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Mapping the Quantum Ecosystems: How Are Economies Positioning Themselves for Innovation Success

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EXECUTIVE SUMMARY

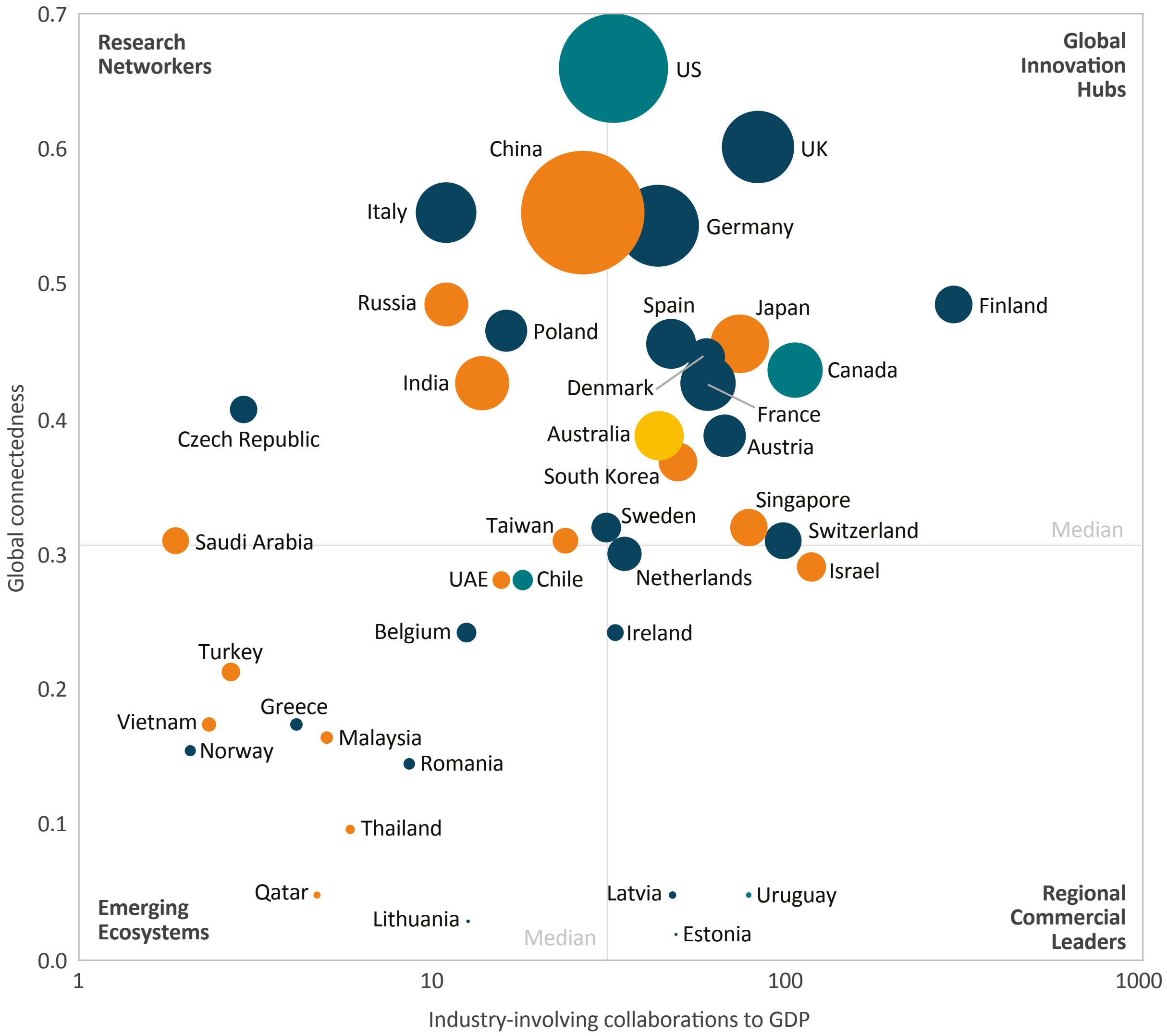
Quantum technologies are among the most complex and promising innovations of our time. Their advancement relies not only on breakthrough science, but also on the capacity of countries, institutions, and companies to collaborate across borders, sectors, and disciplines, bringing together the expertise and resources needed to turn innovation into market-ready solutions.

No country or region alone is in the lead – this is not a race between China and the US. Nor is quantum a development that will elevate one country to "supremacy" or "dominance": cloaking fields of technology development in the terminology of military strategy rather risks making us less capable of understanding what is going on. For the economic and strategic benefits to be captured, countries and regions need to build structures of collaboration that allow researchers and companies to tap into frontier developments and share the costs of complex knowledge generation.

An important way to measure the quantum competitiveness of countries is to benchmark the profile and strength of their collaborative structures. Using the ECIPE Quantum Database, this study analyses over 18,400 bilateral quantum partnerships involving more than 4,100 institutions across over 110 countries between 2018 and 2024. These partnerships encompass universities, research institutes, government agencies, startups, and large firms.

Based on the findings these collaboration patterns reveal, we go a step further to not only map the interactions between different players but also identify a scheme of four quantum archetypes that help show where countries stand in the global quantum ecosystem. One dimension of this scheme reflects the level of industry involvement in quantum collaborations relative to a country's GDP, serving as a proxy for commercial focus and economic prioritisation. The other captures how well-connected a country is internationally through direct quantum partnerships (see Figure a).

FIGURE A: QUANTUM COLLABORATION ARCHETYPES



The archetypes divide the global quantum ecosystem into four distinct categories. The first includes leading countries such as the US, UK, Canada, and Finland, which are classified as **Global Innovation Hubs.** These countries typically have a highly connected and commercially mature quantum ecosystem, characterised by strong international partnerships and dense industrial collaboration.

The second category includes countries like China, Italy, and India, which are classified as **Research Networkers** due to their integration into global scientific networks but weaker commercialisation efforts. China is a partial exception, sitting near the edge of the "Global Innovation Hubs" quadrant, close to the US on both dimensions. With more visible industrial collaboration, or if some existing partnerships come to the public attention, it could firmly move into the top-right quadrant.

The third category, **Regional Commercial Leaders,** includes countries such as Israel, the Netherlands, and Ireland. These ecosystems exhibit high levels of commercial involvement relative to their economic size. They often have a targeted national strategy or dynamic startup environments. While they may not yet be deeply embedded in the global quantum network, they excel at translating research into practical applications.

The fourth category, **Emerging Ecosystems,** includes countries such as the UAE, Chile, Belgium, and Turkey. These countries show limited international connectivity and lower levels of industry engagement. Many are in the early stages of building quantum capabilities and may face structural challenges such as low R&D intensity, skills gaps, or fragmented funding landscapes.

This study also makes key observations about quantum technology development that should inform governments that aspire to quantum success:

- **Quantum is inherently collaborative:** Quantum technologies require a diverse range of capabilities – from physics, computer science and various engineering disciplines; including specialised applications such as cryogenics – making it inherently difficult for any single actor or country to advance in isolation. In this context, collaboration is not optional; it is a structural necessity.

- **Global collaboration is high, but depth and openness vary:** The EU leads in collaboration volume, followed by China and the US. However, countries differ greatly in the nature of their collaborations, whether mostly through academia, government, or industry, as well as in how internationally open their networks are.

- **Industry engagement signals ecosystem maturity:** Countries with a higher share of industry-involving quantum collaborations – such as the UK, the US, Canada, and Finland, among others – tend to have more commercially advanced quantum ecosystems. These collaborations often serve as a proxy for the readiness to turn research into real-world applications.

- **Network roles shape global influence:** The US is the most central player in the quantum collaboration network, serving both as a hub (high number of partnerships) and a broker (connecting otherwise unlinked countries). China, while highly connected, is more inward-focused and less integrated into the international quantum collaboration scene than the US. However, China's partnerships are more specialised, with strong bilateral ties focused on a few countries such as Australia, Canada, and Finland. Within Europe, Germany and the UK occupy strong positions in the global network.

- **University spinouts are key bridges from academia to market:** University-originated startups attract a significant share of funding, accounting for nearly 60 per cent of all private investment in quantum startups. Institutions like the University of Bristol, Massachusetts Institute of Technology (MIT), and the University of Science and Technology (USTC) of China have been particularly successful in producing these high-potential spinouts.

- **Sectoral strengths influence focus:** Countries have patterns of national specialisation in quantum applications that align with their industrial strengths. For example, France excels in aerospace-related quantum partnerships, Germany and Japan in automotive, and Taiwan and the Netherlands in technology hardware.

Quantum success depends on building interconnected, open, and specialised ecosystems. To stay competitive, countries should foster quantum ecosystems that encourage industry participation, cross-country collaboration, and that build on their national strengths. Ultimately, this study argues that collaboration is not just a facilitator of quantum innovation – it is its foundation. Countries that embrace this reality and develop interconnected ecosystems are more likely to lead in the next wave of technological breakthroughs.

1. INTRODUCTION

Quantum technologies are set to become the next "big thing" for technology-driven innovation. Strangely, many observers and commentators reach for simplistic metaphors of "dominance" and "supremacy" when they cover quantum technology. In reality, quantum technologies are not the result of isolated pursuits – nationally or individually. In the first place, the field is inherently interdisciplinary, requiring expertise from physics, mathematics, computer science, engineering, and beyond. Its complexity is daunting, and means quantum cannot be advanced by single institutions[1] alone but demands significant resources and collaboration. For policymakers, then, quantum's continued success is not about beating China or the US – or "getting there" first. Like in other breakthroughs, innovation rather depends on the ability of broad ecosystems to integrate knowledge across disciplines and borders, foster a culture of experimentation, and build institutions that pull in the direction of commercialisation.[2] It is the result of teamwork. The distributed innovation system for quantum already shows different countries and institutions are specialising in distinct areas, such as error correction, cryogenics, control systems, and quantum materials, among others.[3]

A distinctive feature of quantum development is that, despite growing specialisation, global capabilities remain uneven, making international cooperation and information exchange essential.[4] The driving idea behind collaboration is that, even amid geopolitical tensions, leaders can choose to work together on projects that advance science for the common good. History provides many examples[5], reminding policymakers that major scientific breakthroughs often rely on peaceful cooperation, especially in fields that are costly and resource intensive. This is why understanding who collaborates, and how, matters.

The current study, therefore, offers a new perspective on how the global quantum ecosystem is forming. Our current work builds on the foundation laid in our previous study, which tracked quantum investments and research capacities across 33 countries.[6] That initial effort focused on identifying the key actors and tracking their global involvement in the quantum technology ecosystem. This paper takes that endeavour a step further, revealing how these actors collaborate. By shifting the focus from participation to partnerships, this new analysis offers a deep analysis of

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1 The field initially emerged from theoretical discussions around reversible computation and the limits of classical computing. Early figures like Richard Feynman and Charles Bennett laid the groundwork, Feynman notably shifted his perspective after initially conservative views, culminating in his influential paper on quantum computing following and attending the 1981 MIT Endicott House conference, where a small but growing community of researchers began to shape the direction of the field. By the mid-1980s, quantum technologies, particularly quantum cryptography, began to attract serious academic interest. In the early 1990s, regular gatherings in places like Turin further legitimised the emerging discipline. Industry actors such as Hewlett-Packard's Bristol lab became involved, often anticipating future political and strategic interests. Also see: MIT Endicott House. (2018). The Physics of Computation Conference. Available at: https://mitendicotthouse.org/physics-computation-conference/

2 A single research team may focus on a niche material or method that only one laboratory globally has the capacity to synthesise, often located in a different city, country, or operating under distinct institutional or regulatory framework.

3 Expert Insights. On Record.

4 Despite sustained investment by individual companies, there is growing recognition that no single corporation can fully master the quantum field on its own. Expert Insights, On Record.

5 Some big international physics projects include the CERN, the Apollo-Soyuz mission, International Linear Collider (ILC), the International Thermonuclear Experimental Reactor (ITER), and the Synchrotron-light for Experimental Science and Applications in the Middle East (SESAME).

6 Erixon, F., Dugo, A., Pandya, D. and du Roy, O. (2025, March). Benchmarking quantum technology performance: Governments, industry, academia and their role in shaping our technological future. ECIPE Policy Briefs. https://ecipe.org/publications/benchmarking-quantum-technology-performance/

the global quantum ecosystem and maps how different economies specialise, collaborate, and position themselves for scientific and commercial development.

The is based on the unique ECIPE Quantum Database that tracks over 4,100 institutions from more than 110 countries across the globe, involved in over 18,400 bilateral collaborations between 2018 and 2024. This data presents a good view of the world of quantum and its evolving economy, including academia, research institutes, government, startups, and industry. It sets the stage for studying how different regions' strengths can shape international quantum developments.

This study addresses a central policy question: how does the structure of collaboration in quantum technology influence countries' ability to specialise, commercialise, and compete? To explore this, we focus on three lines of inquiry directly relevant to policymakers and industry leaders:

- **Which models of ecosystem development offer the strongest pathways to success?** By applying a framework that combines industry involvement with international openness, we identify archetypes of quantum ecosystems and highlight the policy choices behind them.
- **Which partnerships accelerate commercialisation?** We examine the role of universities, startups, corporates, and governments in the collaboration network, showing which types of partnerships are most strongly linked to commercial maturity.
- **How do countries' existing industrial strengths influence their specialisation in quantum?** We analyse where national patterns of quantum collaboration align with broader industrial capabilities, showing how existing strengths are extended into emerging technology domains.

Section 2 presents evidence from bilateral quantum collaborations worldwide. The EU leads with around 925 institutions and 7,197 partnerships, followed by China with 733 institutions and 4,914 partnerships, and the US with 611 institutions and 3,842 partnerships. Together, these regions represent over half of global quantum collaborative activity. This section also groups national ecosystems by two practical traits: the degree of industry involvement in collaborations and the extent of international openness. This yields four archetypes: Global Innovation Hubs, Research Networkers, Regional Commercial Leaders, and Emerging Ecosystems, to reflect differences in ecosystem maturity and strategic orientation. Finally, the section maps the web of partnerships to show which countries sit at the centre, those that work with many partners and help connect groups that otherwise would remain apart.

Section 3 take a closer look at the institutional actors that underpin the quantum ecosystem, highlighting the central role of universities, public research institutes, and industry players. It reinforces the notion that while research-to-research collaboration dominates, partnerships involving industry, especially those tied to startups, signal greater commercial maturity. University spinouts emerge as a key bridge from academia to market, accounting for nearly 60 per cent of all private funding. Institutions like the University of Bristol, MIT, and USTC (China) stand out for producing globally impactful spinouts.

Finally, **Section 4** delves into revealed comparative advantage (RCA) metrics to uncover deeper national specialisations within quantum collaboration networks. It identifies country pairs with disproportionately strong bilateral ties and categorises countries by the type of collaboration they most intensively engage in. For instance, Canada and Japan are leaders in industry–research collaboration, while Israel and Ireland excel in industry–industry links. The analysis also shows that high-performing ecosystems often align collaboration strategies with existing industrial strengths, such as in automotive for Germany and aerospace for France.

2. MAPPING THE WORLD OF QUANTUM TECHNOLOGY DEVELOPMENT

2.1 The Global Quantum Collaborations Ecosystem

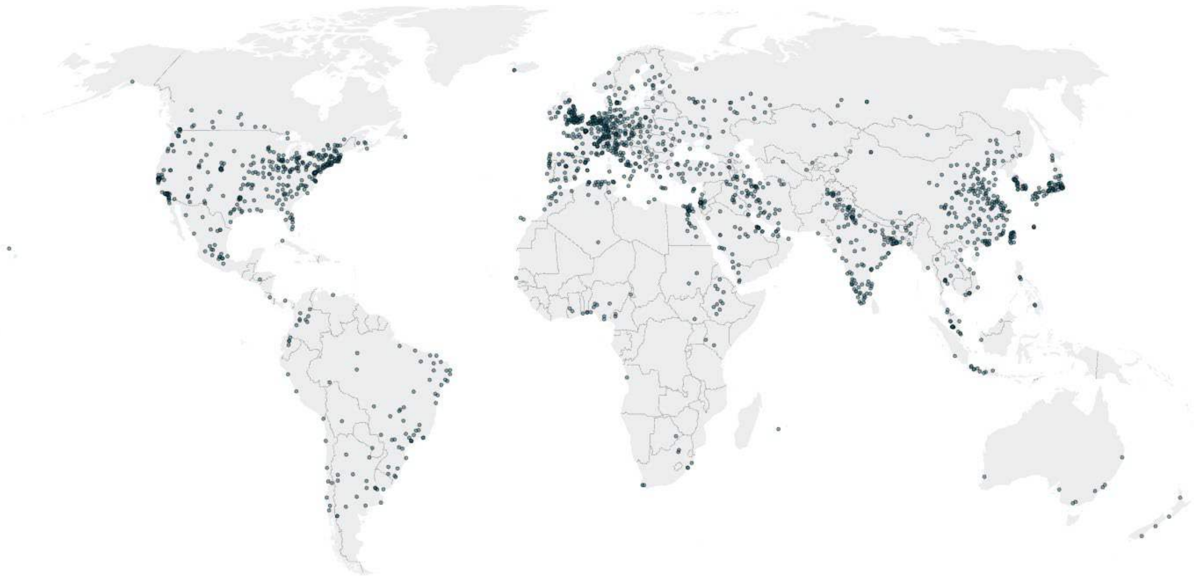
Let us start the analysis by understanding quantum collaboration – how various actors, institutions, and countries cooperate to achieve results. Collaborations are not merely about counts, they are indicators of how capabilities are coordinated across the three main domains of activity: research, government, and industry. Our dataset adopts a broad definition of "collaboration," encompassing any form of interaction or formal engagement between institutions. This includes, but is not limited to, joint research projects, strategic partnerships, shared funding initiatives, and co-authored outputs.[7]

Figure 1 below offers a visual representation of the global reach and density of the quantum technology ecosystem documented in our ECIPE Quantum Database. Each dot marks a city hosting at least one institution engaged in quantum technology tracked in our database. While all dots are rendered in the same colour, varying intensities, where some appear darker, reveal areas where multiple institutions are in close proximity. These overlapping dots signal the existence of dense local clusters of activity.

The broad distribution of these institutions across regions underscores the global character of the quantum innovation ecosystem captured in the data. The intensity of concentration in areas such as the West Coast and the Northeast Region of the US, Western Europe, and parts of East Asia, including Japan, South Korea, and coastal China, reflects the advanced stage of quantum research and ecosystem development in these regions. At the same time, the growing number of institutions across the Global South – most notably in India, the Middle East, North Africa, as well as parts of South America – points to an emerging diversification of the quantum landscape, suggesting the rise of new regional hubs.

[7] For further details on how the dataset was compiled, please consult the Methodology annex.

FIGURE 1: GLOBAL DISTRIBUTION OF INSTITUTIONS INVOLVED IN QUANTUM TECHNOLOGY



Source: ECIPE Quantum Database

The biggest quantum players are, nonetheless, the EU, China, and the US, respectively. Figure 2 (left panel) presents the top 20 countries in our dataset based on the number of entities active in quantum technology, categorised into three main domains: research, government, and industry.[8] The chart illustrates that these regions shape much of global quantum activity by any standard compared to other countries. The EU has the biggest number of institutions (925) engaged in quantum technology, followed by China with 733 and the US with 611. These three actors alone account for over 54 per cent of all institutions involved in quantum technologies globally. In a more distant fourth place is India, with 238 entities, followed by Germany (211) and Japan (203). Completing the top 10 are the UK (181 institutions), France (177), Italy (130), and Russia (128).

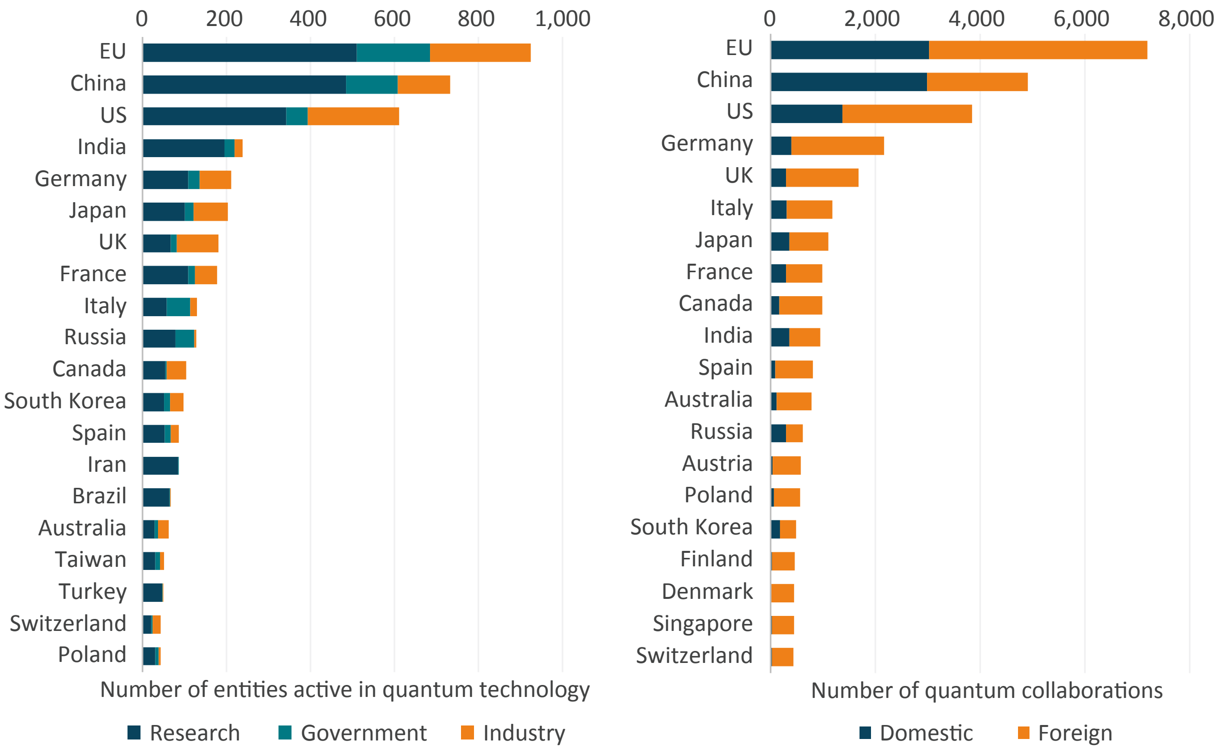
In most countries, the quantum ecosystem is still predominantly rooted in academia, with universities and independent research institutions making up the majority of active entities. This reflects the early-stage nature of the field globally, where fundamental research continues to drive progress.

8 Institutions are classified into seven distinct types: University and Research institute (grouped under the broader Research category); Government agency and Public research institution (under Government); and Quantum startup, Other startup or SME, and Corporate (under Industry). Each institution is categorised by city, country, and region. For those in the Industry category, entities are further classified by industrial sector, following the Industry Classification Benchmark (ICB).

However, crucial differences emerge across regions. In countries such as India, Iran, Brazil, and Turkey, research institutions still account for nearly all quantum-related activity. By contrast, other countries have more varied participation, with a growing presence of private-sector firms, signalling a shift towards commercialisation and applied development. In nations such as Japan, Australia, Canada, Switzerland, and the UK, industry players account for 40 to 55 per cent of all institutions involved in quantum, significantly higher than the global average.

These differences reflect broad variation between countries in economic and technological development. Countries where research institutions dominate are generally earlier in the quantum development curve and tend to have lower levels of economic maturity. Conversely, countries with stronger private-sector engagement typically show more advanced quantum ecosystems. Moreover, these industry-led quantum regions are the same that are supported by higher levels of funding, academic productivity, and intellectual property output, as shown in our previous study.[9]

FIGURE 2: TOP 20 COUNTRIES BY NUMBER OF QUANTUM TECHNOLOGY ACTORS (LEFT PANEL) AND COLLABORATIONS (RIGHT PANEL), BY DOMAIN AND TYPE, 2024



Source: ECIPE Quantum Database. Note: The figure includes both the EU as a whole and individual EU Member States. Including both levels provides a more accurate picture of the distribution of activity and partnerships in the quantum sector. For the EU, domestic collaborations refer to both collaborations within individual Member States and intra-EU collaborations. Foreign collaborations are defined as those between an EU Member State and a non-EU partner.

[9] Erixon, F., Dugo, A., Pandya, D. and du Roy, O. (2025, March). Benchmarking quantum technology performance: Governments, industry, academia and their role in shaping our technological future. ECIPE Policy Briefs. https://ecipe.org/publications/benchmarking-quantum-technology-performance/

The largest players in the quantum space also broadly tend to be the biggest collaborators, as shown in Figure 2 (right panel). The chart displays the top 20 countries ranked by the number of quantum collaborations in which they participate. Collaborations are categorised as either domestic or foreign, depending on whether they take place within a single country or involve institutions from different countries.

The EU, China, and the US top the list in terms of collaborative activity. The EU is involved in 7,197 quantum collaborations, followed by China with 4,914 and the US with 3,842. This means the EU participates in 46 per cent more collaborations than China and 87 per cent more than the US. Interestingly, the EU and China exhibit similar levels of domestic collaboration. The key difference lies in the share of foreign collaborations: in the EU, these represent 58 per cent of all collaborations, whereas in China they account for only 39 per cent.

Completing the top 10 are Germany (2,162 collaborations), the UK (1,685), Italy (1,185), Japan (1,104), France (988), Canada (984), and India (945). Interestingly, several countries that rank highly in terms of the number of quantum actors such as Iran, Brazil, Taiwan, and Turkey do not exhibit similarly high levels of collaboration. While these nations host a significant number of quantum institutions, their engagement in cross-institutional partnerships remains limited. Conversely, countries such as Austria, Finland, Denmark, and Singapore feature among the top 20 in terms of collaborative activity, despite not hosting as many quantum institutions. This suggests that the depth of collaboration, not merely the number of institutions, are critical drivers of progress in quantum innovation.

Remarkably, almost all countries exhibit a high share of international collaborations. Even in the largest regions, such as the EU and the US, foreign partnerships account for the majority of total collaboration activity, highlighting the critical role of cross-border engagement in the quantum field. In smaller, open economies such as Austria, Finland, Denmark, Singapore, and Switzerland, international collaborations often represent more than 90 per cent of total quantum-related partnerships.

In contrast, countries such as China, Russia, and India display significantly lower levels of international collaboration, with domestic partnerships accounting for 40 to 60 per cent of their total quantum-related collaborations. This pattern can partly be attributed to the size of their domestic markets, which support extensive internal quantum networks as seen in coastal China (Figure 1). However, the high share of domestic collaboration may also reflect strategic priorities, institutional openness, or a preference, whether voluntary or policy-driven, for local partnerships over international engagement. In China's case, for instance, the quantum research ecosystem is shaped by a national strategy focused on technological self-reliance. This approach directs public funding and institutional collaboration towards domestic actors and limits international engagement, particularly in sensitive areas.[10]

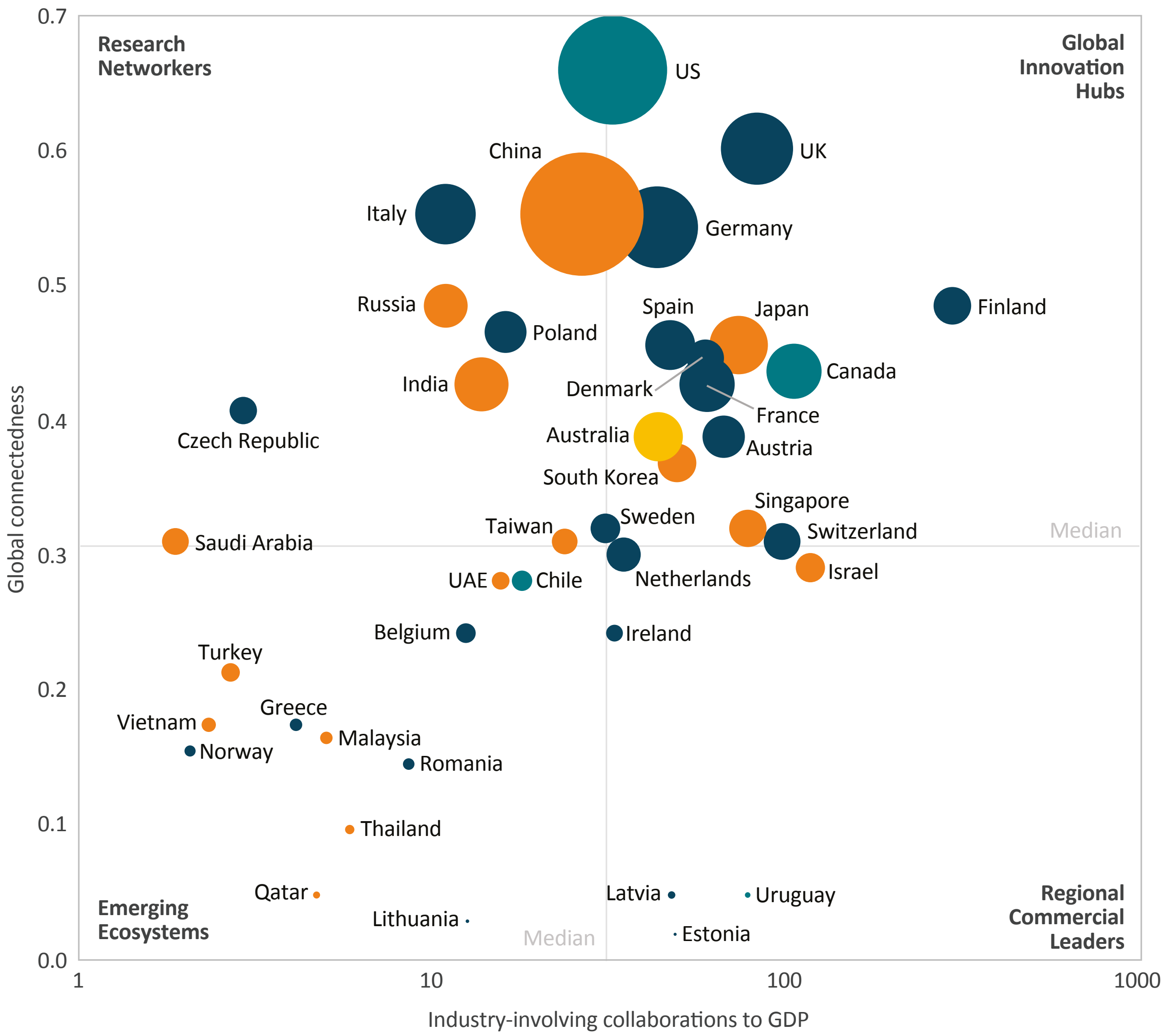
[10] People's Republic of China. (2021). The 14th Five-Year Plan of the People's Republic of China—Fostering High-Quality Development. https://www.adb.org/publications/14th-five-year-plan-high-quality-development-prc

2.2 The Quantum Ecosystem: Archetypes

Our analysis of quantum ecosystems rests on two key dimensions. The first is **commercial orientation:** while basic research is essential, countries that advance more quickly are those able to translate scientific knowledge into commercial applications. A strong indicator of this capacity is the intensity of industry collaboration. The second is **international openness:** countries with broader cross-border partnerships are better positioned to access expertise and capabilities that would otherwise remain out of reach.

Building on these two dimensions, as illustrated in Figure 3, we categorised the main quantum-active countries into four archetypes, which highlight the diverse strategic positions countries occupy within the global quantum landscape and provide a useful framework for further discussion.

FIGURE 3: QUANTUM COLLABORATION ARCHETYPES: INTERNATIONAL OPENNESS AND COMMERCIAL ORIENTATION



Source: ECIPE Quantum Database. Note: Industry-involving collaborations are measured per trillion USD of GDP. Only countries with an industry-to-GDP collaboration ratio of at least 1 were included in the chart.

The chart categorises over 40 countries based on their structural positioning within the global quantum collaboration landscape. Although our whole dataset includes 110 countries, this scheme focuses on those with an industry-to-GDP collaboration ratio of at least 1, capturing the set of nations where commercial engagement in quantum research is at least somewhat significant. The horizontal axis measures the number of industry-involving quantum collaborations relative to GDP, a proxy for the commercial intensity and economic prioritisation of quantum activity. The vertical axis represents each country's global connectedness within the international quantum network, meaning how many direct quantum partnerships it has.

Each bubble represents a country, with size proportional to its total number of quantum collaborations. Colours denote geographic regions: blue for Europe, orange for Asia, green for the Americas, and yellow for others (e.g. Australia). The vertical and horizontal lines show group medians, dividing countries into four quadrants that reveal distinct ecosystem archetypes.

In the top-right quadrant are the so-called **Global Innovation Hubs** – countries that combine strong international reach with high levels of commercial collaboration. These include Finland, Canada, the UK, the US, Japan, France, Germany, and many others. These countries are well-positioned to shape global quantum standards, value chains, and public–private innovation models. Strategic alignment with these hubs can amplify impact.

In the top-left quadrant, **Research Networkers** such as China, Italy, Poland, and India exhibit strong international embeddedness but lower relative industry involvement. These ecosystems are research-intensive and globally connected, but face challenges in converting research leadership into industrial capabilities. Policy measures may need to focus on scaling spinouts, fostering venture capital, and strengthening applied research pathways. China lies near the boundary with the Global Innovation Hubs quadrant, close to the US on both axes. A greater incidence of industrial collaboration would place China firmly in the top-right quadrant. Some of these collaborations may not be publicly disclosed, making China's position possibly within the margin of error. Nonetheless, its current standing is already highly advantageous and just short of full convergence.

The bottom-right quadrant features **Regional Commercial Leaders** – countries that exhibit high levels of commercial involvement relative to their economic size but are less central in the global network. This includes fewer countries, among which are Israel, the Netherlands, Ireland, Estonia, and Latvia. These systems often benefit from focused national strategies or agile startup ecosystems.[11] While they may not yet be globally embedded, they perform strongly in translating research into applications. These systems might benefit from deeper global integration or strategic bilateral agreements to connect local strengths with global markets. Countries such as

[11] Ireland's strategy builds on the vision to make it an internationally competitive hub in quantum technologies at the forefront of scientific and engineering advances, through research, talent, collaboration, and innovation. The Netherlands identified ten sectors where it has excelled scientifically; one of these sectors is quantum technology, which is at the core of QuTech's research and engineering. The Dutch minister intends to position the Netherlands as a global leader in quantum by 2035 through the development of talent, facilities, financing, and market creation. Latvia's Quantum Initiative will monitor and coordinate national activities related to quantum technologies, participate in European quantum cooperation networks, address the needs of Latvian industry, and represent its interests in quantum technology development. Estonia is focusing on leveraging its capabilities in software creation to build competence in quantum software.

Israel and the Netherlands, in particular, lie on the cusp of the Global Innovation Hubs quadrant and require relatively modest effort to transition into the top tier.

Finally, **Emerging Ecosystems** are found in the bottom-left quadrant. These countries – such as the UAE, Chile, Belgium, Turkey, Vietnam, and Greece – display limited international connectivity and lower industry engagement. Many are in the early stages of capability-building and likely face structural barriers such as low R&D intensity, skills gaps, or fragmentation of funding. These ecosystems could benefit from targeted support, regional partnerships, and inclusion in international research programmes to accelerate development. Saudi Arabia lies on the boundary with the Research Networkers quadrant, reflecting the country's growing international connectedness, but continued limitations in industrial involvement.

Notably, Finland stands out as an EU and global quantum frontrunner – both commercially mature and internationally integrated despite its small size. The US is similarly well-positioned, exhibiting strong commercial orientation and extensive global connectivity. China, while highly networked, remains more inward-oriented in terms of industrial collaboration. France and Germany, despite their strong overall positions, rank closer to the median in commercial engagement compared to peer countries such as the UK, Japan, and Canada – suggesting untapped potential for industrial scale-up.

Overall, this quadrant-based scheme offers more than a snapshot. It serves as a directional map of the quantum collaboration landscape, enabling countries to benchmark their position, identify peers, and target policy interventions to shift quadrant over time. It also highlights opportunities for regional complementarity: for instance, pairing research leaders such as Italy with commercial leaders such as the Netherlands could help build more matching European quantum capabilities. Table 1 below summarises the main features, examples, and policy priorities of each archetype.

TABLE 1: SUMMARY OF QUANTUM COLLABORATION ARCHETYPES

Archetype	Description	Typical countries	Main features	Policy priorities
Global Innovation Hubs	Highly connected globally and commercially mature ecosystems	Finland, Canada, UK, US, Japan, France, Germany	Strong international partnerships; dense industrial collaboration; influential in shaping global standards	Scale-up support; international leadership; IP protection; cross-border investment and standard-setting
Research Networkers	Well embedded in global science but with weaker commercialisation	China, Italy, Poland, India	Strong academic output; high international research ties; lower industry collaboration	Spinouts and venture capital; applied R&D funding; incentives for industry–academia cooperation

Archetype	Description	Typical countries	Main features	Policy priorities
Regional Commercial Leaders	Commercially focused ecosystems with limited global integration	Israel, Netherlands, Ireland, Estonia, Latvia	Agile innovation systems, strong startup scenes, and often small economies with targeted investments	Global integration, strategic bilateral agreements, participation in international platforms
Emerging Ecosystems	Limited international connectivity and low commercial engagement	UAE, Chile, Belgium, Turkey, Vietnam, Greece	Early-stage development; often fragmented R&D or lower private sector participation	Capacity building; skills development; inclusion in global research programmes; regional cooperation

Source: ECIPE Quantum Database

2.3 When Industry Joins: A Predictor of Quantum Innovation

As global competition in quantum technology intensifies, the ability to translate research excellence into commercial outcomes is becoming a key differentiator. While many countries boast strong academic capabilities, only a subset are effectively bridging the gap between research and market deployment.

Various indicators can be used to assess commercial maturity, but we utilised a more targeted metric: the degree of industry involvement in quantum collaborations. Partnerships that include industry actors, particularly startups and corporates focused on near-term applications, can provide a tangible signal of a country's proximity to commercial deployment. Unlike other metrics that may capture potential rather than current development, industry-linked collaborations offer insights into where the translation of quantum research into real-world value is already underway. Compared to funding data alone, which can be volatile, lagging, and skewed by a small number of large deals, collaboration activity offers a more structural and sustained view of ecosystem maturity. It reveals not only where capital is flowing, but where trust, knowledge exchange, and strategic alignment are actively taking shape, both within and across borders – factors that are far more predictive of long-term commercial success.

To assess whether industry-linked quantum collaborations can reliably serve as a proxy for proximity to commercial application, it is instructive to benchmark this data against funding levels. The volume of investment, whether channelled into quantum startups or committed by large corporates, varies significantly across countries and offers insight into where investors see the most promise in the quantum market.

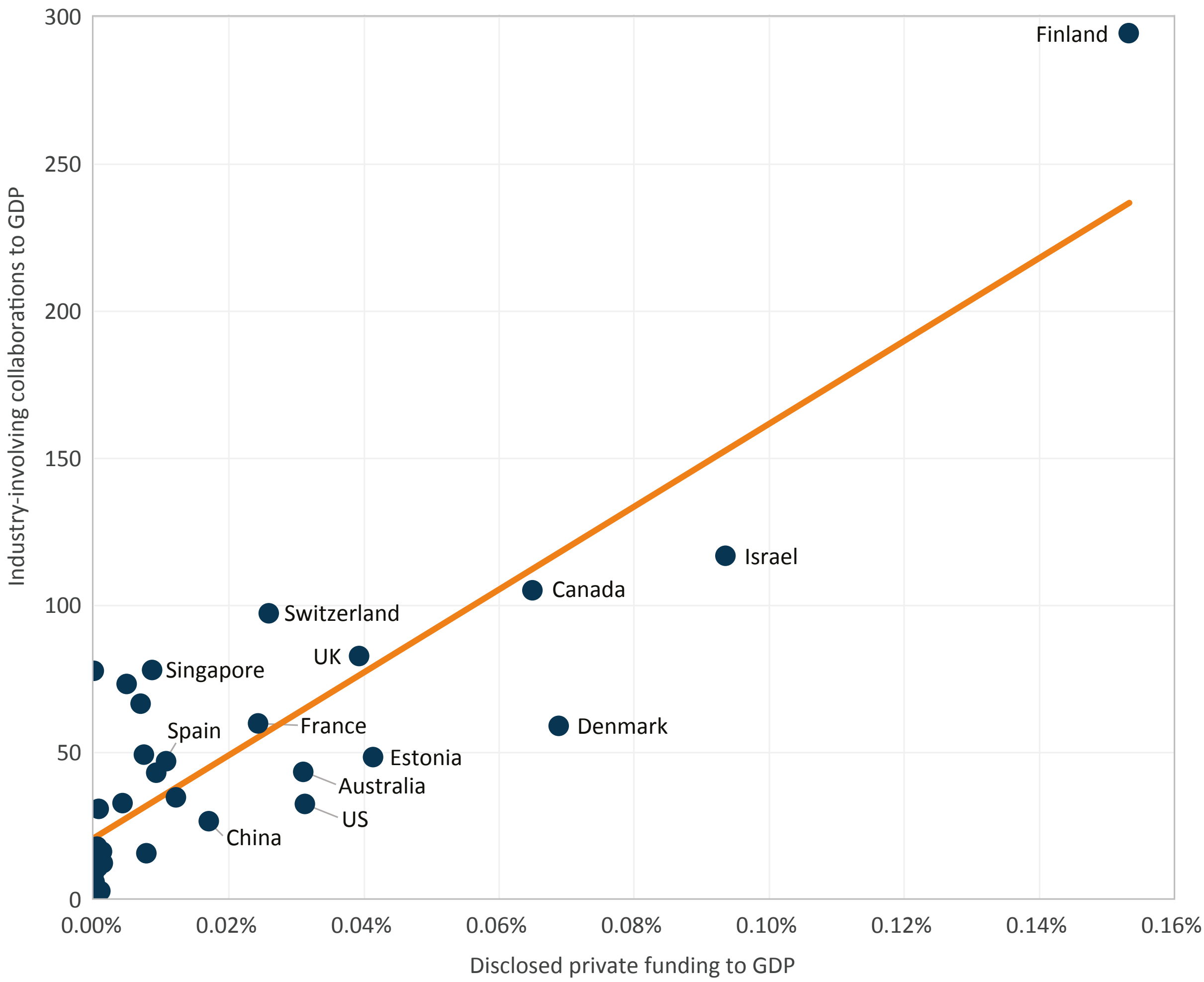
A positive correlation between the volume of industry-involving quantum collaborations and quantum funding levels would support the idea that such collaborations are a strong indicator of commercial readiness. More broadly, it would show that collaboration data can serve as a reliable benchmark for assessing the global quantum landscape. Like funding, it captures where commercial potential is seen, but unlike funding, it is less volatile and more reflective of sustained, ecosystem-wide engagement. This makes it a more stable and comparable measure of national positioning and ecosystem maturity.

The relationship is clearly illustrated in Figure 4, which presents link between industry-led quantum collaborations and private sector funding. The figure plots the number of industry-involving quantum collaborations relative to GDP against disclosed private-sector quantum funding, also expressed as a share of GDP, across all available countries. The positive trend line highlights a clear correlation: countries where quantum startups attract more funding and where large corporations commit greater investment to quantum initiatives also tend to demonstrate a higher density of industry-linked quantum collaborations.

This correlation reinforces the idea that industrial collaboration activity can serve as a proxy for commercial traction in quantum. Finland, Israel, and Canada stand out for combining strong funding efforts with high rates of collaboration involving industry. Notably, Finland is a clear outlier with exceptionally high collaboration and funding intensity, suggesting a particularly integrated and well-supported national ecosystem.

The lower-left quadrant includes many of the world's largest economies – China, the US, Spain, and France among them. These countries exhibit both a relatively low per capita number of quantum collaborations involving industry and lower levels of disclosed private funding in the quantum sector, albeit with great variation. The US, for instance, reports nearly twice the level of funding to GDP as China and simultaneously shows greater industrial collaboration activity.

FIGURE 4: RELATIONSHIP BETWEEN INDUSTRY-INVOLVING QUANTUM COLLABORATIONS AND QUANTUM PRIVATE SECTOR FUNDING AS A SHARE OF GDP



Source: ECIPE Quantum Database. Note: Industry-involving collaborations are measured per trillion USD of GDP. Funding data is current as of April 15, 2025. For visual clarity, only a selection of country labels is shown in the chart.

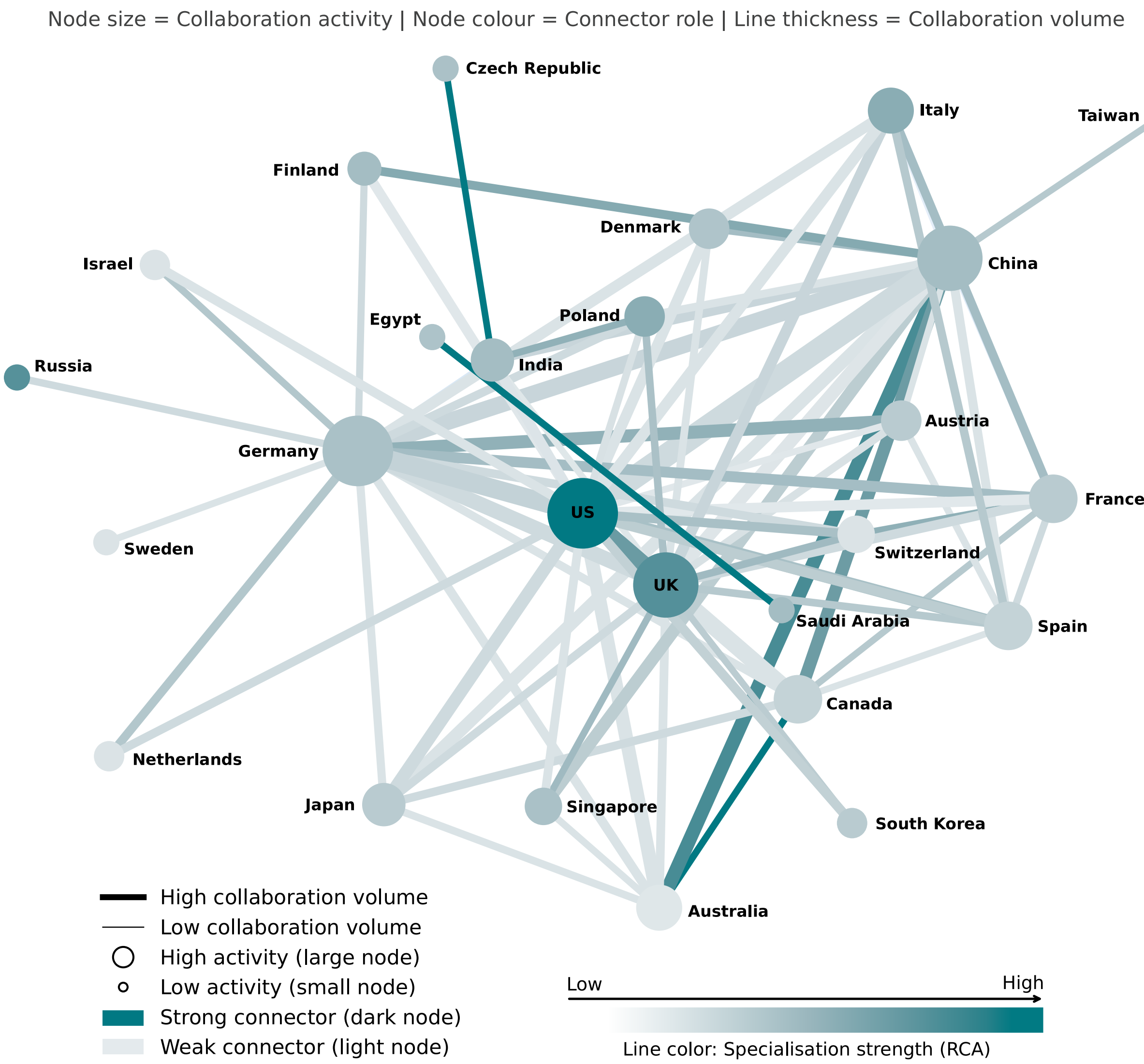
2.4 Network Roles: Centrality and Brokerage

Having examined the volume and commercial orientation of quantum collaborations, we turn to a deeper question: how do these partnerships shape the architecture of the global quantum ecosystem? [12] To answer this, we employ network analysis, not merely to count links, but to understand how countries position themselves as connectors, brokers, or hubs within a globally distributed system of innovation.[13]

[12] Product space and relatedness networks help explain why certain places become hubs for complex industries, and they help understand where a new technology is more likely to emerge. As such, it serves as a tool to inform political and industrial decisions. For instance, in Europe, the key milestone had already come in September 1998, when the European Commission hosted a meeting in Helsinki, a politically motivated gathering that brought together major academic players and representatives from industry, including HP and IBM.

[13] Degree centrality measures the number of direct connections a country has. A higher value means a country is a hub with many direct links (shown in Figure 5 as larger circles). Betweenness centrality shows how often a country sits on the "shortest route" between two others. Countries with high scores act as bridges that connect otherwise separate groups (darker circles in Figure 5). Eigenvector centrality reflects a country's influence based on connections to other influential partners, emphasizing not just how many but who you collaborate with.

FIGURE 5: QUANTUM COLLABORATION NETWORK (≥ 30 COLLABORATIONS)



Source: ECIPE Quantum Database. Note: This network displays bilateral collaborations in quantum science where at least 30 joint activities were recorded. Each country is represented as a node, with its size reflecting how active it is in the network (i.e. how many different partners it collaborates with). The colour of the node indicates its role as a connector; darker shades imply a stronger role in linking different countries together (i.e. higher betweenness centrality). The thickness of the lines represents the volume of collaboration between two countries, while the line colour shows the degree of specialisation between the pair (based on their revealed comparative advantage in quantum fields).

Countries that score highly on quantum centrality, as shown in Figure 5, are not only well-connected internationally; they also play a major role in shaping the flow of information, resources, and influence across the global quantum ecosystem. In the chart, larger circles correspond to countries with more partners[14], darker circle colours to those that connect otherwise separate

[14] Degree centrality. Details in the methodology section

parts of the network[15], thicker lines to more frequent collaboration, and darker lines to partnerships that are particularly strong relative to other links.[16]

Our analysis reveals that the US stands out as the most central actor. It combines the largest number of partners with a strong connecting role, consistently linking otherwise separate parts of the network. This position reflects both its leadership in private-sector quantum R&D and its extensive industry-led collaborations. Its relationship with the UK is particularly strong: it combines a broad volume of partnerships with a high degree of specialisation, making this relationship the backbone of the transatlantic quantum landscape.

China also occupies a central position, with extensive international links and considerable influence. Its collaborations, however, are concentrated within a more tightly connected group, particularly Australia, Canada, Finland, and Denmark, reinforcing earlier observations of its inward-facing orientation and focus on domestic capability consolidation.

European countries collectively form a dense core in the network. Germany is strongly embedded through its links to other major players but is less active in linking sub-networks. The UK, by contrast, serves as a connector across regions, reflected in the darker colour of its circle. Links among Germany, France, Italy, and Austria are both frequent and above expectations, while smaller European countries such as Finland, Denmark, the Netherlands, and Switzerland maintain an outward-looking profile with focused partnerships beyond Europe. These patterns illustrate that Europe's network position comes both from internal density and outward connections.

India has an important bridging role despite a smaller scale of activity. It appears in many of the most significant bilateral collaborations, including those with the US, the UK, Russia, Saudi Arabia, Poland, and Taiwan, helping to link otherwise separate parts of the network. Russia and some Gulf countries also perform similar bridging functions, though less prominently.

3. INDUSTRY, RESEARCH, AND GOVERNMENT: THE INSTITUTIONAL FABRIC OF QUANTUM COLLABORATION

3.1 The Architecture of the Quantum Ecosystem

The quantum ecosystem is shaped not just by countries and collaborations, but by the institutions that drive and support its development – from leading universities and startups to government agencies and large firms. An overall analysis of the quantum ecosystem reveals six distinct partnership types that collectively shape the global architecture of quantum collaboration, which are summarised in Figure 6.

[15] Betweenness centrality. Details in the methodology section

[16] Technical note: the line colour reflects the bilateral revealed comparative advantage (RCA) index which is further developed in section 3. The RCA index is calculated by comparing how often two countries collaborate to how often they would be expected to collaborate, given their total international activity. A value greater than 1 means the partnership is stronger than average, i.e., a focus rather than a by-product of size.

The most common type of collaboration, accounting for 61 per cent of all cases, is research-to-research, that is, between two research institutions. This includes collaborations between two universities, between two non-public research institutes, and between a university and a non-public research institute. The single most frequent partnership is that between two universities, which alone represents over 49 per cent of all quantum collaborations in the dataset. The high share of this type of collaboration reflects the large number of countries that are active in the early stages of the quantum development curve, but which do not yet have a significant industry presence.

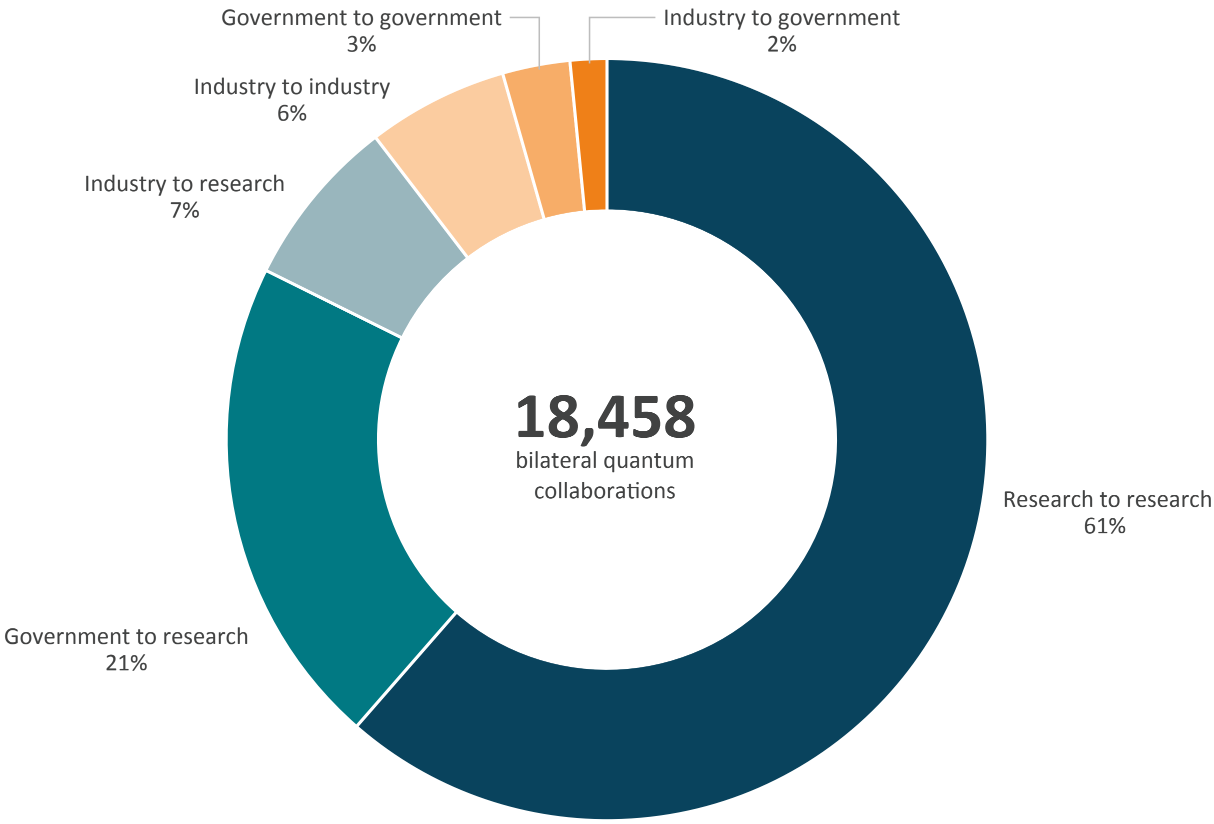
The second most prevalent category, at 21 per cent, consists of collaborations between government institutions and research entities, typically joint projects between universities and publicly affiliated research bodies. Third in line are industry-to-research collaborations, making up just 7 per cent of the total. These are often considered vital to scientific and technological advancement, representing the point where theoretical knowledge intersects with practical application – what some have described as "the essential connection".[17] Yet, they remain relatively limited in number compared to research-only collaborations.

This imbalance likely reflects the current developmental stage of quantum technologies, which remain largely research-driven and have yet to reach the level of commercial maturity that would bring broader industry participation. However, it is reasonable to assume that while fewer in number, industry-to-research collaborations may already carry greater technological and strategic weight per instance, thereby offsetting their lower frequency. In any case, taken together, all collaborations involving industry, beyond industry-to-research, represent 15 per cent in total.

The remaining types of collaborations – industry-to-industry (6 per cent), government-to-government (3 per cent), and industry-to-government (2 per cent) – form a small but not insignificant part of the overall ecosystem.

[17] Shinn, S. (2024, August 6). The Essential Connection: Industry and Academia. AACSB. https://www.aacsb.edu/insights/articles/2024/08/the-essential-connection-industry-and-academia

FIGURE 6: DISTRIBUTION OF QUANTUM COLLABORATIONS BY TYPE OF PARTNERSHIP (PERCENTAGE OF TOTAL)



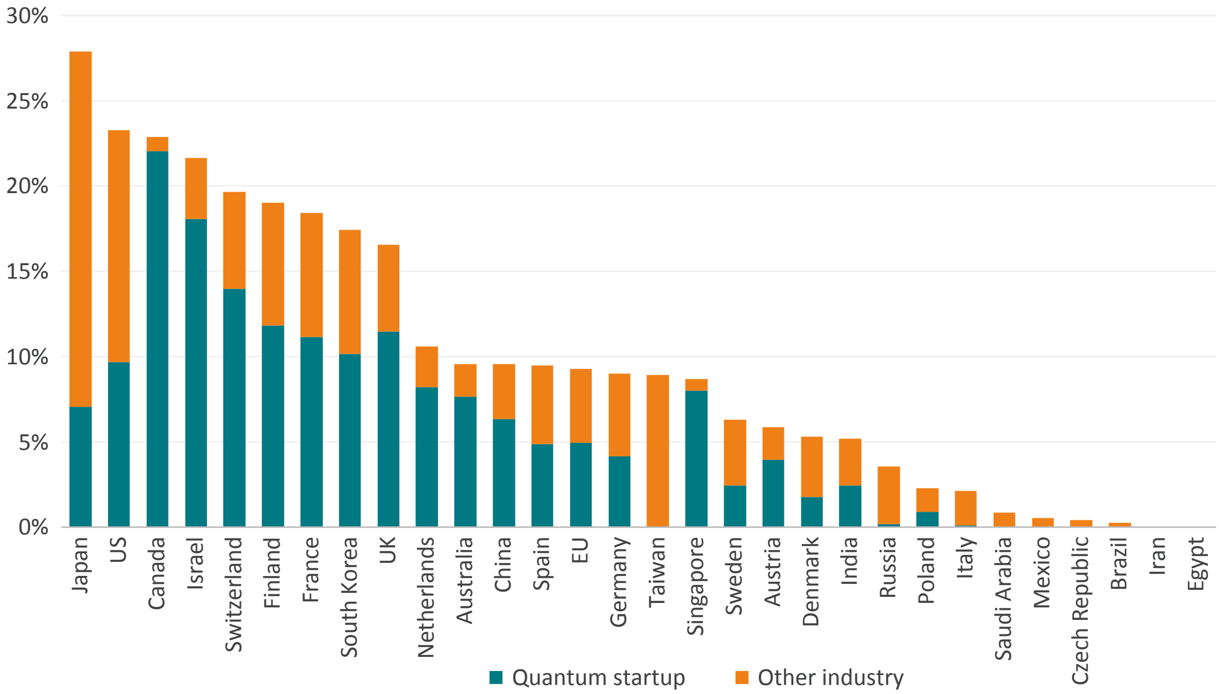
Source: ECIPE Quantum Database

As shown in Section 2, examining quantum collaborations that involve industry, particularly those between industry and academia, is crucial, as they offer a broad indication of how close a country may be to translating quantum research into practical applications.

Some countries significantly outperform others in integrating industry into their quantum ecosystems, as shown in Figure 7. The chart illustrates the share of quantum collaborations involving at least one industry partner relative to total collaborations, across the top 30 countries by overall collaboration volume. Japan stands out with 27.9 per cent of its collaborations involving an industry player. This means that more than a quarter of all Japanese quantum collaborations include participation by a Japanese company. The US and Canada follow, both around the 23 per cent mark. Other countries with a notable share of industrial quantum collaborations include Israel (21.7 per cent), Switzerland (19.7), Finland (19), France (18.4), South Korea (17.4), and the UK (16.6). The EU as a whole and China rank lower, with 9.6 and 9.3 per cent respectively, indicating that their quantum collaboration ecosystems are more heavily weighted towards research and government actors.

Industry involvement in quantum collaboration can be further broken down by firm type. Startups play a critical role in many national quantum ecosystems by driving breakthrough innovations. Figure 7 also illustrates the extent to which startups participate in industrial quantum collaborations, revealing wide variation across countries. In Japan, for example, just over 7 per cent of total collaborations involve a quantum startup, indicating that the majority of industry-involving partnerships are driven by large, established firms. A similar pattern is observed in the US, albeit to a lesser degree. In contrast, countries such as Canada, Israel, and Singapore show a higher reliance on startups in their quantum collaboration networks, underscoring the central role these firms play in shaping their national quantum strategies. China exhibits a similar startup-driven model. Within the EU, the distribution is more even, with startup-led collaborations and those involving larger industry players occurring at roughly equal rates.

FIGURE 7: SHARE OF QUANTUM COLLABORATIONS INVOLVING INDUSTRY PARTNERS BY COUNTRY (PERCENTAGE OF COUNTRY TOTAL)



Source: ECIPE Quantum Database. Note: Only the top 30 countries globally by overall collaboration volume are displayed in the chart. The figure includes both the EU as a whole and individual EU Member States. Including both levels provides a more accurate picture of the distribution of activity and partnerships in the quantum sector.

3.2 Top Performing Institutions in Quantum Collaborations

The structure and direction of global collaborations in the quantum ecosystem are strongly influenced by the institutions involved. Identifying the top performers in the global quantum ecosystem requires a closer look at the institutions driving international collaboration. To that end, Table 2 below provides a detailed breakdown of the top 15 institutions by volume of quantum partnerships, segmented across three domains – industry, research, and government and further categorised by country. This granular view helps shed light on the institutional composition of the global quantum architecture and highlights where leadership is emerging across sectors.

Turning to the **industry** domain in the first panel, the most striking observation is the overwhelming role of North America, particularly the US, in industrial quantum collaboration. Ten of the top 15 industry institutions are based in North America, including eight from the US and two from Canada.

The US list includes a mix of major established corporates – IBM, Google, Microsoft, Amazon, and Nvidia – as well as several fast-growing quantum startups. China appears twice in the list, represented by two leading quantum startups: Origin Quantum and QuantumCTek. However, it is notable that no large Chinese corporations feature in the list. Japan, Finland, and France each make a single appearance, Japan through the corporate giant NTT, while Finland and France are represented by two prominent quantum startups, IQM and PASQAL, respectively. Box 1 below provides background on how some of these industry players have successfully expanded their quantum collaboration networks, enabling them to rise to the top of the ranking.

BOX 1: IBM, NTT, ORIGIN QUANTUM, AND THE IMPORTANCE OF CORPORATE-DRIVEN INDUSTRY ALLIANCES IN FOSTERING QUANTUM COLLABORATION

One of the most effective ways for companies to expand collaboration is by entering industry alliances – structured partnerships that bring firms and other actors together around shared goals. Although the ECIPE Quantum Database tracks only bilateral partnerships, industry alliances often act as launchpads for such one-on-one collaborations.

While industry alliances exist in many forms, those with the most tangible impact on private-sector collaboration tend to be spearheaded by companies themselves. A prime example of this is the IBM Quantum Network, a global community of over 250 organisations advancing quantum computing. Unsurprisingly, IBM is the most collaborative firm in our dataset by a wide margin.

Japan's Q-STAR, founded in 2021 by leading tech firms including NTT, the second most collaborative company globally – follows a similar model. In China, Origin Quantum, the country's top collaborator, leads the Origin Quantum Industry Alliance (OQIA) to drive development and commercial applications.

Germany's QUTAC also brings together major German firms like Siemens, BMW, and Volkswagen, but such efforts in Europe remain less prominent and less specifically high tech-driven than those in the US, Japan, or China. A stronger push for IBM-style ecosystems in the EU could help elevate European firms into the upper ranks of the world's most collaborative companies.

The second panel reports the top **research** institutions, covering both universities and non-public research institutes. Compared to the industrial field, the ranking reveals a significantly more diverse and geographically spread out distribution.

European universities feature prominently, with Aalto University in Finland leading the list with 297 collaborations, well ahead of any other institution. Denmark appears twice in the top five, with the Technical University of Denmark (DTU) and Aarhus University in third and fourth place, respectively. Other notable European entries include RWTH Aachen University in Germany, the University of Oxford in the UK, and Chalmers University of Technology in Sweden. The strong presence of European universities, especially in northern European countries, likely reflects the historical roots of quantum physics and quantum mechanics in this region, and thus the enduring strength of their academic networks.[18]

Europe also benefits from clearly defined policies and funding structures that encourage academic partnerships, such as the Marie Skłodowska-Curie Actions, the European Research Council (ERC), and support from institutions like the European Institute of Innovation and Technology (EIT). These frameworks are often underpinned by broader goals of political and regional cohesion.[19]

Asia also plays a central role in academic quantum collaboration, particularly China, which accounts for four of the top 15 institutions. The University of Science and Technology of China (USTC), based in Hefei – China's quantum valley – ranks second with 273 collaborations. Tsinghua University and two other Beijing-based institutions – the Beijing Academy of Quantum Information Sciences and the Beijing University of Posts and Telecommunications – point to the depth of China's investment in quantum research. Singapore is another standout, especially given its relatively small size. It appears twice in the list: through the National University of Singapore (NUS) and its Centre for Quantum Technologies. This dual presence likely reflects institutional overlap, as the two often collaborate on joint academic initiatives, but highlights Singapore's concentrated research focus on quantum.

North America is less featured in this category, represented by the Massachusetts Institute of Technology (MIT) in the US and the University of Waterloo in Canada. While the US leads in industrial quantum collaboration, the academic sphere presents a more globally distributed picture. Overall, the data suggest that leadership in quantum research collaboration is far less concentrated than in industry, with a broader set of countries contributing through high-performing academic and research institutions.

Finally, the last panel focuses on **government** agencies and publicly affiliated research institutions by the number of quantum collaborations. The distinction between these two types of entities is not always clear-cut, but both refer to institutions that are publicly funded, supported, and generally operate under the guidance of government or state authorities. This segment of the quantum ecosystem is more concentrated in countries with strong, centralised research systems – particularly China and several European states.

[18] Przibram, K., ed. (2015) [1967]. Letters on wave mechanics: Correspondence with H. A. Lorentz, Max Planck, and Erwin Schrödinger. Translated by Klein, Martin J. Philosophical Library/Open Road.

[19] Expert Insights, On Record.

The top three institutions – CNRS (France), the Chinese Academy of Sciences (CAS), and its affiliated Institute of Physics – all report well over 100 collaborations, underscoring their global prominence in quantum science. Both CNRS and CAS are large, multidisciplinary institutions that serve as national anchors for quantum research and enable extensive international partnerships.

China is the only country to appear five times in the top 15, reflecting the breadth and coordination of its state-led quantum research architecture. The inclusion of the State Key Laboratory of Cryptology further highlights the strategic role quantum technologies play in China's national security and cryptographic ambitions.

Among smaller countries, Austria stands out with both the Austrian Academy of Sciences (ÖAW) and its Institute for Quantum Optics and Quantum Information (IQOQI) ranking in the top 10. This highlights Austria's outsized influence in state-backed quantum research – likely owing to its early contributions to quantum physics and sustained institutional focus.

The US is represented solely by the National Institute of Standards and Technology (NIST), which appears in fifth place. While this reinforces NIST's central role as a federal hub for quantum standards and research, overall US presence in this category is modest compared to its dominance in industrial quantum collaborations.

Other noteworthy entries include RIKEN and NICT from Japan, the Harish-Chandra Research Institute from India, Italy's National Institute of Optics, and both the Polish Academy of Sciences and its Centre for Theoretical Physics. These institutions demonstrate that, despite the concentration of collaborations in a few major powers, several smaller and mid-sized countries are contributing actively to global quantum research networks through specialised national institutes.

A final observation concerns the overall volume of collaborations across the three domains. Research institutions consistently account for the highest levels of collaborative activity, followed by government entities, with industry engagement trailing behind. This pattern likely reflects the inherently collaborative and outward-facing nature of academic research, where joint projects and co-authored studies are standard practice and often publicly documented. In contrast, industry collaborations may be fewer in number or intentionally less visible due to commercial sensitivity and confidentiality. The predominance of research institutions also highlights the early-stage nature of the quantum technology lifecycle, where commercialisation remains limited and research continues to drive the majority of ecosystem activity.

TABLE 2: TOP 15 PERFORMERS IN QUANTUM TECHNOLOGY COLLABORATIONS, BY DOMAIN

Rank	Name	Type	Country	Collaborations Count
Industry				
1	IBM	Corporate	US	98
2	NTT (Nippon Telegraph and Telephone)	Corporate	Japan	71
3	Xanadu	Quantum startup	Canada	65
4	Google	Corporate	US	51
5	Microsoft	Corporate	US	50
6	IONQ	Quantum startup	US	39
7	Strangeworks	Quantum startup	US	39
8	IQM Quantum Computers	Quantum startup	Finland	37
9	PASQAL	Quantum startup	France	37
10	Amazon	Corporate	US	36
11	Origin Quantum (本源量子)	Quantum startup	China	36
12	Rigetti Computing	Quantum startup	US	36
13	D-Wave	Quantum startup	Canada	32
14	Nvidia	Corporate	US	32
15	QuantumCTek (国盾量子)	Quantum startup	China	32
Research				
1	Aalto University	University	Finland	297
2	University of Science and Technology of China (USTC)	University	China	273
3	Technical University of Denmark (DTU)	University	Denmark	175
4	Aarhus University	University	Denmark	153
5	Massachusetts Institute of Technology (MIT)	University	US	152
6	National University of Singapore (NUS)	University	Singapore	152
7	Beijing Academy of Quantum Information Sciences	Research institute	China	144
8	University of Waterloo	University	Canada	144
9	Tsinghua University	University	China	141
10	Beijing University of Posts and Telecommunications	University	China	137
11	RWTH Aachen University	University	Germany	134
12	University of Oxford	University	UK	131

13	Chalmers University of Technology	University	Sweden	126
14	Centre for Quantum Technologies at the National University of Singapore (NUS)	Research institute	Singapore	120
15	University of Tokyo	University	Japan	120
Government				
1	French National Center for Scientific Research (CNRS)	Public research institution	France	158
2	Chinese Academy of Sciences (CAS)	Public research institution	China	157
3	Institute of Physics, CAS	Public research institution	China	119
4	Austrian Academy of Sciences (ÖAW)	Public research institution	Austria	89
5	National Institute of Standards and Technology (NIST)	Government agency	US	89
6	Center for Excellence in Quantum Information and Quantum Physics, CAS	Public research institution	China	75
7	Institute for Quantum Optics and Quantum Information (IQOQI), ÖAW	Public research institution	Austria	74
8	Harish-Chandra Research Institute (HRI) – Quantum Information and Computation Group	Public research institution	India	63
9	Institute of Physical and Chemical Research (RIKEN)	Public research institution	Japan	63
10	Polish Academy of Sciences (PAS)	Public research institution	Poland	61
11	National Institute of Optics (CNR INO)	Public research institution	Italy	59
12	Beijing Computational Research Centre, CAEP	Public research institution	China	56
13	National Institute of Information and Communications Technology (NICT)	Public research institution	Japan	55
14	State Key Laboratory of Cryptology	Government agency	China	53
15	Center for Theoretical Physics, PAS	Public research institution	Poland	49

Source: ECIPE Quantum Database.

3.3 Bridging Academia and Industry: The Role of Spinouts

Perhaps the most fruitful of partnerships are the ones between industry and academic institutions. Empirical evidence, corporate successes, and the way groundbreaking inventions occur consistently, point to such collaborations as a powerful catalyst for innovation.

Studies across various sectors demonstrate that firms engaged in structured collaborations with academic institutions tend to achieve higher innovation outputs, including increased patent activity, the development of new products, and improved financial performance. Furthermore, research has also shown that the quality of academic research, rather than geographical proximity, is the strongest determinant of successful collaboration. This indicates that firms are primarily drawn to depth of expertise and research excellence rather than to convenience alone.[20]

Industry-to-research collaborations can take many forms, from contract research and consultancy services to joint ventures, shared facilities, and talent exchanges. One form that is not always given the recognition it deserves but which holds particular importance is university spinouts. A university spinout is a new company formed to commercialise research outcomes developed within a university, typically involving the participation of academic staff, and often supported by the institution's technology transfer office or incubator.

University spinouts represent perhaps the most intimate and primordial connection between an academic institution and the private sector. Unlike more transactional partnerships, spinouts embody a deep, long-term commitment to translating academic research into commercial applications. They are often founded by researchers themselves or in close collaboration with the university's technology transfer office, ensuring that the knowledge transfer is direct, sustained, and grounded in scientific rigour.[21]

In the quantum field, where breakthroughs often stem from cutting-edge, fundamental research, spinouts play a crucial role in bridging the gap between theoretical innovation and scalable technology. They are instrumental in seeding entire ecosystems, attracting private investment, and retaining highly skilled talent that might otherwise disperse internationally. As such, university spinouts are not only a commercialisation pathway but also a strategic asset in national and regional quantum strategies. Box 2 explores a few examples of successful spinouts and how they have been able to make their way in the global quantum network.

BOX 2: QUANTUM SPINOUTS GOING GLOBAL

University spinouts are among the most dynamic actors in the global quantum landscape. By translating frontier academic research into commercially viable technologies, they often become anchors of regional innovation ecosystems. Below are three prominent examples from the world's most active quantum regions:

- **D-Wave** (North America): A pioneer in quantum annealing, D-Wave was spun out of the University of British Columbia. It became the first company to sell commercially available quantum computers and now operates across North America, with major facilities in Palo Alto, California and near Vancouver. Its systems are used in logistics, finance, and AI research.

[20] George, G., Zahra, S. A., & Wood Jr, D. R. (2002). The effects of business–university alliances on innovative output and financial performance: a study of publicly traded biotechnology companies. Journal of business Venturing, 17(6), 577-609. Tseng, F. C., Huang, M. H., & Chen, D. Z. (2020). Factors of university–industry collaboration affecting university innovation performance. The Journal of Technology Transfer, 45, 560-577. Guan, J., & Zhao, Q. (2013). The impact of university–industry collaboration networks on innovation in nanobiopharmaceuticals. Technological Forecasting and Social Change, 80(7), 1271-1286.

[21] Jack, A. (2024, March 14). Turning ideas into technology: the value of university-business links. Financial Times. https://www.ft.com/content/0bf8a055-65b8-4faa-8da5-37f39dd26bc2?

- **PASQAL** (Europe): Emerging from the Institut d'Optique Graduate School in Paris, PASQAL develops neutral-atom quantum processors designed for real-world problem-solving. The company is a European leader in the quantum startup ecosystem and collaborates widely with research institutions and industry players across Europe and beyond. Its technology has applications ranging from energy to finance.

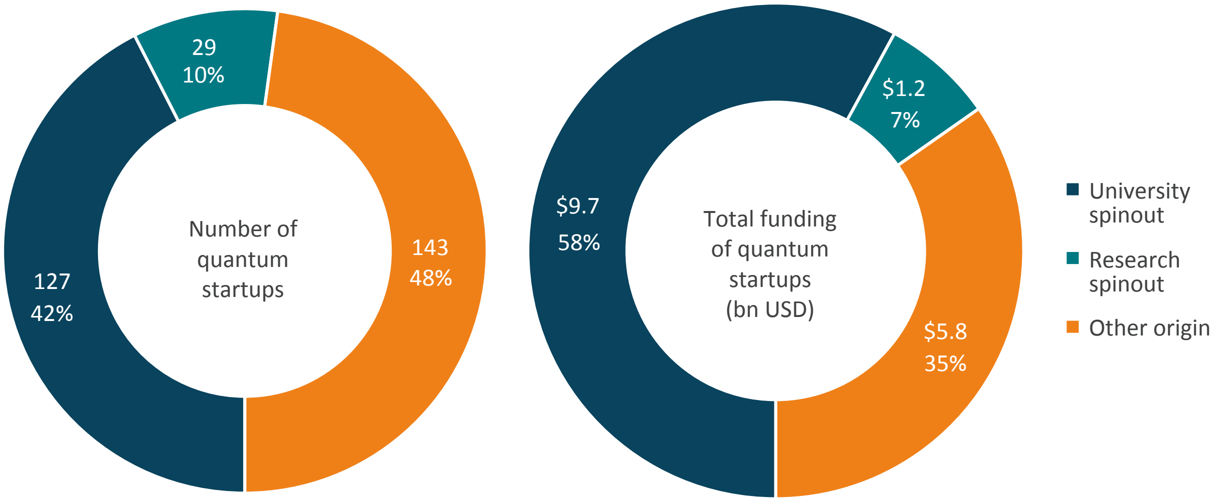
- **XtalPi Technology** (China): Although founded by quantum physicists affiliated with MIT, XtalPi has grown into a flagship of China's quantum industry. Now primarily based in Shenzhen, with facilities also in the Boston area, it applies quantum algorithms to drug discovery and materials science, integrating AI and quantum simulation. The company has forged strategic partnerships with leading global pharmaceutical firms.

These examples illustrate how university-born startups can become global players bridging continents, advancing commercial applications, and shaping the next wave of quantum innovation.

Interestingly, more than half of all quantum startups are born as a spinout. Out of the total of nearly 300 quantum startups tracked in our dataset by origin, 52 per cent are spinouts, as shown in Figure 8. A further breakdown reveals that 42 per cent are startups that originated from universities, whereas 10 per cent stemmed from research institutes. The remaining 143 companies (48 per cent) originated independently of academic or research institutions.

When examining the funding received by these startups, university spinouts account for USD 9.7 billion, or 58 per cent of the total. Research spinouts have attracted USD 1.2 billion (7 per cent), while the remaining startups have collectively raised USD 5.8 billion (35 per cent). This indicates that, despite representing just 42 per cent of the total, university spinouts attract a disproportionately high level of funding, nearly 60 per cent of the overall pool, highlighting their strong appeal to investors and their perceived potential within the quantum ecosystem. It is difficult to determine whether quantum university spinouts attract greater investment due to the superior quality of their technologies or because investors place greater confidence in their prestigious academic origins. Regardless of the underlying reason, the outcome remains clear: on average, university spinouts receive more funding than quantum startups of other origins.

FIGURE 8: NUMBER AND FUNDING VOLUME OF QUANTUM STARTUPS BY ORIGIN



Source: ECIPE Quantum Database. Note: Funding data is current as of April 15, 2025.

Most quantum spinouts originate from top-tier universities and research institutions distinguished by strong research capacity and a high volume of quantum-related collaborations. Table 3 highlights the top 15 institutions globally, ranked by the total funding raised by their quantum spinouts. It also presents each institution's level of collaborative activity in the quantum domain, offering a snapshot of where academic excellence, funding capacity, and ecosystem engagement converge to drive commercialisation.

The table reveals that some institutions significantly outperform others, in terms of the capital attracted by their spinouts as well as their levels of collaborative engagement in the quantum field. For example, the University of Bristol has spun out five startups that together have raised an impressive USD 2.55 billion, placing it at the top of the table for total funding. It also shows 116 collaborations, indicating strong integration into global quantum networks. However, it is important to note that 99 per cent of this funding was raised by a single company, PsiQuantum, the world's most well-funded quantum startup. Despite being born out of the University of Bristol, PsiQuantum later relocated to Silicon Valley, with much of its capital influx being a by-product of its positioning within the US tech ecosystem.

The Massachusetts Institute of Technology (MIT) follows closely, with four spinouts collectively raising USD 1.685 billion and registering 152 collaborations – a testament to MIT's standing as a global hub for quantum innovation. As with Bristol, however, the bulk of this funding – over 75 per cent – has gone to one company, XtalPi Technology, which now operates primarily from Shenzhen, China, having raised much of its capital via the Hong Kong Stock Exchange.

In contrast, China's University of Science and Technology of China (USTC) leads in terms of sheer output, with eight spinouts – the most among all listed institutions – raising USD 1.37 billion and topping the collaboration chart with 273 connections, reflecting both robust academic capacity and extensive international engagement.

In some cases, a single high-performing spinout may trump institutional impact. The University of Maryland has spun out just one company, IONQ, which alone has raised over USD 1.2 billion. Similarly, Aalto University's sole spinout, IQM Quantum Computers, has attracted USD 364 million in funding, and the university is associated with 297 collaborations – the highest number in the table (see Box 3). These examples highlight that even institutions with a very small number of spinouts can wield substantial influence if they are strategically positioned and highly networked.

BOX 3: UNIVERSITY OF BRISTOL AND AALTO UNIVERSITY, EUROPE'S ACADEMIC SUPERSTARS OF QUANTUM COMMERCIALISATION

Although the University of Bristol (UK) and Aalto University (Finland) are not Europe's most prolific institutions in terms of quantum research publications, they lead in turning quantum research into successful commercial ventures. Bristol is the academic origin of PsiQuantum, the world's most well-funded quantum startup, while Aalto launched IQM Quantum Computers, the EU's leading startup by quantum funding.

Their success stems from their ability to bridge world-class research with collaborative innovation ecosystems. Aalto University benefits from close ties with Finland's VTT public research centre and industry partners like Nokia, supporting spinouts through co-funded doctoral programmes. Similarly, the University of Bristol's deep-tech incubators and training grounds such as the Quantum Technologies Innovation Centre (QTIC) provide dedicated facilities, business mentoring, and investor access, nurturing startups from concept to scale-up.

Other European universities seeking to boost their impact on quantum innovation should take note: commercialisation requires more than publications – it demands structured collaboration, entrepreneurial support, targeted infrastructure, and long-term institutional commitment.

Public research institutions and government agencies also play a critical role. The Chinese Academy of Sciences (CAS), VTT Technical Research Centre of Finland, and the National Institute of Standards and Technology (NIST) have all contributed meaningfully, with their spinouts raising USD 424 million, USD 393 million, and USD 250 million, respectively. These figures underscore their strategic relevance in supporting national quantum capacity.

Finally, elite institutions such as Oxford, Harvard, and Cambridge show a strong balance across all three metrics: multiple spinouts, substantial funding, and significant collaboration activity. This reinforces the broader conclusion that academic excellence, research depth, and international connectivity are key interconnected ingredients in enabling successful commercialisation in quantum technologies.

Taken together, this analysis underscores the pivotal role that select universities and research bodies play in advancing quantum commercialisation by producing startups that attract significant investment and by nurturing collaborative ecosystems that bridge scientific innovation with market opportunity.

TABLE 3: TOP 15 WORLD INSTITUTIONS BY TOTAL FUNDING RAISED BY THEIR QUANTUM SPINOUTS, WITH THEIR COLLABORATION LEVELS

Institution of origin	Type	Country	Total startup funding	Quantum spinouts	Institution collaborations
University of Bristol	University	UK	$2,550 million	5	116
Massachusetts Institute of Technology (MIT)	University	US	$1,685 million	4	152
University of Science and Technology of China (USTC)	University	China	$1,370 million	8	273
University of Maryland	University	US	$1,234 million	1	104
University of British Columbia (UBC)	University	Canada	$767 million	1	35
Chinese Academy of Sciences (CAS)	Public research institution	China	$424 million	3	157
VTT Technical Research Centre of Finland	Public research institution	Finland	$393 million	3	16
University of Oxford	University	UK	$387 million	7	131
Aalto University	University	Finland	$364 million	1	297
Harvard University	University	US	$349 million	4	110
Paris Sciences et Lettres University (PSL)	University	France	$296 million	4	35
University of Colorado Boulder	University	US	$250 million	1	60
National Institute of Standards and Technology (NIST)	Government agency	US	$250 million	1	89
University of New South Wales (UNSW)	University	Australia	$224 million	2	53
University of Cambridge	University	UK	$175 million	5	90

Source: ECIPE Quantum Database. Note: Funding data is current as of April 15, 2025. If a quantum startup originated from two institutions, its funding is attributed to both.

4. WHERE COUNTRIES EXCEL: SPECIALISATION PATTERNS IN THE QUANTUM ECOSYSTEM

4.1 Bilateral Comparative Advantage

The previous sections looked at the global scale and composition of quantum collaborations, showing where activity is most concentrated and which types of actors are most engaged, including the position and reach of countries within networks. But being well-connected is only part of the story. For example, the US-China axis is the largest collaboration corridor with 371 recorded partnerships, followed by the UK-US (261), Germany-US (252), and Canada-US (198). These high numbers reflect global leadership, but not necessarily strategic focus. They may be due to the country's size rather than a specific focus on any one partner.

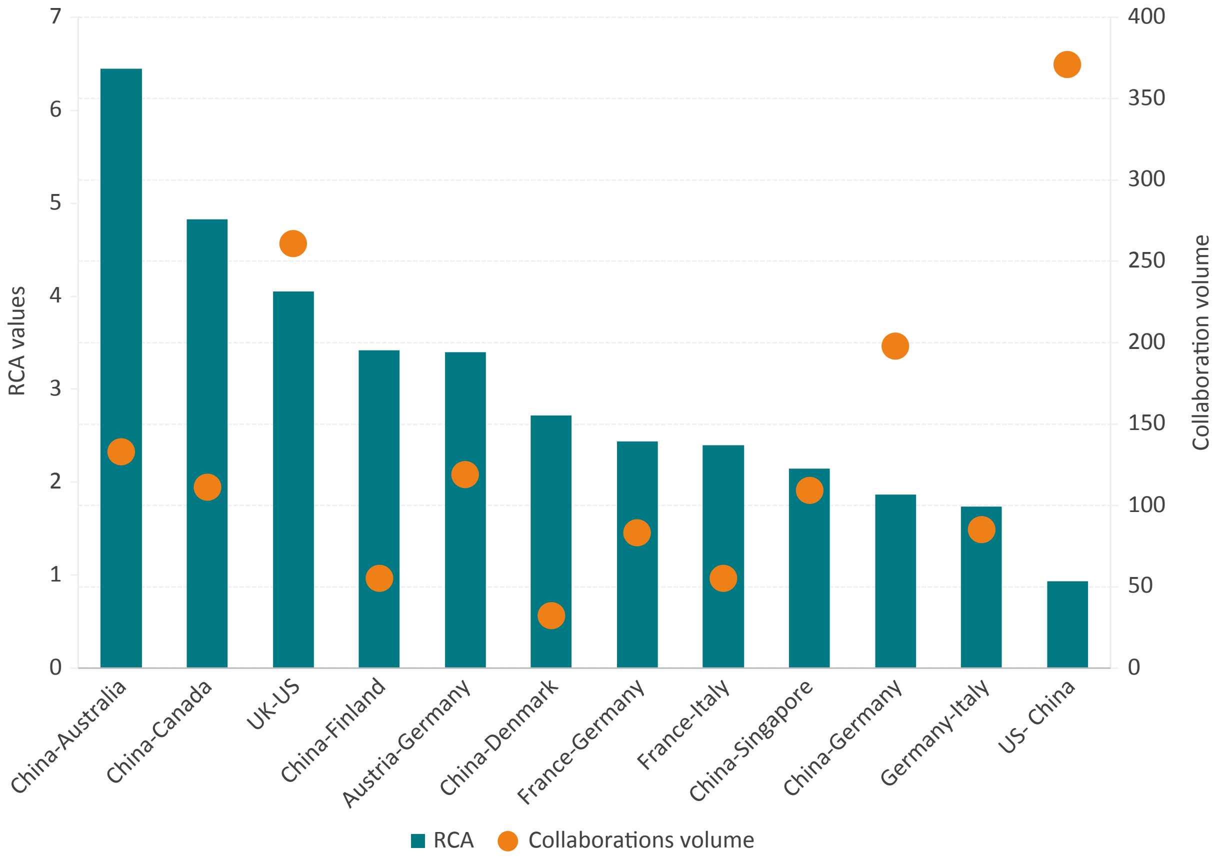
To move beyond raw volume, we turn to revealed comparative advantage (RCA), a method first introduced in our network analysis, to assess where countries are collaborating more intensively than expected, relative to their overall activity. Three questions guide this part of the analysis:

- Which bilateral relationships stand out as especially concentrated
- Which kinds of collaboration do countries prioritise (e.g., industry-to-research, industry-to-industry)
- How do these patterns align with national strengths, using a sector-specific RCA to highlight emerging areas of specialisation?

These measures help reveal where countries are not just collaborating, but specialising within it, aligning collaboration patterns with national capabilities and strategic priorities.

Figure 9 highlights selected bilateral quantum research relationships that combine meaningful collaboration volumes with above-average RCA scores.

FIGURE 9: SELECTED BILATERAL RCA RELATIONSHIPS



Source: ECIPE Quantum Database. Note: The formula and full methodology for calculating RCA are provided in Annex 2.

Despite being the largest collaboration pair in the world by volume, the US-China bilateral RCA score is only 0.93, which indicates that its intensity is about what one would anticipate given the size of the nations' networks. Although not displayed in the chart, similar trends apply to the Germany-US axis: a high volume (252 collaborations) but equally an RCA of 0.93.

By contrast, the US-UK partnership combines high volume (261 collaborations) with an RCA of 4.05, the highest among all large bilateral relationships. This places the US-UK axis at the very core of transatlantic quantum activity, not only in terms of volume, but also in terms of relative specialisation. This likely reflects deep and longstanding ties between leading academic institutions and major industry players, underpinned by cultural proximity and closer regulatory environments.

The second strongest transatlantic partnership is that between the US and the Netherlands, which, despite a more modest volume of 53 collaborations, exhibits an RCA of 1.52. This suggests a relationship that, while smaller in scale, is highly concentrated and likely driven by industry-specific initiatives.

Turning to China, the most specialised partnerships are with countries outside the EU. Australia and Canada emerge as China's strongest bilateral partners, with 133 and 111 collaborations respectively, and RCA scores of 6.45 and 4.83. China is also one of Australia's largest sources of international students, accounting for 20 per cent of the total.[22] Notably, there are strong institutional ties between the Australian National University and the University of Science and Technology of China (USTC). In addition, Australia's national science agency, CSIRO, maintains close research collaboration with China's Peng Cheng Laboratory. These partnerships underscore the strategic value of scientific cooperation – even amid rising geopolitical tensions.

Within Europe, China's most intensive links are with Finland (55 collaborations, RCA 3.42) and Denmark (32, RCA 2.72), an echo of their high levels of academic excellence and strong presence in quantum hardware and photonics, while its highest volume EU ties are with Germany (198 collaborations, RCA 1.86), which exceed baseline expectations, although to a lesser degree.

Within the EU, several high-RCA relationships stand out. The Franco-German corridor combines 83 collaborations with an RCA of 2.44, and Italy-Germany (85 collaborations, RCA 1.74), and France-Italy (55, RCA 2.40) exhibit similar strong ties. Some smaller countries also appear disproportionately active. Austria-Germany, with 119 collaborations and an RCA of 3.40, is one of the most specialised bilateral links in Europe, pointing to Austria's integration into German-led research networks.

Beyond the dominant players, several other partnerships emerge. The bilateral relationship between Egypt and Saudi Arabia, with 63 collaborations and an RCA of 29.57, is the most specialised in the dataset. While the figure is driven by a small number of highly active institutions, it also reflects a concentrated and possibly policy-led collaboration effort. Similarly, the Czech Republic-India partnership (31 collaborations, RCA 6.96) reveals a niche but interesting link, perhaps fostered by institutional agreements or co-funding mechanisms.

Other noteworthy relationships include South Korea-UK (31 collaborations, RCA 2.35) and Switzerland-UK (39, RCA 3.42), both of which underscore the UK's continued global involvement in quantum research.

4.2 Collaboration by Type: An Overview of Capability Structures

Research capabilities in specific domains often serve as the foundation for the emergence of new, related technologies, particularly within regional innovation systems. Technological diversification usually builds on a region's existing strengths. In the context of quantum collaboration, this means that institutions and regions already strong in fields like condensed matter physics, photonics, or cryptography are more likely to develop quantum technologies due to overlapping knowledge bases and infrastructures. This path-dependent process facilitates incremental innovation and lowers entry barriers by leveraging established expertise.

[22] Department of Education, Skills and Employment. (2023). International student data – full year data (based on data finalised in December 2023). Australian Government. Retrieved from https://www.education.gov.au/international-education-data-and-research/international-student-monthly-summary-and-data-tables

However, as capabilities accumulate and diversify, regions become increasingly able to pursue more complex and unrelated technological trajectories that often mark significant innovation potential and are associated with long-term economic growth. Understanding this dynamic interplay between relatedness and complexity offers a more nuanced lens on how quantum ecosystems evolve, not through isolated breakthroughs, but by systematically building on existing capacities while gradually pushing the boundaries of technological possibility.

Moreover, the type of collaboration taking place also reveals how countries are positioning themselves along the research-to-market spectrum. Using a revealed comparative advantage (RCA) metric, we assess whether a given country is relatively more engaged in a specific collaboration type, such as research-to-research, government-to-research, or industry-to-industry, compared to the global average. This allows us to identify not just where collaboration is happening, but how countries are positioning themselves within the global quantum ecosystem.

To ensure robust results, we exclude countries with fewer than 10 total collaborations, or fewer than 5 in the specific type being analysed. We also remove countries whose collaborations are entirely concentrated in one category, as this would inflate RCA scores by default. These adjustments are essential for avoiding misleading signals of “specialisation.”

Most countries take part in a mix of quantum collaboration types, but a few are heavily focused on just one. In many of these cases, more than 80 per cent, and sometimes all, of their international collaborations fall into a single category, usually research-to-research or government-to-research. This is the case for countries like Armenia, Belarus, Malaysia, and Serbia, which collaborate only through academic or government-to-research links. Countries such as Egypt, Pakistan, and Saudi Arabia are also very active in academic collaboration but have little to no engagement with government or industry partners.

While this does not mean these countries are necessarily underperforming, it does suggest a narrower base of participation in the quantum ecosystem. In some cases, this may be due to an early stage of development, a lack of domestic industry, or limited access to funding and policy support.

TABLE 4: COUNTRIES MOST SPECIALISED IN GOVERNMENT-TO-RESEARCH COLLABORATION

Country	Collaborations	RCA
Croatia	13	3.16
Hungary	42	3.02
Slovakia	26	2.77
Romania	13	2.55
Ukraine	21	2.55
Uzbekistan	5	2.55

Country	Collaborations	RCA
Thailand	8	2.15
Argentina	29	2.03
Greece	15	1.87
South Africa	28	1.81

Source: ECIPE Quantum Database.

The countries most specialised in government-to-research collaborations are listed in Table 4. This kind of collaboration remains particularly common in Central and Eastern Europe, with Croatia (RCA 3.16), Hungary (3.02), and Slovakia (2.77) leading the list. The patterns are indicative of a larger legacy of state-led science in the area, where public institutions continue to play a central role in research efforts.

TABLE 5: COUNTRIES MOST SPECIALISED IN INDUSTRY-TO-RESEARCH COLLABORATION

Country	Collaborations	RCA
Canada	98	2.12
Japan	86	2.06
US	250	1.79
Switzerland	35	1.51
Netherlands	28	1.46
UK	111	1.41
Finland	33	1.34
South Korea	23	1.34
France	51	1.30
Australia	48	1.26

Source: ECIPE Quantum Database.

Table 5 shows that Canada, Japan, and the US lead in specialisation in industry-to-research collaborations, an indicator of commercial readiness in the quantum field. These countries were also highlighted as having a comparatively high share of industrial quantum activity in previous sections (e.g., Figure 7). Their presence here supports the point made in the prior section that a key sign of ecosystem maturity is the ability to bridge academic and commercial capabilities.

TABLE 6: COUNTRIES MOST SPECIALISED IN INDUSTRY-TO-INDUSTRY COLLABORATION

Country	Collaborations	RCA
Ireland	13	2.51
Israel	38	2.30
Canada	109	2.06
US	326	2.04
Switzerland	51	1.91
South Korea	34	1.72
UK	154	1.71
Japan	79	1.65
Finland	42	1.49
France	67	1.48

Source: ECIPE Quantum Database.

Finally, Ireland, Israel, Canada, and the US stand out as having some of the most mature quantum ecosystems, as do the countries with the highest RCA scores in industry-to-industry collaboration (Table 6). In these economies, quantum technologies have advanced past the early-stage research and are now backed by a network of firms capable of direct, peer-level collaboration. Such industrial specialisation is often underpinned by high R&D intensity, robust institutional capacity, and established pathways for translating research into application. First, high R&D intensity helps sustain long-term innovation. For example, Israel invests 6.35 per cent of its GDP in R&D, the highest among OECD countries, while the US spends 3.45 per cent, South Korea 4.96 per cent, and Switzerland 3.3 per cent.[23]

Second, some of these countries have strong institutional frameworks that bring together government, academia, and industry. In the US, the Department of Energy (DOE) has established and funded five National Quantum Information Science Research Centres, which accelerate quantum R&D and support commercialisation through collaboration. The DOE most recently allocated USD 625 million to support these centres in January 2025.[24] These efforts are also backed by national legislation, such as the National Quantum Initiative Act passed in 2018.[25]

Third, there are clear pathways for turning research into real-world applications. The US, for example, is now proposing the Quantum Sandbox for Near-Term Applications Act, which will

[23] OECD. (2024). Main Science and Technology Indicators: R&D intensity by country. Organisation for Economic Co-operation and Development.
[24] U.S. Department of Energy. (2025, January). DOE announces $625 million for National Quantum Information Science Research Centers.
[25] U.S. Congress. (2018). National Quantum Initiative Act, Pub. L. No. 115–368.

provide testbeds to help quantum technologies move out of the lab and into practice.[26] These structures make it easier for firms to experiment, scale, and deploy quantum solutions across industries.

BOX 4: MAPPING THE ADVANCEMENTS IN COUNTRIES MOST SPECIALISED IN INDUSTRY-TO-INDUSTRY COLLABORATION

Ireland:

Equal1 announced the development of Bell-1, Ireland's first quantum computer, which integrates quantum processing units with control electronics on a single chip – an architecture that lays the foundation for near-term quantum applications in data-driven environments. In parallel, Equal1 and Centre for Applied Data Analytics (CeADAR) have signed a MoU to establish a structured framework supporting business and academic engagement with quantum-AI technologies. As CeADAR already plays a key role in helping Irish enterprises adopt AI and machine learning, this collaboration strategically extends that focus to quantum-enabled AI.

Israel:

A joint initiative by the Israel Innovation Authority, Israel Aerospace Industries (IAI), Hebrew University of Jerusalem, and its tech transfer arm Yissum successfully developed a 20-qubit quantum computer – demonstrating national capacity to build advanced quantum hardware. Separately, the startup Quantum Machines launched the Israeli Quantum Computing Center (IQCC) at Tel Aviv University, which hosts multiple co-located quantum systems from different vendors. These include Galilee, a 21-qubit superconducting system powered by QuantWare; Negev, an eight-qumode photonics platform built with Orca; and Carmel, another 21-qubit superconducting device supporting the centre's cryogenic testbed.

China does not feature among the top-performing countries in any RCA category, despite its high volume of quantum collaborations. This suggests that while China is broadly engaged across all partnership types, it lacks a clear international specialisation. Its RCA in research-to-research collaborations is slightly above average (1.08), comparable to Germany and the Netherlands. It also shows moderate specialisation in government-led collaborations, highlighting the role of public institutions. However, industry engagement remains limited: China's RCA is just 0.62 in industry-to-research and 0.20 in industry-to-industry links, among the lowest in the dataset.

As mentioned earlier, these figures reflect the scope of international collaboration only. China's low RCA scores in industry-related partnerships likely stem from a more inward-facing strategy, where firms and institutions prioritise domestic networks (see Section 2). Combined with a strong public-sector orientation, this points to a quantum ecosystem focused on national capability

[26] U.S. Congress. (2025). Quantum Sandbox for Near-Term Applications Act, S. 1344, 119th Cong. https://www.congress.gov/bill/119th-congress/senate-bill/1344/text

building rather than international integration. Compared to the US, dominant in industry-driven partnerships and leading EU countries with diverse cross-sector profiles, China appears to be in a capability-building phase, where state investment and domestic coordination take precedence over international industrial integration.

These results support one of the report's broader claims: that the global quantum ecosystem is marked by both growing interdependence and growing differentiation. Most countries do not aim to master the full spectrum of capabilities across the quantum stack. In that sense, collaboration type becomes not just an operational feature but a marker of a country's evolving role in the global quantum system.

These results also highlight the value of encouraging connected ecosystem development for policymakers. Supporting links between academia, industry, and government is not simply about increasing volume but about enabling transitions between fundamental research, experimental validation, and commercial application. Countries that encourage this type of cross-sectoral integration are probably going to accelerate the transition from capability accumulation to deployment as the field develops.

4.3 Quantum Specialisation Across Sectors

To better understand how countries are positioning themselves in emerging quantum value chains, we calculate revealed comparative advantage (RCA) scores by sector following the Industry Classification Benchmark (ICB) and focusing only on collaborations that involve at least one industry actor. This allows us to identify where national strengths in quantum activity align with existing industrial capabilities, such as defence, automotive, electronics, or software.

TABLE 7: RCA IN SELECTED QUANTUM-RELEVANT SECTORS

Sector \ Country	China	Finland	France	Germany	India	Japan	South Korea	Spain	Switzerland	UK	US
Aero & Defence	0.54		7.04	0.39			4.34			0.38	1.33
Auto & Parts				8.38		3.18	3.17				0.39
Chemicals				7.35			0.63		1.55	0.80	0.28
Electronics	1.42	1.01	2.90	0.86		1.81	1.09	1.53	1.48	0.72	0.20
Pharma & Biotech	2.60		0.25	1.42		0.36	2.46		0.75	1.54	0.66
Software	0.70	0.54	0.33	0.80	2.34	1.35	0.61	0.98	1.48	1.19	0.97
Tech Hardware	1.21	2.32	0.19	0.36		0.27		0.43	0.52	0.67	1.53

Source: ECIPE Quantum Database. Note: Empty cells in the heatmap indicate that the country had fewer than 10 industry-linked quantum collaborations in total, or none in the given sector. The sectors shown in the heatmap refer to: Aerospace & Defence, Automobiles & Parts, Chemicals, Electronic & Electrical Equipment, Pharmaceuticals & Biotechnology, Software & Computer Services, and Technology Hardware & Equipment.

While not exhaustive, the heatmap of selected countries reveals a consistent pattern: sector-specific specialisation in quantum collaborations tends to reflect countries' broader industrial structures. In some cases, legacy industries are the dominant contributors to quantum collaborations. In aerospace and defence, France stands out, supported by a well-established defence sector and public-private cooperation. Automotive-related quantum activity is led by Germany, South Korea, and Japan, reflecting their global leadership in this manufacturing. Countries such as France, Japan, and Switzerland are highly specialised in electronics and electrical equipment, aligning with strong photonics and microelectronics sectors. While India and Spain perform strongly in software and computer services, sectors where they already have competitive digital industries. Finland, with its strength in precision engineering, leads in technology hardware and equipment, followed closely by the US.

However, in other cases, such as pharmaceuticals and biotechnology, the quantum specialisation reflects more dynamic, recent developments in the industry. South Korea stands out in this sector, anchored by global firms like Samsung Biologics, Celltrion, and Green Cross, and supported by a fast-growing innovation ecosystem, for instance, the startup PharmCADD, very active in quantum.[27] China shows its strongest RCA in pharmaceuticals and biotechnology,

[27] Intralink. (2025, February). South Korea: a new global hub for biopharma. https://www.intralinkgroup.com/en-GB/Latest/Intralink-Insights/February-2025/South-Korea-a-new-global-hub-for-biopharma

with biopharma now the largest segment of China's biotech industry. This is supported by top companies like XtalPi, which is the largest pharma quantum startup globally, and enabled by policies that have made China the leading global source of biotech research publications and clinical trials.[28]

Beyond the countries shown in the heatmap, several others also demonstrate sector-specific strengths. Poland and Israel, for example, rank among the top three globally in aerospace and defence RCA, with Poland posting the highest value in the dataset. Canada, Sweden, and the Netherlands show strong comparative advantage in electronics. Ireland, Australia, and Singapore are highly specialised in software and computer services, and Taiwan, Austria, and the Netherlands emerge as global leaders in technology hardware, particularly in semiconductors.

In most cases, partnerships involving industry reflect areas where countries already demonstrate strength, whether in aerospace, automotive, software, or electronics. This pattern is consistent with the concept of technological relatedness introduced earlier in the report: countries are more likely to develop quantum capabilities in sectors that are adjacent to their current technological base. Industry-linked collaboration thus serves as both an indicator of quantum maturity and a channel through which existing industrial capabilities are being extended into emerging technology domains.

[28] Brown, A., & Groenewegen-Lau, J. (2025). Lab Leader, Market Ascender: China's Rise in Biotechnology (MERICS Report, April 2025). Mercator Institute for China Studies. https://merics.org/en/report/lab-leader-market-ascender-chinas-rise-biotechnology

ANNEX 1: ECIPE QUANTUM DATABASE METHODOLOGY

As part of our work for this study, we systematically reviewed institutions active in quantum technology, including universities, research institutes, public research institutions, government agencies and companies, all of which are listed in the ECIPE Quantum Database. Our goal was to identify instances of collaboration or partnership with other entities. These collaborations serve as key channels for tracing networks of activity within the quantum research ecosystem, helping us uncover both longstanding and newly emerging institutions involved in the field. We adopted a broad definition of "collaboration," encompassing any form of interaction or institutionalised engagement between institutions. This includes, but is not limited to, joint research projects, formal partnerships, shared funding initiatives, and co-authored outputs.

The specific nature of collaboration is contextual and may vary depending on the type of institution and available data. For industry actors, particularly quantum startups, we adopted a manual data collection approach. We reviewed each startup's website, specifically their newsroom, press release sections, and any dedicated partner pages, to identify publicly disclosed collaborations. We documented every instance where a startup advertised a partnership or collaboration with another institution, such as a university, another startup, or a research centre. For larger companies that are not exclusively focused on quantum technologies, we extended our search beyond company websites to include Google searches, industry reports, and media coverage. This allowed us to identify collaborations specifically related to quantum activities, even when these were part of a wider corporate strategy. It is important to note a methodological caveat: we recognise that our data may reflect only the publicly visible „tip of the iceberg." There may be a significant number of informal or undisclosed collaborations that remain unrecorded. However, all collaborations that were publicly documented and traceable through our methods have been systematically recorded.

To capture academic collaborations in the quantum field, we used the OpenAlex database, a publicly available and open-source repository of scholarly outputs. This allowed us to systematically analyse institutional collaborations through co-authored academic articles, which serve as a reliable final product and proxy for research partnerships. We extracted data for the period 2018–2024, focusing specifically on peer-reviewed articles in quantum information and cryptography, which also includes areas such as quantum computation, simulation, and measurement. While OpenAlex also tracks other research output types (e.g., book chapters, proceedings), we limited our dataset to articles to maintain consistency and relevance to institutional-level collaborations. The raw OpenAlex data required extensive cleaning. We removed records with missing or erroneous metadata (e.g., entries with zero authors or invalid institutional affiliations). For each author, we extracted and standardised their affiliated institution where necessary. We then constructed a dataset of institution pairings based on co-authorship, focusing on the extensive margin of collaboration – i.e., if two institutions co-authored multiple articles, we counted them as a single instance of collaboration. As a matter of example, if Harvard University and MIT jointly authored more than one article, we still recorded this as one collaborative link. This choice was made because the intensity of collaboration is harder to compare across contexts; that is, it is easier to count multiple instances in the case of academic articles, but the same cannot be said of industry-to-research or industry-to-industry partnerships, for instance. We acknowledge that this approach does not capture the depth or frequency of collaboration, but it enables a consistent comparative analysis across thousands of institutions from different domains. The quantum articles from OpenAlex present in our cleaned dataset involve five or fewer institutions. To ensure clarity and manageability, we decided to focus on this subset. This subset still covers over 95 percent of the over 20,000 quantum-related articles from the analysed 2018-2024 period. Attempting to account for all institution combinations in papers with more than five institutions would have introduced disproportionate complexity with limited additional insight.

This method offers a robust picture of the academic quantum collaboration landscape over a critical six-year period. While OpenAlex served as a foundational dataset for identifying academic collaborations, we complemented this with extensive manual verification across institutional websites to ensure broader and more accurate coverage. OpenAlex includes a wide range of institutions – universities, public research organisations, corporations, and startups making it a valuable but incomplete source when it comes to uncovering all collaborative relationships in the quantum domain. For academic institutions, we also manually reviewed the official websites of all universities in our dataset to identify whether they host a dedicated quantum research centre or quantum physics institute. If such a centre existed, we then examined whether it publicly listed collaborations or partnerships with other institutions – particularly international ones. This additional step was necessary because not all institutional collaborations are captured in co-authored publications.

Some are formalised through MoUs, joint labs, training programs, or strategic partnerships that may not yet have resulted in academic output. This mirrors our approach to startups, where websites might either understate or overstate the extent of collaborations. While some startups may have an incentive to advertise numerous partnerships to bolster legitimacy and attract investment, larger players or strategically positioned institutions may choose not to disclose collaborations due to commercial sensitivities or competitive pressures. This phenomenon is consistent with our earlier findings on funding disclosures, where incentives influenced transparency. We strictly limited ourselves to publicly accessible and verifiable sources, press releases, partnership pages, research centre websites, and collaborative announcements. In all cases, we avoided counting the same collaboration more than once; repeat co-authorships or multiple mentions of the same institutional pairing were counted as a single instance of collaboration.

Through this combined methodology, we were able to track over 18,400 unique bilateral collaboration links across more than 4,100 institutions in over 110 countries. In the course of compiling our list, we identified a subset of institutions that are actively working on quantum technologies but for which no verifiable collaborations could be tracked using our methods. These include a handful of quantum startups or research institutions that may either be operating independently, maintaining informal or undisclosed partnerships, or have chosen not to publicise their collaborative activities. Despite the absence of documented collaborations, we decided to retain these institutions in our dataset. Their inclusion ensures a more accurate representation of the broader quantum ecosystem, including actors that may be early-stage, under-the-radar, or operating in niche subfields. This approach acknowledges the limitations of relying solely on publicly available data, especially in a competitive and emerging field like quantum technology, where collaboration is sometimes deliberately kept private.

ANNEX 2: NETWORK ANALYSIS AND REVEALED COMPARATIVE ADVANTAGE METHODOLOGY

To understand how countries collaborate in quantum technologies, we used a network analysis approach. In this framework, each country is represented as a node, and every recorded collaboration between two countries becomes a link (or edge) connecting them. This allows us to visualise and measure how countries are positioned within the global ecosystem, not just in terms of how active they are, but also how important they are in connecting others.

The network is constructed as an undirected weighted graph. "Undirected" means the relationship between two countries goes both ways, and "weighted" means the strength of the connection (how many collaborations) is taken into account. We focus on three key metrics to describe how each country fits into this global map:

1) **Degree centrality**
   This measures how many different countries a nation collaborates with. A higher degree of centrality means a country has more partners. Formally, it is calculated as:

$$C_D(i) = \frac{\deg(i)}{n-1}$$

   where *deg (i)* is the number of nodes it is connected to and *n* the total number of nodes in the network. This is useful for identifying which countries are the most active participants.[29]

2) **Betweenness centrality**
   This captures how often a country sits "between" others on the shortest paths through the network. In other words, it shows how often a country acts as a bridge, helping to connect otherwise separate parts of the network. The formula is:

$$C_B(i) = \sum_{s \neq i \neq t} \frac{\sigma_{st}(i)}{\sigma_{st}}$$

   where δ_{st} is the number of shortest paths between countries s and t, and $\delta_{st}(i)$ is how many of those paths go through i.[30] Countries with high betweenness are often central to the flow of knowledge and collaboration.

[29] Freeman, L. C. (1979). Centrality in social networks conceptual clarification. Social Networks, 1(3), 215–239.
[30] Freeman, L. C. (1977). A set of measures of centrality based on betweenness. Sociometry, 40(1), 35–41.

3) **Eigenvector centrality**
   While degree centrality counts how many links a country has, eigenvector centrality also considers with whom those links are with. A country connected to other well-connected countries gets a higher score. This measure reflects both influence and "prestige" in the network. Mathematically, it's defined by:

$$C_E(i) = \frac{1}{\lambda}\sum_j a_{ij} C_E(j)$$

   where a_{ij} is the strength of the connection between country i and country *j*, λ is the largest eigenvalue of A, and C_E is the eigenvector corresponding to λ. This captures indirect as well as direct importance.[31]

By combining these measures, we can see which countries are active, influential, or strategically positioned to shape the flow of ideas and partnerships in the quantum field. These metrics underpin the visualisations shown in the report, where node size reflects degree centrality, node colour shows betweenness, and the structure of the network reveals key global connectors.

Revealed comparative advantage

While volume provides a useful snapshot, it does not reflect how embedded bilateral relationships are. For instance, the scale of the US-China corridor may overstate the depth of that relationship, which could reflect size rather than focus. Bilateral RCA allows us to identify targeted partnerships. We calculate the bilateral RCA using only international collaborations, excluding all domestic activity. A high bilateral RCA therefore signals a targeted partnership, one that is likely underpinned by shared research priorities, regulatory alignment, or complementary strengths. The formula used is as follows:

$$RCA_{bil} = \frac{collaboration_{ij}}{total_{\ i}} \div \frac{total_j}{global\ total}$$

Where $collaboration_{ij}$ is the number of collaborations between country i (reporter) and country j (partner), $total_i$ is the total number of international collaborations for country i, $total_j$ is the total number for country j, and *global total* is the sum of all international collaborations in the dataset. This method compares how often two countries work together to how often we would expect them to collaborate, based on how active they are internationally overall. To ensure meaningful comparisons, we exclude country pairs with low base levels of engagement, specifically, any country with fewer than 10 international collaborations overall, and any pair that collaborated fewer than three times.

[31] Bonacich, P. (1987). Power and centrality: A family of measures. American Journal of Sociology, 92(5), 1170–1182.