House of Commons

Science, Innovation and Technology Committee

Oral evidence: Commercialising quantum technologies, HC 270

Wednesday 31 January 2024

Ordered by the House of Commons to be published on 31 January 2024.

Watch the meeting

Members present: Greg Clark (Chair); Dawn Butler; Chris Clarkson; Tracey Crouch; Dr James Davies; Stephen Metcalfe; Carol Monaghan; Graham Stringer.

Questions 178 - 216

Witnesses

I: Professor Dominic O'Brien, Professor of Engineering Science and Director, Quantum Computing and Simulation Hub, University of Oxford; Professor Ian Walmsley, Provost and Chair in Experimental Physics, Imperial College London.

Examination of witnesses

Witnesses: Professor O'Brien and Professor Walmsley.

Q178 **Chair:** The Science, Innovation and Technology Committee continues its inquiry into commercialising quantum technologies.

We are very pleased to have as our first pair of witnesses this morning: Professor Dominic O'Brien, director of the National Quantum Technologies Programme, who is responsible for the Quantum Computing and Simulation Hub, University of Oxford; and Professor Ian Walmsley—a regular witness before our Committee's inquiries—who is Provost of Imperial College. He is a specialist in quantum and was previously Pro-Vice-Chancellor at the University of Oxford. While there, he led the Networked Quantum Information Technologies Hub, among many other things.

Why should the country, the world and Parliament be excited about the commercialisation of quantum technologies?

Professor Walmsley: May I declare an interest? I am a co-founder and chair of a start-up company in this domain, ORCA Computing.

Why be excited about this? At base, it is a complete revision of engineering design for information technologies. All technologies to date have been based on principles of science that had been known since the 17th, 18th or 19th centuries. This represents a massive step change.

That means that there is a huge opportunity here. We will no doubt talk later about some of the impacts of that, but what is certainly known is a revolution in the kinds of computing you can do. Not everything will change, but new problems can be solved that simply cannot be solved in other ways—sensors with enhanced precision, well beyond what we know how to build at the moment, and secure communications where their security is governed by the laws of physics and not by trusted parties.

These represent massive changes that will have a large impact on society and the way in which we do business using information.

Professor O'Brien: Turning to some of the engineering that is done these days, computational design, for instance, is a really big part of getting the product to market. Thirty years ago, in designing an aeroplane you would build a plywood mock-up and test it; these days, it is all done computationally. Those things are very important to the marginal gains in aerodynamic efficiency.

The increasing computational power will impact sectors, which will impact us indirectly as citizens—more efficient aerospace, better materials, new drugs. Areas where computation plays a heavy role at the moment will get these transformational capabilities.

Q179 **Chair:** From preparing ourselves for this inquiry, we understand that quantum computers have high error rates—roughly one error per 100 operations before failure. Why does quantum computing include such errors?

Professor Walmsley: One has to think of a quantum computer as a large-scale quantum system. You may have heard of the analogue of Schrödinger's cat. The paradox is that here is a big, palpably tangible system that we see and are familiar with every day that does not behave according to the laws of quantum mechanics. Why is that? The answer is that information and energy leak into the environment—the cat is in touch with lots of things.

In trying to build a quantum computer we are trying to build something at that scale where the laws of quantum mechanics are clear, evident and operate in the everyday world. That means that we have to stop the information leakage.

At the same time, we must have sufficient control over the individual parts of the computer, so we have to have a way into it. That tension between having sufficient control to make it work and not letting the information leak out accidentally is one of the main engineering challenges.

Part of the way in which you deal with that is to have redundancy. Any error correction usually says, "One operation or one bit may go wrong, but if I repeat it several times, I can usually take a poll."

You have to do that in a very sophisticated way in quantum mechanics because you cannot look at the bit itself; otherwise, you destroy the operation of the machine. As you rightly say, at the moment that needs many, many physical bits to make one safe, protected, logical bit. That is the challenge we face.

Q180 **Chair:** I don't know whether Professor O'Brien has anything to add, perhaps to give us examples of the errors that might be inherent in quantum computing.

Professor O'Brien: I would like to add one thing. We are a world that deals with digital information: things are either a one or a zero. Leaving aside the effects of it being a quantum system, we are dealing with an analogue system. The numbers can take a range of values. The one and the zero offer us the opportunity to do correction quite efficiently, because if you have a zero and a one and it is not quite a zero or a one you can make a good decision—you know. The fact that it is an analogue system that you are controlling makes this harder, in addition to all the things that Ian has talked about.

The sorts of errors you get are: this information leakage to the environment means that the linking between the quantum information—the coherence between them—dies away with time. With what you thought was a series of operations, in the end, you will lose that quantum effect that you need to have the operations.

Within the logical operation of machines, there are specific sorts of error. You wanted to put a bit into a particular position, but it flipped to another one. That is a probabilistic process—a process of chance.

There is a range of errors based on, if you like, your ability to control the system—and the fact that it is an analogue system—and the quantum elements within it.

Chair: Graham Stringer wants to ask some questions about errors, but I shall start with Chris Clarkson.

Q181 **Chris Clarkson:** I am particularly interested in use cases being developed for quantum in business. I am not a scientist—I am the token non-scientist on the panel—but I do have a background in the business world.

If you were sat in my office trying to explain why I need quantum computing in my life, how would you make someone like me understand the value of it and why I should be investing in it?

What have we learned from existing industry applications? Say that I am BAE Systems, and I am being asked to invest in quantum to make a better aeroplane. Who else is using it? Are Lockheed or Boeing using it? What have we already learned in business?

Professor O'Brien: Shall I start with the "How can I convince you?" part?

Chris Clarkson: At the "Janet and John" level!

Professor O'Brien: Context is important. In the five decades since the silicon chip was invented our lives have been transformed—the way we interact, the way we do business and all those sorts of things.

At the highest level, as Ian said, this is a new way of doing computing, offering a great deal of opportunity for the future. It takes us beyond where we are with this revolution we have seen.

Specific areas where you would be interested would depend on your business—for instance, if you were involved in logistics with complex supply chain planning.

Those are hard problems to optimise because there are so many inputs and so many different ways to do something. How do you start?

Quantum computing can offer the power that allows you to improve the way you make those complex decisions, and that can have a broad range of applications. Ian will talk more about what has been done thus far, but, for instance, car makers are interested because of their complex supply chains.

On parcel delivery, we talked to people about how they do routeing for their parcels. That is not as efficient as it could be, simply because the computational power available does not allow them the time to do that optimally.

If your business is in pharmaceuticals, for instance, there are elements that are very hard to simulate—it is a heavy computational thing. That will help you, as well.

Professor Walmsley: There are three broad areas where it is known that quantum computing can provide a real advantage. Perhaps the most famous is cryptanalysis—breaking codes—and there is certainly more to say about that.

The second, as Dominic said, is around logistics, which appears in many areas—as he noted, supply chains, but how you deal with the disposition of your fleet or other hardware that you have around the world. The third is materials—chemistry simulation. Applications at the moment focus on all three areas, depending on who you are and what you are interested in.

I can give an example from our own company, ORCA Computing. A number of commercial and Government organisations are interested in the logistics aspect. It is valuable to have early-stage machines available to test ideas before one gets to the full quantum advantage.

That step of saying, "We do not fully know all the applications, but we know there are some and we need to explore that range," is an important one at the moment.

Q182 **Chris Clarkson:** There is foundational evidence that it is making a difference in certain sectors, but it is fair to say that there are other applications.

Professor Walmsley: Yes, absolutely. Dominic noted the computational power needed for logistics. The change in quantum computing is that efficient algorithms can run on a quantum, whereas it is only inefficient algorithms on a classical, regular machine. As you scale things up, the classical system runs out of steam and the quantum one will not.

Q183 **Chris Clarkson:** Instead of doing A, B, C, D, E and F, it will say, "A didn't work, so I'm going to try Z now because that makes a lot more sense."

Professor Walmsley: Yes.

Chris Clarkson: I understood that.

Q184 **Graham Stringer:** Listening to you, I understand the words, but when I think about it I am not sure I do understand; it is a bit like being an undergraduate and coming out with a puzzled expression on your face.

Is the fragility and instability of the system temperature related, or vibration related? What creates the instability? Many of the systems that people use for quantum computing have to be cooled to millikelvin levels—just above as cold as we can go. The temperature at which this stuff is vibrating around will disturb the quantum system.

Professor O'Brien: It is temperature related, but there are physical effects around physical vibration. I would call those more engineering effects, not fundamental. Some of the quantum systems might be very cold in a chamber to make them cold. They have to have laser beams fired at them, and the fact that there is vibration means it is very difficult to make that system work.

Broadly speaking, temperature is very important, but there is a range of other things that need to be controlled quite precisely. These are very delicate systems. You see the quantum effects only when you can control the environment very carefully.

Professor Walmsley: Temperature, with that leakage, is, as Dominic said, one of them. Another one is that in order to make a computer work, your atoms, ions, superconducting elements, photons, what have you, must be able to talk to one another to enable the logical operations that make the computer work.

The ability to do that perfectly is a big engineering challenge. You have to build a correction system that is fault-tolerant and allows you to manage these imperfections as well as the environmental degradation that Dominic talked about.

Some of the platforms need to be really cold—superconducting qubits—but optical machines can work at room temperature, in principle. There are hedges around that, but, interestingly, there are ways to code information that are robust against the environment—there is a price to pay for that—and there are ways to do it by cooling things down.

Q185 **Graham Stringer:** This might be a meaningless question, but how do you know it has gone wrong? Do the answers not make sense, or can you tell that the quantum system has become disentangled?

Professor Walmsley: One of the major steps, in 1995 or 1996, was the invention of quantum error correction. As Dominic noted, you code things in zeroes and ones. The difference in a quantum system is that it can be in what is called the super-position of those two—both and neither.

The challenge in quantum is that it collapses into one or the other, in loose language. You have lost the quantumness, so you have to be able to correct for errors without looking at it, and that is a vastly different approach from—

Q186 **Graham Stringer:** You know it has collapsed, do you?

Professor Walmsley: You can tell when an error has happened by linking it with other qubits and making a collective measurement—measuring several of the ancillas. You can know that something has gone wrong without having measured the system itself. That is at least a 50% UK invention; it arose simultaneously in the UK and in the US.

Q187 **Graham Stringer:** The written evidence we have received is contradictory: some people think that in five or 10 years this problem will be solved; some think it is insoluble. What is your view, and why?

Professor Walmsley: I would say that there is no physics reason why we cannot build a quantum computer. We do not know of a scientific reason why it is impossible. We may find one. Roger Penrose may be right: you build a big enough machine, gravity takes over and that's it. I think that is unlikely, but it is not impossible. No physics reason is known.

The engineering to do this is absolutely fierce. One of the great features of the UK programme is having people like Dominic—real engineers—who are tackling the problem. The risk is that we may not solve all the technical problems.

Professor O'Brien: If you ask for a specific date, the mission puts the date of having something of scale in 2035. Generally, the view is that that is realistic. Whether it will be plus or minus one year or plus or minus two years is very difficult to tell in technology development. As Ian said, it is very challenging engineering.

The general view is that it is an engineering task. At the moment, there is no fundamental reason why this should not happen.

Q188 **Graham Stringer:** I am not sure whether my final question is meaningful. This Committee has been looking at AI, which uses very large, traditional computers. Will there be a link between quantum computers and traditional computers to enhance AI? Will they work together? Will it take us into a different landscape when you put AI and computing together?

Professor O'Brien: I will put aside AI and answer the second part of the question. Will people build combinations of a classical machine that we all know about? Absolutely, yes. That will be the intermediate scale. There will be certain problems, which people research now. Some of it is best on a quantum computer, and some of it is best on a normal machine.

Any quantum computer of scale will have a lot of classical processing. You will hear later from Riverlane, which is working on the classical processing around quantum error correction. Any machine will be a combination of both. Before we get large-scale quantum machines, there will be quantum code processes. Ian can talk more about that, because that is one of the models he has been looking at more than we have.

Professor Walmsley: I fully agree that a hybrid system is likely to be one of the first systems that we find viable.

AI and machine learning is still an exploratory area. There are known ways to do quantum machine learning on putative quantum computers. There are some advantages from that.

There are ways to build physical neural networks that have quantum capacity, but it is still a nascent area and the extent to which there will be a real advantage from quantum is not clear.

Q189 **Tracey Crouch:** These are not my questions, but Graham sent me down a Google rabbit hole when he asked about temperatures and everything else. It stirred my inner Greta and I wondered about the environmental impact of quantum computing. Google tells me that, potentially, it will save the world from climate change. Will you comment on the environmental impact of quantum computing?

Professor Walmsley: There are a couple of interesting dimensions here, but I am not sure I really know the answer to your question.

Q190 **Tracey Crouch:** Is that because it is a daft question or because you genuinely don't know the answer?

Professor Walmsley: It is my lack of knowledge.

A beautiful thing about quantum computers is that they are largely what is called reversible. With a regular computer, with each step you tend to erase information and that generates heat. In principle, quantum computers are reversible until the very end measurement. You might say, "Oh, gosh, that would be a lower consumption of power," but in practice, as Dominic said, the machines will have huge classical control systems around them, so I think that that aspect is probably a bit of a chimera.

In that sense, I would see early stage machines, probably quite a way into the future, having the same footprint as a regular high-performance computer. It will be operated largely with electricity, so you can deal with that in green ways.

There is a second aspect that relates to some of the applications that we talked about earlier. If you can do better materials or chemistry design using these, you can make some of the processes we currently use—say, for fuel generation or fertiliser generation—much more efficient, which potentially will reduce the carbon footprint of the other sorts of things that we do. That is probably where the biggest impact is likely to happen.

Q191 **Tracey Crouch:** Lots of people who are watching are in the same space as Chris and I, so will you give an overview of the national quantum technology programme for quantum computing and simulation and outline whether there have been any commercial successes with the hub?

Professor O'Brien: I will give the outline and talk about what we have been doing. Ian was director of the predecessor hub.

The hub is a partnership of 17 universities, led by the University of Oxford. It works in close partnership with the National Quantum Computing Centre, on which you heard from, I think, Michael Cuthbert.

Where do we fit in that landscape of quantum computing? The hub is where ideas get developed to small-scale demonstration or to a proof where we think somebody might be interested in using it or innovating it. It sits somewhere in that pipeline of technology development.

Before us, the Government fund discovery science in quantum. We take the discovery science and the hub is in the technology domain—between discovery and commercialisation and innovation.

The National Quantum Computing Centre has more of an engineering and scale-up emphasis than we do. The hub is an ideas factory, in a way. People work on the hardware and software of quantum computation at the research level, getting together to try to work out where the critical challenges are.

Our job is not to build any quantum computer. That is not really a role that a research hub would play.

That is broadly where the hub sits in the landscape, and that has been the case since the programme started.

The hub does other things. It does skills training, which we will cover a bit later, and a lot of engagement with a focus on several things, one of which is engaging with Government and business to create an environment in which a quantum economy grows. That might be specific bits of commercialisation; it might be general engagement; it might be advocacy. We do a wide range of things. We are not just a research project; we have an engagement mission as well.

On commercialisation success, I will let Ian talk about some of the specific examples from the earlier hub, from which there were a fair number of start-ups.

From our hub and across the whole programme, possibly, there has been a good number of start-ups. I will send you the numbers in an email rather than tell you here, but off the top of my head it is between eight and 10 whose development can be directly traced to the hubs. There have been licences, patents and all those sorts of things.

There has been a lot of convening. Our engagement team has hundreds of meetings a year with people interested in quantum computing. Latterly, that has been in partnership with the National Quantum Computing Centre because we are a national programme.

Professor Walmsley: On the engagement points that Dominic talked about, the hubs have been successful in providing information to companies and policymakers through reports that have been quite influential, and have participated in a lot of policy backgrounds such as the current DSIT quantum infrastructure inquiry.

Commercially, a great success of the UK programme has been, as Dominic noted, spin-outs. From the quantum computing hubs alone, there have been eight to 10, but there have been others from the rest of the programme. That has seeded a sector in which really bright people want to work. It has attracted ideas, people and investment from around the world.

That positioning between the basic science, which in the UK has been exceptionally strong, taking that in translation and helping to build a quantum sector, both with start-ups and with wider applications, has been a real success of the programme in the last decade.

Yes, I think it is unique in the world in its approach and it has been a model for other countries that have started in this domain.

Q192 **Tracey Crouch:** Is that where the partnership resource fund comes in?

Professor O'Brien: The partnership resource fund was a fantastic decision by our funder, back in 2014. Of the money that we got, roughly 20% was unallocated when we started. We used those funds to seed work with industry so that we have academic-industry collaboration, and bring on new academic ideas. This is a rapidly changing field, so having that flexibility was excellent both for growing the academic base and, particularly, for bringing industry on board.

We have used it for a very wide range of projects, including collaborations with established companies and with small start-ups. The ability to act quickly and seed this has been very important.

For industry to get involved, it is important to be able to point out that they are not funding the whole endeavour. Of course, this sits somewhere in the landscape of public-private partnership. Innovate UK does this as well—but it is fixed calls and a fixed timescale. The flexibility of the PRF has been very useful to us, for the ability dynamically to seed the expansion of the programme and start to build this emerging economy.

Q193 **Carol Monaghan:** I think I did this at the start of the inquiry, but I declare an interest as the chair of the APPG on photonics and quantum.

Professor Walmsley, the company that you co-founded, ORCA Computing, has been working with the Ministry of Defence and, indeed, has delivered a product to the MOD. Are there additional opportunities for the Government to procure quantum computing applications, and what might those be?

Professor Walmsley: You are right that the MOD has bought a machine from ORCA Computing. As to other opportunities, a second one that was recently realised was the tender that the National Quantum Computing

Centre put out for test beds. I should say that ORCA was successful in that competition, too. Those are good examples of the way in which Government procurement can help.

The NQCC and MOD applications had some parallel, in the sense of saying, "These machines are not yet at the level where they will outperform a regular high-performance computer, but they are sufficiently sophisticated that you can test out your applications." At the MOD, that is about logistics: can you build lightweight machines that might be at some point field-deployable?

The NQCC one is more about building an application and user base with many use cases, and open machines for people to get time on, to test their algorithms and ideas. It is also for suppliers to say, "We can build some of those components better and begin to think about what the supply chain is for the commercial market."

Q194 **Carol Monaghan:** Something like that could be used across the public sector, then.

Professor Walmsley: Yes, I think so. There are a few tweaks that might be too specific for this group, although it would perhaps be helpful to talk about them, on how to make that more effective. It is an area where you have to deliver a commercial product early on, so it stimulates the company to do things properly. You have to build a relationship with the user and you can then show that you can begin to deliver these kinds of products. That is the place where investors start to see that a company is serious, and that they can start putting money into it.

Q195 **Carol Monaghan:** Professor O'Brien, the national quantum strategy mission is to have UK quantum-based computers capable of running 1 trillion operations by 2035. Is this achievable? What additional support is needed to make it achievable, and what are the challenges?

Professor O'Brien: That's a question. Do I think it is achievable? I think it is ambitious but achievable.

Q196 **Carol Monaghan:** We are talking 11 years.

Professor O'Brien: I think so. It is interesting. In conversations with particular vendors they have said, "Actually, we think it's achievable," or, "We can do it slightly faster than that." Those are the sorts of conversations we have had about those numbers. Remind me of the second question.

Q197 **Carol Monaghan:** Might additional support be needed to help with it, and what are the challenges in achieving it?

Professor O'Brien: Additional support—of course: this is a mission and it needs to be of scale, nationally.

To answer both the second and third parts of your question, there are areas where I would identify a need for support because of the challenges, and I think infrastructure is important. The UK as a nation is going to need a connected infrastructure to be able to build something.

Q198 **Carol Monaghan:** What does that mean?

Professor O'Brien: Different qubit technologies need different sorts of infrastructure to make them. For instance, superconductors: it looks a bit like a silicon chip fab. It is not a silicon chip fab, but you need a means to make the superconducting chips, to grow them, etc. You then need a means to package them, and to test as well. That is very important. These quantum systems are quite hard to test, normally. The only true way to test them is, often, to cool them down and to build the whole thing. That is a very intensive way of testing, as you might see. All of that infrastructure to get you the systems and the subsystems to be able to deliver on the mission is quite important. It does not necessarily all need to be in one place. It needs to be a connected picture.

That also plays into the second part of the challenge, which is skills. We need the skilled people who are going to be able to do that. I am sure that skills have been mentioned before in the Committee. The element that I would like to inject is the need for a home for those skills. The university sector is not necessarily a great home for long-term skills, because our postdoctoral students go off and do something else. We have a flow of people in and out, so the nation needs a way to identify which skills it needs but also to keep those skills across the commercial and Government sectors.

There are skills and infrastructure. Procurement, which I think Ian talked about, is part of the picture as well. There is a need for a means to stimulate the commercial sector—to create the commercial sector that can deliver on the mission.

Q199 **Carol Monaghan:** On skills, is the current visa situation causing issues?

Professor O'Brien: When we responded to this, we thought that there can be particular issues about the level of salary required for visas, and things like that. I would not identify that as the only issue. There is a general issue around how welcoming we feel as a nation. By that, I mean that we are after global talent—and, clearly there are concerns about where that global talent comes from—but let us say that there is some global talent we want to get: we do not necessarily manage to execute getting it to the UK in a timely fashion. We often add additional expenditure before people have even started their role here. There are particular issues around the talent we want. We need to be welcoming.

Q200 **Carol Monaghan:** There is a hearts and minds issue here, as well as a financial one.

Professor O'Brien: Yes, I think so.

Professor Walmsley: I would add two points, just to build on Dominic's infrastructure point. There are some really interesting models that combine infrastructure and skills, in other domains, such as the advanced manufacturing facility in Sheffield and, in your own domain, the centre for advanced photonics. It is a really interesting play to think about what an advanced quantum manufacturing centre would look like—one that would help companies to do prototyping and testing, with an apprentice programme alongside it to build some broader skills.

You will recognise the points that have been made about visas. I think the work-study visa is a great programme. It is a model thing that we can use in relation to bringing in skilled people and training them through PhD programmes. Care and attention need to be paid to the salary barriers on some of the other visas. I do not know quite what the number is, but we need to worry about that, and the overall tone.

There are clearly sovereign capability issues in this domain and we have to worry about those, but I think that things like the ATAS programme are quite sensible in helping to manage that.

Q201 **Dawn Butler:** How do we stay one step ahead? We have talked about decoding. How do the Government stay one step ahead of the bad guys?

Professor Walmsley: That is a very good question. If I knew exactly the answer to that I would be very happy to tell you.

There are a couple of things here. This is still a domain where ideas are important, so broad collaborations to gather ideas are critical. I think that the partnerships that we have, through AUKUS and relationships with Canada, Australia and elsewhere, are ways in which we can be sure of staying at the front of the field.

On ideas, in the early stage, the UK is in a good position. The challenge may come as we begin to try to scale things up. Can we get to those first computers without finding either that we do not have the public investment or that a major company comes in and buys up our private sector?

Those are risks, but I think they are manageable.

Professor O'Brien: I would add the broad comment that the success that we have had thus far has been a sort of continuing commitment from the whole of the programme—Government, academia, industry and capital. The ability to be confident about continuity is quite important for everybody from the young person deciding which field they would like to go into, to the academic starting their research career and the investor in a company. The connected nature of what we have done has helped that. Now, we have another 10-year strategy. That continues that story of confidence. The ability of Government to think in the long term and create part of that picture is quite important, beyond the detail of what it does. That general feeling is important.

Q202 **Dawn Butler:** Yes, it is not something we can do alone, is it?

Professor O'Brien: No.

Q203 **Dawn Butler:** Now that you have answered about how we keep one step ahead, how does the development and deployment of quantum computing affect national security now, particularly around encryption—because that is what quantum can do, right? Quantum can decrypt things quickly.

Professor Walmsley: Yes, you are right that one of the early and very clear applications of quantum computers was decrypting public-key systems. One might say that one of the stimulations that has arisen from that is the whole concept of post-quantum cryptography. Knowing that there is a capability that might compromise you in the future has led to the exploration of other ways.

I think there is a continual tension, there. You develop new ways; people find quantum algorithms and attack them, and what have you—but there is an element of that in it.

We have talked about some of the other ways in which quantum might support national security, such as things around logistics and the interconnection with other areas of quantum technology, like positioning navigation and timing systems—so GPS-free navigation. That is also a part of that whole system. The UK programme's broad focus is quite helpful in mitigating some of those risks.

Professor O'Brien: There is this encryption risk and, as Ian said, that is being countered by an extensive effort to work out what next-generation digital security would be resistant to that.

There are risks around achieving computational power—that your adversary achieves computational power that you do not have, and thus the ability to take better decisions about conflict and things like that.

Both of those have some sort of risk associated with them. To some extent, the imbalance in the ability of nations to respond to threat is something we see anyway; but we need to be aware of that as well.

Q204 **Dawn Butler:** What are the safeguards and protocols currently, and are they enough? Do you think there should be more?

Professor O'Brien: I can start on the specifics of cryptography. I think in another session you may have chatted to people from the Quantum Communications Hub; you probably talked about it in a bit more detail. There is a process going on at the moment to generate the next generation of digital security that will be resistant to these computers. That is ongoing. We have, of course, the National Cyber Security Centre, and its arms, which comes out with recommendations on when it is time to think about changing the way you secure things. So there is a process by which safeguards are being developed for that risk.

On the risks around the transfer of key knowledge to other nations, I guess that is to do with things we discussed earlier, such as the National Security and Investment Act 2021 and the way we control who researches those sorts of things. So there are protections in place, but I guess it is an ongoing process.

Q205 **Dawn Butler:** Do you have buy-in from other associated industries?

Professor Walmsley: I think that the NSIA certainly applies to companies getting investment. One sees that in action all the time. When we are talking with partners they are, of course, very sensitive about their commercial confidence. I think that is reasonably looked after.

Q206 **Dawn Butler:** Two companies in China have invested £12 billion in quantum and are willing to share their technology. Does that worry you, in any way?

Professor O'Brien: Without seeing the detail of the companies—

Q207 **Dawn Butler:** Baidu and Alibaba.

Professor Walmsley: I do not know their technology per se, or how it is being accessed, so I will not comment on that directly, but there is an area where we need to be continually engaged; but we need to do it carefully. Three is no doubt that the Chinese investment has led to significant advances. There are some ideas out there that they are putting in the open literature that are helpful to us. We can learn from them. That exchange of ideas and people, at that level, is still quite important. Clearly, when things get to a point where they become commercially or nationally important, one needs to work in a different way.

Q208 **Dawn Butler:** So the safeguards will kick in.

Professor Walmsley: Yes, exactly. At the moment, shutting ourselves off from China means that we lose some of the ideas that are going to help us in the long term.

Dawn Butler: Interesting. Thank you very much.

Q209 **Chair:** On that point, Professor Walmsley, doesn't that have to be reciprocal? You said we can learn from some of the things that are being done in China. To do that, do we have to make available to them some of the research that you and your colleagues across the UK are doing?

Professor Walmsley: Yes and no. In the early stage, the way this will usually work is that there will be exchanges of people. We have them at Imperial, of course—there are a number of Chinese postdocs and students working in our laboratories. We manage that through the trusted research engagements with Government, and making sure that people are properly vetted when they come in. Then we capture the IP appropriately; so now it is locked in. At that level, it is reasonable to continue those exchanges.

The other issue, about investment and the use of overseas machines, is a separate question that needs a different approach.

Chair: Carol Monaghan has a follow-up question.

Q210 **Carol Monaghan:** Thank you; the Chair has generously allowed me to come back.

Professor O'Brien, to go back to the questions I was asking about infrastructure, how close are we, as far as you can see, to developing the required infrastructure, and who would have the oversight of that? Who is making sure that these things are in place?

Professor O'Brien: The picture of UK infrastructure, in my view, is that in some areas, relative to the best in the world, we need to up our game. The best labs in the world have been doing this for 20 or 30 years.

Q211 **Carol Monaghan:** Are we talking about the States?

Professor O'Brien: Yes, the US and those sorts of places. We do have the processes that our start-up companies need to be able to build what they want, but this is an ever-changing game and, once you are doing scale-up, what you need from the infrastructure changes. You need to be dynamic about that. Intel makes chips in an enormous $6 billion fab, or whatever it is. The scale that we are going to need to reach for the missions is not where we are now.

Q212 **Carol Monaghan:** Do you think the responsibility is on individual companies to produce the infrastructure?

Professor O'Brien: I think we have a great opportunity, because we have a well-integrated national programme. I do not think that infrastructure sits in once place. It is clear that the skills are distributed across the UK.

I think it comes back to the point I made about continuity and almost a long-term home for the people who understand how to build this stuff, and their skills, as well as some ownership of making sure it is a healthy infrastructure.

Q213 **Carol Monaghan:** That is what I am trying to get at. Who is taking charge? Professor Walmsley, can you shed any light on this?

Professor Walmsley: It is a good question. You may be aware, of course, that DSIT has commissioned a review of infrastructure for quantum, which I guess will be published in the near future. I think it will contain some important recommendations.

Who should own it is an important question. I take Dominic's point as well. The challenge for the start-up sector at the moment is that no company is big enough to do this on its own, so you need a collective. It needs industry buy-in.

I mentioned some of the models. The AMRC in Sheffield has industry buy-in for a common pool. The genomics consortium in Oxford, in a very different domain, works in the same way. You have industry putting in money; you have some public investment to build some of the capability; and then maybe you have a model that provides the capacity for companies to build their prototyping and technology, to get to the next commercial step, as well as a national asset that keeps these skills and capabilities in the UK.

Carol Monaghan: Thank you. We will look out for the report that you referred to.

Q214 **Chair:** On Carol's point, is the Science and Technology Facilities Council the appropriate funder for this infrastructure?

Professor Walmsley: That is a good question. It is certainly one of the possible ones. I do not think NQCC went through that, did it?

Professor O'Brien: Good question. I am not honestly sure what the model for the NQCC is. We would have to get back to you on that—or it might be a better question for them.

Q215 **Chair:** I am sure Carol is right to want to identify who is going to do it. The position we are at now is different from previous decades or Parliaments, in that science funding has been quite buoyant over the last few years. It has maybe doubled during the course of this Parliament. There will be £20 billion a year of science, technology and innovation funding.

In that context, money should be available, but one of the other changes that has happened is that, with the abolition of the industrial strategy challenge fund, a lot of the funding that was available for what we could call translational research and innovation was transferred to UKRI and therefore to the research councils. It is not always clear that the same applications or priorities exist there, so we do need, as Carol says, to know who is responsible for providing this. Are there any further steers? You are both familiar with the funding and innovation landscape.

Professor Walmsley: The national quantum computing programme is largely funded through UKRI. Of course, there are other areas, like the MOD, that fund elements of it, as well. In that sense, your point is well taken that there is a route there to enable that to happen. NQCC, as part of the national programme, is funded through that route as well.

I was focusing a bit more on where the specific thing lies. Is it in a research council, like some of the other institutes such as the RFI or Crick? AMRC is a slightly different partnership between a university, the Government and industry. The CAP in Glasgow is Fraunhofer, Strathclyde and Scottish Enterprise. I think there are models that one could look at, in which UKRI would have a role.

Professor O'Brien: Clearly, there is the issue of where the money goes through, and who is routed through the research councils, but there are two things I would say. First, whichever route is made, it should be flexible. Where we have won as a hub is in the fact that actually EPSRC has been a pretty flexible funder for us. I think that flexibility has been helpful. Thinking about that is quite important.

The other point is on governance, which needs to be pretty spread. We should not have something that industry does not want. It is a big commitment for a single funder to create something when the people who are really going to be building the scaled machines do not find it useful.

Q216 **Chair:** Good, thank you for that. It is an appropriate point at which to turn to some of the companies that are making progress and have made investments in this area. Professor O'Brien and Professor Walmsley, thank you very much indeed for your evidence this morning.