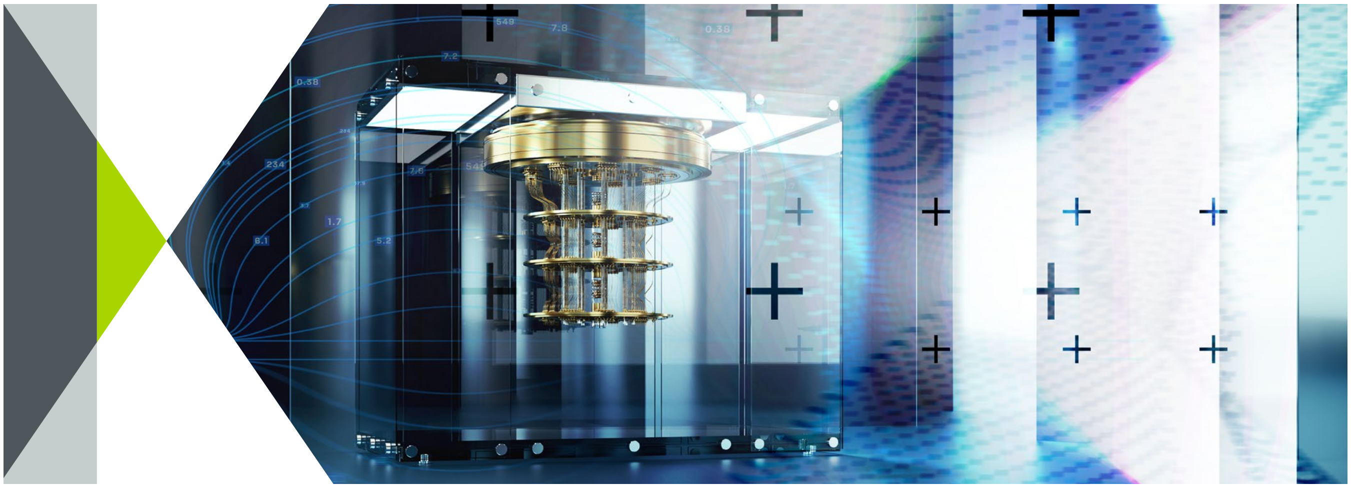


EXECUTIVE INSIGHTS

Quantum Computing — New Paradigm or False Dawn?

Key takeaways

- The businesses that will see the highest impact from quantum computing are those for which complex simulations or optimisation problems form a critical part of their core activities.
- But quantum systems are highly unstable. Sustained growth in quantum bits (or 'qubits') and continued development of the technology are key to producing a commercially viable quantum computer.
- As quantum computing becomes more common, the incentive to increase its availability and ease of use for the entire workforce will grow until it becomes a universally adopted technology.
- By understanding the applications quantum computing can support once it moves beyond the academic stage, business leaders should feel equipped to know when to act and what to look out for.

Google's announcement of the advent of 'quantum supremacy' in late 2019 catapulted quantum computing from the academic realm with its uncertain implications into something far more tangible.

Given the technology's potential to massively parallelise existing computing and thereby reduce calculation times a trillion-fold, hugely speeding up existing solutions while enabling answers to previously unsolvable problems, the value to the global economy of quantum computing is incalculable.

Today, competition is high amongst technologies vying to crack the difficulties that have held progress back in recent years, and companies have more access than ever to rent time on quantum computers (such as AWS Braket). Companies also are increasingly entering into partnerships with the hopes of capitalising on first-mover advantage, as with DP World's exploration of an opportunity for quantum computing to help optimise its shipping operations.

So is this the latest in a series of false dawns for a technology that seems to be perpetually 10-20 years away? Or does it truly represent a new revolution in business technology, akin to the introduction of computing or the recent rise of data science? And if the technology is coming, what are its implications on the day-to-day activities of different businesses?

As with any emerging technology whose activities remain largely in the academic sphere, developing answers to these questions can seem impossible to those without considerable background in cutting-edge science. In these circumstances many executives, especially those whose business activities are unlikely to be disrupted first, can be forgiven for adopting a 'wait and see' policy.

However, this would be a mistake. In fact, for the majority of business leaders, identifying whether your business needs to be a pioneer, an early adopter, a mature adopter or a bystander can be achieved on the basis of existing activities. Furthermore, the impact of quantum computing at different stages of maturity on these different categories can be characterised in advance.

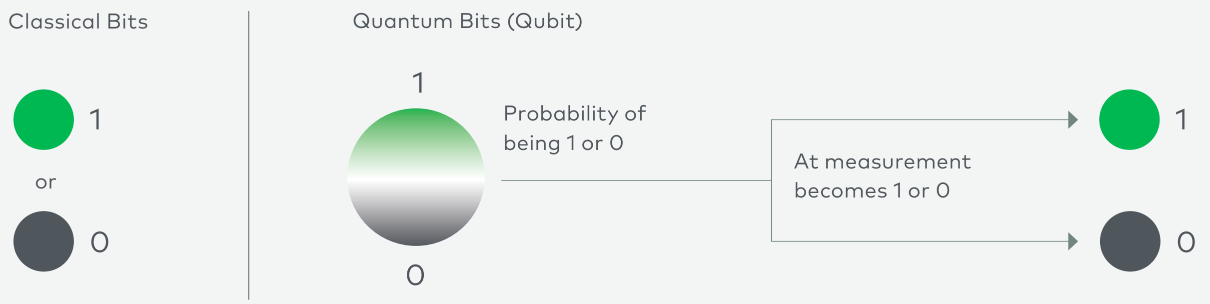
In this *Executive Insights*, L.E.K. Consulting outlines a simple framework based on only two simple questions: 'What impact can quantum computing have on my business?' and 'Where is quantum computing today?' Answering these questions will enable business leaders to plan with confidence for the future of quantum computing.

What impact can quantum computing have on my business?

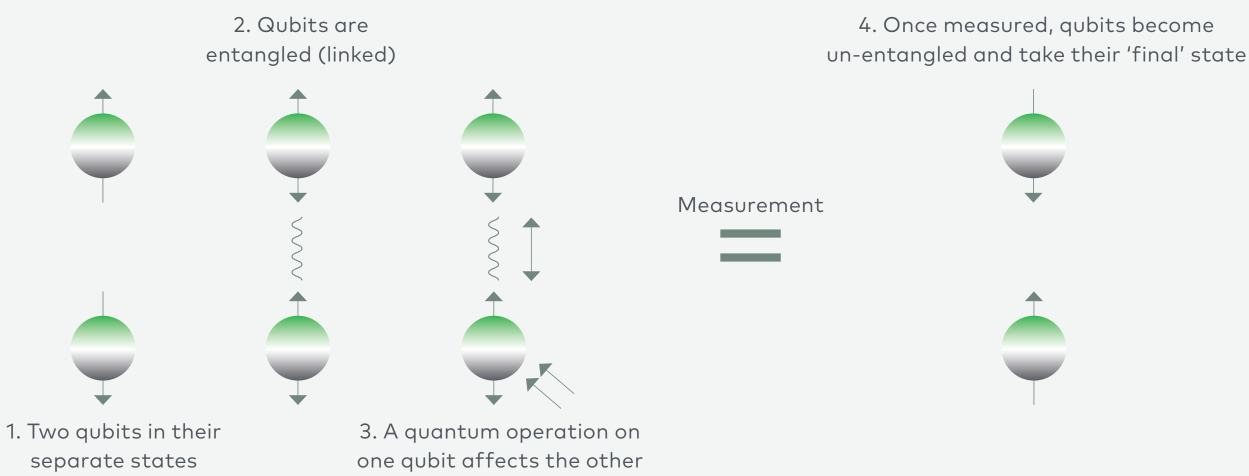
It is worth emphasising first and foremost that quantum computing is an entirely different type of computation to the digital computers we use every day (see 'Quantum computing 101' below). By exploiting the unusual and counter-intuitive properties of physics at the quantum level, quantum computers are able to perform calculations that would be impossible with a digital computer. In particular, this type of computing allows for calculations to be undertaken simultaneously rather than sequentially as is the case with a digital computer, thus enabling the calculation of optimisation problems or simulations in just seconds rather than years.

Quantum computing 101

A traditional computer uses long strings of “bits” (ones and zeros) to encode and process information. Quantum computers use quantum bits — ‘qubits’ for short — that allow information to be encoded as 1s, 0s or a combination of the two. This is accomplished using the quantum phenomena of superposition, where a qubit can have a probability of being 1 and a probability of being 0 at the same time, i.e. a ‘superposition’ of a 1 and a 0. This means that the number of ‘states’ or combinations of possibilities greatly increases in comparison to a traditional computer.



This leads us to the second key difference between classical and quantum computers. In quantum computers, qubits can be ‘linked’ using a quantum phenomenon called ‘entanglement’, where the encoding (or value) of one qubit is linked to the encoding of another qubit. Effectively this means that the changing of one qubit of an entangled two-qubit system also changes the second qubit automatically without intervention. In other words, a process can be run on a single qubit and the result reflected on all entangled qubits.



Because quantum computing is still at an early stage of its development, researchers are implementing quantum computing in a number of ways. The research has largely focused on using the charge or spin of electrons to carry out quantum computing; a standardisation of approach has yet to occur, however, and other candidates such as photons of light are possible alternatives. Importantly, all these approaches rely on cooling the quantum computer to temperatures just above absolute zero (-273°C) to ensure the quantum effects can occur, which generally requires large, specialised equipment.

Realistically, all the methods are all still subject to 'interference' (or instability) in real-world experiments, and error rates of various methods are still in the single-digit percentages — which underlines that unlike traditional computers, multiple hundreds of runs of quantum processes likely will need to take place to inspire confidence in any given answer.

Combining the effects of superposition and entanglement means that quantum computers are especially good at processing problems that involve many combinations.

These benefits mean the businesses that will see the highest impact from quantum computing are those for which complex simulations or optimisation problems form a critical part of their core activities, such as:

- Optimisation:
  - Route planning
  - Fleet and supply chain
  - Electricity generation and supply
  - Investment portfolio balancing
- Simulation:
  - Molecular modelling (drug discovery, genome mapping)
  - Airflow (airplane and vehicle design)
  - Weather/climate change
- Encryption
  - Breaking existing RSA cryptography
  - Quantum cryptography

Whether in pharma, aerospace, tech, or any other sector, businesses affected by quantum coupling will need to move quickly once it becomes commercially feasible — or risk being overtaken by competitors who unlock its value sooner. Businesses without simulations or optimisation problems at their core, on the other hand, can afford to wait.

The question of impact on a particular business can therefore be answered by most business leaders by thinking critically about the importance of optimisation, simulation and encryption to regular business activities — and the answer will define the appropriate stance to take. We characterise the potential stances into four: pioneers, early adopters, mature adopters and bystanders. The right response for today, depending on these stances, is outlined in Figure 1.

Technological evolution

The **academic stage** is characterised by the technology primarily being pursued in non-commercial academic contexts. Though the research may be sponsored by commercial organisations, the work undertaken is focused on the viability and prospective uses of the technology, rather than on direct usage to address a business need. Once the technology is viable and has proven commercial usages, it evolves to the specialist stage.

In the **specialist stage**, a limited number of experts in the field — often former academics — provide their services to businesses in deploying the technology in limited instances. The technology is typically highly specialised with low levels of standardisation but can be used on high-value projects in a bespoke manner. As the number of use cases increases and standards develop, the availability of expertise broadens, and businesses begin to see the value of developing their own in-house capability.

The **in-house stage** is characterised by businesses operating their own internal teams of technology specialists who develop and operate the technology inside the business. The business has seen the value of the technology and wishes to expand the number of use cases and value gained from using it. Tools and software are becoming standardised, although they are likely to still be proprietary or licenced, and some specialised training is still needed. Self-service platforms aim to lower the barriers to using the technology (e.g. WYSIWYG systems), but these remain in use overwhelmingly by those with pre-existing knowledge.

The **universal stage** is characterised by an abundance of technology providers, services and support. In general the new technology is used as and when required and demands very little to no training, with the majority of basic functionality becoming incorporated into daily business operations. The business now operates generally as a 'support' function that enables the rest of the business to use the technology. Using the technology is now a requirement to ensure the business is maintaining parity with competitors.

Figure 1:
Organisational stances and suggested actions

		Pioneers	Early adopters	Mature adopters	Bystanders
		Businesses for which quantum computing will be central to their business model	Businesses for which complex simulations or optimisation problems form a critical part of their core activities	Businesses that will benefit in the long term from quantum computing but have little benefit in being first	Businesses for which classical computing will largely be sufficient
Academic	-	Time to invest	Time to watch for move to specialist stage		
Specialist	Proven commercial viability of quantum computing		Time to invest	Time to watch for move to in-house stage	
In-house	Development of quantum computing standards/improved WYSIWYG* interfaces			Time to invest	Time to watch for move to universal stage
Universal	Easy availability to non-technical workers				Time to invest

*What You See Is What You Get
Source: L.E.K. research and analysis

Where is quantum computing today?

With the first question answered, business leaders now need to consider the second, which — thankfully — does not require a PhD in order to make an informed judgement.

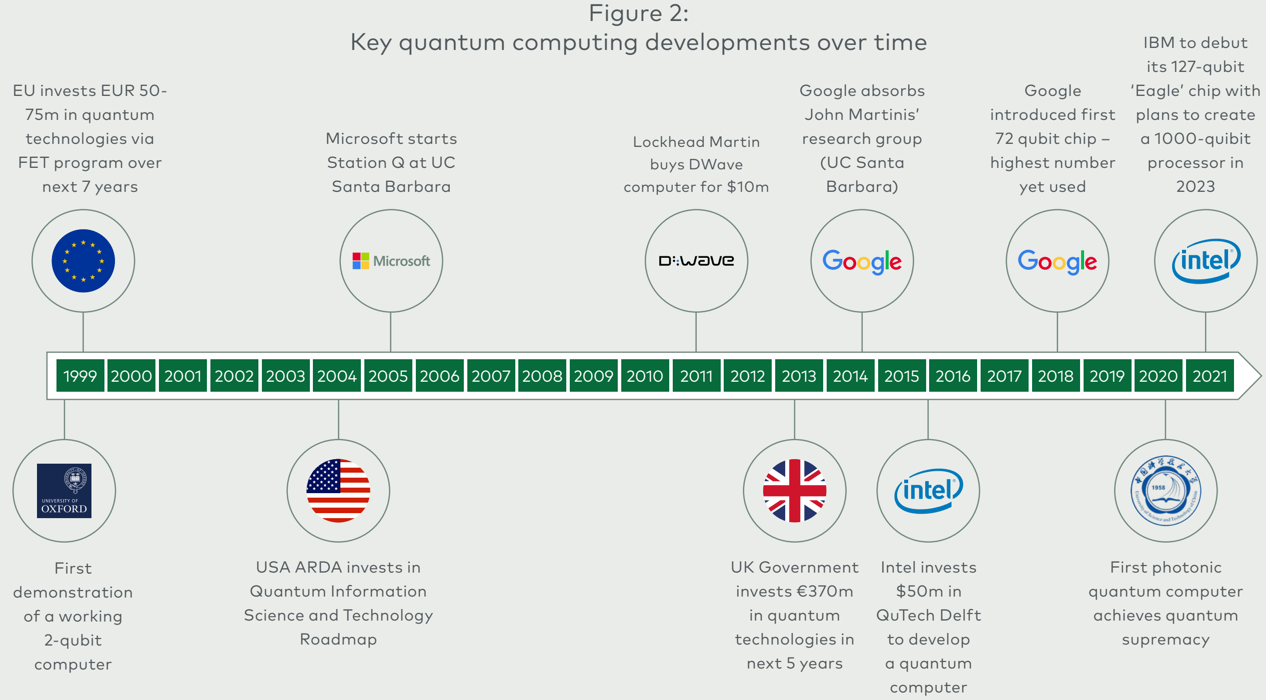
The same physical properties which allow for enormous benefits in parallel computing of quantum computers compared to digital computers come at a cost. Quantum systems are highly unstable, meaning that:

1. The engineering required to make 'quantum bits' (or 'qubits') work together is sophisticated
2. The requirements to check and correct for errors in calculations are high

Addressing these two challenges continues to represent the critical path for engineers and computing experts in developing a quantum computer that is commercially viable.

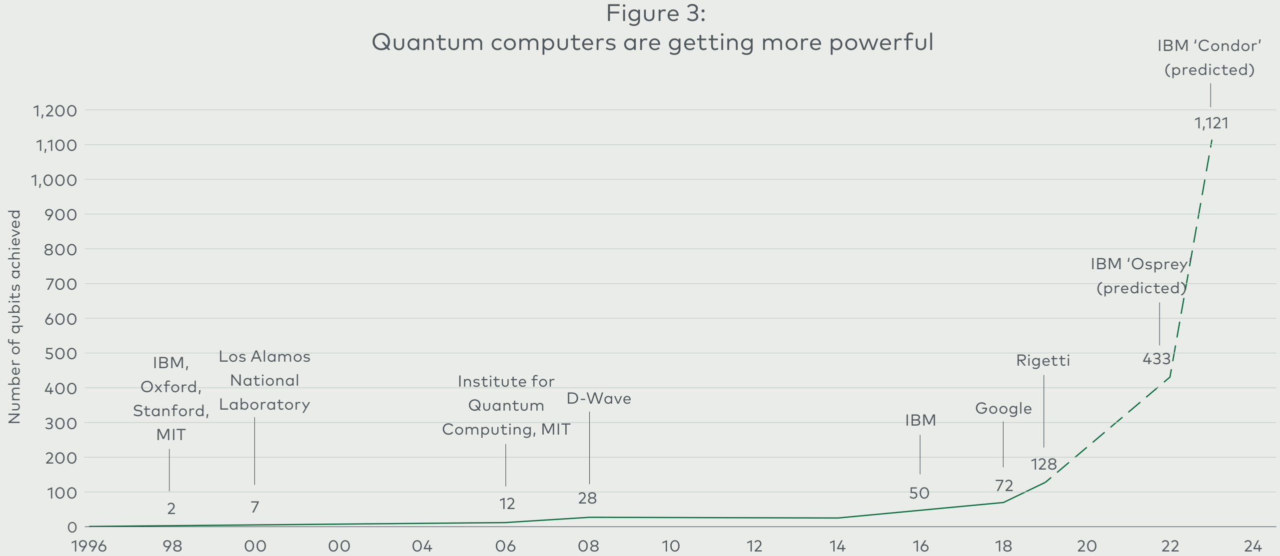
Since the first two-qubit computer was created in 1998, investment in quantum computing has continued to grow (see Figure 2). The most obvious outcome from this has been exponential growth in the number of (logic) qubits achieved in computers (see Figure 3).

Figure 2:
Key quantum computing developments over time



Source: L.E.K. research and analysis

Figure 3:
Quantum computers are getting more powerful



Source: L.E.K. research and analysis

Achieving high numbers of qubits is one of the most important steps in developing a viable quantum computer, particularly as it allows for greater error-checking in calculations. But other important — though perhaps less well known — developments continue across both hardware and software, aimed at improving the stability and quality of quantum calculations, and the ease of human interface with quantum computers. These include the first silicon quantum logic gate in 2015 as well as emerging standards for quantum programming languages.

It is the combination of sustained qubit growth and continued development of the technology that Google is banking on, promising a commercially 'useful, error-corrected quantum computer' within the decade.

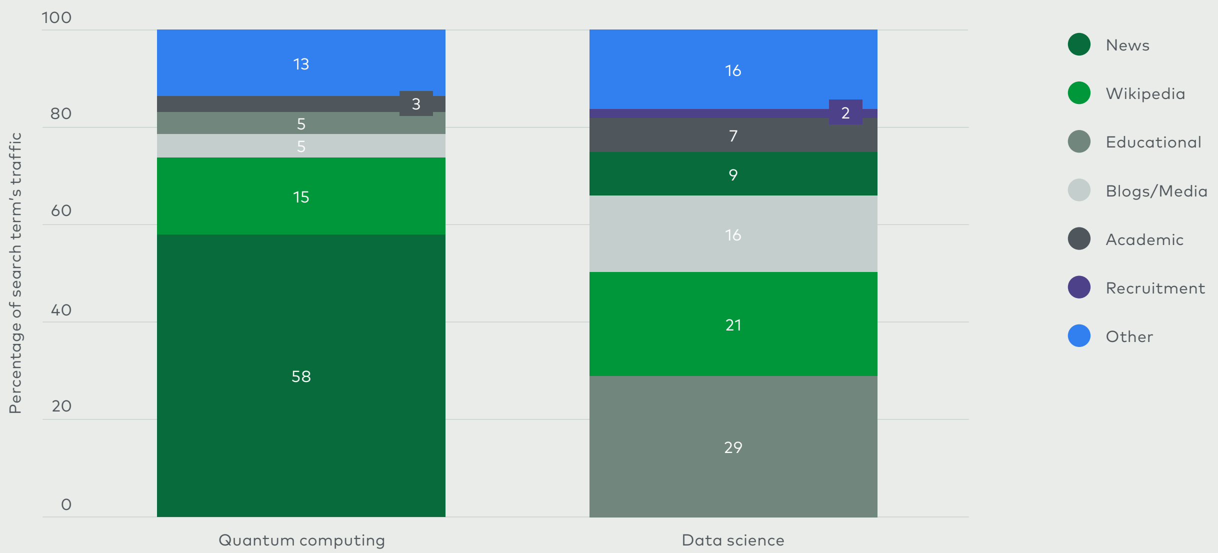
However, overcoming the technological limitations for a quantum computer — while important — is not the only requirement to enable widespread usage of quantum computing in business. Indeed, the emergence of quantum computers that are useful for businesses represents only the start of the technology's commercial evolution, as businesses and their staff grow in their experience and expertise with applying quantum computers to solve their problems.

Our analysis of the emergence of analogous technologies — including the growth in digital computing, the internet and data science — indicates four broad stages to technological adoption in and across businesses: the academic, the specialist, the in-house and the universal (see 'Technological evolution'). Today, digital computing has reached the universal stage, whereby computers are used by everyone in their day-to-day activities; meanwhile, data science has reached the in-house stage, whereby most large businesses have developed their own internal data science capabilities, but its direct use by the general workforce is limited, with most usage coming indirectly (e.g. via AI-enabled apps).

Quantum computing is still in the academic stage today, as indicated by searches for 'quantum computing' that result in traffic predominantly towards news sites, compared to searches for 'data science', which lead to educational sites offering courses and training (see Figure 4 and Figure 5). However, a combination of continued technological improvement and substantial increases in investment — with billions in November 2021 alone — are driving it towards the specialist stage.

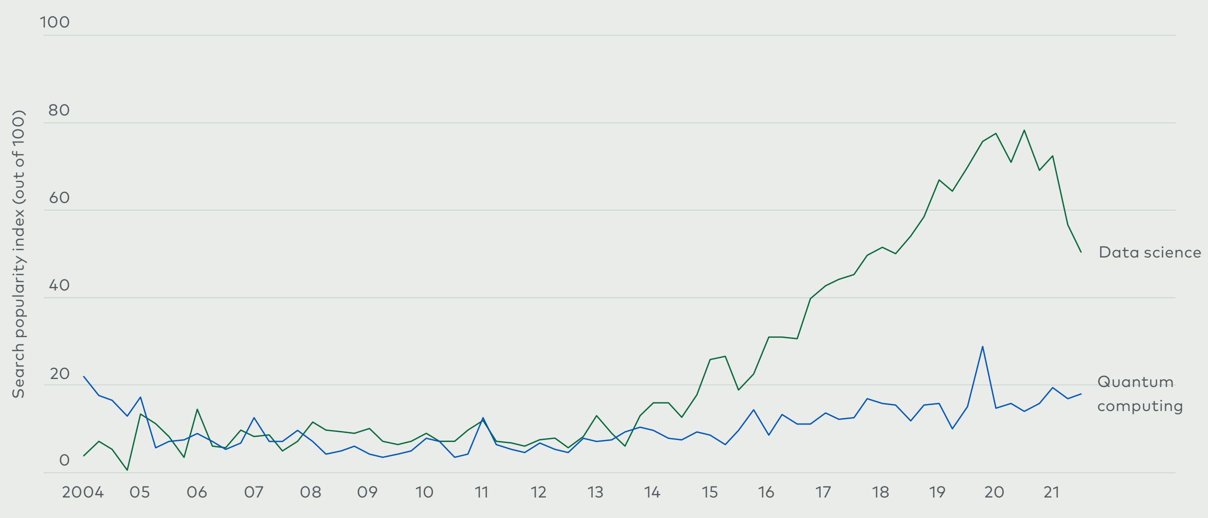
Following the historical path of previous technological advances, we can expect the initial emergence of commercially viable quantum computers to lead to specialist applications for those businesses where optimisation, simulation or encryption are most critical. Following this, hardware and software standards will be developed, enabling common technology 'stacks' to emerge, and creating defined professional paths for quantum computing experts to contribute within businesses, or in-house. As quantum computing becomes a common element of more and more business practices, the incentive to increase its availability and ease of use for the entire workforce will grow, until it becomes a universally adopted technology.

Figure 4:
Destination of web traffic by category of website



Source: SimilarWeb

Figure 5:
Google search term popularity (2004-Jul 2021)



Source: Google Trends

Conclusion: How to respond to quantum computing

Quantum computing advances clearly have the potential to disrupt many different industries in potentially significant ways. Yet rather than resort to inaction (due to its technical complexity) or knee-jerk responses (due to media hype at its potential impact), business leaders can and should take an informed, measured approach to address the future opportunity. As is the case with many potential disruptions, good self-knowledge — alongside a critical and objective assessment of which business activities are most likely to be affected — will ensure that businesses are well prepared to benefit from (instead of simply react to) the associated changes in computer technology (see Figure 6).

Figure 6:
Quantum computing has the potential to support a wide range of critical applications across industries

Sector	Application	Quantum computing value proposition		Examples
Life sciences	Simulation	Characterisation of protein structures	Rapidly characterise 3D protein structures and further disease understanding by simulating protein folding	DeepMind
	Simulation	Identification of drug candidates	Accelerate drug discovery by simulating how vast libraries of existing and theoretical small molecules bind to drug targets to identify the most promising candidates	CQC (Cambridge Quantum Computing)
	Optimisation	Optimisation of treatment decisions	Ensure oncology patients receive optimal personalised treatment plans based on analysis of comprehensive patient data sets collected in real-world settings	Google Quantum AI
Industrials and energy	Simulation	Simulation and digital modelling of real-world phenomena	Unlock the ability to model complex systems such as air flowing over a wing at different angles and speeds to help design an optimal wing structure	AIRBUS
	Optimisation	Energy system optimisation	Identify the optimal combination of power generators and storage capacity that can support expected demand given meteorological and other data	e.on
Financial services	Optimisation	Portfolio optimisation	Optimal asset allocation to maximise returns and minimise risk	JPMorgan Chase & Co.
	Encryption	Cryptography	Classical cryptography methods that previously secured financial transactions could be broken by a quantum computer, requiring the development of new quantum cryptographic techniques	quantropi
Retail and logistics	Optimisation	Travelling salesman problem	Optimise logistics networks from scheduling to last-mile delivery	DP WORLD

Source: L.E.K. research and analysis

By accepting that quantum computing is currently in the academic stage, and by knowing what to look out for in judging when it moves to the specialist stage and beyond, business leaders should feel equipped to know when to act and what to look out for.

For more information, please contact strategy@lek.com

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