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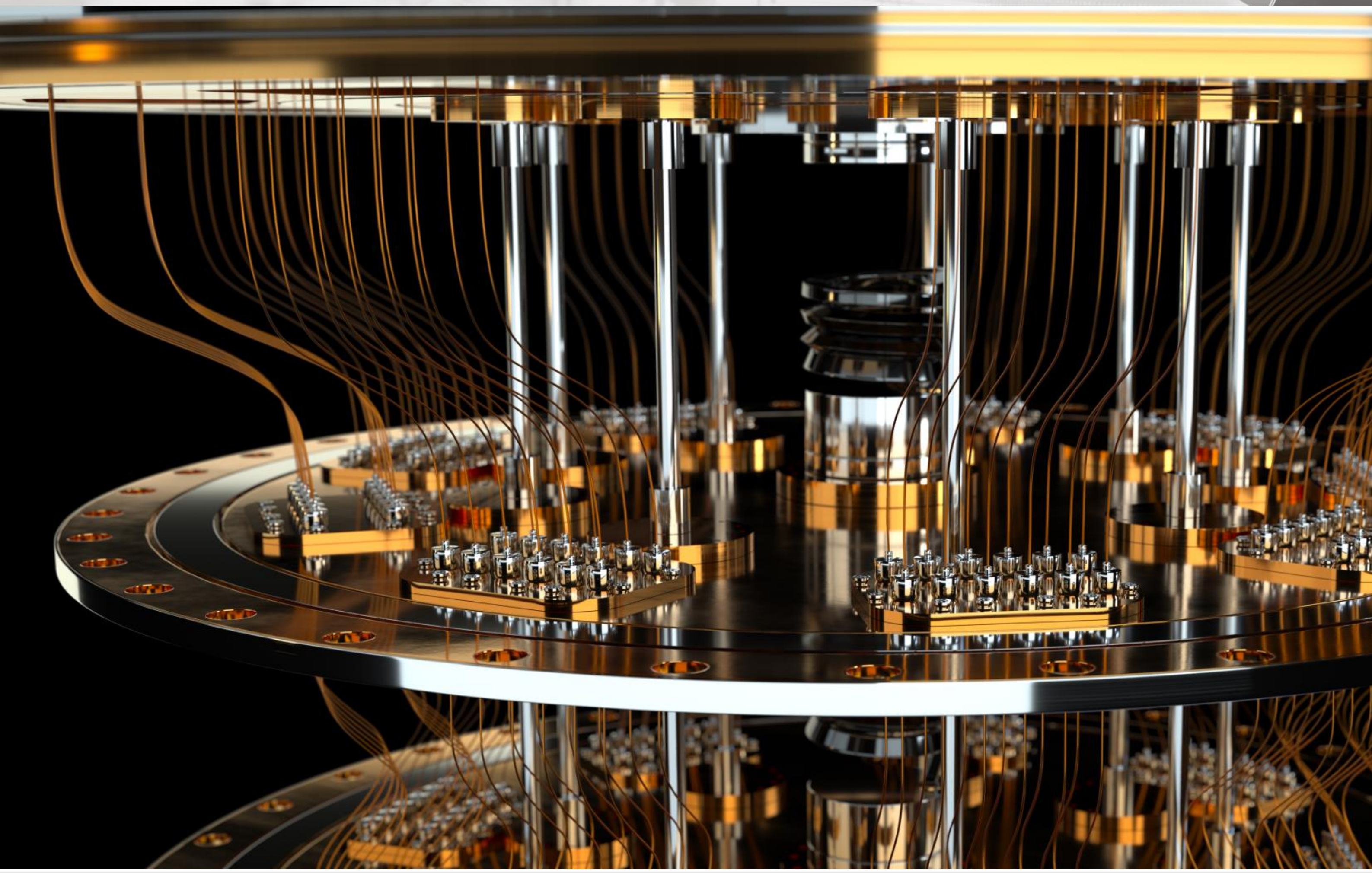


Paradigm Shift: Quantum Innovation

Opportunities and challenges for quantum innovators:

Results of the IOP/CBI Physics Innovation Survey, 2021

March 2022

Commissioned by

IOP Institute of Physics

Contents

Key findings

- **Across the UK and the Republic of Ireland (RoI), quantum innovators[1] are actively investing in scientific discovery and technology**, driven by the goal of developing new products or services and adapting to the emergence of new technologies.

- The COVID-19 pandemic disrupted R&D/innovation activity, but **quantum innovators indicated 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 quantum-based firms play their part in helping the UK government achieve their R&D roadmap ambitions.

- **Quantum physics innovation is costly and risky**, more so than for other physics-based innovation areas. This gives rise to complex financing needs that must be sustained over time. Costs and finance pressures are most acute at the production and scaling up stage of the R&D/innovation journey.

- **Public funding for quantum-related R&D/innovation projects helps attract private investment and generates a return for wider society** through the development of new quantum-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.

- **Skills shortages threaten to derail plans to increase investment in physics-based R&D/innovation**, causing delays to projects, missed targets and missed opportunities. This is especially true for quantum innovators, which face more widespread skills shortages than other physics innovators. Quantum firms report a shortage of people with the physics and/or data skills necessary for quantum innovation, but also those with a blend of technical and commercial skills, with the most acute shortages faced at the commercialisation stage of the innovation pipeline.

- **Quantum innovators frequently benefit from partnerships with other businesses or universities** to access the facilities and equipment they need to undertake R&D/ innovation, as well gaining invaluable knowledge and access to skills. But for a significant minority of quantum innovators, 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.

[1] A quantum innovator is a physics innovator who responded to the survey and selected quantum technologies as an answer to the question “Which of the following technologies, research areas and/or techniques relate to your company? Please tick all options that your firm uses for research purposes, for innovation or for the production of products, including use within your supply chains.”

Methodology

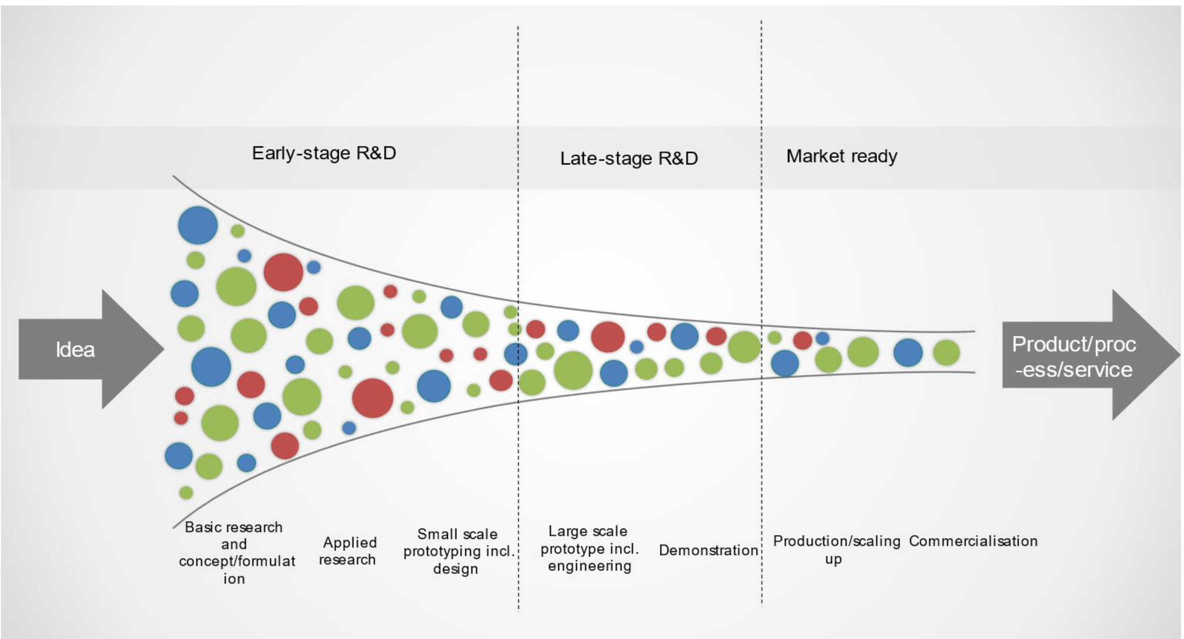
This report provides an overview of the findings of a survey run by the Confederation of British Industry (CBI), commissioned by the Industry of Physics (IOP), that was in field between 14th May and 2nd June 2021. The survey was primarily targeted at senior/C-suite level contacts of “physics-based” firms 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 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 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 that 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.

Figure 1 **The pipeline stages of physics R&D/innovation**



The quantum sample

- Out of 304 physics innovators that responded to the survey, 37 selected quantum technologies as an answer to the question "Which of the following technologies, research areas and/or techniques relate to your company? Please tick all options that your firm uses for research purposes, for innovation or for the production of products, including use within your supply chains."

- These 37 "quantum innovators" operated in a number of sectors, most commonly scientific & technical services (27%), aerospace & defense and "other manufacturing/industrial" (both 14%), as well as computers/electronics and professional services (both 11%).

  - Physics innovators that reported they were not involved with quantum technologies (henceforth referred to as "non-quantum innovators") most commonly operated in 'other manufacturing/industrial' (23%), computers/electronics (11.2%) and scientific & technical services (8.2%).

- All 37 quantum innovators reported having at least one employee in the UK. Overall, quantum innovators in the sample tended to have larger UK workforces than non-quantum innovators in the sample. We have noted below where this may be a factor driving differences with the non-quantum sample.

  - Quantum innovators were more likely than non-quantum innovators to employ 500 or more staff in the UK (35% vs 14% of non-quantum innovators with at least one UK employee).

  - Quantum innovators were also less likely to employ 1-50 staff (38% vs 65% of non-quantum innovators with at least one UK employee).

- 40% of quantum innovators reported having at least one employee in the Republic of Ireland, a similar share to non-quantum innovators (34%).

- The majority of quantum innovators in the sample were UK-owned (76%), with 22% being owned beyond the UK or Ireland. The figures were similar for non-quantum innovators (71% and 17%, respectively).

Innovation activity

- Quantum innovators undertook a broad range of R&D/innovation activity on the whole, with an average of 4.4 out of five R&D/innovation activities being undertaken by respondents in the one-year period prior to responding to the survey (Table 1 below shows the full results).
    - Quantum innovators undertook a broader range of R&D/innovation activity on average than non-quantum innovators (3.8 out of 5). This may be at least partially driven by the fact that quantum innovators tend to have larger UK workforces, which, as noted in the main report, was found to be linked to the breadth of R&D/innovation activity undertaken.
- Quantum innovators were most likely to undertake R&D/innovation activity in the South-East of England (47%), or London (39%).
    - Quantum innovators undertake such activity in 2.5 regions of the UK and/or Ireland on average. This is more than for non-quantum innovators (1.6), which may be at least partially driven by the fact that quantum innovators tend to have larger UK workforces.

Table 1 "Which of the following R&D or innovation activities has your organisation undertaken during the last five years?" (% of respondents)

	In the last year	Not within the last year, but within the last five years	Not in the last five years
Research R&D to gain new knowledge or utilise new knowledge for a practical purpose	91	6	3
Development R&D to facilitate future product development	94	3	3
Product/service innovations - to improve the commercial value of product/service (quality, design, usability etc)	97	3	0
Process innovations - to directly improve the production process of the product (efficiency, etc)	81	14	6
Business practice innovations – to indirectly improve the production process (supply chain management, quality management, knowledge management etc)	78	11	11

- A majority of quantum innovators pointed to a historical presence (56%) as a factor explaining the location of their R&D/innovation activity.
    - Quantum innovators were more likely to report being set up near a known cluster (33% vs 19%), university (28% vs 18%) and physical infrastructure (25% vs 10%) as factors explaining the location of their R&D/innovation activity than non-quantum innovators.
- When asked about significant challenges to undertaking R&D/innovation activities, a majority of quantum innovators pointed to the direct costs of innovation (57%) and uncertainties or risks related to undertaking such activity (51%), as Chart 1 shows.
- Chart 2 below shows that the most common motivation for undertaking R&D/innovation activity for quantum innovators was to develop new products/services (90%).
    - Quantum innovators were more likely to be motivated by the need to adapt to the emergence of new technologies (72% vs 53%) and by advancing general scientific understanding (50% vs 24%) than their non-quantum counterparts.

Chart 1 Significant barriers that physics innovators face when undertaking R&D/innovation activity (% of respondents)

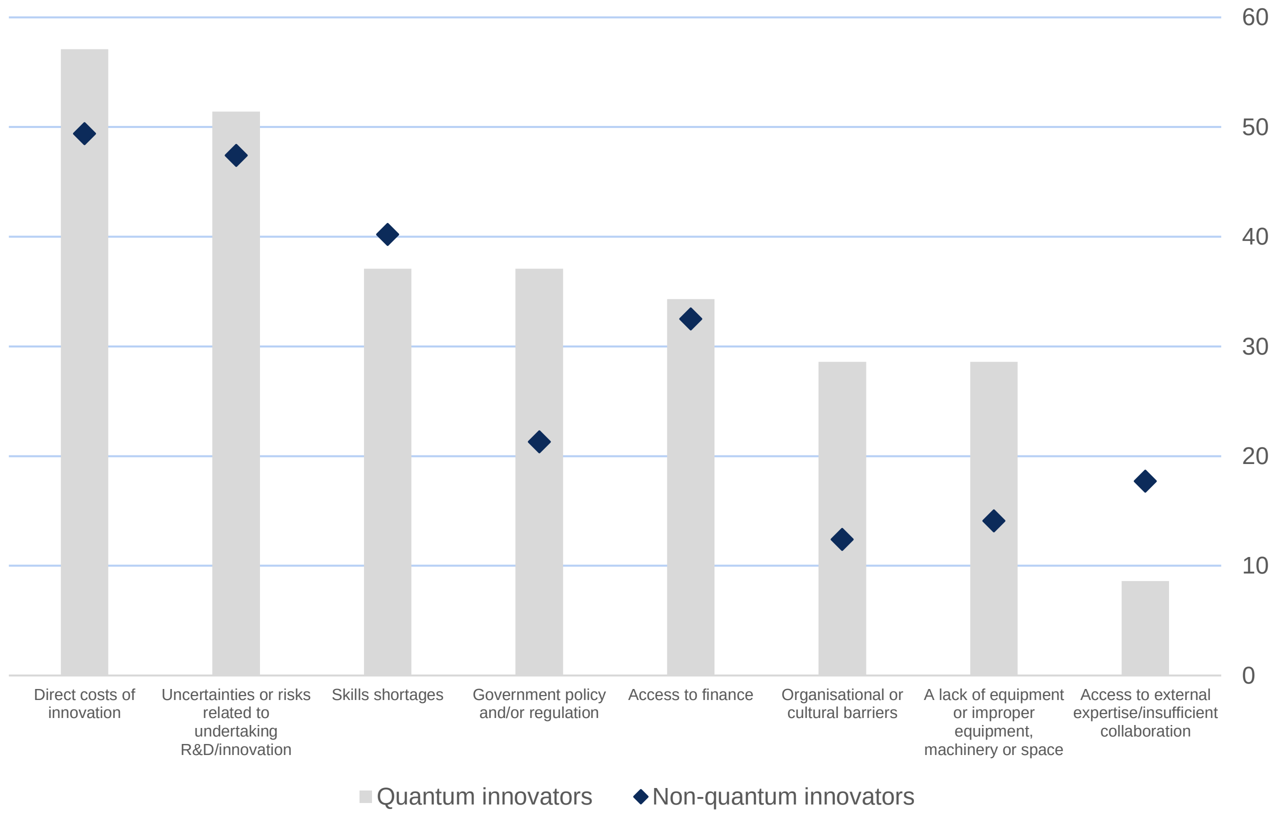
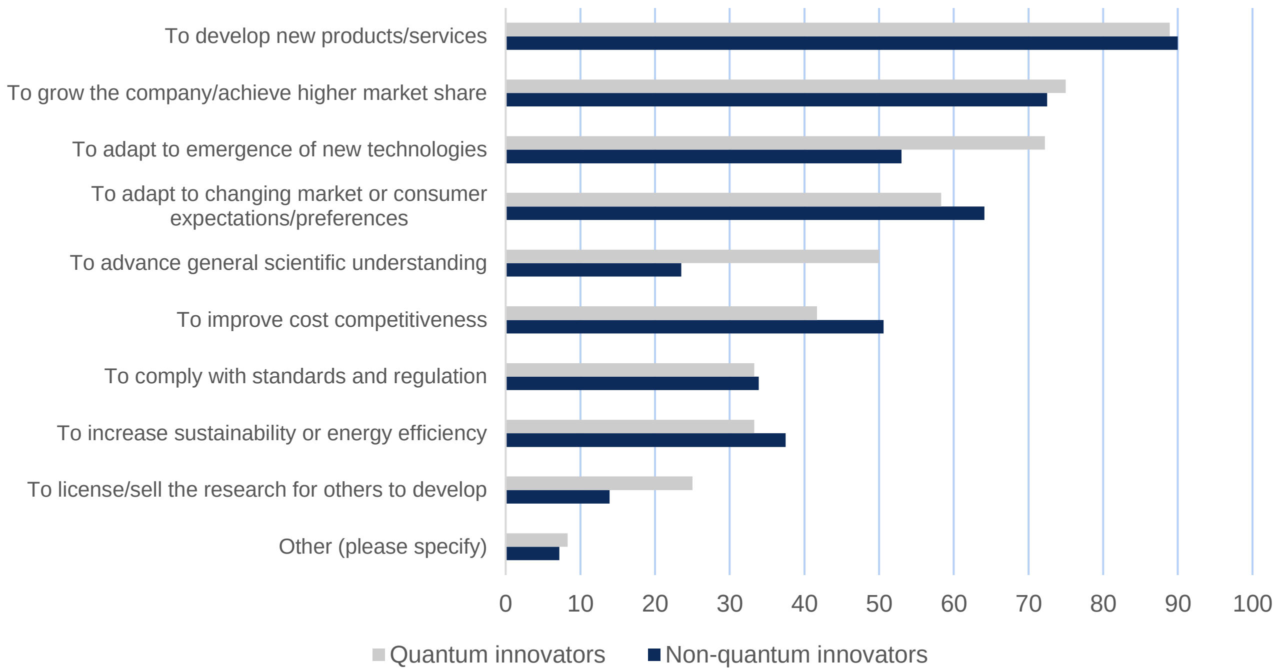


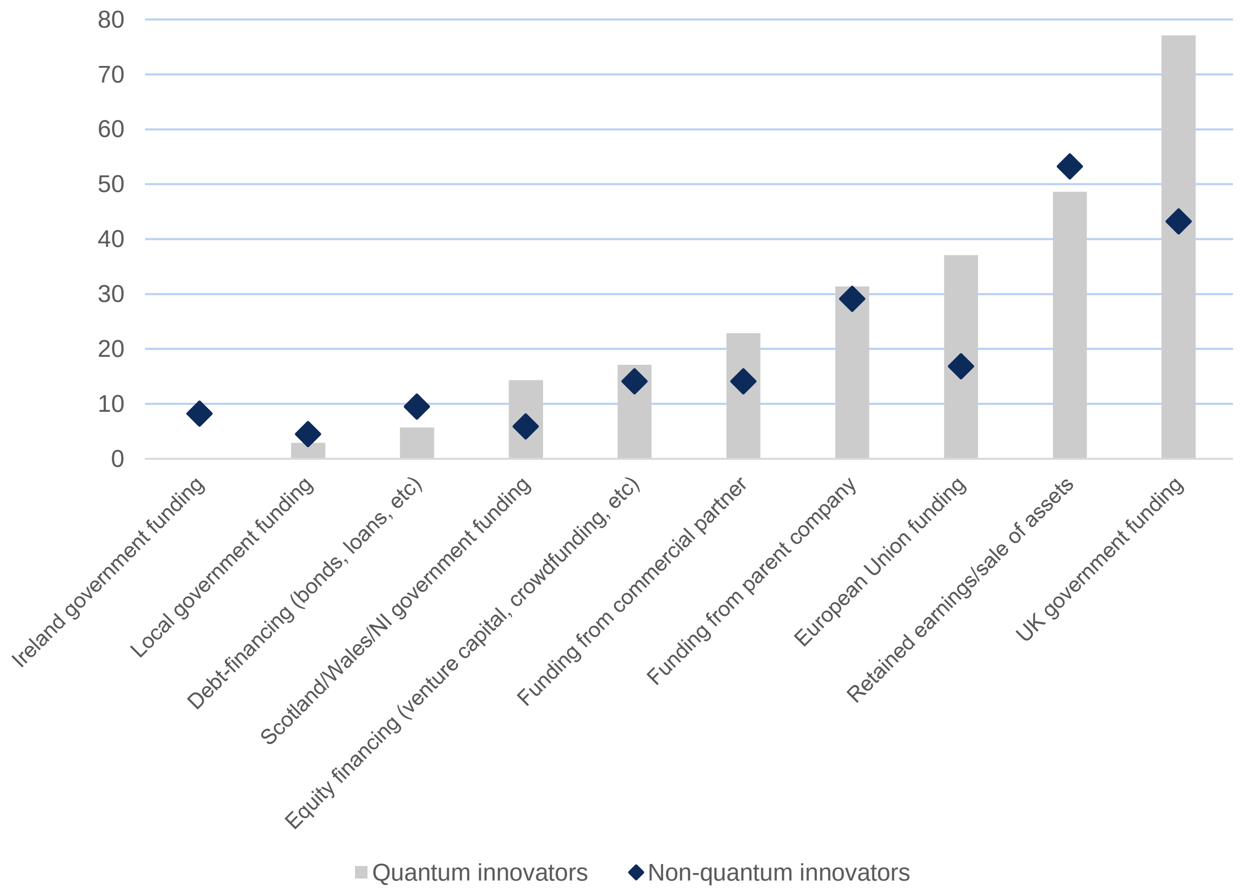
Chart 2 Why physics innovators undertook R&D/innovation activity (% of respondents)



Finance and costs

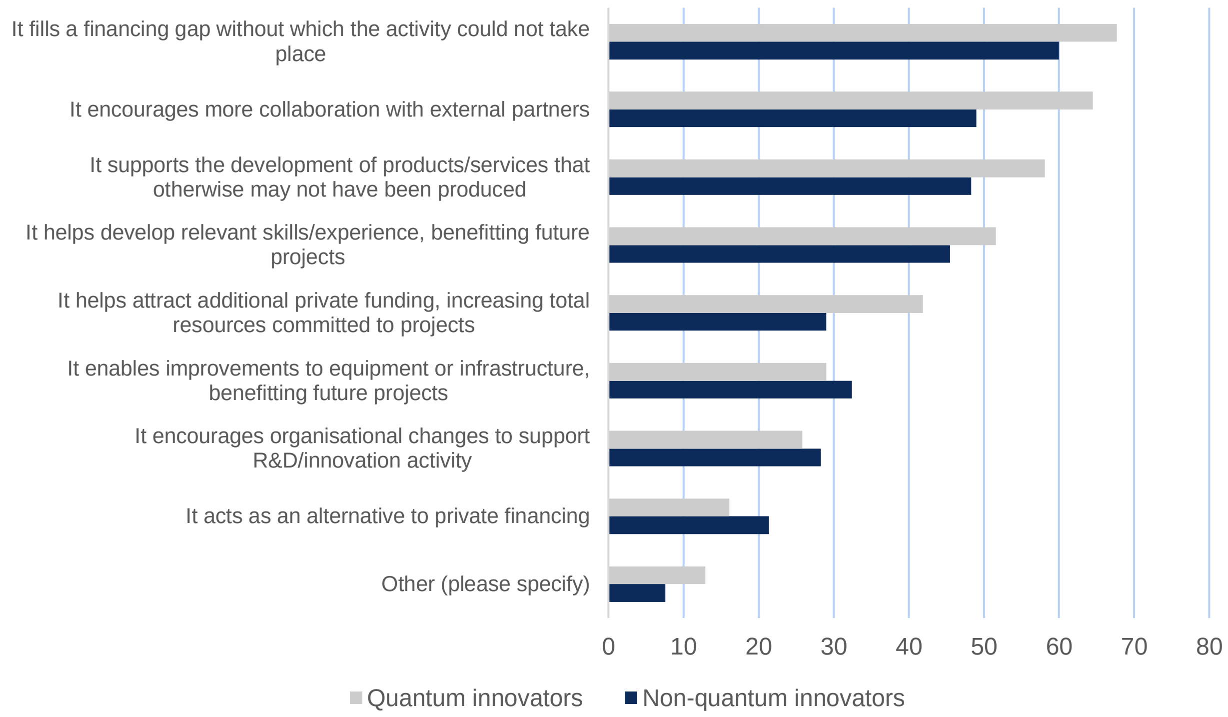
- Quantum firms were more likely to have been recipients of UK government funding for R&D/innovation activity than non-quantum innovators (77% vs 43%, respectively). As Chart 3 below shows, quantum firms were also more likely to have used funding from devolved governments or EU institutions.
    - Among non-public sources of funding, quantum firms were most likely to be draw on retained earnings/sale of assets (49%) to fund R&D/innovation activity or funding from a parent company (31%).
    - Quantum innovators cited more sources of funding than non-quantum innovators on average (2.6 vs 2.0, list of options in Chart 3 below), a result which may be at least partly driven by the fact that quantum innovators tend to be larger.

Chart 3 How R&D/innovation activity has been funded in past five years (% of respondents)



- A majority of quantum innovators that received public funding said it was very important to the R&D/innovation activity taking place (65%[2]).
    - Quantum innovators were more likely than non-quantum innovators to say that public funding was very important where relevant (65% vs 53%), and less likely to say it was not important (9% vs 16%).
- Chart 4 below shows that a majority of quantum innovators that received public funding believed it fills a financing gap without which the activity could not take place (68%).
    - 42% of quantum innovators said that public funding attracts additional private funding, compared with 16% that said it acts as an alternative to private funding. This suggests that public funding is more likely to have a "crowding in" effect rather than a "crowding out" effect.
    - Quantum innovators on average cited more benefits of public funding than non-quantum innovators (3.7 vs 3.2, full results in Chart 4 below), which may be related to the previous result that quantum innovators were more likely to suggest that public funding was very important to the activity taking place.

Chart 4 The ways in which public financing supports R&D/innovation activity (% of respondents who didn't select N/A)



[2] The question was 'If relevant, how important is public funding to the R&D/innovation activity being undertaken?', with N/A as an option. Percentages were calculated with N/A responses removed.

- Quantum innovators were most likely to experience the greatest difficulties securing the necessary financial resources at the production/scaling up stage of the R&D/innovation pipeline (44%—Figure 1 below provides a breakdown of the pipeline stages considered for this question). However, at least a quarter of quantum innovators faced difficulty at any stage of the pipeline.

- This may be linked to the fact that the production/scaling up stage was also where direct costs tended to be highest (47% vs 41% for non-quantum firms).

    - A relatively larger share of quantum innovators faced the greatest direct costs at the applied research stage than for non-quantum innovators (32% vs 19%, respectively) and were also more likely to face difficulties securing necessary funding at this stage (31% from 24%).

- A majority (94%) of quantum innovators said labour costs were among the most significant direct cost of undertaking R&D/innovation activity, as was also the case for non-quantum innovators (84%). Among quantum firms, 41% cited capital costs as significant and 32% cited laboratory/workshop costs.

- A majority (53%) of quantum innovators pointed to the costs of incorrect forecasts of market demand as a significant potential cost or risk associated with undertaking R&D/innovation activity, which was similar for non-quantum innovators (49%). This was closely followed by uncertainty of future funding (47%).

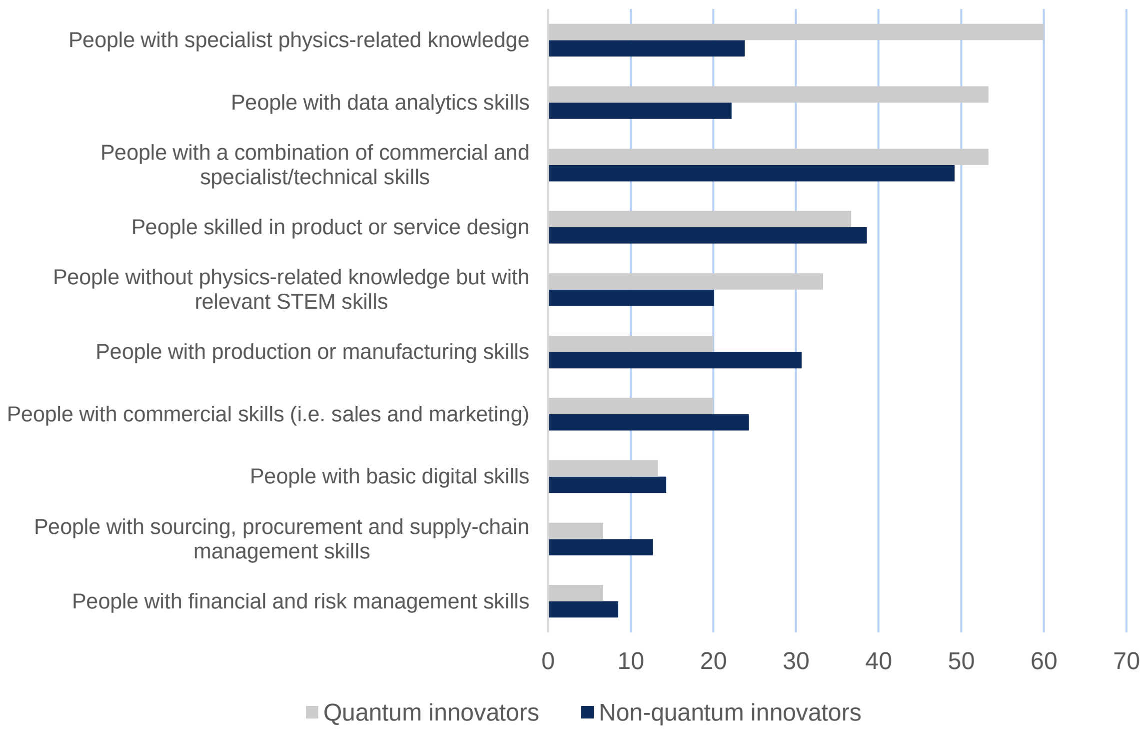
- Over the year up until the respondent answered, 50% of quantum innovators reported a negative impact of Covid-19 on their plans to undertake R&D/innovation activity, while 24% saw a positive impact, providing a net balance of -27%. This was a slightly more negative balance than for non-quantum innovators (-19%).

- Over the five-year period up until the respondent answered, 53% of quantum innovators reported a negative impact of Brexit on their plans to undertake R&D/innovation, with 9% reporting a positive impact, providing a net balance of -44%. This was a slightly more negative balance than for non-quantum innovators (-33%).

Innovation capabilities and capacity

- 37% of quantum innovators reported skills shortages as a significant barrier to undertaking R&D/innovation activity (Chart 1 above).
- Quantum innovators were broadly unsatisfied with their ability to attract and retain talent at the commercialisation stage of the R&D/innovation pipeline (balance of -7%; 36% were satisfied and 42% unsatisfied), as well as at the large-scale prototype stage (balance of -3%).
    - Average satisfaction of recruitment/retention ability across the different R&D/innovation pipeline stages (which are shown in Figure 1 above) was lower for quantum innovators than for non-quantum innovators (+16% from +23%), with the latter group not posting negative balances for any pipeline stage.
- As Chart 5 shows below, quantum innovators were most likely to struggle to recruit people with specialist physics-related knowledge (60%), followed by people with data analytics skills (54%) and people with a combination of commercial and technical skills (54%).
    - The figures for the first two of these categories were higher than for non-quantum innovators (24% and 22% respectively), suggesting a specific skills problem for quantum innovators.

Chart 5 The competencies within roles that physics innovators have experienced difficulties recruiting for in the past five years (% of respondents)



- When asked what causes these recruitment difficulties, a majority of quantum innovators pointed to applicants lacking the required skills/qualifications/experience (55%) and competition from other firms (52%).
    - Quantum innovators were more likely to select the above causes of recruitment difficulties than non-quantum innovators (44% and 31% respectively), as well as being more likely to point to difficulties attracting people to move (39% vs 25% for non-quantum innovators) and rules on international mobility (19% vs 11%).
- 85% of quantum innovators reported that skills shortages led to R&D/innovation activity being suspended or delayed in the five-year period up until the respondent answered, this compared with 62% for non-quantum innovators.
    - 50% of quantum innovators said R&D/innovation activity was sub-contracted or outsourced in this time period as a result of skills shortages (compared with 27% of non-quantum innovators), while 35% said planned R&D/innovation activity didn't take place (compared with 28% of non-quantum innovators).
    - 35% of quantum innovators increased investment in skills in response to skills shortages during this time period, while 19% successfully recruited from beyond the UK/Ireland (compared with 17% and 11% of non-quantum innovators respectively).

Table 2 How physics innovators access the facilities and equipment they need to undertake R&D/innovation (% of respondents)

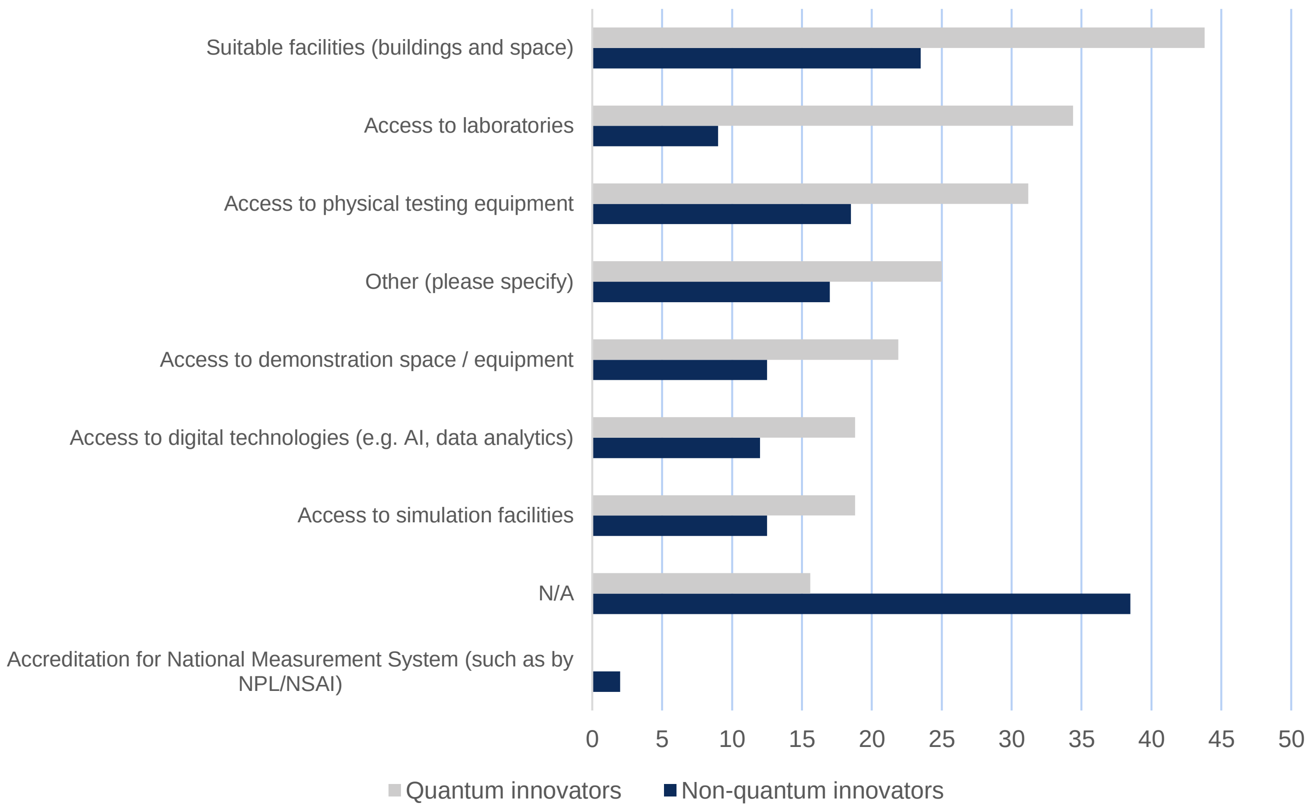
	Quantum innovators	Non-quantum innovators
Our own facilities and equipment	94	86
Through commercial/private sector partners	44	37
Through higher/further education partners	63	32
Through public research organisations/institutes	38	14
Through collaborative public/private partnerships (e.g. UK Catapult Centres, Science Foundation Ireland Research Centres).	25	17
N/A	0	3
Other (please specify)	3	4

- 29% of quantum innovators cited a lack of proper space/equipment/facilities as a significant barrier to undertaking R&D/innovation activity (Chart 1 above).

- As Chart 6 below shows, quantum innovators generally faced a greater number of equipment/machinery/space related issues that limited their ability to undertake R&D/innovation activity.

- 94% of quantum innovators used their own facilities and/or equipment to undertake R&D/innovation activity (compared with 86% of non-quantum innovators).
    - A majority of quantum innovators also accessed facilities and equipment through higher-education partners (63%, compared with 32% of non-quantum innovators).
    - Quantum innovators accessed facilities and equipment for R&D/innovation activity from a greater number of sources on average than non-quantum innovators (2.7 vs 1.9—the full list of options is in Table 2 below), a result that may be at least partly driven by the fact that quantum innovators tend to be larger.

Chart 6 Factors which limit the ability of physics innovators in undertaking R&D/innovation activity (% of respondents)



Collaboration and culture

- 29% of quantum innovators cited organisational or cultural factors as a significant barrier to undertaking R&D/innovation activity, with 9% citing access to external expertise/a lack of collaboration.

- Overall, quantum innovators were more likely to collaborate regularly with key bodies in the UK/Ireland knowledge infrastructure than non-quantum innovators. This includes with universities (77% vs 37%), public-sector research bodies (60% vs 21%) and private research and technology organisations (52% vs 26%).

    - Quantum innovators were also more likely to collaborate regularly with other networks/partners (as can be seen in table 3 below), however this result may be at least partly driven by the fact that quantum innovators tend to be larger.

Table 3 '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)

	Quantum Innovators	Non-quantum innovators
UK/Ireland Knowledge Infrastructure		
Universities or other higher/further education institutes	77	37
Public sector research organisations/institutes	60	21
Private research & technology organisations	52	26
Collaborative public/private partnerships	37	14
Business		
Suppliers	69	53
Customers	66	62
Cluster supply chains	19	12
Consultants	29	23
UK or Ireland-based competitors or other businesses in your industry	18	12
Overseas-based competitors or other businesses in your industry	21	13
UK or Ireland-based businesses outside your industry	21	10
Overseas-based businesses outside your industry	17	13
Networks, Associations and Societies		
Peer networks	62	36
Trade Associations	30	29
Professional Bodies	35	25
Learned Societies	29	13

- A majority of quantum innovators were motivated to collaborate with networks/partners to gain knowledge/information on opportunities or technical matters (90%) and to gain access to expertise/skills (90%), as well as to gain access to facilities and/or equipment (66%).

- Quantum innovators were most likely to collaborate at the applied research (86%) and small-scale prototype (79%) stages of the R&D/innovation pipeline.

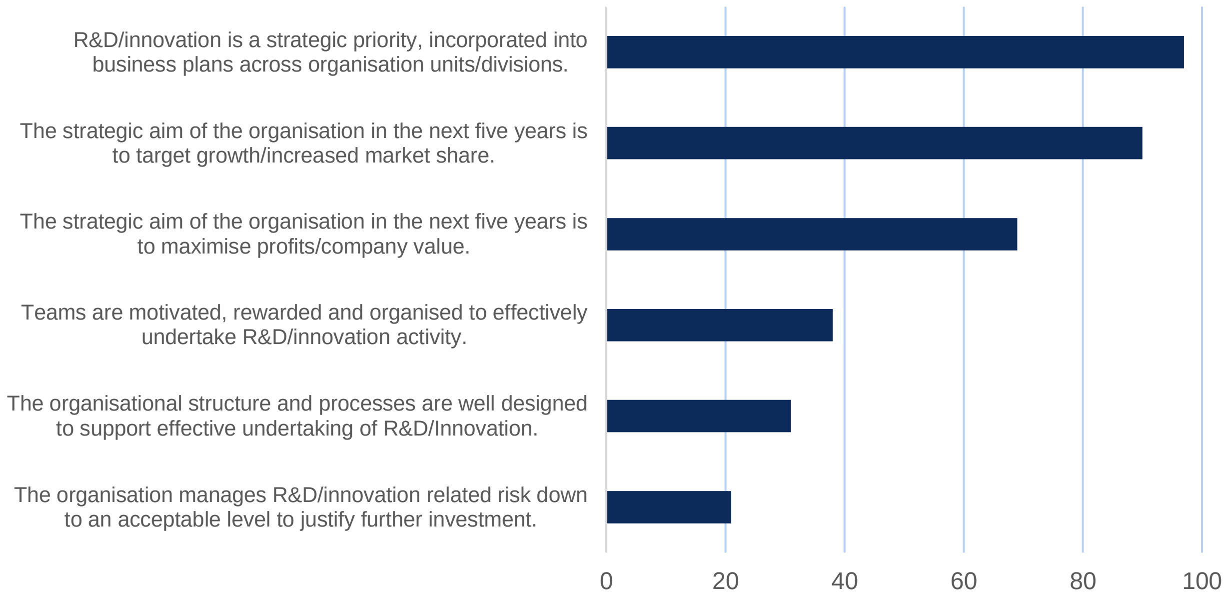
- A majority of quantum innovators collaborated with suppliers at an early phase of new product development (63%). A significant proportion also engaged with suppliers on ethical supply management (41%). Compared to non-quantum innovators, quantum innovators were less likely to engage with suppliers on cost improvements (19% vs 39%).

- Almost all quantum innovators agreed that R&D/innovation is a strategic priority for their business, with 83% strongly agreeing (97% agreed with the statement, 0% disagreed giving a net balance of +97%, compared with +87% for non-quantum innovators).

    - A majority of quantum innovators agreed that their firm's strategic aim over the next five years is to target growth/market share (net balance of 90% vs 91% for non-quantum innovators). A net balance of +55% also said they are aiming to increase profits/company value, which was lower than for non-quantum innovators (+86%).

    - Quantum innovators were less likely than non-quantum innovators to agree that organisational structures & processes are well designed to support effective undertaking of R&D/innovation (balance of +31% vs +56% for non-quantum innovators).

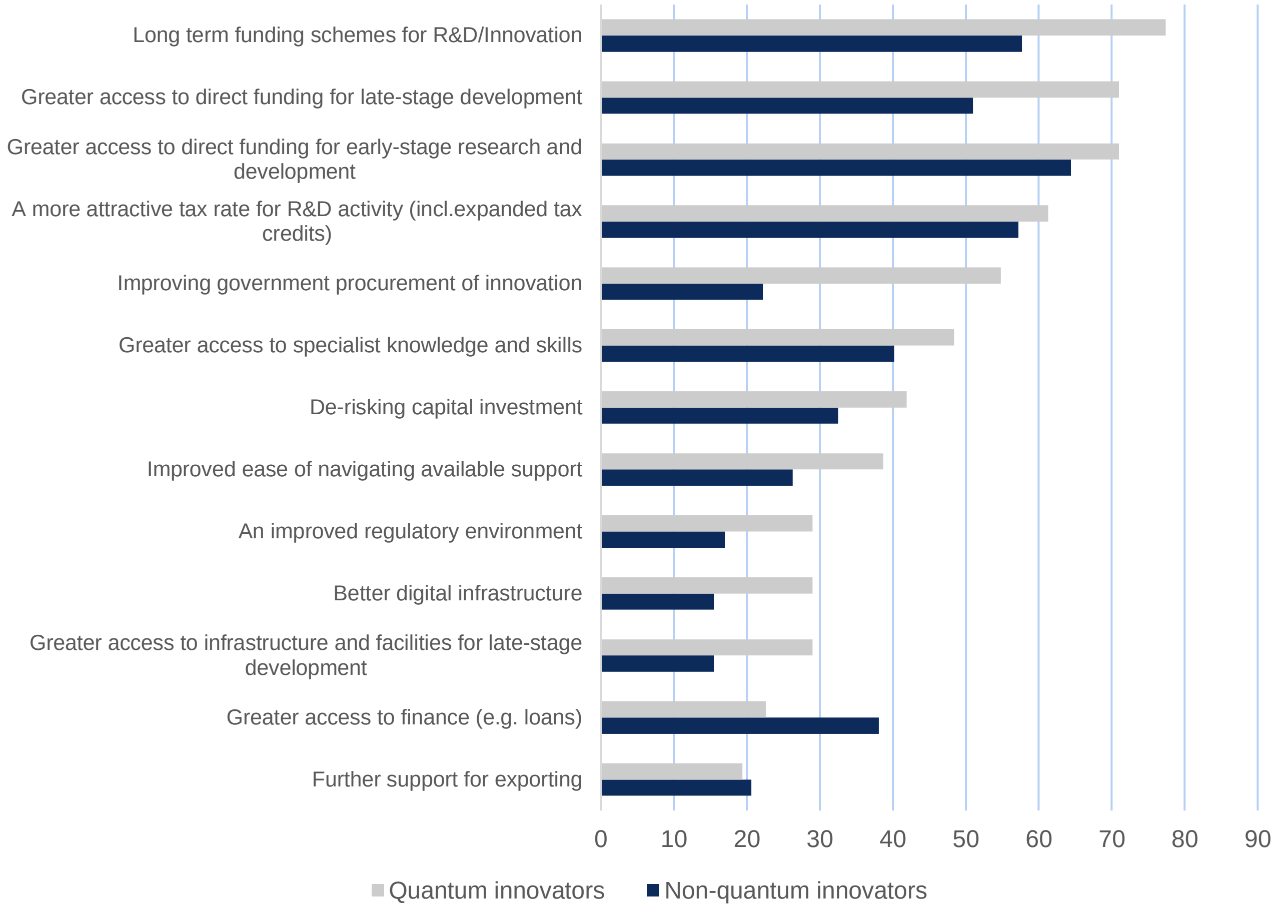
Chart 7 Net balance of quantum innovators that agree with the following statements (%)

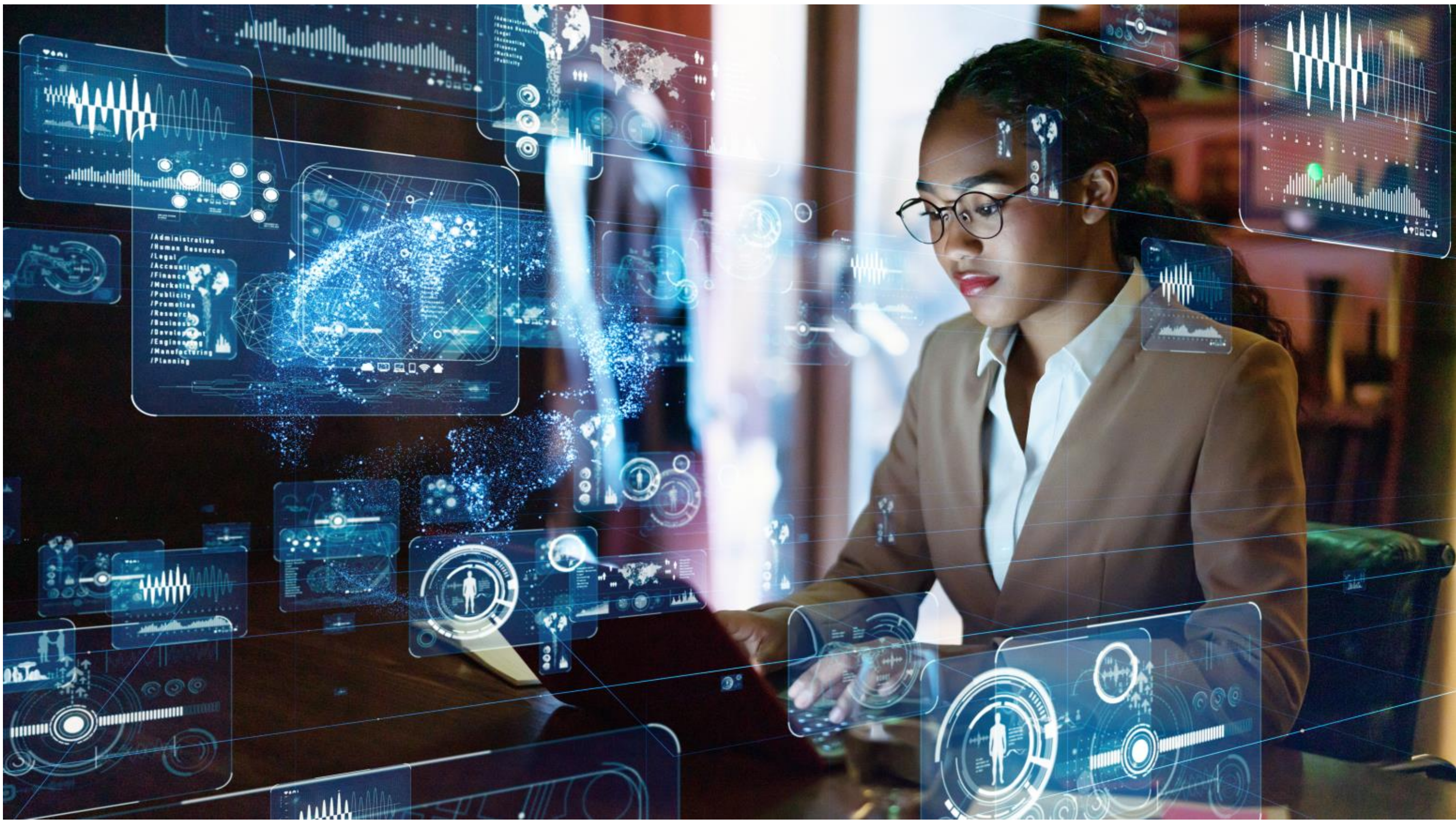


Government policy and regulation, and the future of R&D/innovation activity

- 37% of quantum innovators cited government policy and/or regulations as significant barriers to R&D/innovation activity.
- As Chart 8 below shows, quantum innovators largely believed that enhancements to funding-related policies in the UK would allow more R&D/innovation activity in the next five years. This included long-term funding schemes (77%) and greater access to direct funding for both early-stage (71%) and late-stage R&D (71%).
    - A majority of quantum innovators also believed that a more attractive tax rate for R&D would allow more activity in the next five years (61% vs 57% of non-quantum innovators), as would improving government procurement of innovation (55% vs 22% of non-quantum innovators).
- The administrative burden of securing and maintaining protections such as patents and copyright was generally viewed as having a negative impact on quantum innovator's abilities to undertake R&D/innovation activity (7% saw this as a positive aspect, 23% saw it as negative giving a weighted balance of -16%), although this was viewed less negatively by quantum innovators than it was by non-quantum innovators (-38%).
    - However, the innovation protections themselves were seen as positively impacting their ability to undertake R&D/innovation activity (balance of +23% vs +26% for non-quantum innovators), as were standards and certification rules (+6% vs +5% for non-quantum innovators).
- 75% of quantum innovators expected their R&D/innovation spend to increase in the next five years, with 3% expecting it to fall (giving a balance of +72%, higher than for non-quantum innovators: +59%).
- For those quantum innovators that expected to increase R&D/innovation spending, a majority said that the need to adapt to emerging technologies (82% vs 70% for non-quantum innovators) and to adapt to changing product/market demand (73% vs 74%) were significant factors driving higher R&D/innovation.
    - Among other drivers of increased R&D/innovation, quantum innovators were more likely to cite an improvement in access to people and skills (46% vs 25%), reduction in macroeconomic uncertainty (50% vs 32%) and improvement in availability of internal finance (32% vs 18%) than non-quantum innovators.
    - Quantum innovators were less likely to expect to increase R&D/innovation spend to improve cost competitiveness (41% vs 58%) or sustainability (23% vs 49%).

Chart 8 UK policy enhancements that would allow more R&D/innovation activity in the next five years (% of respondents)





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