Title
Chokepoints, Competition, and Cooperation

Permalink
https://escholarship.org/uc/item/3c37c7mf

Journal
Berkeley Risk and Security Lab Reports

Author
Winter, Ben

Publication Date
2026-05-28

Chokepoints, Competition, and Cooperation

Quantum Computing Export Controls in a New Era of Tech Diplomacy

Ben Winter[1]

[1] Berkeley Risk and Security Lab, Goldman School of Public Policy, University of California, Berkeley

The analysis and conclusions have been informed by engagement with academics, policymakers, think tanks and quantum computing companies. This was anchored by a one-day workshop at UC Berkeley on December 8, 2025. We thank the participants for their insights. The authors thank Cara Wagner for copyediting this piece, and Lindsay Rand, Andrew Reddie, and Leah Walker for reviewing it.

Export Controls as Instruments of Strategic Competition

Export controls emerged in their modern form during the Cold War as instruments of strategic competition, most notably through the Coordinating Committee for Multilateral Export Controls (CoCom), where the North Atlantic Treaty Organization (NATO) and aligned states coordinated controls on exports to the Soviet Union and its close allies.[1] Although export controls were at times developed cooperatively – including with the Soviet Union – to mitigate shared nuclear weapon proliferation risks[2], the underlying policy objective was clear: to constrain an adversary's ability to develop military or industrial capabilities that could threaten the United States and its allies. Our focus is concerned specifically with their use as tools of strategic competition to preserve and extend technological advantage for the United States and its allies vis-à-vis China.

The contemporary landscape directing the evolution of export control policy is more complex. This is because today's export controls must address strategic technologies that are increasingly dual use, often intangible, and largely developed in the private sector at pace,[3] with innovation and production distributed across global supply chains. China, unlike the Soviet Union, is also a deeply integrated market actor within these technology ecosystems. Technological progress is being driven from Beijing, Shenzhen, and Wuhan as much as in Silicon Valley, London, and Berlin. The global diffusion of research and talent, coupled with the intertwining of commercial and security interests, means export controls now serve several – and sometimes conflicting – purposes: safeguarding national security, shaping economic competition, influencing supply chains, and increasingly operating as leverage in trade and broader diplomatic negotiations.

The practicalities and efficacy of the United States' policy to control the supply of advanced chips to China to mitigate the proliferation of Artificial Intelligence (AI) capabilities have been the subject of much scrutiny in recent years. However, this paper does not focus on AI, but another technology poised to reshape economic prosperity and national security: quantum computing. Particularly, it focuses on the challenges of designing and implementing effective export controls to manage risks and opportunities posed by a technology still under development. Quantum's potential to unlock vast computational capacity, disrupt cryptographic norms, and, alongside AI, accelerate scientific discovery makes it a prime example of dual-use technology. It is a widely held view that the nations that achieve sovereign, useful quantum capabilities first

[1] Christopher A. Casey, "Export controls—international coordination: Issues for Congress," Congressional Research Service, September 8, 2023, https://www.congress.gov/crs-product/R47684

[2] Nancy W. Gallagher, Lindsay Rand, Devin Entrikin, and Naoko Aoki, "The Desirability and Feasibility of Strategic Trade Controls on Emerging Technologies," Center for International and Security Studies at Maryland, University of Maryland, June 2023, https://cissm.umd.edu/sites/default/files/2023-06/Strategic%20Trade%20Controls%20and%20Emerging%20Tech_CISSM_Final.pdf

[3] Gallagher et al., "The Desirability and Feasibility of Strategic Trade Controls."

may enjoy outsized economic and strategic advantages – potentially creating "economic moats" that latecomers struggle to bridge.[4] Conversely, dependence on foreign quantum computing access could introduce inherent security risks – including vulnerabilities in secure communications and alliance interoperability – and make a state more susceptible to "technological surprise."[5] These perceived risks have driven policymakers to consider a more proactive approach to export controls.

A number of member states of the Wassenaar Arrangement (WA) (most NATO members, the EU, Japan, South Korea, Australia and others) have taken a notably pre-emptive approach in the case of quantum computing. Rather than waiting for quantum technologies to reach a level where their security implications are fully realised, these states have agreed to impose controls before these capabilities materialize.

As quantum computing progresses toward "useful" status and market applications emerge, allied nations must assess whether current controls – and the policies that govern them – remain fit for purpose in the future. Specifically, can they be "as open as possible and as closed as necessary"?[6] This paper argues that the efficacy of quantum export controls hinge on a unified allied approach: fractures in policy – via divergent national rules, transactional carve-outs, or misaligned enforcement – may undermine shared security and economic objectives. It explores how allied governments can better design and implement export control regimes for quantum computing that are proactive and adaptive, remaining effective and aligned in the face of rapid technological advances, divergent national interests, and evolving supply chain and research security risks. To do so effectively will require a policy of continuously managed instruments that align allied security objectives, industrial strategy, and research ecosystems over time.

---

[4] Mariarosaria Taddeo, Alexander Blanchard, and Kate Pundyk, "Consider the ethical impacts of quantum technologies in defence — before it's too late," *Nature* 634, no. 8035 (2024): 779-781, https://doi.org/10.1038/d41586-024-03376-4; Peter Alexander Earls Davis, Mateo Aboy, and Timo Minssen, "Regulatory challenges and opportunities of export controls on quantum computing," forthcoming in: *Quantum Technology Governance: Law, Policy & Ethics in the Quantum Era*, ed. Mateo Aboy, Marcelo Corrales Compagnucci, and Timo Minssen (Springer, anticipated late 2025/early 2026), https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5404548
[5] Edward Parker, "U.S.-Allied Militaries Must Prepare for the Quantum Threat to Cryptography," RAND Corporation, June 2025, https://www.rand.org/pubs/commentary/2025/06/us-allied-militaries-must-prepare-for-the-quantum-threat.html
[6] Davis, Aboy, and Minssen, "Regulatory challenges and opportunities."

Technological Horizon: Quantum Computing Over the Coming Decade

Quantum computing broadly refers to an array of techniques that leverage quantum phenomena to process information. Whereas classical computers store and manipulate information as binary bits (which can be in one of two states at any point in time), quantum computers rely on "qubits" as the primary processing units. Governed by the laws of quantum mechanics, qubits can exist in superposition states. In addition to superposition, qubits can also harness entanglement, wherein two or more qubits become correlated such that the state of one influences the other. Together, superposition and entanglement allow quantum computers to process certain types of information more efficiently than classical computers.[7]

As a technology, quantum computing is no longer constrained to the laboratory. Today, it represents a rapidly growing industry, with significant private and state investment and increasingly complex supply chains.[8] Companies have reported significant milestones in recent years and have published roadmaps towards fault-tolerant systems by as early as 2029. Although the goals set out in these roadmaps are often moving targets, most companies target hundreds to thousands of logical qubits – crucial for commercial viability – by 2027–2035. [9] Publicly accessible roadmaps for logical qubit milestones are rare, but Table 1 provides examples where the data is available.

[7] J. Preskill, "Quantum computing in the NISQ era and beyond," *Quantum*, vol. 2, p. 79, 2018. Available: https://quantum-journal.org/papers/q-2018-08-06-79/

[8] McKinsey & Company, "Quantum computing: An emerging ecosystem and industry". McKinsey Global Institute, 2023. Available: Quantum Technology Monitor 2025 | McKinsey

[9] M. Swayne, "Quantum computing roadmaps: A look at the maps and predictions of major players," *The Quantum Insider*, Dec. 18, 2025. Available: https://thequantuminsider.com/2025/12/18/quantum-computing-roadmaps-a-look-at-the-maps-and-predictions-of-major-players/

Table 1: Logical Qubit Milestones. Milestones are drawn from company public statements and are not directly comparable across architectures.

Company	**Key Milestone**
Infleqtion	100 logical qubits by 2028 and 1,000 by 2030[10]
IBM	200 logical qubits by 2029 and 2,000 post-2033[11]
Quantinuum	100 logical qubits by 2027[12]
Pasqal	100 logical qubits by 2029 and 200 in 2030[13]
IonQ	800 logical qubits by 2027 and 80,000 by 2030[14]

These targets and timelines align with allied government ambitions: U.S. federal initiatives look to reach useful, fault-tolerant systems within a decade;[15] the UK's National Quantum Strategy and missions set explicit objectives for accessible UK-based quantum computers capable of 1 trillion operations by 2035;[16] the European Union's Quantum Europe Strategy aims to make Europe a global quantum leader by 2030[17] and build coordinated quantum computing infrastructure roadmaps; and Australia's National Quantum Strategy targets global leadership by 2030.[18] These signal a policy expectation that fault-tolerant and utility-scale quantum capability will emerge in the early-to-mid-2030s.

While these roadmaps reflect a spirit of optimism and competition, it is important to recognize that the transition from laboratory demonstrations to practical, large-scale, fault-tolerant quantum computers remains a formidable challenge. Even if headline milestones are met, many experts expect the first real-world uses to be highly specialized, centred on advanced materials

[10] Infleqtion, "Quantum computing," 2026. Available: https://infleqtion.com/quantum-computing/
[11] IBM, "IBM Quantum roadmap: 2033 and beyond," 2025. Available: https://www.ibm.com/roadmaps/quantum/2033+/
[12] Quantinuum, "Quantinuum unveils accelerated roadmap to achieve universal, fully fault-tolerant quantum computing by 2030," Press release, Sept. 10, 2024. Available: https://www.quantinuum.com/press-releases/quantinuum-unveils-accelerated-roadmap-to-achieve-universal-fault-tolerant-quantum-computing-by-2030
[13] Pasqal, "Pasqal releases 2025 roadmap showcasing upgradable platform from today's quantum solutions to tomorrow's fault-tolerant systems," Press release, June 12, 2025. Available: https://www.pasqal.com/newsroom/pasqal-releases-2025-roadmap/
[14] IonQ, "IonQ quantum computing roadmap," 2026. Available: https://www.ionq.com/roadmap
[15] U.S. Government, "National Quantum Initiative," 2025, https://www.quantum.gov/
[16] UK Department for Science, Innovation and Technology, "National Quantum Strategy Missions," 2023, https://www.gov.uk/government/publications/national-quantum-strategy/national-quantum-strategy-missions
[17] European Commission, "Quantum Europe Strategy," 2025, https://digital-strategy.ec.europa.eu/en/library/quantum-europe-strategy
[18] Australian Government Department of Industry, Science and Resources, "National Quantum Strategy," 2023, https://www.industry.gov.au/publications/national-quantum-strategy.

discovery, cryptography research, and complex optimisation tasks.[19] Widespread commercial and governmental adoption depends not only on achieving high logical qubit counts, but also on steady gains in error correction, software tooling, benchmarking, and integration with classical infrastructure.

Regardless of whether more ambitious goals are met, the next decade is likely to see quantum computing move from prototypes to early, application-specific deployments across research institutions, government agencies, and select industries. The ambitions set out by industry and national strategies suggest that, by the mid-2030s, quantum computers could begin to deliver tangible benefits in targeted domains – though broad, transformative impact may take longer to materialise.

Anticipatory export controls have been implemented on quantum computing even though the technology remains pre-utility for the headline national security fear: breaking widely used encryption at scale. The fact that multiple WA members have converged on early controls suggests a widely held view that quantum computing has the potential to be strategically disruptive even before cryptographically relevant machines exist.[20]

However, pre-emptive export controls can only succeed when they are anchored in a current understanding of the capability trajectory of the technology and the true enablers and chokepoints that determine who can scale it[21]. A useful analogue is the rapid emergence of generative AI following OpenAI's release of ChatGPT on November 30, 2022, which revealed to policymakers that frontier AI progress depends heavily on access to large-scale compute. Semiconductor export controls between the United States and China long predated the generative-AI boom.[22] U.S. policy tightened significantly from at least 2018 onward, motivated by concerns about Chinese industrial strategy and military-civil integration, but the practical focus often remained selective: restrictions targeting particular firms and upstream manufacturing chokepoints, while substantial commercial chip trade continued. Controls existed, but they were not yet calibrated around the central constraint that would soon become obvious: frontier AI requires advanced chips and compute deployed at scale.

[19] Raseena, V., "Quantum computing: foundations, algorithms, and emerging applications," *Frontiers in Quantum Science and Technology* 4, no. 1723319 (2025), https://doi.org/10.3389/frqst.2025.1723319

[20] Matthew Sparkes, "Multiple nations enact mysterious export controls on quantum computers," *New Scientist,* July 3, 2024, https://www.newscientist.com/article/2436023-multiple-nations-enact-mysterious-export-controls-on-quantum-computers/

[21] C. M. Vidal Bustamante and J. Burke, "Quantum's industrial moment: Strengthening U.S. quantum supply chains for scalable advantage," *Center for a New American Security (CNAS)*, Mar. 12, 2026. Available: https://www.cnas.org/publications/reports/quantums-industrial-moment

[22] Karen M. Sutter, "U.S. Export Controls and China: Advanced Semiconductors," Congressional Research Service, September 19, 2025, https://www.congress.gov/crs-product/R48642

The change came with the U.S. Department of Commerce's October 7, 2022 export controls, which explicitly aimed to restrict China's ability to obtain advanced computing chips, develop and maintain supercomputers, and manufacture advanced semiconductors. These were capabilities that Commerce deemed linked to military modernisation and advanced AI applications.[23] Those controls were then iteratively strengthened: by 2023, policy updates revised technical parameters and sought to close loopholes by shifting to metrics such as "performance density" and by addressing the proliferation of export-compliant variants engineered to sit just below earlier thresholds.[24] This dynamic illustrates a core policy risk: governments can have export controls "on the books" yet still be late to identify the decisive chokepoint, and late again in anticipating how rapidly private actors will work around static thresholds.

The implication for quantum computing is not that controls should be delayed until the threat is fully realised. Rather, it is that anticipatory controls must be directed at the right capability drivers, and those drivers may shift over time. For quantum computing, today's most visible proxies are hardware-centric (qubit counts, error rates, cryogenic and control stacks), which partly explains the focus of early measures. However, it is likely that the constraint on "useful" quantum capability will not be physical qubit count alone. For example, breakthroughs in error correction, calibration, and control systems could change the relationship between physical hardware and effective capability. This may mean that the most strategically consequential "export" may be an enabling software stack or operational "know-how" rather than a headline qubit count. It should be noted that allied controls – including updates made by the US Department of Commerce and UK Government in 2024 – that extend across software and technology as well as hardware do implicitly recognise this risk.[25]

There is an "AI lesson" for quantum export controls: the central task is not merely to control early, but to ensure that controls track chokepoints as they emerge, whether they lie in hardware, in manufacturing, in the less visible layers of the stack such as error-correction methods, compilers, and operational expertise, or in an area of the technology or supply chain not yet identified. Where controls rely on fragile proxies, they risk either being bypassed (if they miss

[23] Bureau of Industry and Security, "Commerce Implements New Export Controls on Advanced Computing and Semiconductor Manufacturing Items to the People's Republic of China (PRC)," U.S. Department of Commerce, October 7, 2022, https://www.bis.gov/press-release/commerce-implements-new-export-controls-advanced-computing-semiconductor-manufacturing-items-peoples

[24] Emily Benson, "Updated October 7 Semiconductor Export Controls," Center for Strategic and International Studies, October 18, 2023, https://www.csis.org/analysis/updated-october-7-semiconductor-export-controls

[25] Bureau of Industry and Security, "Department of Commerce Implements Controls on Quantum Computing and Other Advanced Technologies Alongside International Partners," U.S. Department of Commerce, September 5, 2024, https://www.bis.gov/media/documents/quantum-press-release-final.pdf; UK Government, "The Export Control (Amendment) Regulations 2024," accessed February 28, 2026, https://www.legislation.gov.uk/uksi/2024/346/regulation/1/made

the true bottleneck) or imposing unnecessary innovation costs (if they over-capture low-risk items).

Consideration 1: Governments should treat quantum computing export controls as a living regime – one that is periodically re-baselined against technical evidence, rapidly updated as bottlenecks and capabilities shift, and coordinated among allies to avoid gaps that can be exploited through regulatory arbitrage.

Consideration 2: Governments should maintain close relationships with academia and industry to predict – as accurately as possible – capabilities and enablers on a short, medium, and long term.

Quantum Computing Export Controls: Current Regimes and Their Efficacy

As previously stated, as quantum computing advances towards practical utility, allied governments have taken a proactive approach to managing the associated security and economic risks through export controls.

Understanding the current landscape of export controls – and their effectiveness – is essential for assessing how well these measures can keep pace with rapid technological change and shifting geopolitical dynamics.

Structural and Coordination Challenges in Quantum Computer Export Controls

Export controls on dual-use technologies like quantum have been governed primarily by the WA, a multilateral regime covering dual-use goods and technologies. Establishing multilateral, non-binding agreements through fora such as the WA can be slow – requiring unanimity from all 42 members – and in some cases face gridlock.[26] Since the 2022 Russian invasion of Ukraine, consensus within the WA has been significantly constrained, reducing agreement on new controls, with fewer substantive list updates being adopted.[27] From 2024 a growing number of Wassenaar members – including the United States, UK, France, Netherlands, Spain, Canada, and

[26] Davis, Aboy, and Minssen, "Regulatory challenges and opportunities"; Altynay Junusova and William Alan Reinsch, "Rethinking the Wassenaar Minus One Strategy," Center for Strategic and International Studies, November 25, 2024, https://www.csis.org/analysis/rethinking-wassenaar-minus-one-strategy
[27] Junusova & Reinsch, "Rethinking the Wassenaar Minus One Strategy"

Japan – have aligned on a "Wassenaar minus one" approach, implementing coordinated national controls on quantum computers, typically restricting the export of systems with 34 or more qubits and below a certain error threshold.[28] These measures are often complemented by national security investment screening and, in some cases, outbound investment restrictions.

Disruptions to the WA present allied nations with new challenges in aligning export controls. There is no realistic method of expelling Russia from the regime:[29] there is no mechanism for expulsion, and Russia can ensure unanimity from members to agree to any such mechanism is not possible. The alternatives – creating a new regime or maintaining the status quo of looser multilateral and plurilateral alignment – have their own shortcomings. Establishing a new regime may prove impractical. Dissolving the WA to create a new international institution would be complex and cumbersome, and create a new set of political and diplomatic challenges. A continued strategy of establishing plurilateral agreements between allied nations could enable a more flexible and dynamic approach to export control alignment, but it would require a consistent shared vision based on close cooperation and information sharing.[30] The ability to do so cannot be taken for granted.

An emerging shift toward more transactional approaches in technology and trade risks creating significant barriers to achieving effective plurilateral export control regimes. As governments weigh economic interests against security imperatives, the risk grows that export controls will become tools of leverage in trade negotiations, rather than instruments of collective security. This may become the case even amongst nations that have been historically "like-minded" in the Western Alliance.

This risk of fragmentation is not theoretical. Recent developments in the United States' semiconductor policy towards China exemplify the challenges of a more transactional, bilateral approach to technology controls. In December 2025 the U.S Government shifted policy to allow Nvidia's H200 GPUs to be sold to China on a case-by-case basis. The formal guidance issued by BIS[31] in January 2026, which included an effective 25% export fee on sales to China, marked a significant departure from the alliance-based, multilateral export control strategies that have

[28] Helder, J., Kläui, C., Denton, R., Tsakanakis, S., Brooks, I., Matson, J., Malhi, S., Ezaz, C., Haynes, O. and Keay, A. (2025) 'The UK continues to expand its controls on emerging technologies'. Akin Gump Strauss Hauer and Feld LLP, 24 March. Available at: https://www.akingump.com/en/insights/alerts/the-uk-continues-to-expand-its-controls-on-emerging-technologies

[29] William Alan Reinsch, "Wa, Wa, Wassenaar!", Center for Strategic and International Studies, July 24, 2023, https://www.csis.org/analysis/wa-wa-wassenaar

[30] Junusova and Reinsch, "Rethinking the Wassenaar Minus One Strategy."

[31] U.S. Department of Commerce, Bureau of Industry and Security (2026) Department of Commerce revises license review policy for semiconductors exported to China. Press release, 13 January. Available at: https://www.bis.gov/press-release/department-commerce-revises-license-review-policy-semiconductors-exported-china (Accessed: 23 March 2026)

underpinned allied technology policy for decades. Although the Blackwell-class remains restricted, by negotiating carve-outs and concessions directly with US companies, the United States has demonstrated a willingness to prioritise its economic interests over the predictability and unity of collective controls.[32] This shift has immediate implications for allied cohesion, exposing the USA's partners to compliance uncertainty and competitive disadvantages. Allies who continue to enforce strict controls across the AI stack may find themselves bearing the costs of compliance without corresponding security benefits. These changes to American policy risk eroding trust in the reliability of plurilateral agreements, as partners may question whether collective commitments will be upheld or traded away in future negotiations. As Stein noted in 1982, "regimes are maintained as long as the patterns of interest that gave rise to them remain. When these shift, the character of a regime may change; a regime may even dissolve entirely."[33]

A continuation of this approach could see a weakening of the multilateral and plurilateral export control architecture. As the United States demonstrates a willingness to negotiate directly with China, other allied nations may be incentivised to pursue their own bilateral deals or to relax their controls to remain competitive. This fragmentation risks undermining the effectiveness of the export control regime, increasing the risk of regulatory arbitrage, and ultimately making it more difficult to prevent the diffusion of sensitive technologies such as quantum computing to strategic competitors. The result could mean a more divided and less effective export control landscape amongst allied nations, with significant implications for both security and economic resilience. It is important to note however that the establishment of the Quantum Development Group in 2024 – of which the United States is a key member – does reflect recognition among leading quantum states of the risks posed by policy fragmentation.

Consideration 3: There may be space for a multilateral forum amongst allied partners – such as the Quantum Development Group – that agrees to no unilateral carve-outs on defined quantum items without prior notice/consultation. This forum could also be used to consider red-teaming reviews for potential loopholes (cloud/remote access, deemed exports, onward re-exports).

[32] Joris Teer, "Tech war 2.0: The dangers of Trump's 'G2' bargaining with an emboldened China," European Union Institute for Security Studies, December 16, 2025, https://www.iss.europa.eu/publications/briefs/tech-war-20-dangers-trumps-g2-bargaining-emboldened-china

[33] Arthur A. Stein, "Coordination and Collaboration: Regimes in an Anarchic World," International Organization 36, no. 2 (January 1982): 299–324, https://doi.org/10.1017/S0020818300018968

Limits of Current Control Criteria

Export controls on quantum computing present both opportunities and challenges for allied nations. Well-designed controls can foster responsible innovation, encourage international collaboration, and provide early leverage to shape the global quantum ecosystem. However, current measures – particularly the 34-qubit threshold – have been described by some in industry as "opaque"[34] and could discourage international research partnerships and slow the pace of scientific discovery. As quantum technologies evolve beyond today's engineering benchmarks, researchers may be hesitant to collaborate across borders or share hardware and software, fearing inadvertent violations of export controls. The effects may also not be evenly distributed across industry. Large, well-funded enterprises are likely to have better access to legal counsel and may feel less constrained by potential compliance costs. Smaller firms may be deterred from international collaboration, placing them at a competitive disadvantage. The complexity and rapid pace of quantum innovation, combined with the global and intangible nature of knowledge flows, mean that controls must be adaptive and transparent to avoid undermining the very ecosystems they aim to protect.[35]

It is also important to consider evidence that export controls, while intended to slow competitors' technological progress, can have unintended consequences – most notably, accelerating the development of domestic quantum supply chains in countries like China. There is already evidence of this happening. American-led and allied export controls have prompted Chinese quantum labs and start-ups to rapidly localise their supply chains, reducing reliance on Western components and expertise.[36] An example is China's rapid expansion of dilution refrigerator manufacturing, following the U.S. decision to prohibit the export of refrigerators – crucial for quantum states to remain coherent and controllable long enough to perform computations – to the country. Since 2023, reports have emerged from China that several companies now have cooling capabilities that are competitive with products from the United States, UK and Finland, which have traditionally dominated the refrigerator market.[37] The drive for further resilience and self-reliance across quantum is likely to continue given strong government support for sovereign

[34] Sparkes, "Multiple nations enact mysterious export controls."
[35] Davis, Aboy, and Minssen, "Regulatory challenges and opportunities."
[36] Elias Huber, "Export Controls Accelerate China's Quantum Supply Chain," Royal United Services Institute, June 27, 2025, https://www.rusi.org/explore-our-research/publications/commentary/export-controls-accelerate-chinas-quantum-supply-chain
[37] Matt Swayne, "Reports: China Mass Producing Dilution Refrigerator Critical To Superconducting Quantum Computing," *Quantum Insider* December 18, 2025, https://thequantuminsider.com/2024/02/28/reports-china-mass-producing-dilution-refrigerator-critical-to-superconducting-quantum-computing/; Elias X. Huber, "Feature Translation: Interview of entity-listed Chinese cryogenics company," China Quantum, November 25, 2025, https://www.chinaquantum.info/p/feature-translation-interview-of

capabilities and the anticipation of future restrictions.[38] In this context, China's manufacturing capabilities – particularly its ability to rapidly scale cost-effective production of hardware – could translate into a consequential advantage as quantum systems move from laboratory prototypes toward deployment and commercialisation.

Insights from the BRSL December 2025 workshop at UC Berkeley highlighted the difficulties of determining who is being disadvantaged by export control regimes without a comprehensive understanding of the capabilities of nations being targeted by export controls, particularly China. Better links within allied governments between those setting industrial strategies, those responsible for export controls, and national security and intelligence communities would allow for a more coordinated and strategic approach to understanding the risk and reward of export control regimes.

Workshop participants advised that export controls have not yet been experienced as a binding constraint by U.S. quantum computing firms. The perceived risk is currently driven more by uncertainty and compliance anxiety than by observed disruptions to procurement or sales. This reflects the sector's early stage of commercialisation, in which volumes are low, a wide range of suppliers can be found, and direct U.S. – China market integration in quantum computing systems remains limited, especially when compared with semiconductors.

However, this does not mean that we should infer that chokepoints are absent, nor that they will not emerge as a critical issue in the future. Rather, at present, progress in quantum computing appears to be constrained primarily by research, engineering integration, and accumulated operational expertise, rather than by a single dominant or universally binding industrial bottleneck. A recent analysis from the Centre for a New American Security (CNAS) argues that quantum supply chains are "thin and globally dispersed," and that scale up will be constrained by vulnerabilities in enabling technologies, particularly photonics and optics, cryogenics, and specialized materials and microfabrication.[39] A supply chain assessment undertaken in 2025 on behalf of NATO's Transatlantic Quantum Community (TQC) identifies cross-cutting dependencies across modalities, including reliance on non-allied sources for rare earths and exotic materials, helium-3 constraints, as well as long lead times and a limited supplier base for critical cryogenic components such as pulse tubes and dilution refrigerators.[40]

---

[38] Jeroen Groenewegen-Lau and Antonia Hmaidi, "China's long view on quantum tech has the US and EU playing catch-up," Mercator Institute for China Studies, December 12, 2024, https://merics.org/en/report/chinas-long-view-quantum-tech-has-us-and-eu-playing-catch

[39] C. M. Vidal Bustamante and J. Burke, "Quantum's industrial moment: Strengthening U.S. quantum supply chains for scalable advantage"

[40] L. Kingma, F. Heijman, and C. Williams, *Critical vulnerabilities in the quantum computing supply chain within the NATO Alliance*. NATO Transatlantic Quantum Community, May 2025. Available: https://www.fheijman.nl/QSC_report.pdf

Uncertainty remains around supply chain visibility and the timelines on which dependencies may become binding. While quantum computing companies may not yet experience acute chokepoints, scaling and wider deployment are likely to expose underlying fragilities in the supply chain. This underscores the need for sustained, allied efforts to map and monitor the global quantum computing value chain, both to anticipate emerging chokepoints and to understand collective capabilities across trusted partners. Such mapping is particularly important in the context of export controls, where measures intended to constrain adversary capabilities may also, if misaligned, restrict allied firms' access to critical enabling technologies and components.

Consideration 4: Governments of allied nations should together regularly test the assumptions and criteria governing quantum computing export controls to ensure that they are not unduly discouraging or disincentivising international research partnerships that are crucial to the development of the technology.

Consideration 5: Governments should explore how they can encourage the safe flow of information between intelligence agencies, industrial and research policy leads, and export control policy makers. This would enable strategic decision-making that ensures export controls do not halt potential sales of products to markets where similar capabilities are already found.

Consideration 6: Allied nations should build on work undertaken by NATO's TQC to conduct regular supply chain mapping to maintain a clear view of potential future chokepoints.

Implications for Future Policy and Alliance Management

Quantum computing export controls are arriving earlier in the technology lifecycle than most historical precedents. This is prudent given the technology's dual-use potential and the asymmetric strategic effects that could follow once useful systems emerge. But early action is not the same as effective action. To respond to a new era of global competition and tech diplomacy, export controls must evolve from static lists towards continuously managed instruments that align allied security objectives, industrial strategy, and research ecosystems over time.

Although it is not yet clear where the future chokepoints in the quantum computing supply chain will emerge, they will define whether controls succeed or fail. Today's controls are anchored in hardware proxies (e.g., qubit counts and error thresholds), but the decisive bottlenecks for "useful" quantum capability may shift rapidly toward error correction breakthroughs, control and calibration systems, specialised materials and cryogenics, or operational knowledge embedded in software and talent. There may even – as evidenced by the issues caused by the rapid emergence of generative AI – still be crucial interconnects between quantum computing and its enabling technologies that have not yet presented themselves. As with AI and compute, controls that miss the true constraint will be strategically ineffective, while controls that over-capture low-risk items will impose unnecessary costs on allied innovation.

Quantum computing export controls sit within a broader context of intensifying competition and more transactional technology politics. If allies drift toward unilateral carve-outs or bilaterally negotiated exemptions, the practical value of coordinated control regimes will erode. The risk is not only that strategic competitors gain access through regulatory arbitrage, but that allies also begin to lose trust in common rules. This could lead to fragmentation, duplicative compliance burdens, and – ultimately – a damaging race to the bottom.

The coordination challenge is now as much political as it is technical. With the WA operating under "minus one" realities, alignment depends on plurilateral trust, shared intelligence baselines, and credible consultation mechanisms. Maintaining unity will require allies to treat export controls as part of alliance management: regular consultation, mutual reassurance, and predictable processes to handle exceptions, enforcement, and updates.

The policy objective of export controls should not be maximal restriction but sustained advantage: ensuring that allied states can innovate collaboratively while constraining pathways that materially accelerate strategic competitors' military-relevant capability. That demands a posture that is "open where possible" to protect research collaboration and legitimate commerce, while "closed where necessary" on enabling components, software, and knowledge flows that plausibly shift the strategic balance. In this sense, quantum computing export controls may yet become a test case for how democracies govern frontier technologies without compromising their own innovation ecosystems.

Summary of Considerations

Consideration 1: Governments should treat quantum computing export controls as a living regime – one that is periodically re-baselined against technical evidence, rapidly updated as bottlenecks and capabilities shift, and coordinated among allies to avoid gaps that can be exploited through regulatory arbitrage.

Consideration 2: Governments should maintain close relationships with academia and industry to predict – as accurately as possible – capabilities and enablers on a short, medium, and long term.

Consideration 3: There may be space for a multilateral forum amongst allied partners – such as the Quantum Development Group – that agrees to no unilateral carve-outs on defined quantum items without prior notice/consultation. This forum could also be used to consider red-teaming reviews for potential loopholes (cloud/remote access, deemed exports, onward re-exports).

Consideration 4: Governments of allied nations should together regularly test the assumptions and criteria governing quantum computing export controls to ensure that they are not unduly discouraging or disincentivising international research partnerships that are crucial to the development of the technology.

Consideration 5: Governments should explore how they can encourage the safe flow of information between intelligence agencies, industrial and research policy leads, and export control policy makers. This would enable strategic decision-making that ensures export controls do not halt potential sales of products to markets where similar capabilities are already found.

Consideration 6: Allied nations should build on work undertaken by NATO's TQC to conduct regular supply chain mapping to maintain a clear view of potential future chokepoints.