noted above, the benefits of public funding go beyond financial considerations, with the survey pointing to long-term legacy benefits from improved skills and facilities & equipment. Nonetheless, almost half (46%) of RoI innovators cited skills shortages as a key challenge to undertaking R&D/innovation activity, slightly higher than for the UK (39%). Only 5% of RoI innovators said they faced no difficulties recruiting. The roles that RoI innovators had most difficulties filling were those requiring a combination of technical and commercial skills (38%) and data analytics (38%). The two most important factors driving skills shortages in RoI were the competition for talent (64% of RoI innovators) and the opportunities for potential applicants to get better compensation elsewhere (50%). This was a very different picture to the UK, where the most commonly cited factors were a lack of relevant skills (46% vs 36% in RoI) or experience (40% vs 27% in RoI) in the applicant pools. A majority of RoI innovators (61%) said that skills shortages had caused R&D/innovation activity to be suspended or delayed in the past five years, with 33% saying the activity had not been undertaken at all. To overcome skills shortages, 44% had tried to recruit from outside the RoI (33% did so successfully), compared to only 16% in the UK.

RoI innovators were less likely than their UK counterparts to say that a lack of proper equipment or space was a significant barrier (7% vs 17% for UK). Greater collaboration with "knowledge institutions" (such as universities, research institutes, etc) may help explain this. RoI innovators were more likely than UK innovators to say that a benefit of public funding was to enable improvements to equipment or infrastructure (45% vs 31%). They were also more likely to access facilities through higher/further education partners (52% vs 34%) and through public/private partnerships (eg Science Foundation Ireland centres; 35% vs 17%). The smaller number of companies and higher education/research institutes in the RoI than in the UK may make it easier to manage collaboration. Nonetheless, in the RoI (as in the UK) collaboration with external partners/networks tends to drop-off beyond early-stage R&D, suggesting there are opportunities to improve collaboration during later stages the innovation pipeline (such as demonstration).

Northern Ireland

**Note: The survey results from Northern Ireland are based on a small sample of only nine responses. The following text compares the results for Northern Ireland with those of whole sample (the UK and Ireland), highlighting where there are similarities or differences. However, due to the small sample the percentages for each question have been omitted.*

For physics innovators in Northern Ireland, the onset of the COVID-19 pandemic added to the disruption caused by Brexit over the previous five years. Of all the regions represented in the survey, Northern Ireland appears to have been most vulnerable to Brexit-related uncertainty, with physics innovators based there the most likely to report a negative impact from Brexit over the past five years. Nonetheless, Northern Ireland innovators are looking to the future, with a majority expecting to spend more on R&D/innovation in the next five years compared with the previous five.

Physics innovators, including those in Northern Ireland, overwhelmingly see R&D/innovation as a strategic priority for their firms, incorporated into business plans across the organisation. Most Northern Ireland innovators in the sample undertook such activity to develop new products/services, improve cost competitiveness and grow the company/achieve market share.

However, physics innovation is uniquely challenging and firms seeking to undertake such activities are presented with a multitude of specific hurdles to overcome. For the Northern Ireland innovators in the sample, the most commonly cited concern was skills shortages (which was the third biggest barrier the UK as a whole, as well as for Ireland). As elsewhere, roles requiring a combination of commercial and specialist/technical skills were the most difficult to fill, while physics innovators in Northern Ireland were the most likely out of any other region/nation to report difficulties recruiting people with specialist physics-related knowledge. Skills shortages were most prevalent at the large-scale prototype and production/scaling up stages of the innovation pipeline, in line with the trend in the UK and Ireland. Almost all Northern Ireland innovators said that in the past five years, skills shortages led to R&D/innovation activity being suspended or delayed.

Reflecting these challenges, perhaps, Northern Ireland innovators appear to be more collaborative than their counterparts elsewhere in the UK and in Ireland, with a majority reporting they regularly engage with universities, public sector research bodies, and public/private partnerships (such as Catapults). Such partnerships were largely driven by the need to gain knowledge on opportunities or technical matters, as well as to gain access to expertise/skills (a trend highlighted in the Seagate case study in Chapter 4).

Public funding is seen as vital for Northern Ireland innovators, with most saying it is "very important" for R&D/innovation activity being undertaken. A majority received funding from the UK government in the past five years, with around half receiving devolved nation funding and one quarter receiving EU funding. Public support was widely regarded as filling financing gaps (without which R&D/innovation could not be undertaken), while also helping to attract additional private financing. In addition to these benefits, public funding was seen to encourage more collaboration, while allowing firms to improve skills and introduce organisational changes which benefits future projects.

Northern Ireland innovators see scope for policy intervention to help unlock more R&D/innovation investment in the five years ahead. A majority of Northern Ireland innovators believe greater access to direct funding for early-stage R&D and late-stage development could help increase spending in the next five years. Long term funding schemes were also a popular option. Given the particular circumstances of Northern Ireland following Brexit, it was perhaps no coincidence that Northern Ireland innovators see a greater role for export support than in any other region/nation.


09.8

Appendix 2: Methodology and sample

This report provides the findings of a survey run by the Confederation of British Industry (CBI), commissioned by the Industry of Physics (IOP), that was in field between 14th May and 2nd June, 2021. The survey was primarily targeted at senior/C-suite level contacts of "physics-based" firms that undertake some R&D/innovation activity within the UK and/or RoI. The contact was then asked to respond on behalf of the organisation.

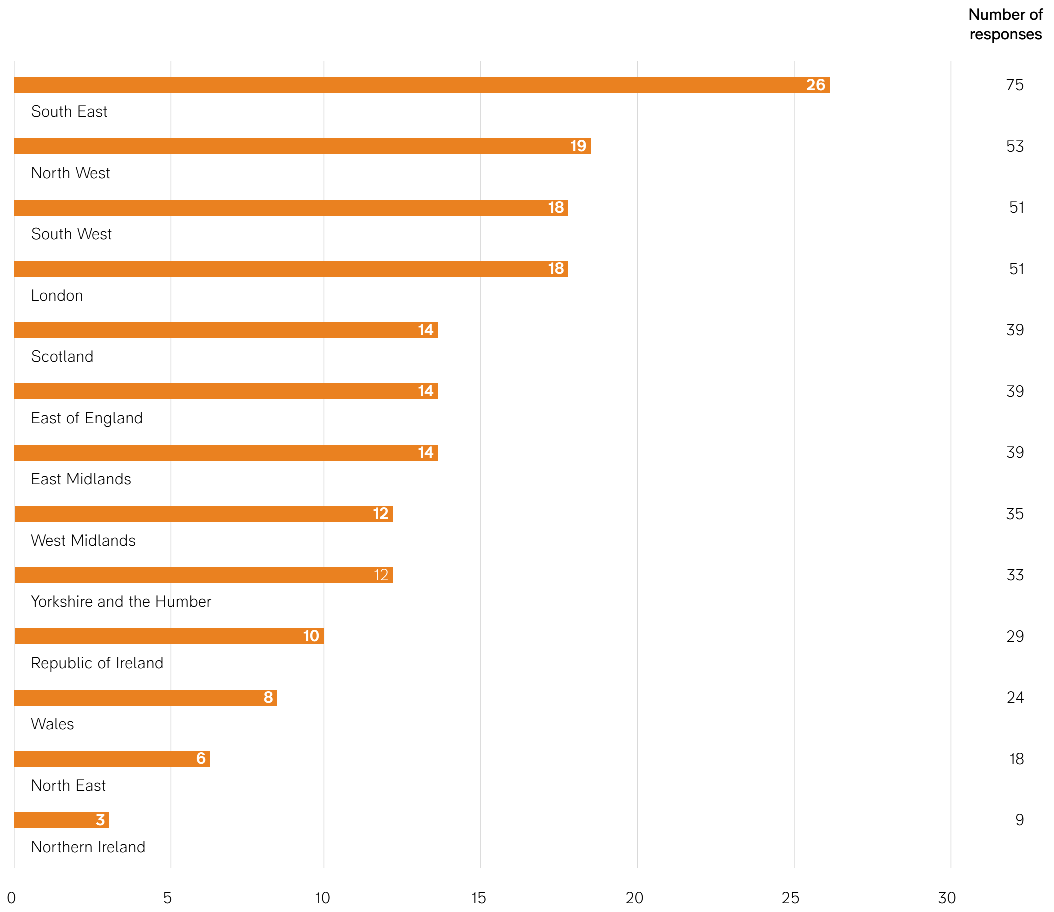
A two-pronged approach was followed to ensure that a sample consisting of only physics-based firms undertaking R&D/innovation was achieved. First, businesses were targeted to fill out the survey based on a categorisation developed by the IOP that classifies each four-digit SIC codes as either "high", "medium" or "low" in their engagement with physics. The survey was sent via email to businesses falling in either the "high-" or "medium-" physics groups only. This was supplemented by targeting of companies that were identified by the IOP as having received public funding for physics-related R&D/innovation activity. IOP and CBI members seen as likely to be physics-based innovators were also targeted, as well as members of the Ibec, the Irish Business and Employers Confederation.

The targeting of certain firms increased the likelihood that a respondent was both 'physics-based' and undertook R&D/innovation activity, but it did not ensure it. To do this, respondents were asked to identify if any physics-based technologies or research areas out of a list of 42 were relevant to their operations. Those respondents who didn't select any were filtered out of the survey, with the remainder being labelled as "physics-based firms". These respondents were then asked if they undertook R&D, product innovation or process innovation within the past five years. Those who didn't were filtered out and the rest were labelled "physics innovators" and proceeded to the main part of the survey.

Overall, 372 respondents entered the sample, with 329 identified as physics-based firms and 304 identified as physics innovators. This indicates that the methods discussed above were largely successful in targeting physics-based innovative firms.

Over half of the sample (55%) came from the manufacturing sector. Within this, the most represented sub-sectors were computers/electronics (11%), aerospace & defence (7%) and other manufacturing (21%). A further 24% of the sample came from the services sector, of which 11% were scientific & technical services and 6% were from professional services. The energy sector was also well represented (12%), while 6% of respondents came from the construction sector. The remainder came from the primary sector or water & gas sectors.

Exhibit A.8 Location of R&D/innovation operations (% of physics innovators)



Physics-based firms are relatively evenly distributed through the UK and RoI **(see Exhibit A.1 in Appendix 1)**. Respondents to our survey also reported carrying out R&D/innovation activity in more than one location (with an average of 1.7 regions/nations selected per respondent). Over one quarter of respondents (26%) carried out R&D/innovation activity in the South East, for example. Almost one in five (19%) had R&D/innovation in the North West, with London (18%), the South West (18%), also common locations.

In terms of regional response rates, most regions/nations were sufficiently well represented in the survey to provide confidence in the results. There were at least 30 respondents reporting R&D/innovation in eight of the nine English regions, as well as in Scotland. However, the sample size for Northern Ireland (9 responses) was low, and results should be treated with caution. The North East (18) and Wales (24) also have relatively lower sample sizes, though to a lesser extent. The sample includes 29 physics-innovators that had innovation/R&D operations in the RoI.

A separate question found that 71% of respondents were UK-owned, 6% were RoI-owned, while 18% were foreign-owned. Within this, 78% of firms with a presence in the UK were UK-owned, while 17% were foreign-owned and 1% were RoI owned; 52% of firms with a presence in the RoI were RoI-owned, with 17% UK-owned and 24% foreign-owned.

Table A.1 Breakdown of respondents by headcount (% of respondents with at least one employee in that country)

Size	UK		RoI	
	Percentage	Count	Percentage	Count
Micro (1 – 9)	28%	79	21%	12
Small	33%	92	35%	20
Medium	17%	47	28%	16
Large (250+)	22%	60	17%	10

278 respondents said they had at least one employee in the UK, 58 had at least one employee in the RoI. The samples were reasonably well balanced across size bands. However, a smaller total sample for the RoI suggests a degree of caution is needed when comparing results across size bands.

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October 2021

Product code: 12687

cbi.org.uk