NOTRE DAME JOURNAL ON EMERGING TECHNOLOGIES

VOLUME 6 March 2025 ISSUE 1

JOURNAL ON EMERGING TECHNOLOGIES

ARTICLES

PROPOSALS FOR THE FUTURE GOVERNANCE OF QUANTUM COMPUTING

MICHELLE M. CRESSWELL

"Doing is a quantum leap from imagining"
—Barbara Sher

Proposals for the Future Governance of Quantum Computing

MICHELLE M. CRESSWELL[*]

INTRODUCTION

"Nature isn't classical, dammit, and if you want to make a simulation of nature, you'd better make it quantum mechanical …"
—Richard Feynman

Imagine a world of clarity in which what has been uncertain in life become instantaneously certain, where choices are not made one by one, but are presented to you all at once. Imagine a world where drug discovery can occur within mere days instead of months and years. Imagine a life lived with less concern about personal future healthcare issues because of the emergence of disease risk prediction. Imagine a system that could erase or revise "digital signatures – which in countries including the U.S. are used to execute contracts in the same way as a handwritten mark –"[1] that are currently protected with encryption keys. The need to imagine quantum computing uses benefits or threats, won't inhabit only our imaginations for too long because it will most likely exist in true form with an operational magnitude exponentially equal to or even bypass the importance of the discovery of nuclear fission with the next decade. "For example, Quantum Defense (QD5)'s executive vice president, Tilo Kunz, told officials from the Defense Information Systems Agency that possibly as soon as 2025, the world would arrive at what has been dubbed *'Q-day,'* the day when quantum computers make current encryption methods useless."[2]

"Even though our traditional computers can operate in amazing ways, they cannot compute nature, where things are not just simply turned on and off but remain in uncertain states at its subatomic level. To understand the smallest scale of our environment, physicists developed quantum mechanics, which is the basis of physics, that

---

[*] Dedicated to my brilliant daughters, the doers of a life only imagined by their mom.
[1] Bijal Vakill, *The opportunities and legal risks of quantum computing*, Allen & Overy (May 12, 2023), https://www.aoshearman.com/en/insights/the-opportunities-and-legal-risks-of-quantum-computing.
[2] David Lague, *U.S. and China Race to shield secrets from Quantum Computers*, Reuters (Dec. 14, 2023), https://www.reuters.com/investigates/special-report/us-china-tech-quantum/.

underlies chemistry, and is the foundation of biology."[3] To accurately simulate and model that which is found in these disciplines, scientists require a computer that can compute the uncertainty of life without error on an enormous exponential level, such as that which is equal to 300 qubits or 10^{90}. Quantum mechanics researchers are in the middle of achieving this technological feat by probing a world on the scale of atoms (one million times smaller than the width of the human hair), to build an operational quantum computer large enough to solve some of life's most complex problems.[4] With an adequate amount of qubits that are stable long enough, a quantum computer would be able to perform exponentially more calculations than current supercomputers. In a single step, it could solve problems that could take classic computers years to do so.[5] For example, quantum computer capabilities could enable computations otherwise not possible in areas like chemistry, such as modeling, that could produce new materials by simulating the behavior of matter at the atomic level.[6]

"Over the past century, a deeper understanding of quantum mechanics has given scientists better control of the quantum world…[which] provides them with new ways to acquire, process, and transmit information as part of a new scientific field known as *quantum information systems (QIS)*."[7] QIS is the unification of quantum mechanics and information theory[8] and "can be broadly broken up into *quantum computing, quantum encryption*, and *quantum sensing*."[9]

The Quantum Computing Cybersecurity Preparedness Act (P.L. 117-260) *defines a* quantum computer as a computer that "uses the

---

[3] Wired UK, *Quantum Computing and Quantum Supremacy, Explained*, YouTube (Mar. 4, 2020), https://www.youtube.com/watch?v=QF7QfE6qgTM.
[4] *NOVA: Einstein's Quantum Riddle* (PBS television broadcast Jan. 9, 2019).
[5] Robert A. Manning, *Emerging Technologies: New Challenges to Global Stability*, Atlantic Council, (2020), http://www.jstor.org/stable/resrep26000.
[6] Will Knight, *"Serious Quantum Computers are Finally Here. What are We Going to Do with Them?"* MIT Tech. Rev., (Feb. 21, 2018), https://www. technologyreview.com/s/610250/serious-quantum-computers-are-finally-here-what-are-we-going-to-do-with-them/.
[7] Chris Jay Hoofnagle & Simson L. Garfinkel, *Law and Policy for the Quantum Age*, 1, (2022).
[8] Mauritz Kop, *ESTABLISHING A LEGAL-ETHICAL FRAMEWORK FOR QUANTUM TECHNOLOGY ESTABLISHING A LEGAL-ETHICAL FRAMEWORK FOR QUANTUM TECHNOLOGY*, YALE J.L & TECH. (Mar. 30, 2021), https://yjolt.org/blog/establishing-legal-ethical-framework quantum-technology.
[9] John Costello, *Chinese Efforts in Quantum Information Science: Drivers, Milestones, and Strategic Implications, Testimony for the U.S.-China Economic and Sec. Rev. Comm'n*, (Mar. 16, 2017), https://www.uscc.gov/sites/default/files/John%20Costello_Written%20Testimony_Final2.pdf.

collective properties of quantum states, such as superposition, interference, and entanglement, to perform calculations."[10] Quantum computing is where the availability of superior computational capacity would likely provide the quantum advantage against classical counterparts in a host of domains, including financial, modelling, predictive analytics, engineering, national security, and defense. "In industry, access to superior computational capacity would provide in principle (ceteris paribus) firms with a competitive advantage (e.g., consider financial market trades, product design, and chemical synthesis etc.)."[11]

The choices that people make to affect global governance, such as how the world addresses climate change, analyzes financial markets, generates food supplies, advances medical research, and bypasses or enhance cybersecurity are among the complex problem sets in which a quantum computer could accurately calculate the results, thereby preventing potential future disastrous scenarios that could occur in an uncertain world. Conversely, quantum computing could threaten the existence of some of these current fields. For example, with the use of Shor's algorithm, the raw computational power of an operational quantum computer could threaten to undermine current public key cryptographic methods,[12] placing sensitive government, military, and business information and communications at great risk.

The global quantum computing market could add a total of more than $1 trillion to the global economy between 2025 and 2035, according to a new analysis from *The Quantum Insider*. "Though policymakers have thus far focused on accelerating quantum innovation, looming practical applications of quantum technologies demand prompt conversations about designing comprehensive governance frameworks" to regulate this industry before it leaves the station.[13] In general, the U.S. Congress faces three policymaking considerations: (1) how to accelerate the development of practical quantum computers with near-term, useful

[10] 6 U.S.C.A § 1526 (West, Pub. L. No.117-260).
[11] Elija Perrier, *The Quantum Governance Stack: Models of Governance for Quantum Information Technologies*, 1 DISO 22 (2022), https://doi.org/10.1007/s44206-022-00019-x.
[12] LILY CHEN ET. AL., *NISTIR 8105, REPORT ON POST QUANTUM CRYPTOGRAPHY* , U.S. NAT'L INST. STANDARDS & TECH. 1, 2
(2016), https://nvlpubs.nist.gov/nistpubs/ir/2016/nist.ir.8105.pdf; see also Dorothy Denning, *Is Quantum Computing a Cyber Security Threat?*, CONVERSATION (Dec. 20, 2018, 6:34 AM), https://theconversation.com/is-quantum-computing-a-cybersecurity-threat-107411 [https://perma.cc/23FD-26GA].
[13] Walter G. Johnson, *"Governance Tools for the Second Quantum Revolution"*59 JURIMETRICS 487, 487-522, (2019), https://www.jstor.org/stable/27009999.

applications; (2) how to support the development of accessible, sustainable, and secure quantum supply chains and quantum domestic manufacturing capabilities; and (3) how to facilitate the development of a quantum-literate workforce.[14] Congress must prepare to govern quantum computing in a world that requires a globalized ideology or optimism, where multinational organizations can agree on the methods of governance, balanced with the sensibility of political realism, in which such multinational organizations are most likely not going to include the same robust membership as the United Nations.

For example, one conceivable situation that would require the realism of global governance is how to prepare for the "public/private East/West bloc" scenario. This scenario is where government and the private sector collaborate, but faces sharp competition dividing the East (e.g., China) and the West (e.g., U.S. and EU). "Key policy characteristics [of the public/private East/West Bloc scenario] include global expansion and influence in developing countries, secrecy, limits on immigration, and the return to industrial policy in pursuit of technological sovereignty."[15]

One can reflect on the history of the four Industrial Revolutions and imagine the future fifth Industrial revolution, particularly regarding the social costs of designing industry with a reactive versus proactive governance process. For example, the first Industrial Revolution (1760 to 1830) was described as the process of change from an agrarian and handicraft economy to one dominated by industry and machine manufacturing.[16]

The Fifth Industrial Revolution should be ushered in through quantum computing. "Research shows that societal attitudes towards quantum computing and quantum technologies are currently reasonably positive - and in order to maintain (and be worthy of) societal trust and acceptance, good governance is essential."[17] Therefore, to maintain public trust and protect this technology from malicious use and undermining encryption, it is imperative to formulate a quantum computing governance movement, goals, strategies, programs,

---

[14] Ling Zhu, *Quantum Computing: Concepts, Current State, and Considerations for Congress*, (Sep. 7, 2023), https://crsreports.congress.gov/product/pdf/R/R47685.
[15] Hoofnagle & Garfunkel, *supra* at 363.
[16] *Industrial Revolution,* Encyclopedia Britannica, Inc., (Jan. 18, 2024), https://www.britannica.com/event/Industrial-Revolution.
[17] CAROLYN TEN HOLTER ET AL., CREATING A RESPONSIBLE QUANTUM FUTURE: THE CASE FOR A DEDICATED NATIONAL RESOURCE FOR RESPONSIBLE QUANTUM COMPUTING (2021), https://ora.ox.ac.uk/objects/uuid: 8e175e19-f879-4827-9cbd-c4849cb6bd60.

principles, and most importantly, follow these good intentions, which are fair and equitable for all humankind who will be affected by this technology, with industry best practices.

Typical paradigms of governance contrast 'hard law', characterized as legal obligations that are binding on the parties involved and which can be legally enforced before a court,[18] with 'soft law', characterized as legally non-binding instruments that are utilized for a variety of reasons, including to strengthen member commitment to agreements, reaffirm international norms, and establish a legal foundation for subsequent treaties.[19] Governance literature often represents regulation along such a spectrum with 'harder' or more formal governance, characterized by formal instruments (e.g. treaties or legislation, dependent upon the relevant governance hierarchy), followed by a mixture of policy-driven government regulation and instruments to motivate private compliance (e.g., sanctions, punishments or incentives).[20] I propose that the liberalization, the loosening of future government controls, which still must exist to shepherd technology, of quantum policy through the soft law approach will lead the western development of quantum governance. In contrast, China's development of quantum computing will likely be heavily controlled by an authoritarian government, which may, in fact, slow its scientific progression of quantum technology. China is working towards operationalizing quantum computing, but its primary attention is focused on producing quantum communication systems.

This paper will examine these two different social movements that will play a role in shepherding authoritarian and democratic quantum computing governance and address policy considerations of both ideals. Access to information, particularly to innovative technology, plays an important role to support equity across all stakeholder and societal domains. In this paper, I will explain how communication of such information will fall within the movement, goals, and strategies to develop quantum computing within China and the U.S. and describe how they compare with one another. For example, while American strategy

---

[18] *Hard Law/Soft Law*, *European Center for Constitutional and Human Rights* (2023), https://www.ecchr.eu/en/glossary/hard-law-soft-law/.

[19] Dinah Shelton & Jonathan Blavin, *Commitment and Compliance: What Role for International Soft Law?*, CARNEGIE ENDOWNMENT FOR INT'L PEACE (Nov. 22, 1999), https://carnegieendowment.org/1999/11/22/commitment-and-compliance-what-role-for-international-soft-law-event-47.

[20] IAN AYRES & JOHN BRAITHWAITE, *RESPONSIVE REGULATION: TRANSCENDING THE DEREGULATION DEBATE*. (Oxford Univ. Press. 1992), https://doi.org/10.2307/2938772.

has included historical adventurism, Chinese strategy, informed by its own classical tradition and modern history, has been fundamentally protectionist.

In this paper, I will (1) begin by examining the history of the three industrial revolutions, particularly their social outcomes, the development of quantum computing within industry 4.0, and the ushering of the fifth industrial revolution by way of the quantum computer, (2) briefly reflect upon the history of quantum computing, (3) explain the critical fundamentals of quantum computing, (4) introduce the key stakeholders involved with the global development of the quantum computing industry, (5) explore the "public/private, East/West bloc" scenario regarding the future of quantum governance, (6) compare the legal theories of hard and soft law in the context of governing this scenario of the future of quantum computing, and (7) present my reasoning in choosing soft law, through the social movement triangle, as the most effective and appropriate governance pathway to legally shepherd a just quantum computing industry into society within the confines of the "public/private, East/West bloc." The questions that I will respond to regard the equity of global stakeholders involved in the development, education, funding, access, challenges, and suggestions regarding how to govern the future of quantum computing.

I. HISTORY OF THE INDUSTRIAL REVOLUTION

"Every industrial revolution brings along a learning revolution"
—Alexander De Croo

Xi Jinping argued in a 2018 speech: "From the mechanization of the first industrial revolution in the 18th century, to the electrification of the second industrial revolution in the 19th century, to the informationization of the third industrial revolution in the 20th century," each round of "disruptive technological innovation" has shaped history.[21] Regarding the effect of the Industrial Revolutions upon America, the U.S. economy has gone through staggering changes. It has gone from agrarian to industrialized, from primarily rural to primarily urban and suburban - from one in which primarily men worked to one in which by 2010 more

[21] Rush Doshi, *The United States, China, and the Contest for the Fourth Industrial Revolution*, BROOKINGS (July 31, 2020), https://www.brookings.edu/testimonies/the-united-states-china-and-the-contest-for-the-fourth-industrial-revolution/.

than half of professional workers were women.[22]

First Industrial Revolution

"Revolutions have occurred throughout history when new technologies and novel ways of perceiving the world trigger a profound change in economic systems and social structures."[23] The first modern Industrial Revolution, spanning from about 1760 to 1830, began in Great Britain and soon spread to the west to the United States, changing society from an agrarian and handicraft economy to one dominated by industry and machine manufacturing.[24] Consumerism began to flourish. At the most general level, there are views such as Thomas Sowell's, that Britain's early economic transformation happened when it did because Britain had established before almost everywhere else '*a framework of law and government that facilitated economic transactions*,' particularly by pioneering the establishment of economic freedom.[25] Without strict regulation and with the encouragement of capitalism, invention soared, but society ended up paying a steep price. Inventions and technological advances, such as the spinning jenny, steam power, rail transportations, and telegraph communications led to rapid urbanization.[26] Notably, the spinning jenny increased the tax on slavery and may have taken part in the hastening of the U.S. Civil War. Without regulation, this led to a rise in multiple negative externalities, such as the exploitation of workers, use of child labor, lack of safety regulations, and overcrowded urbanization living with unsanitary conditions.

Second Industrial Revolution

Between 1870 and 1914, the Second Industrial Revolution, also known as the Technological Revolution, ushered in inventions, such as the internal combustion engines, railroads, airplanes, telephones, radios, and steelmaking for construction. This resulted in unprecedented growth and innovation of the era that led to massive wealth for some, forced

---

[22] David Rothkopf, *The Third Industrial Revolution, in* FOREIGN POLICY, no. 196, at 88 (2012), http://www.jstor.org/stable/41726724.
[23] KLAUS SCHWAB, THE FOURTH INDUSTRIAL REVOLUTION: HISTORICAL CONTEXT 11 (2017).
[24] Adam Zeidan, *INDUSTRIAL REVOLUTION,* ENCYCLOPEDIA BRITANNICA, https://www.britannica.com/event/Industrial-Revolution.
[25] THOMAS SOWELL, CONQUESTS AND CULTURES: AN INTERNATIONAL HISTORY 32, 87 (1998).
[26] *Industrial Revolution: Definition, Inventions & Dates*, HISTORY (Mar. 27, 2023), https://www.history.com/topics/industrial-revolution/industrial-revolution.

poverty onto others but also grew the middle class. One primary difference between the First and Second Industrial Revolutions was the regulation of labor.

Third Industrial Revolution

The Third Industrial Revolution, also known as the Digital Revolution, began in the United States in the 1960s and was based on a new convergence of global communication (the Internet), energy, and the growing use of credit purchases. The Communication Internet is converging with the digitized renewable Energy Internet and the digitized Transportation and Logistics Internet, creating an "Internet of Things" platform for a Third Industrial Revolution.[27] Regulation fell far behind the innovative digital industry, which led to great economic and social negative consequences. What followed were global dotcom and banking financial meltdowns.

Industry 4.0

Industry 4.0 is the fusion of technologies and their interaction across the physical, digital, and biological domains that make the fourth industrial revolution fundamentally different from previous revolutions.[28] Research from the University of Oxford notes that there is a "window during which technologies can be interrogated on questions around societal impact" before such technologies achieve wide practical use.[29] Quantum technology is already here within that window. Now the Fourth Industrial Revolution is upon us, in which the quantum realm not only remains on the list of top emerging technologies but is also considered to be the technology that will quickly usher in the Fifth Industrial Revolution. The disruptive changes brought about by the Fourth Industrial Revolution are redefining how public institutions and organizations operate. These changes compel governments at the national, regional, and local levels to adapt by reinventing themselves and by finding new ways of collaboration with their citizens and the private sector.[30] "The integration of quantum computing, AI, and

[27] Jeremy Rifkin, *Welcome to the Third Industrial Revolution*, WHARTON MAGAZINE. (2015), https://magazine.wharton.upenn.edu/issues/summer-2015/welcome-to-the-third-industrial-revolution/.
[28] Schwab, *supra* note 24 at 7.
[29] Carolyn Ten Holter et al., *Reading the Road: Challenges and Opportunities on the Path to Responsible Innovation in Quantum Computing*, 35 Tech. Analysis & Strategic Mgmt., 844, 845 (2021).
[30] *Id.*

classical computing into hybrid cloud workflows will drive the most significant computing revolution in 60 years. Quantum-powered workflows will radically reshape how enterprises work."[31] Therefore, it is critical that countries worldwide focus to ensure access to information and communication technologies on which much of Industry 4.0 depends upon. Quantum computers can close the four gaps (its existence, access, governance, and usability) and give countries, regions, and cities many additional abilities that can enhance their developments.[32] Currently, we are leaving the Fourth Industrial Revolution, an era "characterized by the seamless integration of the physical, digital, and biological worlds, fueled by artificial intelligence (AI), robotics, and the internet of things (IoT)."[33] As we are entering the Fifth Industrial Revolution, characterized by an unprecedented synergy between human and machine intelligence, quantum computing will become strategically important to solve the challenges of harmonizing human integration with machine learning, such as AI.

China views quantum computing as a primary technological objective, coupled with economic dominance of a nation, as the means required to inevitably lead the world through Industry 4.0. Therefore, China's President, Xi Jinping, likely considers the next decade as pivotal to obtain quantum dominance over the world as the U.S. was at obtaining global nuclear technology dominance.

The global question is: Would the law react to the possible destructive aftermath of quantum technology gone terribly wrong, or will it preempt this technology to allow humanity to justly shepherd in the quantum realm harmoniously to shape a better future for us all? Before we can begin to understand how to govern quantum computing, it is important to first understand the technology itself.

II. HISTORY OF QUANTUM COMPUTING

"We are analog beings living in a digital world, facing a quantum future"
—Neil Turok

Computation has an extensive and complex history interwoven throughout the development of the modern scientific and mathematical

---

[31] IBM, THE *QUANTUM* DECADE 2 (2015), https://www.ibm.com/quantum.
[32] Schwab, *supra* note 24, at 67–68.
[33] John Nosta, *The 5th Industrial Revolution: The Dawn of the Cognitive Age*, PSYCHOLOGY TODAY, (Oct. 6, 2023), https://www.psychologytoday.com/us/blog/the-digital-self/202310/the-5th-industrial-revolution-the-dawn-of-the-cognitive-age.

disciplines. For example, the first computers of the 1940s descended from the invention of the 1890 U.S. Census punch cards and card-sorting machines.[34]

In the 1940s "Albert Einstein, Niels Bohr, Max Planck, Werner Heisenberg, and others led what is known as the 'first quantum revolution' when they created quantum mechanical theory . . . [which then led to] profound consequences. Fission and fusion bombs are quantum [nuclear] weapons. Other quantum devices powered by the first quantum revolution include the atomic clock, lasers, the transistor, and medical imaging technology." [35] In the first quantum revolution, scientists and researchers used quantum mechanics to understand what already existed. They could explain the periodic table, but not design and build atoms. They could explain how metals and semiconductors behaved but were generally unable to manipulate their behavior.[36] "In 1982, theoretical physicist Richard Feynman predicted that it should be possible to develop a new type of computer based on quantum phenomena—what is now termed a quantum computer."[37] In 1985, physicist David Deutsch mapped out how a quantum computer would operate, a blueprint that underpinned the nascent industry of today. In 1994, mathematician Peter Shor wrote "an algorithm that could tap a quantum computer's power to break widely used forms of encryption."[38]

Shor's Algorithm

The most famous use case so far for quantum computers, which has yet to come to fruition, is computing Peter 'Shor's algorithm.' Shor's algorithm would allow the factoring of large integers quickly by quantum computers. "Factoring integers—working out which numbers were multiplied together to give larger resultant numbers—is a function used in 'public-key encryption,' a common form of encryption used throughout the digital economy. The speed-up afforded by quantum

---

34 Hoofnagle & Garfunkel, *supra*, note 7, at 80.
35 *Id.* at 472.
36 Jonathan P. Dowling & Gerard J. Milburn, *Quantum Technology: The Second Quantum Revolution*, 361 PHILOS. TRANS. OF THE ROYAL SOCIETY A: MATHEMATICAL, PHYSICAL AND ENG'G SCIENCES 1809, 1655–1674 (2003).
37 EDWARD PARKER ET AL., AN ASSESSMENT OF THE U.S. AND CHINESE INDUSTRIAL BASES IN QUANTUM TECHNOLOGY, RAND (2022) (citing Richard P. Feynman, *Simulating Physics with Computers*, 21 INT'L J. OF THEORETICAL PHYSICS (1982)).
38 Tom Simonite & Sophia Chen, *The WIRED Guide to Quantum Computing*, WIRED, (Feb. 22, 2023), https://www.wired.com/story/wired-guide-to-quantum-computing/.

computers will effectively allow them to break public-key encryption."[39]

After IBM demonstrated proof of concept for running quantum calculations on a classical system in 2001, a growing industry has made significant progress in scaling up these initial designs in revolution.[40]

To date, the most advanced quantum computing technologies make use of about 100 qubits (the basic unit of information in quantum computing, analogous to the bit in classical computing), which falls significantly short of what is required to run complex calculations such as Shor's algorithm. Quantum computing has yet to be developed into a meaningful existence in the human world, but British astrophysicist Sir Arthur Eddington's "arrow of time" now points humanity towards the quantum realm's eventual arrival.

III. QUANTUM COMPUTING FURTHER EXPLAINED

"If you can't explain it simply, you don't understand it well enough"
—Albert Einstein

Imagine you had several doors which were all locked except for one and you needed to find out which one was open. A traditional computer would keep trying each door, one after the other, until it found the one which was unlocked. It might take five minutes, or it could take a million years, depending on how many doors there were. But a quantum computer could try all the doors at once. This is what makes quantum computing so much faster than classical computers.[41] Quantum computers operate to model that which may seem uncertain or throughout the binary, whereas classical computers operate either one state or the other in the binary.

The fundamental theory of quantum mechanics predicts how the microscopic world affects the macroscopic and astronomical one.[42] Quantum technology is any technology that uses the principles of quantum physics. Quantum computing is computation that exploits the

---

[39] Kaniah Konkoly-Thege & Mark Jackson, *The Legal Implications of Quantum Computing*, ABA, Apr. 22, 2022, https://www.americanbar.org/groups/science_technology/publications/scitech_lawyer/2022/spring/the-legal-implications-quantumcomputing/ (citing EDWARD PARKER ET AL., AN ASSESSMENT OF THE U.S. AND CHINESE INDUSTRIAL BASES IN QUANTUM TECHNOLOGY, RAND (2022)).
[40] Johnson, *supra* note 14, at 493.
[41] Peter Ray Allison, *What is Quantum Computing?*, LIVESCIENCE, Mar. 28, 2024, https://www.livescience.com/quantum-computing.
[42] JENANN ISMAEL, QUANTUM MECHANICS, STAN. ENCYC. OF PHIL. ARCHIVE, (Edward N. Zalta ed., 2020), https://plato.stanford.edu/archives/win2020/entries/qm/.

nature of storing and manipulating quantum information.[43]

Quantum computing is a fundamentally different model of computation than classical computing because quantum computers are inherently probabilistic versus deterministic. "The main distinguishing features of quantum as opposed to classical computation are the availability of (i) superposition states and (ii) entanglement. These two primary quantum phenomena are responsible for the (widely believed) *effective* advantage of quantum computation over classical computation (quantum supremacy)."[44] The most important quantum computing concepts to understand are uncertainty, qubits, entanglement, superposition, and interference.

The Uncertainty Principle

The uncertainty principle is a fundamental concept of quantum mechanics where particles, such as photons or electrons, behave like invisible waves. These particles' position and speed cannot be accurately measured simultaneously.[45] This is where uncertainty lies. "In a regular, classical state that doesn't behave quantum mechanically, the uncertainty in the position and momentum are fixed values. But if we have quantum control of a state, we can bend the rules in our favor."[46] Quantum computers would then be able to lessen the uncertainty of the answer to a problem set. For example, imagine that uncertainty is a round balloon. If you take a round balloon, the curvature will show an equally filled balloon regarding its volume. Imagine squeezing the balloon in the middle and note that the portion that is squeezed has a smaller area than the outside of the balloon. Therefore, the smaller squeezed area has an easier prediction rate of measurement, whereas the larger ends of the balloon have more area and are more uncertain. The volume has not changed, but the shape has. "This is essentially what we do when we squeeze a quantum state. We make the uncertainty in the

---

[43] Jerry Chow et al., *State of Quantum Computing: Building a Quantum Economy,* WORLD ECONOMIC FORUM (2022), https://www.weforum.org/reports/state-of-quantum-computing-building-a-quantum-economy/.

[44] Elija Perrier, *The Quantum Governance Stack: Models of Governance for Quantum Information Technologies*, DIGITAL SOCIETY (2022), https://link.springer.com/article/10.1007/s44206-022-00019-x.

[45] Aalto University, *Evading the Uncertainty Principle in Quantum Physics*, SCIENCEDAILY, May 6, 2021, https://www.sciencedaily.com/releases/2021/05/210506142138.htm.

[46] Katherine McCormick, *Decoherence Is a Problem for Quantum Computing, But…*, SCIENTIFIC AMERICAN BLOG, Mar. 30, 2020, https://blogs.scientificamerican.com/observations/decoherence-is-a-problem-for-quantum-computing-but/.

dimension we care about skinnier, but as a result we suffer a larger [state of] uncertainty in the other dimension, in keeping with the uncertainty principle."[47]

Bits & Qubits

Classical computers (our modern computers) operate using "bits", which is short for *binary digit*. These bits can be placed in one of two positions: either one (1) or zero (0); also described respectively as either on (1) or off (0). Quantum computers use quantum bits (qubits), which can exist in either the on or off state, in both states at the same time, or in neither of the states simultaneously. The more technical and accurate description of a qubit in superposition is a qubit is a bit that has a complex number called an amplitude attached to the possibility that it's 0, and a different amplitude attached to the possibility that it's 1.[48] "Qubits come in different designs. Some take the form of circuits made of superconducting material. Others are devices that control individual atoms, individual charged atoms known as ions, or single photons."[49] "Qubits are the building blocks of matter – electrons, protons, neutrons and photons."[50] They are extremely more powerful nodes of computational power than bits. "Imagine you had 100 perfect qubits," said Dario Gil, the head of IBM's research lab in Yorktown Heights, N.Y., in a recent New York Times interview. "You would need to devote every atom of planet Earth to store bits to describe that state of that quantum computer. By the time you had 280 perfect qubits, you would need every atom in the universe to store all the zeros and ones."

Superposition is when the combination of two distinct physical phenomena of the same type (such as spin or wavelength) coexist as part of the same event.[51] When multiple qubits jointly enter into superposition, they are referred to as being entangled together. In entanglement, two particles are linked together, even if they're physically separate, through a commingled wavelength.[52] "[I]f a quantum computer's qubits are entangled together, then it can mathematically

---

[47] *Id.*
[48] *See* Simonite, *supra* note 39.
[49] *Id.*
[50] Stew Magnuson, *Quantum* 101: *Understanding the '*Spooky', NAT'L DEF. INDUS. ASS'N, Mar. 13, 2019, at 23, https://www.jstor.org/stable/27022508.
[51] *See* WIRED UK, *Quantum computing and quantum supremacy, explained*, *WIRED Explains*, YOUTUBE (Mar. 4, 2020), https://www.youtube.com/watch?v=QF7QfE6qgTM.
[52] *See Id.*

process all of the corresponding bitstrings simultaneously, whereas a classical computer is forced to process each bitstring one at a time."[53] In quantum mechanics, probabilities can be negative. In a quantum algorithm, one can create a quantum superposition between bitstrings by entangling the qubits. By applying the right sequence of quantum operations, one can eliminate bit strings from the superposition that are not the correct solution. What remains at the end is, if things go correctly, the bitstring that corresponds to the solution. This is not parallel computing. Instead, it is a way of computing that uses the power of negative probabilities that quantum mechanics enables.[54] It is these strange properties of superposition and entanglement, the latter of which Einstein famously referred to as *"spooky action at a distance,"* in which two seemingly separate and independent particles operate in unison, despite the distance between them, that give these technologies their unique power.[55]

<u>Insulation of Qubits</u>

This power though, requires carefully insulating qubits from external environmental conditions (noise) that would cause an undesired action on the qubit, which would then result in decoherence, thus creating errors in calculations.[56] Decoherence is when the qubit that is in superposition is disturbed. For example, simply observing the qubit would cause it to collapse it into a single position. "For certain types of qubits, such as superconducting qubits, to work, they must be kept in a 'super-fridge' at extremely cold temperatures of 10 to 20 millikelvins—colder than the vacuum of space."[57] To make quantum computing broadly applicable in solving practical problems, researchers have recognized the need for technical advances to increase the reliability of quantum computers.[58] "One of the most difficult engineering steps in

---

[53] EDWARD PARKER ET AL., AN ASSESSMENT OF THE U.S. AND CHINESE INDUSTRIAL BASES IN QUANTUM TECHNOLOGY, RAND 5 (2022), https://www.rand.org/pubs/research_reports/RRA869-1.html.
[54] Cresswell, Michelle M, and Tim Menke, Co-founder & COO of Atlantic Quantum | Harvard-MIT PhD in Quantum Computing. "Quantum Computing Governance." (Nov. 10, 2023.)
[55] Costello, *supra* note 9, at 2.
[56] *See* Armando Perez-Leija et al., *Endurance of quantum coherence due to particle indistinguishability in noisy quantum networks*, SPRINGER NATURE LTD. (Sep. 27, 2018), https://www.nature.com/articles/s41534-018-0094-y/.
[57] Interview with Dr. Tim Menke (Jan. 27, 2023).
[58] *See* Frank Arute et al., *Quantum supremacy using a programmable superconducting processor*, 574 SPRINGER NATURE LTD. 505 (2019), https://doi.org/10.1038/s41586-019-1666-5.

achieving true quantum computing dominance is with fault tolerance, in which the calculation error rate must be less than 1/10th of a percent."[59]

Finally, "the principle of interference allows a quantum computer to cancel unwanted solutions and enhance correct solutions." [60] "Quantum interference is when subatomic particles interact with and influence themselves and other particles while in a probabilistic superposition state. It can influence the probability of the outcomes when the quantum state is measured."[61]

Quantum computers, once realized, may excel in solving complex mathematical problems such as prime factoring (cybersecurity and cryptography) and package delivery route optimization. Quantum computers are also ideally suited for discovering novel materials, such as next generation batteries and high-performance flat optics, and for developing new lifesaving drugs by simulating their quantum mechanical properties more accurately.[62]

Some experts believe that "we are at least five to ten years away"[63] from operationalizing quantum computing technology, but when this technology is fully functional, "quantum computing is likely to impact three different areas - cryptography, optimization, and simulation."[64] "Due to the influx of quantum computer hardware ideas and the lack of a consensus over which development path will yield the best computer, there is a general push to make framework-agnostic quantum computing software."[65]

IV. GLOBAL QUANTUM COMPUTING BENEFITS AND RISKS

"We cannot solve our problems with the same thinking we used when we created them"

---

[59] IBM CORPORATION, *The Quantum Decade* (2021) https://www.ibm.com/thought-leadership/institute-business-value/en-us/report/quantum-decade.
[60] IBM QUANTUM COMPUTING (2015), https://www.ibm.com/quantum.
[61] Gavin Wright, *Quantum Interference*, TECHTARGET, https://www.techtarget.com/whatis/definition/quantum-interference (underlining removed) (last updated Feb. 2023).
[62] *See* Mauritz Kop, *Establishing a Legal-Ethical Framework for Quantum Technology*, YALE J. L. & TECH. (Mar. 30, 2021), https://yjolt.org/blog/establishing-legal-ethical-framework-quantum-technology.
[63] Cresswell & Geller, *Future of Quantum Governance* (Feb. 2, 2023).
[64] NICKLAS BERILD LUNDBLAD, QUANTUM COMPUTING, THE GLOBAL CHALLENGES FOUNDATION (2021), https://globalchallenges.org//app/uploads/2023/06/Quantum-computing--overview-extract-from-Global-Catastrophic-Risk-report-2021.pdf.
[65] Lindsay Rand et al., *Quantum Computing Technology, in* EMERGING TECHNOLOGIES AND TRADE CONTROLS: A SECTORAL COMPOSITION APPROACH, CENTER FOR INTERNATIONAL & SECURITY STUDIES, U. MARYLAND 52 (2020), http://www.jstor.org/stable/resrep26934.8.

—Albert Einstein

Some of the most pressing global benefits and risks conceived from quantum computing include the following:

Benefits

- ⇒ Discovery of new materials for solar panels to obtain clean energy more efficiently.
- ⇒ Drug development that would normally take a decade coming to fruition in months.
- ⇒ Creation of personalized medicine, matching therapeutics to an individual's genome.
- ⇒ Contribute to developing efficient fertilizers to support the global food supply chain.
- ⇒ It could become a key player in investigating how our universe is stitched together.

Risks

- ⇒ Risks affecting the stability of the economic and financial systems, including blockchain and cryptocurrency protocols.
- ⇒ Risks concerning data privacy, data security, legal certainty, and trust.
- ⇒ Risks pertaining to hacking and misuse of encryption and imaging technologies.
- ⇒ Risks associated with authoritarianism, state surveillance, and control.
- ⇒ Risks of distorted geopolitical relations, quantum arms race, and cyber warfare.
- ⇒ Risks pertaining to human extinction scenarios.[66]

"Quantum computing will not replace classical computing; it will extend and complement it. Quantum computing completes a trinity of technologies: the intersection of classical bits, qubits, and AI 'neurons.' The synergies created by this triad are driving the future of computing."[67]

V. QUANTUM COMPUTING STAKEHOLDERS

[66] *See generally* Mauritz Kop, *Establishing a Legal-Ethical Framework for Quantum Technology*, YALE J. L. & TECH. (Mar. 30, 2021), https://yjolt.org/blog/establishing-legal-ethical-framework-quantum-technology.
[67] IBM QUANTUM COMPUTING, https://www.ibm.com/quantum.

"We are the product of quantum fluctuations in the very early universe"
—Stephen Hawking

Due to the tremendous resource requirements needed to build a quantum computer, proliferation of the hardware itself is of low risk and creating timely control policies on quantum computers and key components could not only be feasible, but also effective.[68] Quantum computing governance stakeholders include a variety of interested parties, such as governments; academics and universities; international organizations (IO); civil society groups; private sector entities that develop and use the technology; individual developers; and consumers of quantum computing. For example, government institutions possess legislative capabilities and set economic, science and technology, and national security policies that shape the future of quantum computing development. Another example are universities, which possess the highest number of practicing quantum researchers, laboratories, and research programs.[69] "Fault-tolerant scalable quantum computers (if achievable) are almost certainly only going to be realised in large-scale infrastructural setups within universities, industry or governments."[70]

Public and private investors have fueled a multibillion-dollar race for the worldwide quantum advantage. Quantum computing is a global endeavor, in which states "must also adapt to the fact that power is also shifting from state to non-state actors, and from established institutions to loose networks."[71] For example, countries with quantum computers, and the companies that maintain them, could offer remote access or a share of access to a quantum computer to clients, as opposed to directly selling a computer to make the enormous cost more economically efficient for these consumer states and private entities.[72]

Governments and a multitude of other stakeholders from one or more industry members, NGOs, academia, think tanks, and public

---

[68] *See generally* NANCY W. GALLAGHER ET AL., *Crafting a path forward: socio-technical dimensions to guide policy decisions, in* THE DESIRABILITY AND FEASIBILITY OF STRATEGIC TRADE CONTROLS ON EMERGING TECHNOLOGIES, (Ctr. for Int'l & Sec. Stud., U. Maryland) (2023), http://www.jstor.org/stable/resrep52041.11.
[69] REBECCA COATES ET AL., QUANTUM COMPUTING GOVERNANCE PRINCIPLES 7 (World Econ. F.) (Jan. 2022), https://www3.weforum.org/docs/WEF_Quantum_Computing_2022.pdf.
[70] Elija Perrier, *The Quantum Governance Stack: Models of Governance for Quantum Information Technologies,* DIGIT. SOC'Y, Oct. 2022, at 7, https://doi.org/10.1007/s44206-022-00019-x.
[71] Klaus, *supra* note 24 at 66.
[72] Gallagher, *supra* note 70 at 76.

institutions can collaborate in generating codes of conduct.[73] Over the past several decades, corporations spanning multiple jurisdictions have increasingly developed codes of conduct for a variety of technological policy issues of concern at the international level. Private sector stakeholders have incentives to develop voluntary codes of conduct, as the initial standards they propose may influence the shape of future public governance.[74] As long as these codes of conduct are met, governments will also continue to be a highly profitable customer for the private sector. Regarding quantum computing, the benefits of higher salaries and profit-making in the private sector will continue to drive quantum innovation. Private sector companies, like Amazon, Google, and IBM, sit on approximately $100 billion, and the industry does not have the level of secrecy to comply (unlike the government), which would traditionally slow innovation. IBM is already working with strategic partners to build national quantum ecosystems, develop workforces, and accelerate research and development on a national and global scale.[75]

Therefore, the government would continue to work with the private sector in the quantum industry in a customer/seller relationship. This relationship with the government is defined as the *public/private sector utopia*.[76]

QED-C

Another key stakeholder, and example of the public/private sector utopia in the development of standards, is the Quantum Economic Development Consortium (QED-C); a "consortium of stakeholders that aims to enable and grow the quantum industry. QED-C was established with support from the National Institute of Standards and Technology (NIST) as part of the [U.S.] Federal strategy for advancing quantum information science and as called for by the National Quantum Initiative

[73] Rhys Jenkins, *Corporate Codes of Conduct: Self-Regulation in a Global Economy*, UNITED NATIONS RSCH. INST. FOR SOC. DEV., (Apr. 1, 2001), at 20, http://www.unrisd.org/80256B3C005BCCF9/(httpAuxPages)/E3B3E78BAB9A886F80256B5E00344278/$file/jenkins.pdf; Webb & Morrison, supra note 109, at 107.
[74] *See generally* VIRGINIA HAUFLER, A PUBLIC ROLE FOR THE PRIVATE SECTOR (Carnegie Endowment for Int'l Peace) (2001), https://www-jstor-org.proxy.library.nd.edu/stable/j.ctt6wpjtw.
[75] *See generally* IBM QUANTUM COMPUTING, https://docs.quantum.ibm.com/responsible-quantum-computing (last visited Sept. 20, 2024).
[76] *See generally* CHRIS JAY CRESSWELL & SIMSON L. GARFUNKEL, *Quantum Technologies and Possible Futures in* LAW AND POLICY FOR THE QUANTUM AGE, 347–361 (Cambridge Univ. Press) (2022), https://www.cambridge.org/core/books/law-and-policy-for-the-quantum-age/quantum-technologies-and-possible-futures/899CC60821F7FBFF5251D8327A37CECF#.

Act enacted in 2018."[77] The QED-C works to accelerate a robust quantum computing supply chain and infrastructure through a consortium of companies and/or organizations to create an output of production that is bigger than the effort of just one company working on the problem set. QED-C also provides the government with a collective industry voice in guiding research and development investment priorities, using cases and quantum workforce topic.

VI. U.S.-China Quantum Race

"The United Nations organization has proclaimed 1979 as the Year of the Child. Are the children to receive the arms race from us as a necessary inheritance?
—Pope John Paul II

States play an important role in supporting nascent technology industries by funding scientific research. An international quantum "space race" has been launched to determine which nations and/or technology corporations will be the first to produce operational quantum computers and communication devices.[78] The global patterns of the strategic competition in the 21st century are more complex, unpredictable, and diverse, reflecting multiple competitions under different or overlapping sets of rules. "At the core of the emerging strategic competition … is whether China will have the requisite capabilities to project power in the Indo-Pacific on par with the United States, and how the United States and its key allies, in unison with other major powers, will respond" to this technological challenge from China.[79] Quantum has become a core technology of China-U.S. competition. The first country to operationalize quantum technologies will possess the capabilities that can overwhelm unprepared adversaries.[80]

[77] The Quantum Economic Development Consortium, https://quantumconsortium.org/ (last visited Sept. 20, 2024).
[78] Gabriel Popkin, *Update: Quantum Physics Gets Attention—And Brighter Funding Prospects—In Congress*, Sci. (June 27, 2018, 12:30 PM), https://www.science.org/content/article/updated-quantum-physics-gets-attention-and-brighter-funding-prospects-congress (quoting the director of the U.S. National Institute of Standards and Technology as saying quantum computing "is the equivalent of a space race now").
[79] Michael Raska, *Strategic Competition for Emerging Military Technologies,* 8 PRISM 65, 66 (2019), https://www.jstor.org/stable/26864277.
[80] Sam Howell, *The China-US Quantum Race*, The Diplomat (Jan. 13, 2023), https://thediplomat.com/2023/01/the-china-us-quantum-race/.

China

In recent years, Beijing embraced an aggressive industrial policy in the form of its Made in China 2025 strategy, which outlines Beijing's ambition to achieve global dominance in ten high-tech industries, including electric vehicles, quantum computing, advanced rail and shipbuilding, and artificial intelligence. "In early 2020, China announced the successful transmission of a message through a quantum satellite at a record-breaking 1,120 kilometers land distance."[81] The government has poured subsidies into the development of these industries to enable globally ambitious, indigenous innovation. The Chinese quantum effort is led by quantum physicist Jian-Wei Pan and managed by a tightly centrally coordinated group of Chinese academic, government and industry partners.[82]

China seeks to move from a traditionally technological follower to a global leader in quantum computing, as well as other digital and disruptive technologies. Beijing's goal is to reduce, if not eliminate, China's reliance on imported technology and to bolster its internal supply chain. China views this innovation as central to economic growth, effective governance, control over citizens, international influence, and military modernization. China is boosting its own innovation, not only through domestic investment, but also through the provisions of market-distorting subsidies, protectionism, and the absorption of foreign corporations. China's measures continue to threaten the competitiveness of countries playing by market rules. Chinese domestic markets are largely closed to foreign digital services because of its cloud computing restrictions, web blocking, data localization requirements, and investment restrictions. These restrictions mean that Chinese firms maintain exclusive access to China's domestic market.[83] "The European Union Chamber of Commerce in China described the plan as a regression to 'top-down decision-making' while the U.S. Chamber of Commerce suggested it was a 'strategy to use state resources to alter and create comparative advantage in these sectors on a global scale'."[84]

---

[81] RAND*, supra* note 67 at 48.

[82] Duncan Earl, *Why the US needs a 'quantum Oppenheimer' to beat China in the quantum race*, QUANTUM (May 8, 2023), https://physicsworld.com/a/why-the-us-needs-a-quantum-oppenheimer-to-beat-china-in-the-quantum-race/.

[83] *See generally* Julianne Smith, et al., *Charting a Transatlantic Course to Address China*, CTR. FOR NEW AM. SEC. (Oct. 20, 2020), https://www.cnas.org/publications/reports/charting-a-transatlantic-course-to-address-china.

[84] INSTITUTE FOR SECURITY AND DEVELOPMENT POLICY, *Made in China 2025* (June 2018), https://isdp.eu/publication/made-china-2025/.

China's Quantum Policy Organizations

The Central Commission on Financial and Economic Affairs (CCFEA), China's highest economic and financial policy-making body, extended its authority to the State Council of the People's Republic on China over the Science and Technology policymaking and related strategic industrial development plans. The Ministry of Science and Technology (MST) and the Ministry of Industry and Information Technology (MIIT) at the State Council are the two major departments that dominate policy specification and implementation.[85]

China's Funding Arm

"China has taken a characteristic state-led approach to funding and conducting [research and development] of quantum technologies."[86] The Chinese quantum computing effort is heavily financially dependent on the National Natural Science Foundation of China (NSFC). The NSFC "is responsible for funding 50 percent of quantum computing publications, 50 percent of quantum communications publications, and 49 percent of quantum sensing publications in China."[87]

China's Leading Group on Scientific Work

China's Leading Group on Scientific Work (LGSW) has three major responsibilities: (1) mapping out strategies, outlines, and major policies in scientific areas; (2) planning major tasks and projects; and (3) coordinating major scientific affairs among different central government departments and local governments. Government agencies such as the MIIT, the Ministry of Human Resources and Social Security, the People's Bank of China, the State-owned Assets Supervision and Administration Commission (SASAC), and the Science and Technology Commission of

---

[85] *See generally* Alex He, *China's Techno-Industrial Development: A Case Study of the Semiconductor Industry Centre for International Governance Innovation*, CTR. FOR INT'L GOVERNANCE INNOVATION, May 3, 2021, https://www.cigionline.org/publications/chinas-techno-industrial-development-case-study-semiconductor-industry/.

[86] Brian Hart, et al., *Is China a Leader in Quantum Technologies?*, CTR. FOR STRATEGIC AND INT'L STUD. (Aug. 14, 2023), https://chinapower.csis.org/china-quantum-technology/.

[87] EDWARD PARKER, ET AL. AN ASSESSMENT OF THE U.S. AND CHINESE INDUSTRIAL BASES IN QUANTUM TECHNOLOGY 81 (Rand) (2022), https://www.rand.org/pubs/research_reports/RRA869-1.html.

the Central Military Commission have been added to the LGSW since 2018.

China's 14th Five-Year Plan (2021-2025)

China's 14th Five-Year Plan (2021-2025) prioritizes the development of quantum computing and communications by 2030 that aids national security and overall development of other industries. China's near-term aspiration was to build "the country's first nondestructive probe electrical measurement platform dedicated to the production of quantum chips in Hefei"[88] by 2022. Acquiring operational quantum computers would provide Chinese national security with impenetrable communications against foreign intelligence agencies. China could also use secure quantum-based communications in its bids for international agreements in space since it would possess a strategic advantage in the industry. This strategic advantage could be leveraged as part of a future U.S.-China agreement in managing competition in space.[89] China's economic drivers include: human capital development, state education spending, Chinese universities' development, and leadership in emerging technologies such as energy, artificial intelligence, and 5G.[90]

China's quantum research and development remains concentrated in government-sponsored laboratories that have demonstrated rapid technical progress with a minority-level private sector showing. "According to McKinsey, the [Chinese Communist Party] has allocated $15.3 billion for quantum that outpaces European and American government funding."[91] It must be understood that China's view of private ownership is different from that of the West. Government officials and their ideology mesh and influence all aspects of business

[88] *China develops NDPT-100 platform to assist production of quantum chips*, GLOBAL TIMES (Dec. 1, 2022), https://www.globaltimes.cn/page/202212/1280887.shtml (last visited Jan. 23, 2023).
[89] *See generally* Tom Stefanick, Commentary, *The State of U.S.-China Quantum Data Security Competition*, BROOKINGS (Sept. 18, 2020), https://www.brookings.edu/techstream/the-state-of-u-s-china-quantum-data-security-competition/.
[90] *See generally* Chinese Communist Party Central Committee, *Outline of the National Innovation-Driven Development Strategy*, XINHUA NEWS AGENCY (May 19, 2016), https://cset.georgetown.edu/publication/outline-of-the-national-innovation-driven-development-strategy/.
[91] Brandon Kirk Williams, *The Innovation Race: US-China Science and Technology Competition and the Quantum Revolution*, WILSON CTR. 398, 405 (2023) https://www.wilsoncenter.org/sites/default/files/media/uploads/documents/Williams_2022-23%20Wilson%20China%20Fellowship_Understanding%20China%20Amid%20Change%20and%20Competition.pdf.

operations. China has recently announced quantum computing capabilities that match or surpass the U.S. state of the art. These announcements have not been peer-reviewed. With that said, China and the U.S. agree over one issue: whichever nation achieves quantum dominance will achieve international dominance in the foreseeable future.

United States

Historically, America converted domestic and foreign challenges into opportunities for innovation and reform. Recently, the U.S. has signaled its intention to not only compete against strategic rivals, but to lead collective action against global threats, thereby shaping rules for technology, cybersecurity, trade, and economics. These four areas are interlinked. "America's continued technological and scientific leadership will depend, at least in part, on the Nation's ability to maintain a competitive advantage in quantum computing and QIS."[92] The United States plans to create a visible, systematic, national approach to quantum information research and development, organized under a single brand and coordinated by the National Science and Technology Council's (NSTC) Subcommittee on Quantum Information Science (SCQIS).[93] The U.S. views quantum technologies as of strategic national importance. Multiple U.S. executive departments, including Defense, State, and Homeland Security, have listed quantum technologies among the top emerging threats to national security.[94] In September 2022, "National Security Adviser Jake Sullivan said quantum would have 'an outsized importance over the coming decade,' adding that export controls could be used to maintain U.S. advantage."[95] Since FY19, the United States has

---

[92] *National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems,* THE WHITE HOUSE (May 4, 2022), https://www.whitehouse.gov/briefing-room/statements-releases/2022/05/04/national-security-memorandum-on-promoting-united-states-leadership-in-quantum-computing-while-mitigating-risks-to-vulnerable-cryptographic-systems/.

[93] *See generally The National Quantum Coordination Office*, NATIONAL QUANTUM INITIATIVE, https://www.quantum.gov/nqco/ (last visited Sept. 20, 2024).

[94] U.S. GOV'T ACCOUNTABILITY OFF., GAO-19-204SP, NATIONAL SECURIT: LONG RANGE EMERGING THREATS FACING THE UNITED STATES AS IDENTIFIED BY FEDERAL AGENCIES(2018).

[95] Charlie Campbell, *Quantum Computers Could Solve Countless Problems—And Create a Lot of New Ones,* TIME (Jan. 26, 2023), https://time.com/6249784/quantum-computing-revolution/.

invested approximately $2.85 billion,[96] and Congress has authorized $10 billion dollars to fund quantum research.[97] The National Institute of Standards and Technology (NIST) has taken the lead in developing standards. NIST established quantum safe encryption methods and headed a subcommittee on quantum research for the last decade.[98] With that said, the whole of the national effort to build operationally relevant quantum computers remain under the umbrella of loose networks versus under a center of government control of strategic development of emerging technologies.

U.S. Policy Organizations and Laws

"Since the [National Quantum Initiative (NQI)] Act was enacted in December 2018,[99] it has been amended by the National Defense Authorization Act (NDAA) for FY2022 (P.L. 117-81) and the CHIPS and Science Act (Division B of P.L. 117-167)."[100]

In addition to these amendments, the American COMPETES Act (Title XV of P.L. 116-260), and the NDAAs for FY2019 (P.L. 115- 232), FY2020 (P.L. 116-92), FY2021 (P.L. 116-283), and FY2023 (P.L. 117-263) contain other provisions pertinent to research and development activities in quantum computing.[101] This section summarizes highlights of those provisions.

In December 2022, the Biden Administration and Congress passed H.R.7535 - Quantum Computing Cybersecurity Preparedness Act.[102] The Act encourages the migration of federal government information technology systems to quantum-resistant cryptography. The

---

[96] NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, NATIONAL QUANTUM INITIATIVE SUPPLEMENT TO THE PRESIDENT'S FY 2023 BUDGET (Jan. 6, 2023), https://www.quantum.gov/wp-content/uploads/2023/01/NQI-Annual-Report-FY2023.pdf.

[97] Stew Magnuson, *Quantum 101: Understanding the 'Spooky,'* 103 NAT'L DEF. 22, 23 (2019), https://www.jstor.org/stable/27022508.

[98] *Our Quantum Future: Some Assembly Required*, QUANTUM WORLD CONG. (2022), https://www.quantumworldcongress.com/whitepaper (last visited Apr. 25, 2023).

[99] LING ZHU, CONG. RSCH. SERV., R47685, QUANTUM COMPUTING: CONCEPTS, CURRENT STATE, AND CONSIDERATIONS FOR CONGRESS 6 (2023) https://crsreports.congress.gov/product/pdf/R/R47685. Division B of P.L. 117-167 has been commonly referred to as the CHIPS and ScienceAct, while it may also be cited as the "Research and Development, Competition, and Innovation Act" (Section 10001 of P.L. 117-167)

[100] *Id.*

[101] LING ZHU, CONG. RSCH. SERV., R47685, QUANTUM COMPUTING: CONCEPTS, CURRENT STATE, AND CONSIDERATIONS FOR CONGRESS 6 (2023), https://crsreports.congress.gov/product/pdf/R/R47685.

[102] Quantum Computing Cybersecurity Preparedness Act, Pub. L, No. 117-260 (2022), https://www.congress.gov/bill/117th-congress/house-bill/7535.

Act states that

> Quantum computers might one day have the ability to push computational boundaries, allowing us to solve problems that have been intractable thus far, such as integer factorization, which is important for encryption…The rapid progress of quantum computing suggests the potential for adversaries of the United States to steal sensitive encrypted data today using classical computers and wait until sufficiently powerful quantum systems are available to decrypt it.[103]

The Quantum Sandbox for Near-Term Applications Act of 2023 (S. 1439/H.R. 2739), would have amended the NQI Act by directing the Department of Commerce (DOC), in coordination with NIST, to establish a public-private partnership focused on quantum computing application development acceleration for quantum, quantum communication, quantum sensing, and quantum-hybrid computing near-term use cases.[104] At this time, though, the bill remains stagnated in the House of Representatives and its success of becoming a law is minuscule due to the overall lack of presented bills passing the highly partisan 118th Congress.[105]

With that said, Congress must contend with a plethora of issues to consider regarding the near and long-term future of QIS. Generally, emerging technologies such as quantum computing pose a challenge to governance efforts of such technologies since their full ramifications are yet to be realized until they become operational. Some of these challenges are to decide if investment of quantum technologies should be led by the public or private sector or if the QED-C can synchronize the public and private sectors to work together in harmony. For example, Congress decided to reauthorize and continue funding current NSF/DOE research and education centers and NIST activities, possibly for a period paralleled to previous sunset date of December 21, 2023, when the authority to carry out the National Quantum Initiative in the NQI Act would have expired.[106] Congress must also decide whether to encourage quantum research and development collaboration and coordination

---

[103] Quantum Computing Cybersecurity Preparedness Act, Pub. L, No. 117-260 § 2 (2022), https://www.congress.gov/bill/117th-congress/house-bill/7535/text.
[104] *See generally* Rep. Jay Obernolte, *To lead in tech innovation, we must expand our quantum program*, THE HILL (July 18, 2023), https://thehill.com/opinion/congress-blog/4102364-to-lead-in-tech-innovation-we-must-expand-our-quantum-program/.
[105] *S. 1439: Quantum Sandbox for Near-Term Applications Act of 2023*, GOVTRACK, https://www.govtrack.us/congress/bills/118/s1439 (last updated May 4, 2023).
[106] *See* 15 U.S.C. § 8815(a).

among federal agencies, national laboratories, academia, industry, and like-minded entities in allied nations, and whether to direct agencies that conduct authorized and funded quantum research and development activities to report their progress to Congress on a regular basis.[107] With that said, will this collaboration be limited to preferred private sector vendors, and/or will all stakeholders involved in quantum computing with the government be required to hold security clearances, such as when the U.S. government led the private sector in the development of the nuclear weapons program known as the Manhattan Project, where contracted private firms and corporations built and managed these communities to house the Manhattan Project workers, which included a mix of military members and civilians?[108] Overall, over 120,000 Americans were employed by the Manhattan Project.[109] One could at least consider establishing a similar programmatic effort to the Manhattan Project to operationalize quantum computing due to the significance of the consequences of this technology around the globe. Realistically, the Manhattan Project will not be repeated in its exact manner to develop operational quantum computers, but, at the very least, physicists, scientists, and academics who are specialists in the topic should be given opportunities to form ethical policies in concert with traditional policymakers through a unity of effort.

Another Congressional quantum issue to decide upon is how to build quantum computers at scale. Industry identified the strategic priority of developing an accessible, sustainable, and secure supply chain and independent manufacturing capabilities that can foster a healthy and stable quantum computing ecosystem through the availability of "key raw materials" and "key manufacturing/assembly equipment," which at this point, due to the lack of these plentiful materials, causes experts to see this issue as a vulnerability within the quantum-related supply chain. Because the demand is low, as this technology is not operationally used widely, the market demand will remain low and therefore, the supply of quantum hardware "goods" will remain low. As of December 2023, "U.S.-allied nations supply various key components in the quantum technology

[107] *See generally* LING ZHU, CONG. RSCH. SERV., R47685, QUANTUM COMPUTING: CONCEPTS, CURRENT STATE, AND CONSIDERATIONS FOR CONGRESS (2023), https://crsreports.congress.gov/product/pdf/R/R47685.
[108] *See generally What is the Manhattan Project?*, NAT'L PARK SERV., https://www.nps.gov/mapr/learn/manhattan-project.htm#:~:text=The%20 Manhattan%20Project%20was%20an,atomic%20weapons%20before%20Nazi%20Ge rmany (last visited Sept. 21, 2024).
[109] *51f. The Manhattan Project*, U.S. HISTORY, https://www.ushistory.org/us/51f.asp (last visited Sept. 21, 2024).

supply chain."[110]

The U.S. Government has also funded academic quantum research through programs such as the "Intelligence Advanced Research Projects Activity" (IARPA). IARPA sponsors high-risk, high-payoff research and development to deliver innovative technologies to the intelligence community and the federal government. Over the last decade, these efforts involved several research programs in quantum computing, with recent and ongoing programs on Quantum Enhanced Optimization (QEO) for quantum annealing,[111] Logical Qubits (LogiQ) for development and demonstration of error-corrected logical qubits,[112] and the newly announced Entangled Logical Qubits (ELQ).[113]

Q-12 Quantum Education Program

The incorporation of Information and Communication Technology (ICT) integration requires a series of pre-conditions (e.g. economic opportunity, political will, availability of suitable equipment, support infrastructures, and professional development among other requirements). [114] Importantly, the quantum workforce should be diverse, inclusive, and reflect the whole of society. It should be a government priority of effort to provide opportunities to all Americans to benefit from participation in quantum computing.[115] In 2020, the U.S. Government launched an initiative to develop a K-12 curriculum relating

[110] Daniel Pereira, *Allied Nations' Quantum Industrial Base and the Reauthorization of the U.S. National Quantum Initiative*, OODA LOOP (Dec. 4, 2023), https://www.oodaloop.com/archive/2023/12/04/the-u-s-and-allied-nations-quantum-industrial-base-and-the-reauthorization-of-national-quantum-initiative-act/.
[111] *Qeo Quantum Enhanced Optimization*, IARPA, https://www.iarpa.gov/research-programs/qeo (last visited Sept. 21, 2024).
[112] *Logiq Logical Qubits*, IARPA, https://www.iarpa.gov/research-programs/logiq (last visited Sept. 21, 2024).
[113] NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, NATIONAL QUANTUM INITIATIVE SUPPLEMENT TO THE PRESIDENT'S FY 2023 BUDGET 28 (Jan. 6, 2023), https://www.quantum.gov/wp-content/uploads/2023/01/NQI-Annual-Report-FY2023.pdf.
[114] Andrew Fluck, *Some national and regional frameworks for integrating information and communication technology into school education* 4 J. EDUC. TECH. & SOC'Y 145, 145 (2001), http://www.jstor.org/stable/jeductechsoci.4.3.145.
[115] *See* Daniel Pereira, *Allied Nations' Quantum Industrial Base and the Reauthorization of the U.S. National Quantum Initiative*, Ooda Loop (Dec. 4, 2023), https://www.oodaloop.com/archive/2023/12/04/the-u-s-and-allied-nations-quantum-industrial-base-and-the-reauthorization-of-national-quantum-initiative-act/.

to quantum computing called Q-12.[116] The National Science and Technology Council Subcommittee on Quantum Information Science recommended four strategic actions: (1) understanding the workforce needs in the QIST ecosystem; (2) introducing broader audiences to QIST through public outreach; (3) enhancing QIST-specific education and training opportunities; and (4) making careers in QIST and related fields more accessible and equitable.[117] The United States National Q-12 Education Partnership program enhances the participatory democracy of quantum computing, in which education widens the aperture of knowledge to the public to increase democratically aligned knowledge societies.

The U.S. federal budget for QIST research and development activities within federal agencies totaled nearly $2 billion between FY2019-FY2021.[118] These expenditures supported research and development activities executed by NIST, NSF, DOE, DOD, the Department of Homeland Security (DHS), and the National Aeronautics and Space Administration (NASA), which reported an enacted budget authority of $918 million for FY2022 for QIST research and development activities, and a requested budget authority of $844 million for FY2023.[119]

Academics and Universities

The principal contribution of quantum computing academia basic research is either of pure scientific interest or at the early stages of applications, with a goal of open publication in scientific literature.[120] "The university sector remains the one with the highest number of practising quantum researchers, laboratories, and research programmes."[121] For example, Cleveland Clinic, the University of Illinois Urbana-Champaign and the Hartree Centre have each entered "'discovery acceleration'" partnerships with IBM, anchored by quantum

---

[116] NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, QUANTUM INFORMATION SCIENCE AND TECHNOLOGY WORKFORCE DEVELOPMENT NATIONAL STRATEGIC PLAN 4 (Feb. 2022), https://www.quantum.gov/wp-content/uploads/2022/02/QIST-Natl-Workforce-Plan.pdf.
[117] *Id.*
[118] NATIONAL SCIENCE AND TECHNOLOGY COUNCIL, NATIONAL QUANTUM INITIATIVE SUPPLEMENT TO THE PRESIDENT'S FY 2023 BUDGET 3 (Jan. 6, 2023), https://www.quantum.gov/wp-content/uploads/2023/01/NQI-Annual-Report-FY2023.pdf.
[119] *Id.*
[120] Parker et al., *supra* note 55, at 2.
[121] Coates, *supra* note 71 at 7.

computing, that have attracted $1 billion in investment.[122] Universities and private sector companies are engaging in extensive international collaboration in quantum technology research and development between the United States and allied nations through multi-national and bilateral agreements. The U.S. government and universities within the nation are also collaborating to train a quantum-literate workforce.

With research and development for quantum technologies occurring in universities,[123] academic institutions themselves have opportunities to build codes of conduct. Codes crafted by universities could also offer an opportunity to include insights from experts in other disciplines, including ethicists, social scientists, and lawyers.[124] At the present time, academics have primarily focused on developing quantum technology, such as quantum computing, but without the governance intersectional frame of mind, quantum technology developers have not given the same attention to how this technology will be governed in society. It is imperative that science and policymaking become intertwined with one another to begin to holistically develop a long-term quantum future for multi-discipline stakeholders. Think tanks involved in the quantum space may participate as another set of civil institutions to contribute to the codes of conduct conversations.[125] Think tanks traditionally shepherd in policy initiatives that fuel new government laws. Therefore, it is imperative that think tanks also take up the mantle of quantum computing policy development that considers social, economic, and security impacts, among others, when quantum computing becomes operational.

Multinational Stakeholders

As with every new technology, particularly one as transformative as quantum computing, new socioeconomic, political, and ethical challenges arise on a global level. As of December 2023, twenty-four nation-states have created some form of national strategy to support the

---

[122] JEAN-FRANÇOIS BOBIER ET AL., WHAT HAPPENS WHEN 'IF' TURNS TO 'WHEN' IN QUANTUM COMPUTING?, BCG 1 (July 21, 2021), https://www.bcg.com/publications/2021/building-quantum-advantage.

[123] *See, e.g.*, *About Institute for Quantum Computing*, INST. FOR QUANTUM COMPUTING, https://uwaterloo.ca/institute-for-quantum-computing/about [https://perma.cc/XF3B-4QHS] (last visited Sep. 21, 2024).

[124] Walter G. Johnson, *Governance Tools for the Second Quantum Revolution*, 59 JURIMETRICS 487 (2019).

[125] *See generally* PROJECT Q: PEACE & SECURITY IN A QUANTUM AGE, https://projectqsydney.com/ [https://perma.cc/H47H-5GYD] (last visited Sept. 15, 2024).

development of quantum technology.[126] Several governments explicitly acknowledge a need to shepherd the implementation of ethical, social, legal, and economic externalities of quantum technologies. For example, the EU has launched several initiatives, including the Quantum Flagship, a ten-year EUR1 billion research and innovation program, and is in the midst of developing the European Quantum Communication Infrastructure (EuroQCI) with the goal of building a secure quantum communication infrastructure spanning across all EU Member States.[127] The University of New South Wales in Australia offered the world's first bachelor's degree in quantum engineering.[128] Multilateral governance "comprises numerous state and non-state actors located at different levels, such as the local (sub-national), the national and the global (supranational)."[129] The transnational nature of quantum research programs and quantum technological development means that multilateral institutions, both public and private, have an important role to play in encouraging consistent approaches to quantum governance globally. For example, in April 2022, the United States, the United Kingdom, and Australia signed the AUKUS agreement to develop military applications from digital technologies, especially quantum computing technologies.[130] The U.S. and Europe should jointly develop norms and standards on strategic technologies, such as embarking on joint pilot projects in quantum computing, to bake democratic values into the technology.[131] Overall, it continues to become apparent that "[n]o single nation can be expected to sustain all the elements necessary for a thriving quantum economy, and so progress will rely on international collaboration and the creation of international trade

---

[126] KELLY RICHDALE ET AL., QUANTUM ECONOMY BLUEPRINT: INSIGHT REPORT, WORLD ECON. F. 3 (Jan. 2024), https://www3.weforum.org/docs/WEF_Quantum_Economy_Blueprint_2024.pdf.

[127] Bijal Vakil, *The Opportunities and Legal Risks of Quantum Computing*, A&O SHERMAN (May 12, 2023), https://www.allenovery.com/en-gb/global/news-and-insights/publications/the-opportunities-and-legal-risks-of-quantum-computing.

[128] Tom Simonite & Sophia Chen, *The Wired Guide to Quantum Computing*, WIRED (Feb. 22, 2023, 10:00 AM), htps://www.wired.com/story/wired-guide-to-quantum-computing/.

[129] MOEKO SAITO-JENSEN, THEORIES AND METHODS FOR THE STUDY OF MULTILEVEL ENVIRONMENTAL GOVERNANCE 2 (2015).

[130] François Candelon et al., *The U.S., China, and Europe are Ramping Up a Quantum Computing Arms Race. Here's What They'll Need to Win*, FORTUNE (Sept. 22, 2022, 5:30 AM), https://fortune.com/2022/09/02/quantum-computing-cryptography-companies-arms-race/.

[131] Julianne Smith et al., *Charting a Transatlantic Course to Address China Charting a Transatlantic Course to Address China*, CTR. FOR NEW AM. SEC. (Oct. 20, 2020), https://www.cnas.org/publications/reports/charting-a-transatlantic-course-to-address-china.

agreements specifically designed to facilitate the necessary flow of value across borders."[132] Multinational and bilateral agreements must be intentionally formed to work the quantum computing global race.

Corporations

The list of U.S. companies investing in quantum research is extensive. Spending on quantum computers should reach hundreds of millions of dollars in the 2020s and tens of billions in the 2030s.[133] Private and public corporations have traditionally played an important role in the development and commercialization of emergent technologies. "Once a technology reaches sufficiently matured in which a commercial market appears imminent, late-stage development and deployment (i.e., scaling and commercialization) usually shifts from academia to the private sector industry, such as through licensing opportunities. At this point, many of the later-stage technical developments are protected via intellectual laws such as trade secrets or by patenting [the technology]."[134] It is the private sector industry that will determine whether quantum technology proves practically transformative or remains a primarily scientific pursuit. The U.S. relies on its "Big Tech" companies, operating at the vanguard of quantum sciences. Leading the charge are Google, IBM, NVIDIA, and Microsoft, which have made significant efforts to develop this technology.[135] There are several hundred pure-quantum startups developing their own products. Over 40,000 quantum-related patents were filed in just the past five years.[136] A February 2022 RAND Corporation report found that private industry is driving quantum technology deployment within the United States. There are at least 182 companies, from ten-person startups to large technology companies, with a variety of technical approaches and applications.[137] In 2021, IonQ became the first publicly traded pure-play quantum computing company, at an estimated initial valuation of $2 billion. The quantum computing industry could create

[132] Richdate et. al., *supra* note 128, at 7

[133] DUNCAN STUART, TECHNOLOGY, MEDIA, AND TELECOMMUNICATIONS PREDICTIONS 2019, Deloitte Insights 1, 97 (Dec. 11, 2018), https://www2.deloitte.com/content/dam/insights/us/articles/TMT-Predictions_2019/DI_TMT-predictions_2019.pdf

[134] Parker et. al.., *supra* note 55, at 3.

[135] Who are the Main Players in the World of Quantum Computing? INRIA (2021), https://www.inria.fr/en/quantum-computing-main-players.

[136] Mathew Alex, Quantum Technologies: A Review of the Patent Landscape, ARXIV (Feb. 3, 2021) https://arxiv.org/abs/2102.04552.

[137] Parker et. al.., *supra* note 136, at vi.

value of $450 billion to $850 billion in the next 15 to 30 years.[138] In 2019, "ExxonMobil signed a partnership agreement with IBM to advance the potential use of quantum computing in developing next-generation energy and manufacturing technologies. As part of the agreement, ExxonMobil becomes the first energy company to join the IBM Q Network, a worldwide community of Fortune 500 companies, startups, academic institutions and national research labs working to advance quantum computing and explore practical applications for science and business".[139]

Developers and Consumers

"The emerging quantum economy will be underpinned by entire value chain connecting producers to consumers in ways that go well beyond traditional quantum fields." [140] Developers will be vital in harnessing the potential transformative capabilities of quantum computing. "Individuals will likely have many touchpoints with quantum computing through direct interaction or indirectly through a third party."[141] The key to creating good governance within the developers' network is to "shape a healthy quantum computing ecosystem, enabling access to education and technology in order to build the required developer workforce." [142] It would be more than a shame to allow quantum computing efforts to parallel previous AI development due to AI's biased nature through its development.

Quantum computing is still in its infancy stage, and there is time to develop governance models, such as "anticipatory governance," to regulate this technology. '"Quantum's 'known unknowns' include potential ethical considerations from abuse, misuse, or unintended consequences." The challenge is [to] design guardrails for a technology

---

[138] Jean-François Bobier et al., WHAT HAPPENS WHEN IF TURNS TO WHEN IN QUANTUM COMPUTING F? BCG GLOBAL L. (July 2022), https://www.bcg.com/publications/2021/building-quantum-advantage.

[139] EXONNMOBILE, https://corporate.exxonmobil.com/news/news-releases/2019/0108_exxonmobil-and-ibm-to-advance-energy-sector-application-of-quantum-computing (last visited Jan. 6, 2025).

[140] Kelly Richdale et al., *Quantum Economy Blueprint*, World Economic Forum 1, 7 (Jan. 2024), https://www3.weforum.org/docs/WEF_Quantum_Economy_Blueprint_2024.pdf.

[141] Coates et al., *supra* note 71, at 8.

[142] *Id.*

that currently has undefined powers and applications.[143] "Any approach to quantum governance must factor in the primary objective of developing QIS itself. The development of technology should not be considered separate or parallel to governance. Rather, it should be considered as a primary objective itself to be compared with other fundamental normative objectives, such as maximizing social welfare."[144]

Quantum computing should not require a catastrophic worldwide event to become governed responsibly by the world. If a catastrophic event were to happen, the power of quantum computing, misused, could decimate world financial systems, cripple military and civil communications, or create an asymmetric advantage that could entice the state without this capability to preemptively attack the actor with the quantum technology. A quantum cold war threat could cause a freeze of the development of quantum for a lack of progress and concern for humanity's inability to harness such an invention would thwart the world's progress when the world needs responsible invention to save the Earth from antiquated technologies currently harming the globe. All these scenarios would harm the globalized world, possibly creating a permanence of chaos. Therefore, quantum computing stakeholders must be prepared to be governed (regulated) before this technology is operationalized.

VII. GOVERNING QUANTUM COMPUTING APPROACHES

"The disruptive potential of quantum technology will make the change of the Internet era look like a small bump in the road!"
—Kevin Coleman

How can one regulate that which has yet to exist? Is quantum governance *sui generis*, requiring its own specific governance regimes, or can it piggyback off current international and domestic laws (e.g., intellectual property, cyber, environmental, space laws)? Quantum computing development brings with it, ethical questions regarding the externalities from this technology, such as how the quantum divide will be managed, where some will have access to quantum computers and others will not. Will quantum computing give those with access to this technology a leg up in the financial and medical sectors over those

---

[143] Scott Buchholz & Beena Ammanath, *Quantum Computing Ma Create Ethical Risks For Businesses. It's Time to Prepare, Deloitte Insights* (May 12, 2022), https://www2.deloitte.com/us/en/insights/topics/cyber-risk/quantum-computing-ethics-risks.html.

[144] Perrier, *supra* note 45, at 9.

without? How does the quantum advantage enhance or degrade the security of the state and/or private entities? These are some of the questions that need to be examined as quantum computing technology continues to march forward faster than Moore's Law through the 21st century. Quantum computing governance could initially fall under the umbrella of current transnational regulations, but eventually specific quantum laws must be developed, independent of other technological fields, to reach the full expanse of quantum justice outside of existing legal parameters within the multiple industries affected by this technology leap. Therefore, for governance to be relevant to this technological field, this paper will make a few assumptions regarding the near-term future of quantum computing:

a. "It will be possible to build a fully programmable universal fault-tolerant quantum computer within the next decade.
b. Quantum computing will make computation of certain specific problems more efficient and/or precise.
c. Quantum computing will accelerate computation towards solving problems currently deemed intractable with classical machines (e.g., breaking of currently deployed public-key encryption schemes)."[145]
d. Quantum computing will create a government/private sector synergy to develop this technology, but it will also create an East/West global divide, primarily between China and the U.S. and EU.

The World Economic Forum's <u>Quantum Computing Governance Principles Insight Report January 2022</u> offered the following principles to govern the future of quantum computing: transformative capabilities, access to hardware infrastructure, open innovation, creating awareness, workforce development and capability building, cybersecurity, privacy, standardization, and sustainability.[146] This paper builds upon such contributions by "providing an outline of an (idealized) actor and instrument model of quantum governance."[147] Unfortunately, even though the more abstract the principle, the greater the consensus of legal systems, it also manifests into less useful rules.[148]

The <u>World Economic Forum Principles</u> for quantum computing is

---

[145] Coates et al., *supra* note 71, at 6.
[146] *Id.* at 2.
[147] Perrier, *supra* note 45, at 2.
[148] Keitner Chimène I. (2016, February 24). International Law Frameworks 4th Edition.

a useful starting point towards quantifying these principles into an operational archetype or set of international and/or domestic laws.[149] Merely identifying a need for standardization does not provide a quantifiable suggestive roadmap on how to reach an ideal legalization of quantum information science industry standards among multiple stakeholders. However, it should be noted that it is almost an impossible feat to design a new system of laws for a technology that has yet to become fully mature. Designing new laws for an emerging technology could be viewed as iterative. Therefore, building upon existing transnational international and domestic laws could provide quantum computing legalization with valid touchpoints, principles, and core values. The World Economic Forum also recognized the potentially transformative impact of quantum computing, identifying three types of problems that quantum computing will help to solve. They are the simulation and modeling of quantum systems and processes occurring in nature, the search for the ideal or "optimal" solution to a given problem with multiple existing answers, and algebraic problems such as factorization.[150]

More communities and individuals are turning to more deliberative and collaborative processes—such as community dialogues, assemblies, stakeholder negotiation processes, and other inclusive public participation efforts to address their most pressing problems. Therefore, deliberative democracy is an approach to politics in which interested parties, not just technocrats or politicians, can be involved in public decision making and problem-solving in advanced technology social development, such as quantum computing.

Individuals involved with the "deliberative democracy" movement are a result of many stakeholders from many directions. Some are academics seeking to create stronger connections to their intellectual community. Some work with other governmental institutions to find more effective methods of solving problems and working more productively with their citizens. Some are community organizers that have gravitated to more collaborative, nonpartisan processes for engaging communities in problem solving. [151]

---

[149] Keitner, C. I., & Bederman, D. J. (2016). Chapter 4: General Principles and Other Sources. In *International Law Frameworks* (pp. 47–47)

[150] Tim Wright, Quantum Computing and the Law, IOTWORLDTODAY (Feb. 15, 2023), https://www.iotworldtoday.com/industry/quantum-computing-and-the-law.

[151] Martin Carcasson & Leah Sprain, *Key Aspects of the Deliberative Democracy Movement*, PUBLIC SECTOR DIGEST (2010), https://www.libarts.colostate.edu/cpd/wpcontent/uploads/sites/4/2014/01/carcasson-key-aspects-of-deliberative-democracy.pdf.

Quantum information technology (QIT) governance is likely to be complex and multifaceted. Its technological breadth will span across multiple industries (e.g., material science, finance, machine learning, natural language processing, cybersecurity, and task optimization), thereby affecting a diverse range of government, corporate, individual, as well as supranational stakeholders' operations and capabilities. Therefore, deliberate democracy methods should provide a framework for developing future domestic and international quantum computing policies. It cannot mirror how domestic and international nuclear law was developed because the key stakeholders do not live within the realm of the reach of government control, such as when nuclear technology was developed through the Manhattan Project under a single whole of government and private sector effort. Unlike nuclear development, in which the activities were centralized by the U.S. government, quantum computing's fate rest in the hands of several government entities and private sector actors, at times working independent from one another.

Deliberative democracy is where stakeholders, such as a nation's citizens and its representatives and industry experts, discuss the political decisions regarding the issue at hand. It can include reasonable arguments by those involved in the free and fair process of decision making, ultimately finding solutions for such pollical topics. Well established deliberative procedures in modern democratic nations are suited to addressing governance issues in QIT due to the interdisciplinary effects on industries because of this emerging technology.[152] In most circumstances, deliberation includes relatively small, well-informed participants considering different perspectives to arrive at a consensus on what can be strongly agreed upon. Unless a civic lottery or some other unbiased method for choosing public participation in such a deliberation is used, this method of democracy would favor the smaller number of elite technocrats over the population of lay persons, in which the indirect stakeholders would be affected by this technology without a 'vote' in how they would be impacted. Therefore, the education of the lay person to become quantum aware is pivotal to create a more equitable decision-making process for humankind by creating a wider aperture of participants in deliberate democratic processes.

Educative deliberation by a more inclusive stake holding population is central to how other institutions and stakeholders, such as the private sector, multilateral, or civil society groups respond to QIT. The more educated the population becomes, the more responsible the

---

[152] John S. Dryzek, FOUNDATION AND FRONTIERS OF DELIBERATIVE GOVERNANCE 3 (2010).

creators of the future quantum realm will have to be due to the expectations levied upon them by the people. This includes the practice of informing governmental stakeholders about QIT issues via experts, industry lobbying, and/or community activism in a way that reaches those from diverse backgrounds and locations.[153] This is extremely important in any effort to reach all corners of the education and workforce ecosystems if there is an appetite for inclusivity. Unfortunately, these fields have among the lowest participation rates for people from backgrounds historically underrepresented in STEM, including Hispanics or Latinos, Blacks or African Americans, American Indians or Alaska Natives, persons with disabilities, and women from all backgrounds.[154]

Therefore, a socio-political movement should be created to provide a grassroots initiated advocacy for quantum aware inclusivity within the nation. The above examples are just a few representations of a *movement* affecting formal governance. From this, governing bodies, held to a higher responsibility by the people that they serve at the local level, can form recommendations and regulatory answers that correctly responds to the short and long term needs of its citizens, ranging from policy adjustments to legislative proposals.[155]

"Today's political, legislative, and regulatory authorities are often overtaken by events, unable to cope with the speed of technological change and the significance of its implication."[156] "Governance can be *responsive* (typically legislation or regulation after harm has been caused or a need is perceived) or *pre-emptive* (utilizing anticipatory techniques, and aspects of responsibility such as care and responsiveness)."[157] Responsive legal instrumentalities, often described as 'hard' governance (e.g., treaty making, regulation design, and legislation implementation), are often not initiated until industry harms have already ensued because of the difficulty of creating laws for theoretical advances in technology. Prospective, forward-looking law, such as 'soft' forms of governance include responsible innovation and other approaches (e.g., Real Time Technology Assessment and Participatory Design) to improve societal

[153] Perrier, *supra* note 45, at 15.
[154] Karen Hamrick, *Women, Minorities, And Persons With Disabilities In Science And Engineering* NATIONAL CENTER FOR SCIENCE AND ENGINEERING STATISTICS 1, 6 (2021), https://womenengineers.gwu.edu/sites/g/files/zaxdzs5566/files/downloads/nsf21321-report.pdf
[155] Perrier, *supra* note 45, at 16.
[156] Schwab, *supra* note 24, at 68.
[157] Ten Holter et al., *supra* note 18, at 4.

outcomes and prevent harms from happening.[158]

Concepts of regulation began with a binary approach of either a complete free market approach, (*anarchy form of legalization*) or heavy-handed *hard law* through "command and control" tactics administered by a central governing body.[159] To escape this binary, scholars characterized alternative approaches to governance in the late twentieth century, creating more of a linear spectrum of governance, dependent on the organizational and regulatory needs to enforce normative obligatory behavior.[160] What came about was some blend of classic regulation and emerging trends in industry self-regulation and civilian-centered oversight, which offered more practical and responsive approaches to regulation.[161]

An international convention (treaty) would be the most relevant hard law international legal tool to manage and regulate quantum computing. Even though international law could pull from the general principles law recognized by civilized nations, the concerning issue would be that not enough nations have experience operating quantum computer systems before global governance would be properly incorporated into the hard law realm. The difference between quantum computing and other international issues that require governance, such as the nuclear non-proliferation treaty, maritime law, and international communications treaties, is that whoever achieves quantum computing superiority at the operational level will reach technological superiority in several other affected industries and lay the groundwork for how other non-quantum stakeholders will react. Therefore, a quantum computing non-proliferation treaty may become an effective international legal tool to address quantum computing after the technology is settled, but in preparation for this emerging technology to become operationalized, soft law continues to remain at the forefront of developing behavioral and legal norms of the industry.

"Agile" governance means that coordinating effective, efficient, and reliable public and private institutions effectively manage problems through a forward-looking approach that seeks to anticipate problems

[158]*Id.* at 9.
[159] MARTIN LODGE ET. AL., THE OXFORD HANDBOOK OF CLASSICS IN PUBLIC POLICY AND ADMINISTRATION 561-62 (2015).
[160] ROBERT BALDWIN, THE HUMAN FACE OF THE LAW 65, 66–68 (Keith Hawkins ed., 1997).
[161] Darren Sinclair, *Self-Regulation Versus Command and Control? Beyond False Dichotomies*, L. & POL'Y 529, 532–33 (1997).

before they materialize.[162] Agile governance is where that regulators must find ways to adapt continuously to a new, fast-changing environment by reinventing themselves to understand better what they are regulating. Governments and regulatory agencies must closely collaborate with business and civil society to shape the necessary global, regional, and industrial transformations.[163] As previously discussed, the end users, such as the individual citizen who is quantum aware, must be included in this collaboration through representatives who understand how quantum can cause both positive and negative externalities, to ensure that their constituents are not harmed or left behind by this technological feat.

Quantum computing governance includes good science and diverse stakeholders to ensure that societal interests are equitable and diversity of thought is welcomed.[164] It is noteworthy to mention, China President Xi's "tight command-and-control model gives responsible bureaucrats more incentive to try a campaign-style and short-cut approach for short-term ornamental technological progress instead of real market-oriented innovation."[165] Whereas the U.S. civil society stakeholders, such as corporations, work towards long-term scientific solutions to generate quantum computing technologies.

Though softer regulatory approaches lack the binding force of law, pressures from liability and insurance stakeholders may promote participation in and compliance with such nontraditional regulatory programs, such as in quantum computing and other novel technological leaps forward.[166] As quantum computing becomes operational, more private sector organizations will need to develop methods to limit liability and keep insurance policy premiums down regarding their quantum computing products. Therefore, it is important for the private sector to create compliance schemes that are not purely reliant on state constructed regulations, but instead on private insurance entities that in turn, answer to the ultimate stakeholder, the citizen that may pay the insurance premiums in other similar industries to offset the cost of insuring quantum computing. "Governance approaches blending public

[162] Hertie School, Strategic Intelligence, WORLD ECON. F. (2024), https://intelligence.weforum.org/topics/a1Gb0000000pTDaEAM.
[163] Schwab, *supra* note 24, at 68.
[164] Cresswell, M. M., & Menke, D. T. (Feb 2, 2023). FUTURE OF QUANTUM COMPUTING GOVERNANCE. personal.
[165] Alex Hi, *China's Techno-Industrial Development*, CTR. FOR INT'L GOVERNANCE INNOVATION 5, 7 (2021).
[166] Gary E. Marchant, *'Soft Law' Mechanisms for Nanotechnology: Liability and Insurance Drivers*, 17 J. RISK RES. 709, 709–10 (2014).

and private roles and responsibilities in enforced self-regulation or meta-regulatory capacities can offer intermediate solutions that facilitate cooperation where command and control oversight might create conflict between public actors and industry."[167] "Soft law approaches provide key benefits in their adaptability and capacity to respond swiftly to new information about the regulated products or associated risks."[168] Hard law governance can typically only apply within the borders of the state(s) authorizing that oversight.[169]

With respect to how to frame the future governance of quantum computing, there is room for international alliances to form and expand to address this emerging technology. A nimble and inclusive technology alliance framework would include the capacity to work with other countries. There are numerous countries that, while lacking broad-based technology capabilities and economic heft, or not being fully aligned on all technology alliance goals, have significant expertise that is well suited to broader technology policy objectives. A technology alliance could "require consensus among [its] core members for any specific course of action to avoid a [deterioration] to fractious, ad hoc decision-making on [quantum technology] policy matters" that would exclude minority quantum computing stakeholders."[170] "This approach will be essential to ensuring the technology alliance concept is viable…Decisions that entail regulatory alignment most likely would require unanimity.[171] Therefore, this approach would address the challenge of creating a landscape of full participation by interested stakeholders, despite their ability or inability to develop and build indigenous quantum computers. Participatory democratic decision making includes large numbers of participants (both direct and indirect stakeholders) and encourages working through a diversity of opportunities to engage in the topic.

"Quantum technologies arise from an atypical industry in which development pressures and funding arise in large part from national security applications, yet various commercial and civilian uses will follow

---

[167] Marius Aalders & Ton Wilthagen, *Moving Beyond Command-and-Control: Reflexivity in the Regulation of Occupational Safety and Health and the Environment*, 19 L. & POL'Y 415, 426–27 (1997).
[168] Neil Gunningham & Joseph Rees, *Industry Self-Regulation: An Institutional Perspective*, 19 L. & POL'Y 363, 366 (1997).
[169] Fabrizio Cafaggi et al., *Transnational Private Regulation and Water Management*, 3 INT'L REGUL. COOP.: CASE STUD. 1, 11 (2013).
[170] MARTJIN RASSER ET. AT., *Common Code An Alliance Framework for Democratic Technology Policy A Technology Alliance Project Report*, CTR. FOR A NEW AM. SEC. 1, 18 (2020), https://s3.us-east-1.amazonaws.com/files.cnas.org/backgrounds/documents/Common-Code-An-Alliance-Framework-for-Democratic-Technology-Policy-1.pdf.
[171] *Id.*

closely behind."[172] The quantum computing field will develop informal customary legal standards that comply with industry norms. This form of soft law can harden to become domestic statutes and international convention law. "To date, limited efforts globally to implement regulatory standards in the quantum industry have occurred, with policymakers instead calling to accelerate innovation."[173] Why is the development of industry legal norms through customary law so important in the expansion of quantum computing governance? Customary international law "allows international legal actors to develop rules of behavior informally, without the need to resort to more formal [and difficult] means of lawmaking" (such as treaties).[174]

However, one concern with relying upon international customary law to develop hard laws for quantum computing is the inequitable participation of states in the future of quantum computing. Therefore, the network architecture of stakeholders becomes just as imperative as the number of direct and indirect stakeholders involved in quantum computer development funding and norms to enable a more fulsome participatory system of actors, increasing democratic value in this technological field. "[D]emocratic…decision making concerning where funding is allocated can permit a form of public democratic engagement of what spheres of innovation should receive attention."[175]

Direct stakeholders create, manage, develop, and work with the technology, and indirect stakeholders are affected by it. Participatory democratization is imperative to create ethical norms that benefit the greatest number of both direct and indirect stakeholders. For quantum computing to be ethical, it should be fair. The first challenge to this declaration is that the idea of "fair" means different things to different stakeholders. Fairness could focus on the involvement of parties in the quantum construct process and on the other hand, fairness could focus on the outcomes of the technology that are equitable throughout humanity. For example, some experts consider AI unethical because of the biased outcomes derived from unfair algorithms. In this instance, the process and outcome of AI could be labeled as unfair because it leads to

---

[172] Johnson, *supra* note 14, at 507.
[173] *Id.*
[174] Chimene I. Keitner, INTERNATIONAL LAW FRAMEWORKS 32 (5th ed. 2021).
[175] Zeki C. Seskir et al., *Democratization of Quantum Technologies*, 8 QUANTUM SCI. AND TECH. 1, 4 (2023).

real people being harmed.[176]

Other than fairness, access to this technology is ethically important to create a stronger and more inclusive outcome benefits and solutions that quantum computing would tackle. Access provides the technology with the strength of diversity of stakeholders, from the founding members of the quantum realm to the lay person who becomes "quantum aware", creating a more fulsome solutions-based technology that is relevant to the world.

Governing emerging technologies presents unique challenges in the uncertainty over the risks they pose and must therefore simultaneously protect the public while promoting research.[177] Governing such technologies is also difficult to accomplish because the relatively small number of experts in the field counters the natural democratization of the field. Governance for these nascent technologies generally operates in the shadow of a "pacing problem" or "legal lag," where the innovation process outruns regulatory responses and ethical considerations.[178] "While these approaches will lack legal enforceability in the early phases, both corporate and government research entities could suffer public blowback upon reports of mishandling quantum devices, with potential economic, liability, or political consequences."[179] The quantum computing geopolitics story weaves together a threat narrative that supports exclusionary mechanisms to stifle participatory democracy regarding this technology, while overemphasizing the need for security-oriented stakeholders' participation in the development of quantum computing industry norms.

Industrial policy is the cornerstone of creating state-driven novel governance, which in turn may lead to technological supremacy. "[I]ndustrial policy is generally defined as actions by a country's leadership to develop, grow, or reorient parts or all of its economy to

---

[176] WILLIAM APPLEGATE ET. AL., POTOMAC QUANTUM INNOVATION CTR., *Our Quantum Future: Some Assembly Required* 20 (2022), https://static1.squarespace.com/static/631b582046e1a77ed0202794/t/6390d0b6a4afea3612ab562f/1670435006881/Our+Quantum+Future+Some+Assembly+Required-2.pdf.

[177] Gregory N. Mandel, *Regulating Emerging Technologies*, 1 L., L. INNOVATION AND TECH . 75, 80 (2009).

[178]Gary E. Marchant, *The Growing Gap Between Emerging Technologies and the Law*, *in* 7 THE INT'L LIBR. OF ETHICS, L. AND TECH., THE GROWING GAP BETWEEN EMERGING TECHNOLOGIES AND LEGAL-ETHICAL OVERSIGHT: THE PACING PROBLEM 19, 22-28 (Gary E. Marchant et al. eds., 2011).

[179] Johnson, *supra* note 14, at 509.

achieve a specific objective."[180]

Even though industrial policy was once a barrier to effective globalization pursuits, industrial policy is making a comeback. With more countries enacting measures to support certain industries and establish new ones, the revival of industrial policy was a major topic at last year's meeting of the World Economic Forum in Davos."[181] Industrial policy also refers to government efforts to support industries that are considered strategically important. "A smart industrial policy should focus on high-value industries that compete internationally, have civilian and military applications, and are difficult to revive once lost", says Robert D. Atkinson of the Information Technology and Innovation Foundation.[182]

Industrial policy supporters advocate that a new U.S. industrial policy is essential to respond to China's state-led development, secure a supply of critical materials and products, and develop technologies that could preserve the planet without a reliance on imports. Critics view such a policy as inevitably distorting the free market and rewarding companies not for the quality of their products and services, but for their skill at lobbying lawmakers. Policy measures could be protective tariffs or other trade restrictions, direct subsidies or tax credits, public spending on research and development (research and development), or government procurement (goods and services, such as military equipment, that the government buys).

Having a small number of distinct research institutions reduces the risk of research duplication and siloing, but having many institutions encourages a variety of research approaches and priorities and decreases the risk of a single key institution reducing its research activities.[183] Similarly, [n]ational government [research and development] investment can be concentrated in a single agency or distributed across multiple agencies….[E]ach approach has its advantages and disadvantages. A centralized approach reduces the risk of duplication

[180] MARTJIN RASSER & MEGAN LAMBERTH, *Taking The Helm: A National Technology Strategy To Meet the China Challenge*, CTR. FOR A NEW AM. SEC. 1, 18 (2021), https://s3.us-east-1.amazonaws.com/files.cnas.org/backgrounds/documents/Taking-the-Helm_FINAL-compressed.pdf.

[181]Ricardo Hausmann, *Why Industrial Policy Is Back*, PROJECT SYNDICATE (Jan. 6, 2023), https://www.project-syndicate.org/commentary/why-economists-have-rediscovered-industrial-policy-by-ricardo-hausmann-2023-01.

[182] Anshu Siripurapu & Noah Berman, *Is Industrial Policy Making a Comeback?*, COUNCIL ON FOREIGN RELATIONS (last updated on Sep. 18, 2023, 9:45 AM), https://www.cfr.org/backgrounder/industrial-policy-making-comeback.

[183] Parker et. al., *supra* note 55, at 19.

and can allow for focused and long-term development of specific technologies. But a decentralized approach increases technology diversification, provides stability against a sudden decrease in investment based on agency-specific contingencies…and increases the range of government priorities being considered.[184]

Civil society groups are important stakeholders in most societies, including organizations, such as trade unions, political parties, and charities which tend to have a social objective nexus, such as securing conceptions of justice and advocating for the overall welfare of society.[185] Civil society groups have historically played an important role in how technology is governed within societies.[186] Civil society group objectives are defined by the constituencies they represent and ideologies they advocate.[187]

Since quantum computing governance is a global topic, it will have both social and economic consequences. Multilevel governance is one way to embark on developing quantum computing law. The term multilevel governance (MLG) was developed by the political scientist Gary Marks (1993). The concept aimed to capture and understand political processes related to the emergence of supranational institutions such as the European Union and to facilitate analysis of decentralized decision-making processes, in which sub-national level governments and civil society have increasing influence.[188] I suggest that an applicable overarching social/economic paradigm to describe MLG, pertaining to the development of quantum computing law, can be demonstrated through "the movement triangle."

Movement: Movements address areas of society (e.g., demands for justice, polarizing narrative pronouncements, geopolitical competition, technological interdependence) in which formal law fields have yet to take shape. Movements "are purposeful, organized [mission-oriented] groups…striv[ing] to work toward a common [overarching]…goal."[189] "Social movements enhance public participation in scientific and technical decision-making, encourage inclusion of public perspectives even in specialized fields, and contribute to changes in the policy-making process that favor greater participation from

---

[184] *Id.* at 22.
[185] Perrier, *supra* note 45, at 36-37.
[186] *Id.* at 37.
[187] *Id.*
[188]Saito-Jennssen , *supra* note 131, at 2.
[189] Tonja R. Conerly et. al., *Introduction to Sociology* 3E, at 631 (2021), https://openresearchlibrary.org/viewer/7ded526f c467-4182-8c7e-12346996103e.

nongovernmental organizations and citizens."[190] A policy *movement* is unified by a common interest in the improvement of policy decisions through scientific inquiry.[191]

Legally, *movements* could be viewed akin to international law in Category V on the "Form of International Legalization Chart,"[192] in which policy obligation is high, but its precision and delegation are low. Areas informally within the quantum legal realm that social and legal *movements* could jointly address include global health, workforce and employment, justice and the law, climate change, trade and investment, social justice, economic progression, migration, and the future of equitable computing.[193]

The emerging technology of quantum computing will benefit from having a clear starting point, such as a policy *movement*, in which legalization begins with both informal interested parties and formal stakeholders working together within this one *movement*. Therefore, the quantum policy *movement* could focus on the global responsibilities of quantum stakeholders and the social conscience committed to protecting this technology, assuring malign actors do not possess quantum technology, and shepherding equal access for society to justly reap the benefits of quantum computing. For example, scientists can enter the political arena in collaboration with social movements to oppose elite policies and advocate alternatives. Social responsibility in science continues today in at least four major organizational forms: (1) boundary organizations, located in universities or government agencies and mediate scientific, political, and industrial worlds; (2) public interest science organizations, located outside the government and overtly aligned with social movements; (3) professional scientific associations, which defend scientists' autonomy; and (4) grassroots support organizations, which are social movement organizations, rather than organizations of scientists, that draw on scientific expertise to develop critiques of and promote alternatives to existing government and industry policies.[194] Specifically regarding quantum computing, access to

---

[190] David Hess et al., *Science, Technology, and Social Movements*, *in* THE HANDBOOK OF SCIENCE AND TECHNOLOGY STUDIES 473, 473 (Edward J. Hackett et al. eds., 3rd ed. 2008).

[191] Ronald D. Brunner, *The Policy Movement as a Policy Problem*, 24 POL'Y SCIENCES 65, 65 (1991).

[192] Kenneth W. Abbot et al., *The Concept of Legalization*, 54 INT'L ORG. 401, 406 (2000).

[193] WORLD ECONOMIC FORUM, STRATEGIC INTELLIGENCE: WORLD ECONOMIC FORUM STRATEGIC INTELLIGENCE, https://intelligence.weforum.org/topics/a1Gb0000000LHN2EAO/key-issues/a1Gb00000003cNgiEAE.

[194] Hackett et al., *supra* note 190, at 473-74.

the technology can be acquired by the person or smaller company that may not own a quantum computer, through grants, subsidies, and other policies that broaden such access.[195]

Just like customary law is created by legally normalizing social customs of legal behavior, *movements* can be assembled to craft purposeful action to work quantum computing within societies' normative boundaries. "UN resolutions, while usually not regarded as sources of international law, do form important secondary and normative sources motivating state behavior which in turn can influence the development of customary international law covering QIT."[196] Once again, this is when the landscape of stakeholders becomes extremely important to create a cooperative network to shepherd quantum computing through its development of becoming an equitable technology.[197] At this stage of creating a governing system, identify "islands of agreement" between the most prevalent nation state stakeholders; China, the EU, and the U.S. "Islands of agreement" in negotiations are when two or more parties can find common values to begin negotiation versus focusing on antagonistic differences. These issues that are of common concern or commonly valued could include energy transition, as well as protecting food security, banking, and capital markets. Third party stakeholders can also provide a setting that connects these primary states during such negotiations.

The quantum computing revolution though, will likely result in two parallel movements that will shape differing primary quantum computing governance policies, one (the West) that leans towards the liberalization of the technology and the other (the East) that is driven by autocrats to towards unilateral state control of quantum computing; thus, causing further social, political, and economic divide between the East and West. Within the West, "there will be a competition between states to host and develop the technology in their respective country, so that the respective country can capture most of the welfare (e.g., technology, revenue, taxes) that quantum computing will create. This is in part why countries are becoming more protective."[198]

How does one inject action into a network of stakeholders to

[195] Scott Buchholz & Benna Ammanth, *3 Ways Quantum Computing May Create Ethical Risks*, THE WALL STREET JOURNAL (June 2, 2022), https://deloitte.wsj.com/articles/3-ways-quantum-computing-may-create-ethical-risks-01654189917.
[196] Perrier, *supra* note 45, at 26.
[197] Cresswell, M. M., & O'Riley, M. Quantum Computing Governance. Personal. (Mar. 2023).
[198] Interview with Dr. Tim Mehke, Co-Founder & COO, Atlantic Quantum, in Cambridge, Mass. (Nov. 11, 2023).

create a socially cohesive movement to support the equitable development of quantum computing? The next step of this process is to identify the *movement's* goals and risks. A commonplace means of bridging the semantic gap between discursive governance values and operational task, goal, and assurance processes is via risk management protocols. These provide variegated approaches to management of risk by or related to institutions, organizations, and projects. A risk-management approach specifies methods and decision procedures for how abstract objectives, such as ethical constraints, may be operationalized by stakeholders.[199] As previously discussed, ethical norms must be built within the architecture of the developing quantum landscape. Without ethics, technology stakeholders, especially those within the business sphere, may focus exclusively on meeting business objectives, which could lead to unintended negative consequences.[200] "Quantum Ethics" is an emerging applied ethics field, focusing on moral behavior of the multiple technological domains within the quantum realm (e.g., quantum computing, quantum sensing, quantum communications, etc.). Key principles that emerge are fairness, transparency, harm avoidance, sustainability, and autonomy. For example, regarding transparency, how can we work within the principles of open science and discovery if it conflicts with the desire to keep new quantum computing information secret? One way to deal with these ethical dilemmas is for humans to abide by the standards of ethical practice and conduct, in which actions have desirable consequences, with the most virtuous action compared to other acts in rank order. When a conflict of action arises, virtue supersedes fewer moral pathways. Through this method among the several quantum fields, a multi-layered, interdisciplinary ethical framework can be formed.[201]

Global governance *goals* fall within the sphere of multilateral and international organizations, which provide states with a forum to meet and design international norms for the use of QIS. "Global development *goals* have become increasingly used by the United Nations and the international community to promote priority global objectives. The Millennium Development Goals (MDGs) are one of the most prominent

[199] Perrier, *supra* note 45, at 17.
[200] Buchholz & Ammanth, *supra* note 195.
[201] Maurita Kopp, Ethics in the Quantum Age, Physics World 31 (Dec. 1, 2021), https://law.stanford.edu/wp-content/uploads/2022/01/Physics-World_Dec21Forum-Kop_Ethics-in-the-Quantum-Age.pdf.

examples of such *goals*."[202] Global *goals* set priorities, frame debates, create a language to mobilize financial and human resources, strengthen accountability, and create peer pressures for aligning national policy with the global *goals*. As norms, global *goals* are prescriptive rather than regulatory in that they define what "*ought to be done*" rather than prevent what "*should not be done.*" As norms, global *goals* are intended to lead to behavior change, notably policy change on the part of governments. Several of today's global indexes and country rankings are used to nudge behavior in a subtle way, by assigning a "score card" that creates incentives to improve performance and allow countries to adopt policies to improve their ranking without being pressured to do so by some global oversight body or peer group countries.[203] Regardless, one must remain wary of ranking subjective and nuanced goal successes of quantum computing's work to improve complex problems, such as health care and financial speculation, by assigning them simple numerical values.[204]

Quantum computing *goals* should set a general framework for society to utilize this technology that would achieve the equitable common good for all humankind. It is sensible that quantum computing *goals* should mirror and support the UN Sustainable Development Goals, particularly those that researchers already envision quantum computing positively affecting. UN Sustainable Development Goals, in line with quantum computing enablement, include good health and well-being, industry innovation and infrastructure, sustainable cities and communities, climate action, peace, justice, and strong institutions.

Strategies, policies, and standards are clearly governance levels within the dominion of states (governments), which are the primary agents of regulation in their role in international and domestic formal lawmaking. 'The primary stakeholders within states are constituted governments, whose instruments of governance can be categorized as (i) legislative and (ii) executive.'[205] "In addition to providing financial assistance for basic research projects and companies pursuing novel quantum computing efforts, the [U.S.] national strategy includes plans

---

[202] Sakiko Fukuda-Parr, GLOBAL DEVELOPMENT GOAL SETTING AS A POLICY TOOL FOR GLOBAL GOVERNANCE: GLOBAL DEVELOPMENT GOAL SETTING AS A POLICY TOOL FOR GLOBAL GOVERNANCE: INTENDED AND UNINTENDED CONSEQUENCES, 1 (INT'L POL'Y CTR. FOR INCLUSIVE GROWTH, WORKING PAPER NO. 108, 2013), https://sustainable development.un.org/content/documents/863IPCWorkingPaper108.pdf.

[203] *Id.* at 4.

[204] Kevin E. Davis et al., *Indicators as a Technology of Global Governance*, 46 L. & Soc'y Rev.71, 83 (2012).

[205] Perrier, *supra* note 45, at 28.

to capitalize on the economic benefits of quantum computing leadership."[206]In reference to these governance levels, the U.S. has shed some of its market-based approach regarding quantum computing towards government funding and China has continued to primarily finance quantum computing development through state labs and state owned enterprises. Nevertheless, these are the levels of governance that have proven to be the most difficult to quantify because of the lack of knowledge of exactly what quantum computing will be capable of in the future. Therefore, more effort should be focused on strategies for the proper development of quantum computing, leveraging the knowledge learned from attempts to regulate other transnational fields of law, such as cyber and environmental law.

Furthermore, just as quantum computing is a novel technology, the law may have to take a novel shape to govern the future of a quantum aware next generation. As of June 2023, the primary U.S. governmental agencies responsible for the nation's quantum information science progression are Congress' National Science and Technology Council (NSTC) Subcommittee on Quantum Information Science (SCQIS), the NSTC Subcommittee on Economic and Security Implications of Quantum Science (ESIX), and the National Quantum Initiative Advisory Committee (NQIAC), the Federal Advisory Committee created in response to the National Quantum Initiative (NQI). "The [NQIAC] . . . advise[s] the President, the [NSTC] Subcommittee on Quantum Information Science (SCQIS), and the NSTC Subcommittee on Economic and Security Implications of Quantum Science (ESIX), and ... make[s] recommendations for the President to consider when reviewing and revising the NQI program."[207]

According to an article from McKinsey titled *Quantum computing use cases are getting real-what you need to know*, "Six key factors—funding, accessibility, standardization, industry consortia, talent, and digital infrastructure—will determine the technology's path to commercialization."[208]

"Although quantum technologies are in a relatively nascent stage

---

[206] Rand, *supra* note 67, at 56.
[207] NAT'L QUANTUM INITIATIVE ADVISORY COMM., RENEWING THE NATIONAL QUANTUM INITIATIVE: RECOMMENDATIONS FOR SUSTAINING AMERICAN LEADERSHIP IN QUANTUM INFORMATION SCIENCE 2 (2023), https://www.quantum.gove/nqiac-report-on-renewing-the-national-quantum-initiative/.
[208] Matteo Biondi et al., *Quantum computing use cases are getting real—what you need to know*, MCKINSEY DIGITAL (Dec. 14, 2021), https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/quantum-computing-use-cases-are-getting-real-what-you-need-to-know.

of production, . . . [several] technical and social trends have shaped the industry thus far." [209] Industrial and commercial stakeholders, universities and academia, individual producers, and consumers of QIT, civil society, and technical community groups are those that will develop the principals, practices, and standards of the quantum computing realm. The diversity of quantum contributors and users, (the quantum ecosystem), requires a workforce that is prepared to grow the industry in a responsible manner to take the first step to create appropriate policies for emerging technologies, such as QIS. Workforce development is key to sustaining this emerging technology once it becomes operationally viable. "[A]ttracting and retaining professional talent . . . [has] become more of a global enterprise, requiring both domestic training and international cooperation." [210] As of today, there are not enough domestically located quantum experts to develop the program at the national level.

According to a report, "Quantum Information Science and Technology Workforce Development," by the U.S. Subcommittee on Quantum Information Science Committee on Science, "[b]uilding the Nation's QIST workforce will require coordination among U.S. Government agencies, academic institutions, professional societies, non-profit organizations, industry, and international partners."[211] Currently, no comprehensive source of data exists that provides definitive, quantitative information regarding the QIST workforce landscape. But based on the information that is available, there appears to be a talent shortage at all levels in the United States. No singular approach to educating a quantum workforce will accurately determine the need for this workforce to address the requirements to develop quantum computing to lead the world's quantum technology without studying the actual magnitude of the educational gap between what is required to build an appropriate quantum workforce and what is fear driven conjecture which overstates the actual need.

With that said, the most important policy development to support long term quantum computing advancement in the U.S. is a K-12 (Q-12) educational effort to build a strong, diverse, inclusive, and sustainable workforce. The United States' quantum workforce talent shortage is a national security risk and no wholistic answer has been given that would adequately respond to this concern. The cocoon of quantum education

[209] RAND, *supra* note 67, at 51.
[210] SUBCOMM. ON QUANTUM INFO. SCI., QUANTUM INFORMATION SCIENCE AND TECHNOLOGY WORKFORCE DEVELOPMENT NATIONAL STRATEGIC PLAN 3 (2022).
[211] *Id.* at v.

remains closed for much of the K-12 students in 98,577 U.S. public schools (2020-2021).[212] This must change, not just to become quantum stable for the future, but to become quantum equitable. "Education in QIS and related cybersecurity principles should be incorporated into academic curricula at all levels of schooling to support the growth of a diverse domestic workforce. Furthermore, it is vital that we attract and retain talent and encourage career opportunities that keep quantum experts employed domestically."[213] The National Q-12 Education Partnership was launched by the White House Office of Science and Technology Policy and the National Science Foundation to extend access to K-12 quantum learning tools to inspire the next generation of quantum minded participants. But the reality is that the Department of Education does not seem to be a primary stakeholder in this consortium and the department does not possess the current resources or capacity to roll this program out in a uniform manner across the nation's 98,577 public schools in an equitable manner.[214] At the U.S. high school level, a portion of schools still do not offer physics courses, and many students will not have taken a physics course during their K-12 education.[215] Congress, in concert with the Department of Education and the NIST, should consider policies to support domestic high school and college students (including community colleges) and promote student "participat[ion] in related STEM (science, technology, engineering, and mathematics) education courses and programs that are foundational to QIST."[216]

Without a strong 'quantum' workforce, the development of quantum computing will atrophy, therefore not reaching practical operational levels. This quantum smart workforce includes educators, technicians, engineers, operators, quantum aware policymakers, academics, and scientists. Collaboration, trans-sector approaches, among academia, industry, and the public sector, is essential to build a strong quantum workforce pipeline.[217] Outside the expected sectors to be trained or exposed to quantum computing, such as computer science,

---

[212] U.S. DEP'T EDUCATION, EDUCATIONAL INSTITUTIONS, NAT'L CTR, FOR EDUC. STAT. (2023), https://nces.ed.gov/fastfacts/display.asp?id=84.

[213] National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems, *supra* note 94.

[214] SUBCOMM. ON QUANTUM INFO. SCI., *supra* note 214, at 4.

[215] Raymond Y. Chu & Susan White, *High School Physics Overview*, AM. INST. PHYSICS: NEWS & ANALYSIS (May 1, 2021), https://www.aip.org/statistics/reports/high-school-physics-overview-19.

[216] Zhu, *supra* note 15, at 13.

[217] Law Offs. Salar Atrizadeh, *Quantum Computing: Navigating State and Federal Rules,* INTERNET LAWYER BLOG (Apr. 14, 2023), https://www.internetlawyer-blog.com/quantum-computing-navigating-state-and-federal-rules/.

information theory, theoretical and experimental physics, chemistry, information theory, materials science, and engineering, non-traditional areas of study could include art, media, and cultural institutions.[218] Broader outreach in the K-12 educational system must find ways to provide cross-disciplinary studies, still bed rocked in science, to create a diverse community of a quantum smart workforce to then develop a holistic effort to shepherd quantum computing into a more equitable future. It is no secret that a competitive quantum workforce must hold science, technology, engineering, and math (STEM) skills, as well as a quantum-specific expertise.[219] These hurdles to build such a workforce cannot be addressed after quantum becomes globally operational. The U.S. must have the answer of how to sustain such an effort before the question of which nation will have the edge if America wants to take this technology seriously. Unfortunately, as of now, the curriculum needed to teach the next generation of a quantum workforce is not adequately provided to K-12 public schools. It is predicted that by 2025, less than 50 percent of quantum computing jobs will be filled unless significant interventions occur by stakeholders that can respond to this emerging technological workforce crisis.[220] As AI applications became part of everyday life, it was painfully clear that organizations needed to do more to attract individuals from underrepresented groups to AI's foundational fields of computer science, math, and statistics. It is too early to know what industry sector innovations will emerge from quantum technologies, but we assume similar challenges if we do not build a diverse quantum workforce. This requires efforts to encourage diverse representation in quantum-adjacent fields.[221]

Without exposure to quantum physics and other complimentary scholastic endeavors, students (particularly in lower socioeconomic areas) will remain uninformed of the opportunities that quantum careers can hold. A portion of the National Quantum Initiative Act (NQI Act) and the FY 2019-2022 National Defense Authorization Acts (NDAA) should be earmarked directly to the public school system nationwide to directly bolster the efforts to build such a force. But $525 million total throughout

---

[218] SUBCOMM. ON QUANTUM INFO. SCI., NATIONAL STRATEGIC OVERVIEW FOR QUANTUM INFORMATION SCIENCE 3 (Sept. 2018), https://www.quantum.gov/wp-content/uploads/2020/10/2018_NSTC_National_Strategic_Overview_QIS.pdf.
[219] Howell, *supra* note 82, at 2.
[220] Niko Mohr et al., *Five lessons from AI on closing quantum's talent gap—before it's too late*, MCKINSEY DIGITAL (Dec. 1, 2022), https://www.mckinsey.com/capabilities/mckinsey-digital/our-insights/five-lessons-from-ai-on-closing-quantums-talent-gap-before-its-too-late.
[221] *Id.*

FY 2024 to FY 2028 is not enough to transform the education system curriculum at the national level and develop a workforce that started from quantum blindless to quantum aware. Also, the NSF Quantum Education Pilot Program, authorized in the CHIPS and Science Act $32 million allotment over the course of five years, will not adequately support the progress needed to create an equitable quantum aware force across the U.S. public school system.[222]

Without exposure to quantum physics and other complimentary scholastic endeavors, students (particularly in lower socioeconomic areas) will remain uninformed of the opportunities that quantum careers can hold. A portion of the National Quantum Initiative Act (NQI Act) and the FY 2019-2022 National Defense Authorization Acts (NDAA) should be earmarked directly to the public school system nationwide to directly bolster the efforts to build such a force. But $525 million total throughout FY 2024 to FY 2028 is not enough to transform the education system curriculum at the national level and develop a workforce that started from quantum blindness to quantum awareness. Also, the NSF Quantum Education Pilot Program, authorized in the CHIPS and Science Act $32 million allotment over the course of five years, will not adequately support the progress needed to create an equitable quantum aware force across the U.S. public school system.[223] I would propose $1.2 billion per year in direct investment to 98,577 public schools in the education system, earmarked to support the development of quantum awareness in concert with the Department of Education, with $25 million of this investment earmarked for postgraduate studies, as industry also funds quantum computing postdoctoral education and research. Programmatic feedback is also required by the stewards of these efforts and the executive oversight should be left to the National Science Foundation (NSF) and the National Institute of Standards and Technology (NIST) to re-evaluate the positive progress and areas of stagnation of the effort to build a quantum workforce through educational awareness and opportunity.

CONCLUSION

Revolutionary could best describe the impact of the emergence of operational quantum computing. Revolutions are more than critical moments in the history of individual states. Organized revolutions are often global watershed events. Revolutions can cause abrupt shifts in the

---

[222] NAT'L SCI. & TECH. COUNCIL, *supra* note 119, at 3.
[223] *Id.*

balance of power, place alliance commitments and other international agreements in jeopardy, and provide inviting opportunities for other states to improve their positions.[224] Most importantly, revolutions are moments in time that can transform our past and present into a future that is deserving of the humanity that we require in our world. Quantum computers will not replace classical computers. Instead, like many technologies that are developed throughout time, they will work together to solve computationally complex problems that classical computers cannot handle quickly enough by themselves.

Technological development has become an important topic of international relations. "It would be naïve to assume that China doesn't harbor longer-term strategic ambitions in the region that would allow it to emerge not only as a 'theater peer' of the United States but also as the most formidable Asian power that would be able to contest and effectively deter the United States." [225] Under the last two U.S. administrations, the nation took increasingly aggressive measures to stifle China's technical might, such as focusing on export controls and deterring China's most competitive companies, such as Huawei. "These trends could produce a scenario where two factions, one including China, Russia, and perhaps even some Westernized nations enticed by the Belt and Road [Initiative], and a second representing the US, Japan, and Europe, compete to reach quantum technology superiority." [226] "Competing post-quantum security standards across Washington's and Beijing's spheres of influence have the potential to cleave the world into divergent blocs, with grave implications for global trade. '[The] balkanization of what we know today as a free and open internet is distinctly possible,' [U.S. National Cyber Director Chris] Inglis says."[227] "In order to rebuild and establish an international order that the U.S. and China are each aspiring to lead, cooperation among countries that can actively participate in and contribute to such an order is first required."[228]

This scenario does not automatically spell out doom for the world because the technology is not a pure weaponized system. This 'East/West' bloc race to quantum superiority are more akin historically to the international space race than an arms race. These competitions

[224] Stephen M. Walt, *Revolution and War*, 44 WORLD POLITICS 321, 321 (1992), https://doi.org/10.2307/2010542.
[225] Chung Min Lee, FAULT LINES IN A RISING ASIA 190 (2016).
[226] Hoofenagle & Garfinkel, *supra* note 7, at 363.
[227] Campbell, *supra* note 97.
[228] ASAN INST. FOR POL'Y STUD., *Overview: The Competition to Rebuild the International Order*, *in* REBUILDING 6, 15 (2021), https://www.jstor.org/stable/resrep39829.4.

would produce greater investment in technology and provide new venues of employment in the quantum field. Most importantly, "[t]he United States needs a national technology strategy not only to compete with China but to articulate and pursue its own technology policy goals and priorities."[229]

This is not an avoidable issue that can be ignored until American talent has fallen behind its international competitors/adversaries in QIS. Therefore, public education should be considered a national security issue because it directly impacts America's advanced technological leadership capability in a growing globalized world. This is not an impossible feat. For example, Australia has only 0.3 percent of the world's population but 10 percent of the world's quantum scientists.[230] Talent will decide this international quantum race. [T]he countries and regions that succeed in establishing tomorrow's preferred international norms in . . . [quantum computing] . . . will reap considerable economic and financial benefits. In contrast, countries that promote their own norms and rules to give advantages to their domestic producers, while also blocking foreign competitors . . . risk becoming isolated from global norms, putting these nations at risk of becoming the laggards of the new . . . [quantum computing] . . . economy.[231]

With so much uncertainty regarding different technology stacks and software development within the quantum computing realm, China, the U.S., and other nations could produce different research and scientific methods to achieve independent modes of acquiring quantum computers, working at an operational level. Therefore, the race would be relatively even and both sides would remain deterred from conducting any offensive quantum computing attacks on each other, due to the very real threat of retaliation by the other state. So much of how quantum computing will be ushered into our world may remain a mystery until the point of convergence is reached between humanity and the quantum realm. To achieve positive results in the future governance of quantum computing, "governments will need to engage citizens more effectively and conduct policy experiments that allow for learning and

---

229 Rasser & Lamberth, *supra* note 173.

230 Bronte Munro, *The U.S. Can't Lead on Quantum Computing Alone*, FOREIGN POLICY (Oct. 25, 2023, 3:30 PM), https://foreignpolicy.com/2023/10/25/quantum-computing-united-states-australia-cooperation-allies-science-technology-chips/.

231 SCHWAB, *supra* note 24, at 72 (citing Stephen Ezell & Robert D. Atkinson, *The Middle Kingdom Galapagos Island Syndrome: The Cul-De-Sac of Chinese Technology Standards*, INFORMATION TECHNOLOGY & INNOVATION FOUNDATION (Dec. 15, 2014)), http://www.itif.org/publications/2014/12/15/middle-kingdom-galapagos-island-syndrome-cul-de-sac-chinese-technology.

adaptation."[232] Quantum governance, with its focus on stakeholder rights, duties and interests, and empirical evaluation, articulates core necessary conditions required for the development of appropriate QIT governance by states, governments, technical communities, private sector participants, public institutions, individuals, and civil society groups. Governments and citizens must examine their respective roles and how they interact with one another to raise the bar of governance, such as acknowledging the need to incorporate multiple perspectives from across the globe. What can be predicted is that "QIT governance globally represents an important emerging branch of technology governance applicable to what is potentially among the most profound set of technologies ever created."[233] *May the odds be ever in our favor.*

[232] *Id.* at 69.
[233] Perrier , *supra* note 11, at 40.