Spring 2024

Economic Entanglement: The Quantum Race Between the United States and China

Isabella Willhite
Regis University

ECONOMIC ENTANGLEMENT

The Quantum Race Between the United States and China

A thesis submitted to

Regis College

The Honors Program

in partial fulfillment of the requirements

for Graduation with Honors

by

Isabella Liberty Willhite

Thesis written by

Isabella Liberty Willhite

Approved by

_______ _______________________Thesis Advisor

________ _________________ Thesis Reader & Co-Advisor

Accepted by

___ _________________ Director, Regis College Honors Program

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

Thank you to my advisor, Dr. Kras, for your immense support throughout this thesis writing process. Thank you also to my reader, Dr. Gray, who provided the subject-matter expertise in quantum computing that made this thesis possible. Thank you also to Dr. Narcisi and Dr. Schreier who allowed me the space to explore my research interests in these interdisciplinary topics. Finally, thank you to my Mom, Dad, brother and sister who have always lended a listening ear.

ABSTRACT

Name: Isabella Liberty Willhite Majors: Political Economy Minors: Asian-Pacific Studies, Communications

The Quantum Race: An Economic Tale Between the United States and China

Advisor's Name: Dr. Hellen Rabello Kras

Reader's Name: Dr. Fred Gray.

The United States and China are both currently home to the strongest economies and militaries in the world. Despite their interdependence, trade wars have escalated between the two countries in the past few years. While past trade wars have been focused on purely economic protectionism or ideological stances, the trade wars of today signify a shift towards protecting critical emerging technologies. The important emerging technology of today is quantum computing, which will forever change the way that computers encrypt, process, and decode information. The United States and China are on the eve of the "quantum race," in which they will attempt to outcompete each other as they vie for the technology that will shape the future of warfare, information technology, and arguably, the new global order. Alarmingly, existing sanction literature operates on the assumption of unassailable American hegemony and has not caught up to recent developments like the rise of the yuan and China's impressive technological capacity. I begin this paper by outlining the physics that makes quantum computing so revolutionary. Then, I draw on the historical precedence of sanctions to outline the conditions for sanctions to be effective, and their various impact scenarios.

CHAPTER ONE: INTRODUCTION

Sanctions have been used to shape policy outcomes since they were first used by the Athenian empire in 432 B.C. (Abughris, n.d.). Yet, despite having 2,000 years to evolve, the effectiveness of sanctions has yet to drastically improve. Whether levied on individuals, corporations, or entire countries, sanctions do not fully guarantee their intended policy outcomes, but they do guarantee costs to both the imposer and the receiver. They can also come with unintended externalities that range from supply chain shortages to the mass death of civilians. It is quite puzzling: sanctions are ineffective, yet they have been used time and time again as a policy tool.

Now, sanctions are growing in popularity between two of the largest economies in the world – the United States and China. Perplexingly, despite their economic coupling, both countries have publicly named each other as growing threats to economic development and national security. In October of 2023, a China Military Power Report presented to the United States Congress began with the chilling statement that “the People’s Republic of China (PRC) is the only competitor to the United States with the intent and, increasingly, the capacity to reshape the international order” (Garamore, 2023). During that same month, the Chinese Minister of Defense offered a rebuttal, calling the U.S. the “world’s biggest disruptor of regional peace and stability” (Robertson, 2023). In recent years, and now months, both countries have escalated their sanctions against each other. While some sanctions may be leveraged for purely protectionist measures, such as on steel or rare Earth minerals, it cannot be denied that some are being leveraged to cripple war-making industries. These industries specialize in emerging technologies that have the power to reshape not only civilian life but also to drastically redefine military capabilities.

Interestingly, the emerging trade technology war begins with a story in neither the United States nor China. The story is not necessarily new, either. This story has been culminating over the past 20 years at Germany's oldest university and one of the most prestigious research institutions in the world: Heidelberg University. In 2003, a Chinese researcher named Pan Jianwei joined Heidelberg as a researcher and professor specializing in quantum communications. Pan was quickly recognized for his work. From 2004 to 2013, his research in Germany received millions of euros in funding both at the state and EU levels. At Heidelberg, Pan would also act as a mediator to develop a strong university partnership on behalf of Heidelberg with his alma mater, the University of Science and Technology of China (USTC). The USTC is touted as China's equivalent to CalTech and is known as the "country's most important institution dedicated to the quantum field" (Hart et al., 2023).

Pan recruited several promising quantum students from USTC to attend and conduct research with Heidelberg. Later, in 2011, the two schools would initiate a formal contract to facilitate the exchange of students and staff. When Pan returned to the USTC, he brought much of his lab equipment and network of researchers back with him. While Pan was in China, Heidelberg's Institute of Physics brought on Matthias Weidenmuller. As relationships between the two universities continued, Weidenmuller received a job offer from the USTC as part of the Thousand Talents Program. The Thousand Talents Program is a program sponsored by the Chinese government to recruit experts in science and technology, typically by offering them hefty sign-on bonuses and research stipends. Weidenmuller accepted the offer and established a lab at the Hefei National Lab for Physical Sciences, staying on for a five-year contract as an honorary professor. In 2016, Pan and Weidenmuller established for a cutting-edge quantum research center in China. While the plans never came into fruition, it is notable that they included the National University of Defense Technology, China's top military university that reports directly to President Xi Jinping.

Pan is currently at USTC and is hosting eleven other Chinese quantum researchers who went abroad to Heidelberg. He is now a world-known physicist that has received recognition from prominent magazines like *Nature* and *Science*. In China, his work has been selected on eleven different occasions to be highlighted in "The Top Ten Annual Scientific and Technological Progresses in China." Pan also went on to play a key role in the founding of Guodun Quantum, or Quantum CTek (国盾量子). The company specializes in quantum communications and has publicly listed its involvement in several Chinese military projects. The company maintains six locations, including Xinjiang, which is a highly militarized region known for being the site of immense Uyghur persecution and genocide. Over 2 million Uyghurs have been forcefully detained, prompting investigations from the United Nations (Felden & Petersmann, 2023).

A 2019 report by Strider, an American-based data analysis company, details that Pan has maintained extensive research contacts with the Chinese defense sector while simultaneously being a physics professor at USTC. The report details that in 2018, Pan initiated a scientific cooperation contract between the university and the China Electronics Technology Corporation (CETC). Notably, CETC is known for developing a policing app for the surveillance of Uyghurs in Xinjiang. The Strider report also emphasizes that "Heidelberg University is arguably the most important foreign partner behind China's rapid progress in dual-use quantum technologies" (Quantum Dragon Report - Strider Intel, 2019). Alarmingly, dual-use technologies have both civilian and military applications.

Quantum CTek and the USTC HFNL lab, where Weidenmuller worked, have been subjected to American sanctions as designated entities. These sanctions were rolled out in

November of 2021 by the US Department of Commerce and include 28 total entities based in China, Russia, Pakistan and Japan for "distributing quantum computing technologies to military and nuclear weapons programs." These sanctions forbid US companies, at both the supplier and customer level, from establishing any business connections with these organizations. This includes the flow of capital, raw materials, or technology sharing (Cimpanu, 2021). In response, Chinese embassy spokesperson Liu Pengyu articulated the concerns that Washington has been employing abuses of state power to suppress all Chinese enterprise. Another spokesperson at the Chinese foreign ministry warned that China may take countermeasures against the sanctions (Sanders, 2021).

While sanction escalation between the United States and China may seem like a bilateral issue, the relationships between these two countries exceed state lines and into international contexts, as the case of the German Heidelberg University represents. Moreover, the United States and China represent two of the largest economies in the world. The United States has the largest GDP by sheer number (nominal), and China the largest GDP by proportional purchasing power (PPP). The US and China far outpace Japan and India, the countries that rank third in the measures of nominal and PPP GDP, respectively (*Report for Selected Countries and Subjects*, n.d.). In recent years, China has experienced immense growth that has resulted in its displacement of the United States on the stage of global trade. As the Lowy Institute, an independent policy think-tank based in Sydney, Australia, explains:

> "In 2001... over 80% of countries with data available had a larger volume of trade with America than China. By 2018, that figure was down to a little over 30% – with two-thirds of countries (128 out of 190) trading more with China than the United States."
> (*The US-China Trade War: Who Dominates Global Trade?*, n.d.)

Thus, the escalating trade war between the United States and China is incredibly important to consider, not only for the interests of both countries, but also for the stability of the global economy. Like their economic powers, the two countries also represent the global leaders in technological development, especially in the development of quantum technologies.

There are also several justifications as to why it is important to examine quantum technologies, which can be further aggregated into sensing, communication and computing. While I will dedicate a chapter that delves into how each of these technologies differ from one another, and how they revolutionize the technology landscape, for now, there may be a few holistic justifications. Without getting into science just yet, quantum computers are much more powerful than the computers of today and can solve problems that the computers today find to be impossible (*Why Quantum Tech Will Change Our Future*, n.d.). As such, quantum has a vast array of social, political, and economic implications that we will also be exploring. These implications are alluded to in the fact that quantum technologies are predicted to experience immense growth in market share. Spherical Insights & Consulting contextualizes that "the Global Quantum Computing Market Size was valued at USD 13.67 Billion in 2022" and that this number is expected to skyrocket and reach "USD 143.44 billion by 2032" (*Global Quantum Computing Market Size To Grow USD 143.44 Billion By 2032*, 2023). Some estimates put these numbers even higher – some say that quantum computing alone could reach a market value of $1 trillion by 2035 (Howell, 2023).

In my review of the existing literature around trade wars, I have found lots of analysis regarding the historical precedence and efficacy of punitive sanctions (Abughris, n.d.; Baran, 2022; Freddy, 2022) which tend to be a centerpiece of US foreign policy. Much of this analysis tends to operate on the assumptions of US political hegemony and US economic hegemony with the power of the dollar. These assumptions seem to be deteriorating on an almost daily basis with the simultaneous rises in US noninterference and legitimate challenges to the dollar, like the Chinese yuan. Moreover, much of this literature does not contend with the emergence of Chinese power writ large, which may also intensify with President Xi's Civil-Military Fusion Policy and the nation's goal to become the most powerful military in the world by 2049. Thus, the question of how punitive sanctions leveraged by the United States may be impacted amid these developments will be an important consideration and new contribution to the literature that I will outline in this paper.

Also, in my review of the existing literature, I have found some analysis on the social, political, and economical effects that quantum technologies will bring to innovator-states (Alaminos et al., 2022; DelVisico et al., 2021). However, this literature often fails to account for the emerging trade wars and punitive sanction landscape between the United States and China. This lack of literature is concerning as these tensions will certainly impact the flows of critical supply chains and subject matter expert labor, which in turn will impact the countries that get to develop quantum technologies and how those technologies will be leveraged.

In this paper, I will further contribute to the literature landscape by arguing (1) why it is that these topics in sanctions and quantum ought to be considered in conversation with one another and (2) by highlighting the possibility of five different outcomes in the game theory of sanctions, with the underlying question of whether or not US sanctions will remain a united front.

I will also analyze the justifications for emerging technologies, in this case, quantum computing, to be included in the impact calculus of the game theory behind whether a sanction trade war should occur. The following questions outline my research design.

RQ 1: What is quantum computing, and why is it unique?

RQ 2: What is the historical nature of trade wars between the United States and China?

RQ 3: Will US sanctions on Chinese quantum computing be effective?

I will begin by outlining the revolutionary scientific advancements of quantum technologies and the major actors and structures behind their development. Secondly, we will trace the historical route that has solidified the precedence of sanctions as a foreign policy initiative. Then we will outline the theoretical approaches to understand whether a sanction is effective. Finally, we will ground the analysis of sanction effectiveness into the specific context of the race to quantum computing between the US and China.

Methodology

To capture the importance of quantum computing, I performed a content analysis of peer-reviewed scientific journals which was verified via Dr. Fred Gray, a subject matter expert in quantum physics. To explain the puzzling phenomena of sanctions being ineffective yet widely implemented, I also performed a content analysis on peer-reviewed literature regarding the sanction escalation between the United States and China. Finally, I conducted a content analysis of current American foreign policy towards China to combine these topics in quantum computing and punitive economic measures. To answer my research question of whether future American sanctions on Chinese quantum computing will be effective, I problematize existing sanction effectiveness frameworks that have been highly recognized in the field of Political Economy.

Given this situation's ongoing nature and the time and space limitations of this study, evolving bilateral sanction events were captured up to February 2024. The upcoming 2024 US

Presidential race, and the possibility of the re-election of Donald Trump, an outspoken instigator of economic warfare with China, may change the course of future research.

Moreover, given the inherency of what has been dubbed the "quantum race" between the United States and China, my research is grounded in the specific analysis of these bilateral relations. Thus, it may be important for future research to explore how other quantum innovators like Germany, Australia, the Netherlands, the United Kingdom, and Japan may impact the outcome of the race.

CHAPTER TWO: WHAT IS QUANTUM?

Broadly speaking, quantum mechanics is a framework that describes the behaviors of subatomic particles - including photons, the nuclei, or electrons. More specifically, the field explores the Wave-Particle Duality theory, which states that waves can exhibit particle-like properties, and particles can exhibit wave-like properties (*DOE Explains...Quantum Mechanics*, n.d.).

Quantum technologies can be categorized into three primary areas: sensing, communication and computing.

1. Quantum sensing is a field developing ultra-sensitive devices capable of measuring minute changes in electromagnetic and motion fields. Quantum sensors can detect minute leaks of light, along with tiny changes in temperature, pressure, gravity, and magnetic fields, among others. Developments in these levels of precision have implications for biomedical industries, imaging, geophysics and navigation. They have been commercially available for more than half a century (Garfinkel, 2022).
2. Quantum communication is a field seeking to promise the ultra-fast and simultaneously highly secure transmission of data. Unlike conventional electronics that use bits (ie. 1 or 0) to communicate, qubits, or quantum bits, can represent both 1 and 0 simultaneously, which allows for nearly unbreakable lines of communication. This phenomenon is called superposition, and it is an essential feature of quantum physics. In the realm of communications, Quantum Key Distribution (QKD) has been leveraged, which involves sending encrypted data over as classical bits (public communication sphere), while the keys to decrypt the information are encoded and sent in the qubits (private

communication sphere). The most popular protocol for QKD is the BB84, developed by Charles Benett and Gilles Brassard in 1984. BB84 highlights that quantum communications are secure because if an attacker or other third-party tries to observe their state, they will immediately collapse into a 0 or 1. In other words, quantum communication takes advantage of photons being measured without disturbing their state (Giles, 2019).

3. Quantum computing is a field that leverages quantum mechanics to process information. Like quantum communications, computing leverages the properties of superposition which means that qubits can represent multiple states simultaneously. In the context of computing, this enables enormous amounts of calculations to occur simultaneously (Hart et al., 2023).

Overall, these quantum technologies carry immense potential market value. But, for this paper, we will be focusing specifically on quantum computing, which is seen as the most promising field. Indeed, quantum sensing is already seen as a largely developed field with lots of commercially available products. Quantum communications is largely headed down that same path, and China has already made impressive strides. In 2017, they launched the Micius quantum communications satellite which conducted the world's first intercontinental QKD-secured video conference between Beijing and Vienna (Giles, 2019).

Quantum computing, on the other hand, is still very much under development. Experts in the field have reached a consensus that in the span of the next 10-15 years, the major research gaps in quantum will be filled (Lewis & Wood, 2023). International observers assume that the widespread practical use of quantum computing may begin as early as 2025 (Blinova, 2023).

Shifts in this direction are already beginning. Indeed, major corporations like Exxon Mobil and the Spanish Bank BBVA are already receiving early quantum-computing services via the cloud (Walsh, 2022). Meanwhile, Amazon has launched the 'Amazon Quantum Solutions Lab,' which highlights the opportunity to work with "leading experts in quantum computing, machine learning, and high-performance computing" in a "collaborative research program." More specifically, the Lab acts as a consulter for identifying areas of quantum need, iterating the process, and innovating for long term implementation, including components like workforce training on quantum computing (*Quantum Consulting - Amazon Quantum Solutions Lab - AWS*, n.d.).

How is quantum computing different from traditional computing?

Bill Phillips, a Physics Nobel Prize winner for his work in the cooling of trapped atoms, explained that "a quantum computer is as different from a classical computer as a classical computer is from an abacus" (Rose, 2020). To understand the importance of quantum computing, it may be important to understand the way they differ from the traditional computers we use today. As DelViscio et al. with the *Scientific American* explain, quantum computers are fundamentally different from the computers we are used to today both in the way they look, and perhaps more importantly, in the way they process information. While there are several ways to build a quantum computer, the leading design incorporates chandeliers, which are supercharged refrigerators that use a special liquified helium mix to cool the quantum chip down to near zero kelvin – which is a temperature that prevents the particles from becoming energized. It is this temperature that allows the processing chip to take on near quantum properties.

Traditional computer processors work in binary, using bits, or binary digits, and gates to perform computations. Instead of using bits, quantum computers use quantum bits, or qubits, that operate according to the laws of quantum mechanics. As we discussed above, instead of representing 0 or 1, qubits represent multiple states simultaneously. This phenomenon is known as superposition and it occurs because a qubit spins in every direction possible within a sphere, meaning that its projection onto any given axis can be represented in fractions between –1 and 1. The number of possible states increases exponentially with the number of qubits, meaning that quantum computers offer exponentially more bits of information compared to classic computers (DelViscio, 2021). This relationship is described in the table below, where I've highlighted these calculations (Table 1).

Table 1: The Number of Possible States in a Traditional vs. Quantum Computer

N **bits, or quibits**	**Traditional Computer (bits)**	**Quantum Computer (qubits)**
Starting equation	2^n	2^{2^n}
0	$2^0 = 1$	$2^{2^0} = 2$
1	2	4
2	4	16
3	8	256
4	16	65,536
5	32	4,294,967,296
6	64	18,446,744,073,709,551,616
7	128	340,282,366,920,938,463,463,74,607,431,768,211,456
8	256	115,792,089,237,316,195,423,570,985,008,687,907,853,269,984,665,640,564,039,457,584,007,913,129,639,936

As the table highlights, the number of possible states in a traditional versus quantum computer are exponentially different. For example, with one bit (2^1) in a traditional computer, 2 states can be represented: 0 or 1. With two qubits (2^2) in a quantum computer, there are four states that can be represented: 0, 1, 2 or 3. Unlike the exponential growth for every new qubit added in a quantum computer, traditional computers only increase in computational power linearly with each new transistor. It is for these reasons that a quantum computer could reduce the number of computing hours of a traditional computer from n to √n (Choi, 2023).

These universal explanations that outline why quantum particles act in superposition were first outlined by Niels Bohr, Warner Heisenberg, and Max Born in 1920. Though Bohr and Heisenberg had some differing ideas on how to view the mathematics behind quantum mechanics, they are known for their contributions to what would come to be known as the Copenhagen Interpretation, which was the first attempt to understand the world of atoms in quantum mechanics (Faye, 2019).

Erwin Schrödinger, another prominent physicist of this time, was not afraid to challenge some of these strange phenomena. In his most famous thought experiment, he argued that if a cat were placed in a box with radioactive material, there would be a 50/50 chance the cat would live or die, and that the cat would similarly be in superposition. The impossibility of an animal being both alive and dead intended to highlight the absurdity of the Copenhagen Interpretations (Moloo, 2021).

Another important distinguishing characteristic of quantum computing also highlighted in the Copenhagen Interpretations is quantum entanglement. During entanglement, the individual states of particles are not factored in, and they are instead treated as a single unit. As such, the system of these multiple particles is treated with one space vector, which describes where the system is in space, and how it is moving. In other words, entangled particles are correlated with one another, as opposed to operating separately (Brezinski, 2006). While two particles could typically be factored into their own separate state vectors, when they are entangled, they cannot be factored. As the Wave-Particle Duality theory explains, even though these particles may move through space and time as waves, they are observed as localized particles, as observation collapses the state vector. The state of a quantum particle exists as a superposition, but it does not take on a definite individual value until it is measured – and then, it will either be up (1), or down (0) (NTT Research, 2021). And, when the state of one particle is observed, the other particle's wave function also collapses. These observations were first introduced by Einstein, Boris Podolsky and Nathan Rosen in 1935. In their paper, they introduced the EPR paradox. This paradox identified that the observation has instantaneous effects are that when observed, entangled particles will instantly display the opposite of each other (i.e. 0 for the second if the first is 1, 1 for the second if the first is 0). The reason that particles will cancel each other out can be linked back to the conservation of angular momentum, a physical property of a spinning system, that states in the absence of external torque the total angular momentum of the system is conserved. In other words, even when particles are entangled, their angular momentum is conserved, and additional spin cannot be created or destroyed.

Like Schrödinger's experiment, the EPR papers can also be taken to highlight the ways that quantum mechanics is not a complete theory of nature. Indeed, Einstein described entanglement as "spooky action at a distance" that appears to violate the tenet of the theory of relativity which states that information cannot be transmitted faster than the speed of light. Thus, Einstein postulated the existence of hidden variables (Tretkoff, 2005). However, a 1972 experiment conducted by Stuart Freedman and John Clauser at the Lawrence Berkeley Laboratory ruled out the presence of local hidden variables and confirmed the Wave-Particle Duality Theory (Freedman & Clauser, 1972). Overall, there are several debates about the theories of quantum mechanics that continue today. These debates translate into our next section about the varying prospective applications of quantum computing.

What kind of problems will quantum computers solve?

It is important to characterize that while quantum computing is an emerging and truly revolutionary technology, it will not always be faster than traditional computing. Indeed, what sets quantum computers apart from traditional computers is their ability to solve problems with enormous numbers of variables. There is a direct relationship here: as the number of potential outcomes and steps a problem has increases, the efficiency of the use of quantum computing will also increase over a traditional computer (NTT Research, 2021).

Given this relationship, what sorts of problems will quantum computers be best equipped to solve? Robert Davis, a technical writer for IBM Quantum, explains that:

> "An optimization problem is any problem where your goal is to find *the best of all possible worlds* with respect to certain variables and constraints — i.e., the best, or "optimal," solution from a finite (or countably infinite) set of possible solutions" (Davis, 2021).

Optimization problems include those that seek to answer, for example, how to maximize profits, minimize costs, minimize travel costs or maximize utility. Humans solve optimization problems in their decision-making on a day-to-day basis. Quantum computers are uniquely poised to solve optimization problems as they can leverage superposition and operate many values simultaneously, whereas computers must use one input after another. Optimization problems that quantum computers may solve include those related to AI, protein folding and image and speech recognition (*Chinese Threats in the Quantum Era*, n.d.). Overall, quantum computers can outperform traditional computers by a factor of 10,000 (Choi, 2023).

Another realm of problems that quantum computing is uniquely poised to solve are those relating to encryption. Cryptography, the art of encryption, is the process of using complex mathematical processes to encode data so that it is protected yet accessible by those with the means to decode it. Encryption is foundational to many functions across society – whether it be protecting credit card information for online purchases, or national security defense systems from attacks. However, the speed of quantum computers and their ability to solve these complex problems make them able to "break" encryption and create great threats to existing software. More specifically, large classes of encryption algorithms are vulnerable to being cracked with quantum, given that again, the computing powers of quantum machines increase exponentially in these scenarios (Lewis & Wood, 2023). Scientists predict that as early as next year, quantum computers may be able to factorize the large prime numbers that underlie our public encryption systems, meaning our most vital infrastructure will no longer be protected. This day is ominously dubbed Q-Day (Varanasi, 2023). In a chilling statement, in an article for The European Physical Journal, Krelina argues that "the risk that hostile intelligence is gathering encrypted data with the expectation of future decryption using the power of quantum computers is *real*, *high*, and *present"* (Krelina, 2021).

Finally, quantum computers are also uniquely able to model quantum systems. While classical computers can still do this type of modeling, they are inefficient and require exponentially more memory as systems increase in complexity. Rather, since quantum computers already use quantum phenomena, they are more adequate in modeling systems with quantum principles. Remember, all systems at molecular scales are quantum systems. So, when we are studying molecules, we are doing quantum calculations. For this reason, protein folding is a major implication of quantum computing as it may contribute to our understanding of how specific genetic sequences respond to a protein's molecular structure. While this may sound complex, these relationships are the major underlying foundation of biotechnology which has varying implications for health outcomes all the way from the microscale of human bodies to the macroscale of earth systems. Other quantum systems that may advance with quantum computing also range from those related to lasers or superconductive materials (*Chinese Threats in the Quantum Era*, n.d.).

What are the barriers to quantum computing?

There is some debate oriented around when quantum computing will become wide scale. Indeed, there are some scientific advancements that may be an indicator of this question. On the one hand, classical computers require more transistors to increase their efficiency. For quantum computers, more qubits are added. However, quantum states are fragile, and it is difficult to stop qubits from interacting with their outside environment. Qubits require near-absolute zero temperatures and near-vacuum environments. To reach the scale of these millikelvin temperatures, which are colder than outer space, dilution refrigerators are used to mix Helium-3 and Helium-4 isotopes ("How Does a Dilution Refrigerator Work?," 2023). When these conditions are not met, decoherence of the quantum state occurs, superposition breaks down, and the computer loses information. There are different potential methods for error correction. One option is to utilize logical qubits, which consist of one or more physical qubits and have a longer coherence time. Another would be to utilize algorithms to adjust for the noise, or to use qubit sources that are less susceptible to noise, though these options may be costly and are currently hypothetical (DelViscio et al., 2023).

Moreover, there are more barriers when it comes to obtaining Helium-3. On the one hand, the super lightweight Helium-3 does not exist naturally. Rather, it is a byproduct from radioactive tritium decay (*Helium | NIDC: National Isotope Development Center*, n.d.). In the United States, the only supplier is the U.S. government because its manufacturing and use are tightly controlled. While it is predicted that the existing shortage of Helium-3 will not be a severe barrier to the quantum industry as it represents a one-time cost, the quantum supply chain represents another reason as to why politics, economics and sanctions are so inherent to the quantum outcome ("Helium Shortages and Quantum Computing," n.d.). In 2022, China made advancements on the front of Helium-3, extracting the isotope from lunar soil (Whittington, 2022).

Other difficulties for quantum computing can come down to costs. Indeed, quantum computers require special chips that are different from conventional semiconductors. While a conventional chip is priced at around $200, a singular quantum qubit can cost upwards of $10,000. The first quantum chip was made in 2009 by the National Institutes of Standards and Technology (NIST), and now, the largest quantum processors have a few hundred qubits. Thus, comparing the costs of a conventional chip, versus a quantum processor, it comes down to roughly $200 versus $3,000,000 or more. Indeed, the more chips a computer has, and the more bits or qubits on that chip, the more effective at processing information the computer becomes. The race to develop these quantum chips has been known as the race to "quantum supremacy" (Lewis & Wood, 2023). Lewis et al. continue with more specific barriers to quantum:

> Given the need for specialized support equipment and the fragility of qubits, it is not currently feasible to install a quantum computer on every desk; however, internet-enabled computers can allow researchers to use quantum computing capabilities without requiring physical access. This is also known as "quantum-as-a-service." Since quantum computers are complex, high maintenance, and expensive, quantum-as-a-service allows researchers and companies to access quantum computers owned, operated, and maintained by another company—often using cloud services or over the internet—without needing to own the hardware. Quantum-as-a-service is already used by universities and a few national programs.

The analysis from Lewis et al. has held true insofar as companies using quantum computing have not necessarily made their own quantum computers, but they have used the service in the cloud. Whether this will stay true in the future may depend on the actors who continue to develop it, and whether there are true incentives to mass-produce the quantum computers over simply allowing access to their services.

What are the impacts of quantum computing?

Given the high costs of quantum, it is important to consider the commercial, profit-making applications of the technology. From this perspective, quantum computing's ability to optimize supply chains is one incentive that will benefit private companies across all sectors. As IBM explains, quantum can provide solutions for "persistent supply chain and logistics problems" (*Exploring Quantum Computing Use Cases for Logistics*, 2022). As highlighted by the COVID-19 pandemic, and Russia's invasion of Ukraine, international events can certainly disrupt manufacturing and the flow of products, especially in already vulnerable supply chains. Sandia National Laboratories is currently utilizing quantum computing to reconfigure supply chains on short notice, with the goal of "restoring global security during times of unrest" (Rummler, 2023). Economically, as quantum computing has implications for decryption, it is also relevant to banking systems. Finally, quantum algorithms can exponentially speed up machine learning tasks while requiring much less data. While quantum machine learning remains largely theoretical, it has the great potential to reduce the cost and amount of training data associated with AI (Choi, 2023). For these reasons, quantum computing also has social implications that come with the prospect of democratizing AI.

Quantum computing also has serious implications for military use. In an article for The European Physical Journal, Krelina argues that quantum technologies as a whole can impact all domains of modern warfare. However, he characterizes these impacts as ones that will "improve sensitivity and efficiency," "introduce new capabilities," and "sharpen warfare techniques rather than lead to new types of weapons" (Krelina, 2021). Getting into the specific implications that quantum computers pose, Potter explains that quantum optimization has implications for revolutionizing missile routes by reducing fuel usage and dodging radar detection. Moreover, he discusses how missile systems may operate on quantum computing networks soon, and that these technological convergences represent "a significant leap in military capabilities" (Potter, 2023).

There are additional implications as even current encrypted data is at risk for HNDL attacks – harvest now, decrypt later. As Choi highlights, this poses significant risks for classified information. Krelina expands on this threat, explaining that "the post-quantum cryptography implementation is the must-have technology that should be carried out as soon as possible." He furthers with the chilling statement that "the risk that hostile intelligence is gathering encrypted data with the expectation of future decryption using the power of quantum computers is *real*, *high*, and *present*." The United States government has already identified this threat and is working to transition encrypting methods to quantum-resistant algorithms (Choi, 2023).

During a May 2021 quantum working group, the Advanced Technology Research Center identifies twelve very specific potential military applications for quantum computers (Table 2).

Table 2: The Military Applications of Quantum Computing

Battlefield or Warfighter Simulations	Potential use for mission-scale simulations of military deployments to provide real-time analysis for commanders
Radio Frequency and Satellites	Potential use for better understanding the movements of adversaries via detecting magnetic anomalies (ie. directions of ships and submarines)
Logistics Management	Potential use for route optimization and maximizing the transportation and storage of military materials
Supply Chain Optimization	Potential use for enabling smarter supply chain decisions and enabling end-to-end visibility
Energy Management	Potential use for energy optimization
Predictive Maintenance	Potential use for maintaining global fleets
Autonomous and Robotic Vehicles	Potential use for optimizing autonomous vehicles and unmanned robotic systems
Medical Advancement & Response	Potential use for modeling complex simulations to design medical advancements
Material Sciences	Potential use for simulating realistic molecules and complex materials
Emergency Response	Potential use for expediting analysis during times of crisis
Tracking Space Debris	Potential use for identifying and tracking space debris and optimizing satellite positioning
Quantum-Safe Communication	Potential use for cyber-security infrastructure

Source: Advanced Technology Academic Research Center, 2021.

One of the major takeaways from this table is the broad applications for quantum computing in optimization, modeling, and simulation problems with massive variables. As discussed above, these are the most accepted applications of quantum computing. However, the use of quantum computing may largely depend on the actors who develop it, and what their incentives are. This brings us to another interesting crossroads between quantum computing and political economy, whether quantum computing is a public good.

Is quantum computing a public good?

At its most basic level, an economic good is defined as a product or service which can command a price when it's sold. However, there are public goods, which are those that satisfy two conditions: first, they are non-rival in consumption, meaning that one individual's consumption of the good does not come at the direct expense of another's ability to consume it, and, they are non-excludable, meaning that an individual cannot be denied consumption (Fernando, 2024). The most classic example of a perfect public good is national defense, insofar as it is enjoyed by all citizens of a state, and nobody can be denied it. Thus, given the applications of quantum computing in the space of national defense and military, in one scenario, it could be viewed purely as a public good that the government ought to provide.

However, technological developments have also been historically a good that is excludable, which can make them artificially scarce. For example, even though one's consumption of a TV show does not necessarily take away from the ability of another person to watch the show, the creation of streaming platforms like Netflix have monetized shows to make them scarce.

The question then comes down to whether the government, the private industry, or both will provide quantum computing. When talking about public goods, another important question is whether quantum technologies should be democratized. As Seskir et al. highlights, there are efforts to democratize quantum computing in both the private and public spheres. In the status quo, quantum technology (QT) is seen as a 'public good' and there are global efforts to lower the barriers of entry to quantum computing. Despite some of this democratization already happening, Seskir et al. highlight three major obstacles to opening QT to a wider public, which come down to the incomprehensible nature of quantum, its threats to cyber-infrastructure, and importantly, geopolitics and the US-China quantum race escalating into sanctions and restrictions on academia. Seskir et al. go into an analysis of the counter-narratives and actions supporting democratization. Overall, the paper concludes that the term democratization posits necessary contextual considerations; it is necessary to understand the narratives and counter-narratives that exist around the democratization of QT, and while there are initiatives that exist within the QT field, it cannot be considered democratized (Seskir et al., 2023).

The answer to this question may be a pre-requisite to understanding how perceptions of quantum will impact the actions taken by the United States and China. What happens if the United States sees quantum as something that should be democratized, and China doesn't? Or, if the inverse is true? Both support this idea, or both oppose this idea? To satisfy these questions about who ought to provide quantum computing, the United States and China both offer differing examples insofar as their quantum computing markets are driven by the opposite actors of the private industry and the state.

How do the United States and China compare in quantum development?

Before we get into the market structures of quantum computing in both countries, it is important to justify why these countries make for relevant case studies. One way to understand the biggest players in quantum technology development may be to look at those countries who are investing the most relative to their GDP. Based on this measure, China is the biggest spender, investing $15 billion of its $17.73 trillion GDP (a proportion of 0.088%). Following China is Israel, then the Netherlands, Germany, Canada, France, the United Kingdom, India, and finally, the United States (Swayne, 2023). However, there is some contention around the amount that China has invested. US consulting firm McKinsey estimates that if this number is truly at $15 billion, this would double the investments of the European Union ($8.4 billion), and almost triple those of the United States ($3.7 billion). However, other estimates put Chinese investment at a wide range of somewhere between $4 billion and $17 billion. It becomes evident, though, that China is a major player in quantum.

From a comparative lens, it is incredibly important to distinguish China's pursuit of quantum technologies as one that is primarily state led. Their private sector developments are substantially smaller than those in the United States. McKinsey further states that from 2001 to 2022, Chinese quantum startups received $482 million from the private sector. In the United States, this number is $3.3 billion (Hart et al., 2023). The Quantum Insider really puts these numbers in comparison, finding that US private investment in quantum is over 1350% higher than in China, and there are over 10x the number of quantum startups and 6x quantum investors in the US than in China (Pii, 2023).

It is also worth noting, however, that during a one-year period from 2021 to 2022, Chinese private investments in quantum startups more than tripled to $194 million. For this reason, Chinese private industry may be important to monitor going forward (Pii, 2023). There are swaths of interesting theoretical debates about the economic system in China, and whether it can be truly classified as a capitalist country. While the nuances of these debates should not be undercut, for the purposes of this paper, it is important to highlight that the Chinese economy has not transitioned into a true market economy. As the Library of Congress explains, China has several "industrial policies, mega state-owned enterprises, investment restrictions, and many other government controls" that result in a state co-option of the private industry (Nagashybayeva, n.d.).

And, on a global scale, quantum investments have been rising. Over the ten-year period from 2010 to 2020, the number of investments in quantum technology startup companies have skyrocketed. In 2017 alone, there was almost triple the amount of investment as in 2016. Figure 1 highlights that over these ten years, there has been $1.5 billion in investments, and the largest recipient of these investments has been quantum computing (Kurek, 2020). In the United States, they are planning $3 billion in federal quantum projects, with another $1.2 billion coming from recent National Quantum Initiative (Salerno-Garthwaite, 2023).

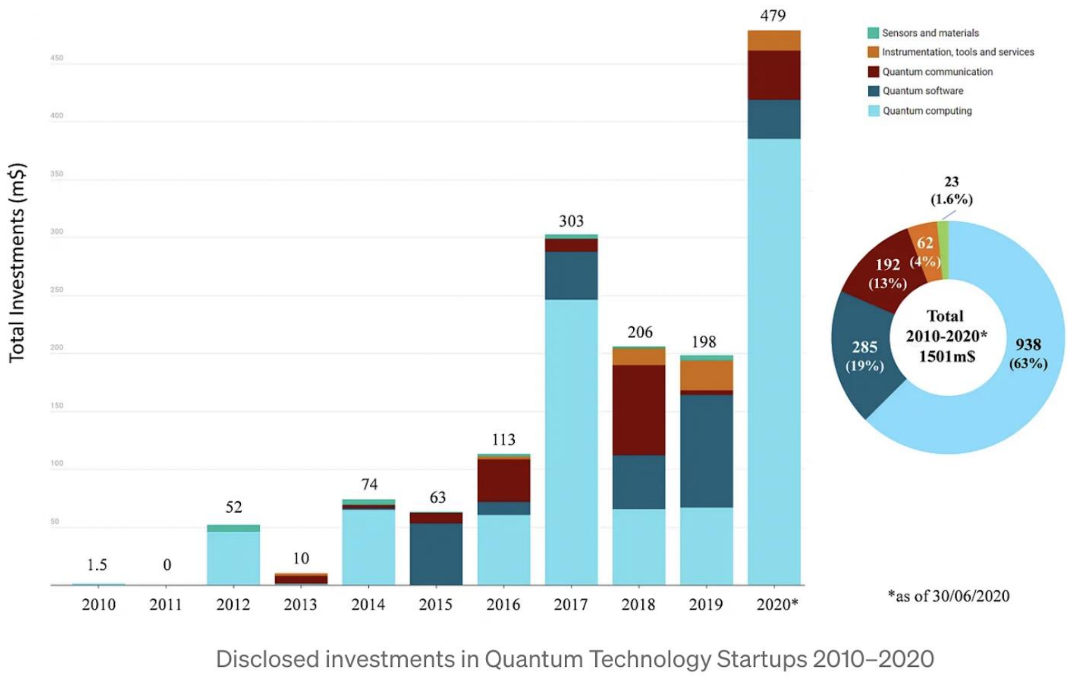

Figure 1: Investments in quantum computing are growing (Kurek, 2020).

An alternative measure for understanding the relative competition between quantum technologies between countries is to look at the Hirsch Index, which measures the total number of research papers relating to quantum technology published in a country, and the number of subsequent citations that the research receives. As Figure 2 below illustrates, the United States and China are the two highest ranking countries on this index, with China leading in quantum communications, and the United States leading in quantum sensing and computing (Hart et al., 2023).

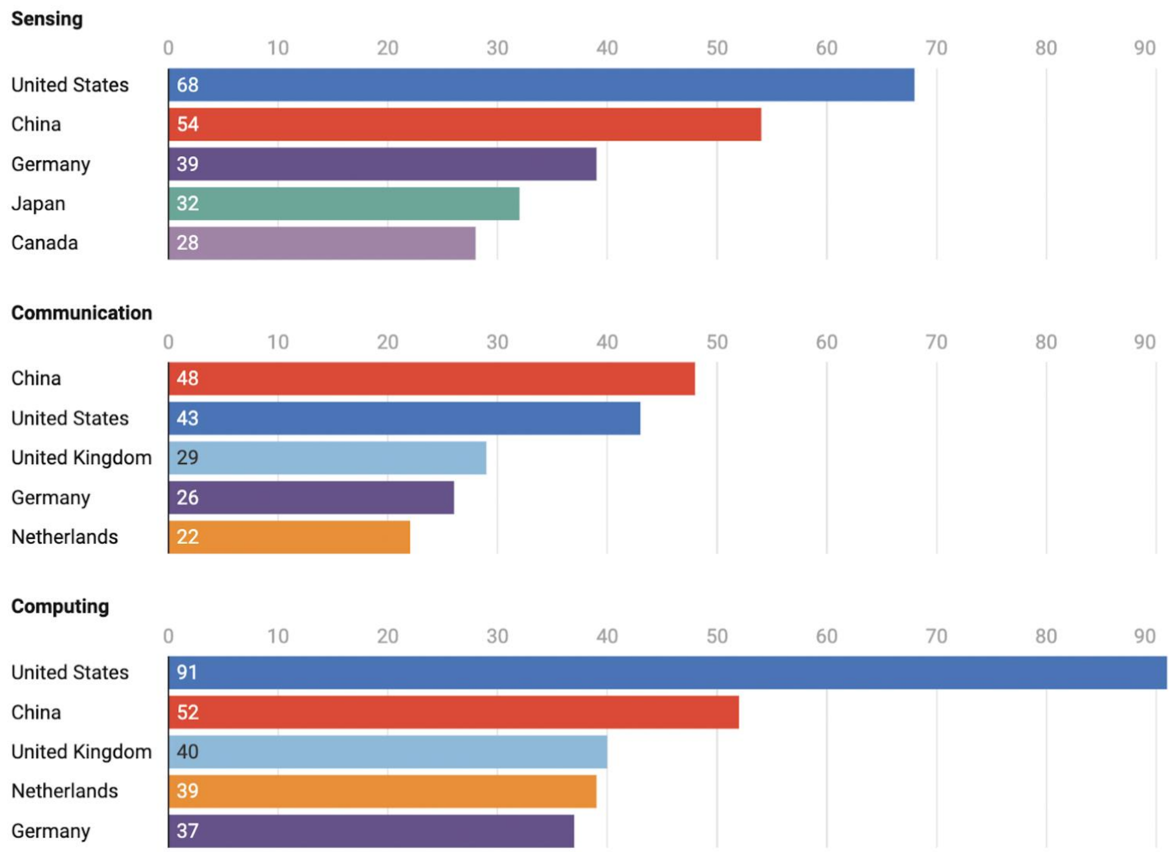

Figure 2: Top H-Index Scores for Quantum Technology by Country from 2018-2022 (CSIS China Power Project).

Given how China's investment in quantum is highest by measure of proportion of GDP, coupled by its rise in the private sector which may directly challenge the United States, along with the United States' high ranking on the Hirsch Index, the significance of these countries in quantum development is also clear.

Part A: China

As it stands currently, China is the world leader in the specific field of quantum communications (see Figure 2). China's progress on this front is highlighted by the Micius satellite program, which was launched in 2016. Notably, the team that launched this satellite was led by no other than Pan Jianwei, who is known as the face of China's quantum industry.

By 2017, the satellite had achieved the world's first encrypted teleconference. It is difficult to pinpoint the precise points of innovation here as it later came out that the satellite had some security issues, but then researchers responded by saying they had resolved these problems, and that their methods have improved. More specifically, they claimed to have increased the security of QKD, which "allows the creation of encryption keys that are encoded and transmitted using qubits, making them more difficult to break, to a level that was unprecedented." Notably, this project began in cooperation with the Institute for Quantum Optics and Quantum Information (IQOQI), Vienna, of the Austrian Academy of Sciences in 2011 (Lewis & Wood, 2023). Like the case study with Heidelberg University, China is no stranger to leveraging quantum research partnerships abroad. Indeed, China is leading the world with their largest demonstrated QKD network (Choi, 2023).

In terms of quantum computing, one of the most notable actors is the private company Baidu which has just released its first quantum computer. The computer is dubbed as "Qianshi" and has a 10-quantum-bit processor ("China's Baidu Reveals Its First Quantum Computer Called Qianshi," 2022). The U.S. State Department says that Baidu, along with other leading tech giants in China, "have no meaningful ability to tell the Chinese Communist Party 'no' if officials decide to ask for their assistance…Such aid may not necessarily occur routinely, but it certainly can occur—and presumably will—whenever the Party considers this useful and cares to demand it" (Li, 2019).

In the public sector, China is also making strides. Since last year, in a government restructuring, the Communist party has been granted more power in making tech-related policies. And, according to a government work report released in March of 2024, they are going to further prioritize their development of emerging industries, including quantum computing, to reach major strategic and industrial development goals ("China to Step up Quantum Computing, AI in Tech Self-Sufficiency Drive," 2024).

Part B: The United States

Due to the strategic aspects of quantum technologies, it is difficult to pinpoint exactly where the United States lands on innovation. However, it is rumored that despite the competition with China, the United States remains a slightly stronger front. In terms of major players in development, the United States quantum computing industry is largely driven by the private sector. These actors include but are not limited to IBM, Amazon, Intel, Google, Quantinuum, IonQ, Microsoft, Quantum Computing Inc., and Rigetti Computing (Lague, 2023). However, the public sector has also been ramping up in recent years as well. Due to the large amounts of government subsidies and contracts made recently available by the Federal government, there have been scrambles for private industries to secure funding. Other direct revenues of government involvement can be seen in the National Laboratories, with leaders at Sandia, Oakridge and Argonne.

Amid this race for quantum technology, policymakers and scientists have articulated routes that the Biden Administration, and future Administrations, should pursue. These routes tend to be hinged on collaboration with both foreign and private allies. On the one hand, allies like France, Switzerland and Denmark, who are already developing similar technologies themselves, could be used to "spur innovation," "advance democratic technology models" and to "ensure the interoperability of U.S. and allied tech systems" (Howell, 2023). The administration has also hinted that quantum related trade restrictions may be necessary to address the China threat in the future. Finally, the administration also argues that semiconductors may be a good case study to learn from, insofar as the struggle to impose multilateral restrictions has created a haphazard regulation landscape and has demonstrated the need for coalition-building among allies.

The US is advised to leverage the private industry to “build on recent science and technology research security initiatives” and to share foreign threat information with industry partners that are also engaged in quantum questions. Overall, the narrative of the quantum race is that it is one that “the US cannot afford to lose” (Howell, 2023).

CHAPTER THREE: DEFINING SANCTIONS

The previous chapter defined the science behind quantum computing, its unique differences from classical computing, its cross-cutting implications for both civilian and military purposes, and a high-level strategy of quantum computing development in the United States and China. This next chapter of this thesis will draw the connection between quantum computing and sanctions. More specifically, it will answer the questions around the definition of sanctions, their historical usage and the sanction landscape between the United States and China.

The Historical Evolution of Sanctions

During a 1919 speech in Indianapolis, U.S. President Woodrow Wilson described sanctions as a force "more tremendous than war," bringing pressures that "no modern nation [can] resist" (Mulder, 2022). Indeed, compared to other traditional forms of war like air strikes, gas wars, and economic blockades, it is the latter that have been the deadliest as they can aggravate poverty, unemployment, and hunger (Freddy, 2022).

In this chapter, we will understand the historical evolution of sanctions over time, questioning what they are, who they have targeted, what their goals are, and how to measure their effectiveness. Let's begin with the definition of sanctions. On their most basic ground, sanctions are a tool of international diplomacy that are leveraged to achieve a certain end. Freddy explains that while the post-WWII order established the United Nations as the key instrument to implement sanctions, they may be synonymous with blockades, embargoes, boycotts, and similar concepts that gained notoriety during the 20th century (Freddy, 2022). Even though the first recorded use of sanctions occurred back in 432, they appeared again in the 19th century with the

Continental Blockade imposed by Napoleon Bonaparte on the British Isles. During WWI, Britian and France imposed economic sanctions on the German, Austro-Hungarian and Ottoman Empires to systemically restrict the flow of goods and services. These sanctions were crippling, and ultimately resulted in over 400,000 deaths from starvation and illnesses. Sanctions are a story that have been told again and again; in 1917 and 1940-1941, the US imposed sanctions on Japan to disrupt their military aggression. Then, the UK and League of Nations imposed sanctions on Italy during 1936-1937. But, in these specific cases, the sanctions failed. They were interpreted as acts of war by the receiving countries who took extreme measures to sustain their economies (Freddy, 2022).

In recent years, sanctions have been leveraged to address a wide range of issues including environmental concerns, promoting labor rights, establishing democracy, returning captured lands, or preventing the proliferation of nuclear weapons (Freddy, 2022). Since the mid-1990's, sanctions have also become increasingly targeted so that their impacts may be maximized on responsible individuals and minimized for innocent populations. In other words, sanctions have been less comprehensive and oriented towards governments, and rather, more targeted, or aimed at individuals and non-state actors. Two types of new sanctions have emerged. On the one hand, there are selective sanctions, which are less broad than comprehensive embargoes, and involve restrictions on certain financial flows or products. There are also targeted sanctions, which focus on certain groups or individuals in the target country. Of course, there may be some overlap between the two (Hufbauer & Oegg, 2016). Targeted sanctions became a sort of art that was crafted heavily under the George W. Bush Administration which leveraged financial, and not trade, sanctions onto individuals (Reinsch, 2022). Both targeted and selective sanctions may include stipulations like travel bans, asset freezes, or arms embargoes (Giumelli, 2015). With targeted sanctions, methods of evasion have also evolved to include things like the use of black markets, safe havens, identity changes, or informal value transfer systems to circumvent financial sanctions. Overall, targeted sanctions have raised new design and implementation questions that need to be carefully tailored to the type of crisis and the type of target (Giumelli, 2015).

Who tends to impose sanctions?

Sanctions have precedence in international law. The Security Council of the United Nations is empowered to pass sanctions resolutions by a majority vote. Before 1990, the council had only imposed sanctions on two states: Southern Rhodesia and South Africa. Since the end of the Cold War, however, they have doled out sanctions another 20+ times, though several have also been vetoed by Russia and China (Masters, 2019). However, critiques of Security Council sanctions argue that they are “political instruments” in which targets can be chosen strategically and without much oversight or democratic processes (Giumelli, 2015). And, while sanctions could hypothetically be leveraged by other state actors, it may also be worth noting that sanctions imposed by the US are incredibly strong. Kathy Gilsinan with *The Atlantic* explains that “the strength of American sanctions... comes from the centrality of the United States financial system in the global economy, and the dollar’s status as the world’s dominant reserve currency” (Gilsinan, 2019). Indeed, the use of unilateral sanctions imposed by the United States dates to the 19th century. The United States remains the top state that uses unilateral sanctions as a major tool in foreign policy (Baran, 2022).

While the United States dollar has been historically strong, its power is now being challenged. BRICS, an intergovernmental organization comprised of Brazil, Russia, India, China and South Africa, hosted a conference in August of 2023. A major outcome of the conference was the debate that emerged around de-dollarization, and the need to transition to an alternative currency to reduce vulnerability to dollar exchange rate fluctuations. While the conference did not come to a consensus on what the BRICS currency should be, or how it might come about, experts agree that it may include a basket of currencies from the countries in the bloc, using gold as a peg, or perhaps even a common central bank digital currency. Indeed, in recent years, more countries have moved towards carrying out trade in currencies other than the dollar, especially in Latin America and Southeast Asia, which were among the hardest hit during the 2008 financial crisis. Another important development that may challenge the US dollar is China's recent launch of the digital Yuan app, which hit 1.8 trillion yuan in transactions ($249. 33 billion USD) by the end of June 2023 (Caudevilla, 2023).

These recent developments challenge the assumption that the American dollar will remain strong. Moreover, these developments also highlight the potential for the harms of American sanctions to be lessened in the future, making them less coercive and less powerful.

A History of US-China Sanctions

Now that we have traced the historical evolution of sanctions, and the ways to measure their effectiveness, let us ground these broader conversations into the specific context of the United States and China. China has been subjected to American sanctions for more than half a century, beginning with a full trade embargo from 1949 to 1971, and then with subsequent targeted sanctions (Yang et al., 2004). When the Communists emerged victorious against the Nationalists during the Chinese Civil War in 1949, the United States did not extend any diplomatic recognition to the People's Republic of China (PRC). This relationship certainly did not improve when, in 1950, the PRC supported the North Korean invasion of South Korea.

In 1971, the process of normalization began, and trade and travel restrictions began to ease. In 1972, President Nixon made a historic visit to Beijing. By 1979, diplomatic relations were established, and the following decade was characterized by cautious yet increasing cooperation and trade under the U.S. support for Deng Xiaoping. The support flowed both ways. Chen Jian, a scholar in modern Chinese history and writer for The Wilson Center, argues that "cooperation with the United States was from the beginning the cornerstone of Deng Xiaoping's design for China's reform and grand opening project," and he thought that the United States should "play a central role in China's drive toward modernity and beyond" (Jian, 2019). While the emergence of the Cold War tested the relationship between the US and China in various ways, Jian argues that it did not totally undermine it. Over time, the Chinese economy became increasingly integrated with the world market and capitalist systems, despite still being governed by a 'communist' party. Jian argues that for a two-decade period, the United States and China withstood the Asian Financial Crisis of 1997-1998, the shockwaves of September 11th, and the 2008 financial crisis. He contends that the two countries have been fellow stakeholders in "maintaining and enhancing world peace, stability, and prosperity." Jian characterizes that these relations took a turn for the worst under the Trump regime.

It may be important to consider some of the conflicts between the two countries that perhaps manifested over time into Trump's extreme stance. Arguably, US-China relations began to take a hit in June of 1989, when the Chinese government brutally suppressed peaceful pro-democracy movements in what would come to be known as the Tiananmen Square massacre. During this crackdown, hundreds, and perhaps thousands of demonstrators were killed and or wounded. Following the events at Tiananmen Square, then President Bush took various punitive actions, including the suspension of "arms trade, military exchanges, high-level government exchanges, and sought postponement of multilateral development bank loans" ("China: U.S. Economic Sanctions," 1997).

Jian argues that the Chinese "communist" state, which has jettisoned the practice of communism, has faced deep-seated challenges to its legitimacy and has responded with severely repressive approaches. Indeed, in 2018, President Xi Jinping and Chinese lawmakers effectively revised a Constitutional amendment that Deng Xiaoping implemented to prevent a leader from staying in power for more than two terms. Now, Xi will likely remain in power for the rest of his life, and as Freedom House aptly points out, this move dwindles freedom for the 1.4 billion people living in China who are now subjected to a larger timeframe of Xi's repressive regime, which is known for its brutal crackdown on dissidents (*China: Xi Jinping's Third Term Will Mean Dwindling Freedom for 1.4 Billion People*, 2022). Another shift in Deng Xiaoping's policy is reflected in China's behavior on the world stage – while he once advocated for a policy of 'laying low,' Chinese foreign policy has become increasingly assertive. This shift is perfectly exemplified by the Belt and Road Initiative - in which the Chinese Communist Party (CCP) is investing 67.8 billion in developing the infrastructures of countries throughout Africa and Southern Asia (Jian, 2019).

The increasingly repressive CCP regime, coupled with China's dominance on the world stage, has greatly shifted the US's perceptions towards the country away from being a strategic partner and towards the country being a rival that presents serious challenges to the vital social, political, and economic interests of the United States. During the Trump administration these tensions manifested into more sanctions. In 2017, Trump levied tariffs on billions of dollars of Chinese goods. Then, in 2018, Trump banned US agencies from using any systems from the tech giant Huawei out of the suspicion that the company was aiding the CCP's espionage activities (Tellez, 2023). Later, in 2020, Congress passed the Uyghur Human Rights Policy Act and leveraged several targeted sanctions upon two dozen of the highest-ranking Politburo members. These targeted sanctions also extend to the family members of these members and barred them all from travel to the United States. These sanctions were the first of their kind since the consensus building in 1979, with their telos being explicitly to "hold human rights abusers accountable" and to "send a strong signal to Beijing" (Ruwitch, 2020).

Sanctions under the Trump administration continued to 25+ Hong Kong officials and vice chairpersons in the National People's Congress of China for reasons oriented around their restricting of freedoms in Hong Kong. In November 2020, Trump would sign an executive order banning the investment or purchase from Chinese companies designated as "Communist Chinese military companies" by the US Department of Defense (Tellez, 2023).

Since Trump, the Biden Administration has continued the sanction regime. One of the most relevant examples are the rounds of sanctions placed on Chinese companies like Sinno Electronics and Spacety China, after it became evident that they were fueling the Russian military and Wagner group mercenary war machines in Ukraine. Specifically, these companies were placed on the U.S. Department of Commerce Entity list, which subjugates them to restrictions on exports and specific license requirements that bars them from engaging in American markets. In October of 2022, the Biden administration announced export controls on technologies in the semiconductor supply chain to protect American tech industry and curb China's access to the important emerging tech. In December 2022, the administration also sanctioned two individuals and ten entities for their connections to human rights abuses, and interestingly, illegal fishing practices (Ruwitch, 2020).

Larisa Kapustina et al. (2020) argues in the EDP Sciences Journal that the incentives for the US to engage in a trade-war with China have been four-fold. These incentives include to "reduce the deficit of bilateral trade and bring American jobs back home" and to "cut the federal budget deficit." However, importantly, the other two incentives are hinged on reducing the "high-tech capacity of China" and to preventing "the growth of China's military strength." Recent events have really suggested that it may be the latter incentivizes, to curb both technological development and the emergence of China's military strength, that will continue to drive the trade-war. Moreover, this paper does not include analysis on the incentive for the US to take a moral high ground against Chinese human rights abuses, which does seem to be a recurring theme in the sanctions regime, but perhaps this rhetoric is more of a virtual-signal and the intentions may be purely driven by technology and military.

Firstly, regarding emerging technology, President Biden has made several recent policy decisions that have explicitly outlined America's concern for rapid technological progress. In August of 2023, President Biden signed an Executive Order on Addressing United States Investments in Certain National Security Technologies and Products in Countries of Concern. In this order, he directly highlights the connection between advancements in sensitive technologies that enhances the "military, intelligence, surveillance or cyber-enabled capabilities" of foreign adversaries to "conduct activities that threaten the national security of the United States." More specifically, these activities may include the "development of sophisticated weapons systems" and the "breaking of cryptographic codes." He cites specific technologies of concern repeatedly, which include semiconductors, microelectronics, artificial intelligence, and, of course, quantum information technologies. The intent behind these regulations stems from the need for the U.S. to not inadvertently contribute to the technological advancement of countries engaging in activities that are directly harmful to our country's national interests (The White House, 2023).

While the annex of the order is continuously updated, there is one sole country that remains of concern: China. Importantly, this order enables the U.S. Treasury to prohibit or restrict U.S. investments in Chinese entities in quantum, AI, and microelectronics. The order has already received scrutiny from Republicans for not including more technologies, and for certain loopholes that may still allow for investment. Moreover, the Chinese government has also been quick to critique the plan. Their Foreign Ministry stated that it is “gravely concerned” about the order, and that it “resolutely opposes the U.S.'s insistence on introducing investment restrictions on China.” This order has been seen as a stray in Biden’s promise that he would not decouple the United States from China, or that he would obstruct the country's economic development (Freifeld et al., 2023). On top of investment restrictions, this order also requires U.S. citizens to notify any transactions regarding these technologies to foreign nationals, and this order largely expands the scope of prohibited transactions (The White House, 2023). Finally, it establishes a working framework with which agencies like the Departments of Defense, Justice, State and Commerce must cooperate (The White House, 2023).

Prior to this executive order, in May 2022, The White House released a National Security Memorandum regarding the need to increase U.S. presence in quantum computing, while also mitigating the risks that this technology can bring. The memorandum explicitly outlines the U.S. goal of maintaining leadership in quantum through continued “investment” and “partnerships,” and made it mandatory for all agencies working on quantum computing to coordinate with the Director of the Office of Science and Technology Policy (The White House, 2022). Moreover, both executive orders and memorandums were preceded by the National Quantum Initiative, passed in 2018. Importantly, this Initiative paves the way for the national development of quantum computing.

While the Chinese government has yet to announce a formal response or policy to this Executive Order, they have already been trending towards sour relations with America. Though the meeting between President Joe Biden and President Xi Jinping in November of 2023 may signal better relations, it is difficult to see where these talks will go. And, earlier, in July of 2023, China imposed export controls on gallium and germanium, two rare elements that are essential for manufacturing semiconductors. They cited a need to protect "national security interests" as the primary reason for these controls. Meanwhile, China has a monopoly on these goods, producing 80% of the global supply of gallium, and 60% of germanium. Laura He with CNN emphasizes the significance of these actions, writing that they are "indicative of China's willingness to retaliate against the United States... as a tech war simmers" (He, 2023). Indeed, He also characterizes the tech sanction wars over the last year or so. In October of 2022, the Biden administration unveiled export controls to ban Chinese companies from buying advanced chip-related materials without a license to do so, with Japan and Netherlands also joining. Beijing responded by launching a probe into the US chipmaker Micron, before banning its sales to Chinese companies working on critical infrastructure-related projects. He also predicts that more chip curbing attempts from Biden may be coming after Huawei introduced the Mate 60 Pro Smartphone, which uses a new super chip, and has been sending shockwaves through the tech world (He, 2023). Overall, the argument that Kapustina et al. (2020) present regarding the U.S. incentive to sanction China to deter their high-tech capacity is strongly supported by literature and actions that have come directly from the White House. And quantum computing is also becoming an increasingly important part of the emerging technology threat.

Now let us transition to the latter incentive based on curbing China's military might that Kapustina et al. (2020) present. As explicitly highlighted in U.S. foreign policy documents, the link between emerging technologies and military advancements is inherent. In other words, technological changes, while having more menial use, are also directly empowered to bolster things like weapons programs and other specific military capabilities. Independent of technology, the growing strength of the Chinese military is becoming more pronounced. Senior American defense officials identify China as the Department of Defense's "top pacing challenge." Remember the beginning of this paper, where I highlighted the rhetoric of the 2023

China Military Power Report presented to Congress in October, which began by stating that China is the only competitor to the United States with the intent and capacity to reshape the international order (Garamore, 2023). The report also gives light to why China is perceived as an aggressive military threat. On the one hand, the report includes the increasing number of unsafe intercepts of non-allied crafts operating in international sea and airways in the Indo-Pacific region. It also includes China's mounting campaign against Taiwan, including increased ballistic missile overflights, and simulated strike operations after Nancy Pelosi and others in the American delegation visited the island. Moreover, China has allied itself with other U.S. adversaries, including Russia and North Korea.

But, even then, it becomes difficult to separate military policy from technological development. The report also highlights concerns relating to "the PRC continuing to quite rapidly modernize" its military – the People's Liberation Army (PLA) - in all domains of warfare. Indeed, China's Military-Civil Fusion Policy is seeking to maximize linkages between the military and civilian sectors to build China's economic and military strength. The policy dates to Mao Zedong, experienced promotion under President Hu Jintao in 2007, and has since been elevated by President Xi Jinping who has made it the goal of the People's Liberation Army (PLA) to be the strongest military in the world by 2049. However, much of this policy leverages the use of academia and research to advance technology. Key players in this strategy are the Seven Sons of Defense, a group of seven universities that have significant historical ties to China's defense industry and are directly administered by the State Administration for Science, Technology and Industry for National Defense. Georgetown's Center for Security and Emerging Technology found that over 75% of graduates recruited by Chinese state-owned enterprises come from China's Seven Sons of National Defense. Graduates who do not go on to SOEs often directly join the PLA, as well as the Chinese Academy of Engineering Physics (CAEP), which is

China's leading nuclear weapons lab (Center for Security and Emerging Technology, 2020). Many private industries have initiated deals with these universities. These include IBM China and the Beijing Institute of Technology, Microsoft Research Asia and the Harbin Institute of Technology, and Texas Instruments and Harbin Engineering University.

However, academic institutions more broadly have come to play a role in the Military-Civil Fusion strategy with direct integration with defense and security. Indeed, universities undertake research that is at the frontier of defense technology and greatly complement the work necessary for defense conglomerates and defense research organizations. Moreover, the Military-Civil Fusion policy is also connected to the Double First-Class University Plan, with the goal of transforming 98 of China's best universities into competitive, world-class institutions by 2050 (Joske, 2019).

In summary, while the United States may have economic incentives for sanctioning China, or imposing other protectionist measures, these are far outweighed by the technological and military incentives. As we have established in this sub-chapter, technological development is important for China's economy, but also, for its military. Even when technology is decoupled from military, it still becomes clear that China's growing military strength alone has sparked immense concern from the United States.

CHAPTER FOUR: SANCTION EFFECTIVNESS & FRAMEWORK EVALUATION

What makes a sanction effective?

In a journal piece analyzing sanctions as security policy tools, Biersteker & van Bergeijk (2015) argue that there will always be examples of when sanctions work, and when they do not. Thus, to really get down to the efficiency of sanctions, example debates do not work insofar as they can support both sides. And there are various aims of sanctions, including constraining a target in their ability to engage in proscribed activities or send a message. Analysis from the Targeted Sanctions Consortium (TSC) at the United Nations leveraged quantitative summaries of 62 case episodes of targeted sanctions, their purposes, and the responses from the targeted actors. Their findings were that sanctions meant to send a message are nearly three times as effective (27% of the time) compared to those that are intended to coerce a change in behavior, which only work 10% of the time (Bapat et al., 2013). Still, though, these numbers are relatively low.

Despite differing goals of sanctions, Biersteker & van Bergeijk (2015) provide a broad yet helpful framework that poses seven necessary contextual considerations to determine how successful a sanction may be. These determinants include that (1) pre-sanction trade volumes need to be important for economic sanctions to bite, (2) sanctions tend to succeed most in the initial years of implementation, (3) psychological factors can play a major role, (4) sanctions are more likely to succeed if the target is more democratic and less authoritarian, (5) multilateral political commitment makes a sanction more effective, (6) narrowly defined goals and multiple policy instruments increase the success rate of sanctions, and (7) targeted sanctions can be as effective as comprehensive sanctions.

Meanwhile, Freddy (2022) includes that sanction effectiveness can be measured based on the costs to their targets, whether they are impacting their desired targets or if they have external consequences, based on the likelihood of future conflict engagement, and finally, whether they are brought unilaterally or through a coalition (Freddy, 2022). Indeed, Bapat et al. (2013) corroborate these findings, emphasizing the involvement of international institutions and severe costs on target states to be positively and robustly related to sanctions success at “every stage” in sanctions episodes (Bapat et al., 2013, p. 2). One interesting implication they raise is that ending sanctions, whether they are effective or ineffective, remains difficult once implemented.

General Effectiveness of US-China Sanctions

In making the evaluation of sanctions more specific, who have been the winners and the losers of the US-China trade war as it has played out so far? Along with the incentives for a continued trade war that the Kapustina et al. (2020) paper highlights, it goes on to establish four potential scenarios of trade-war outcomes between the US and China. They conclude, however, that no trade war has a winner, but rather, there are three losers: both trade partners, and the global decline in trade which results in a slowdown of global economic growth (Kapustina et al., 2020).

On the one hand, analysis from the Center for Strategic and International Studies finds that sanctions may legitimize Chinese nationalist narratives proliferated by Xi Jinping, and the concept that China is emerging from a “century of humiliation” (Reinsch, 2022). Recent U.S. policy, whether it be Biden’s Executive order to restrict investments in technology, or the CHIPS Act, have explicitly defined the U.S. national strategy to restrict China’s access to emerging advanced technologies. China may retaliate against these actions with measures like shutting down US business in their country or cutting off key exports. This puts American companies in a unique bind in that China is “simultaneously their biggest customer and their biggest threat.”

Ultimately, “companies will decide for themselves how to navigate the divide, but the trend toward moving away from China is clear, and the Chinese approach to trade weaponization will only accelerate that process” (Reinsch, 2022).

Yang et al. (2004) allude to some of the complexity of understanding the effectiveness of sanctions in the specific US-China context. They characterize US economic sanctions against China into three major categories: those that apply to China but are not exclusive to China, multilateral sanctions that the US leads or participates in that again apply but are not exclusive to China, and finally, those that are specific to China. These different categories of sanctions have different objectives, which is one aspect that complicates pinpointing whether a sanction is effective, on top of understanding the causality of the results. During the embargo years, they argue that US economic sanctions were effective in stopping trade flows. Since the embargo has been lifted, they also argue that sanctions have hindered the transfer of technology from the US to China, though the impacts are difficult to quantify. In the years since, however, they posit that based on the high performance of the Chinese economy, US sanctions may not have had an adverse impact at all (Yang et al., 2004).

But, have these sanctions been intended to cripple the Chinese economy, or to nudge them towards certain behaviors? They contend that if the true intention of sanctions is the latter, then they may be effective insofar as the ‘history of US China relations shows that China has made specific nonproliferation commitments only under the threat or imposition of sanctions’ (Helms, 1999). This, however, is where the question of causality also comes into play: has China come to the playing-table due to punitive US measures? Or is it already embedded in China’s incentive to cooperate with the United States, to avoid a confrontation that would not be good for either country?

Going forward, Tiffert (n.d.) establishes a framework of conditions that must be met for engagement with China to meet American national interest. These include (1) transparent relationships, (2) reciprocity in access for all partners, and (3) robust efforts to protect democratic institutions (Tiffert, n.d.). However, it is unclear to what extent the US will hinge their conversations with China on these values. Moreover, China has not explicitly stated that they share similar values, and their entire state apparatus hinges on relationships that are not transparent, all partners do not get access to benefits, and perhaps most importantly, there is a true lack of democratic institutions.

Are U.S. quantum sanctions effective right now?

The existing literature contains an important gap around sanction effectiveness. The gap comes from the assumption that the United States has the strongest economy, and that sanctions will generally be placed from a stronger actor to a weaker actor. These assumptions fall in our current situation given the debates around whether China or the United States is the stronger economic power. There is not a consensus that the United States is fully outpacing China right now, and there is certainly not a consensus about how the two countries could compare in the future. Thus, existing literature cannot fully predict trade-wars or sanction escalation between what seem to be two evenly matched economic powers, who, to make matters more complicated, are simultaneously coupled to one another. Moreover, in the specific context of emerging technologies, the roles of the sanction coercer and sanction target are not completely defined insofar as both countries fluctuate between the two roles. When we get more specific into the context of quantum computing, these roles may be easier to assign insofar as the United States is the only one out of the two who is currently ‘coercing’ or targeting Chinese quantum. For this reason, we will go ahead and assume that the United States continues to play the role of the 'coercer,' with the caveat that this may change in the future.

While little literature addresses the questions highlighted above, Lacy and Niou (2004) offer a helpful framework. They point out the perplexing puzzle about sanctions that we began with: if sanctions are so unlikely to succeed in the first place, as the majority of sanction literature suggests, then why do they continue to be imposed? Why have they not been phased out? In response to this question, they highlight the methodological failure of existing literature insofar as sanctions are only observed when "the threat of sanctions has failed" (Lacy & Niou, 2004, p. 25). Rather, the real success of sanctions will not be "observable in cases where sanctions are imposed" and their success is found when they are *not* imposed (Lacy & Niou, 2004, p. 38). They argue that their true success can be found when threatened sanctions change the behavior of targets. Using this definition of success, sanctions imposed by the United States on the Chinese quantum computing sector have already failed given that they have already been implemented, meaning that they had no impact during the threat stage. Lacy and Niou highlight a total of five potential sanction scenarios in Table 3.

Table 3: The Five Scenarios of Sanction Outcomes

Scenario #1	The coercer does not threaten sanctions
Scenario #2	The coercer threatens, the target complies, and there are no sanctions
Scenario #3	The coercer threatens, the target does not comply, the coercer sanctions, the target does not capitulate
Scenario #4	The coercer threatens, the target does not comply, the coercer sanctions, the target does capitulate
Scenario #5	The coercer threatens, the target does not comply, the coercer does not imply sanctions

Source: Lacy & Niou, 2004

Given the status quo, scenarios 3-4 are the most important to pay attention to. Step one of the coercer (US) threatening sanctions has already occurred. Now, we stand at step two in compliance. At the time of this paper, China has not responded with their own sanctions directly on the US quantum computing industry. However, their actions to heavily restrict gallium and germanium during the summer of 2023 have signified that they may be willing to respond with restrictive measures in the future to further cut off US supply chains for critical resources. China does not seem to be a compliant actor. However, it may also be worthwhile to understand what China could necessarily do to make them 'compliant' with the interests of the United States. Here, it may be helpful to draw upon Tiffert's framework of conditions that would make Chinese engagement on the terms of American national interest[1]. However, the feasibility of compliance specifically on quantum computing seems unlikely for several reasons.

[1] Again, these include (1) transparent relationships, (2) reciprocity in access for all partners, and (3) robust efforts to protect democratic institutions (Tiffert, 2023).

Firstly, from the perspective purely from that of the literature review, there seems to be hardly any analysis that supports the idea that the United States and China would collaborate on this issue, and all analysis seems to support the concept that a technology race has emerged. Because this analysis draws from an amalgam of economic and security policies, and statements from top government officials from both countries, the institutions and individuals who would be the most directly empowered to foster collaboration are not focused on collaboration but competition. Secondly, it is not intuitively clear why two countries who are vying for the rankings of the most powerful economy and army in the world would want to collaborate on a technology that could push them ahead in these races. Finally, it is also unclear if there will be a force that will compel China to comply insofar as they are strong as they stand.

All of this is not to say that compliance is completely impossible. Indeed, there have been recent conversations between the two countries, such as the step forward in diplomatic relations between President Biden and President Xi in November of 2023. And, even if compliance was the outcome, it may also be interesting to ponder if that world is preferable to one of competition? It may be hard to say. However, as Lacy and Niou (2004) argue, sanctions have the potential to represent improvements to the status quo, writing that "the resolute coercer is certainly no worse off imposing sanctions that are ignored than it is continuing under the status quo" (Lacy & Niou, 2004, p. 38). Indeed, this conclusion sets them apart from the rest of the literature that suggests sanctions will tend to always lead to detriments. However, it could certainly be a benefit for the United States to follow-up its ideological and principled beliefs with tangible actions like sanctions. However, it is hard to say that sanctions will for sure lead to some sort of net benefit when compared to the status quo. Moreover, it is also difficult to pinpoint who exactly benefits from those sanctions, and why that group ought to gain at the expense of the losers, which are similarly difficult to pinpoint. The weighing of this increase, then, is muddled and unsure.

Then, if the party does not comply, scenarios three, four and five become most likely. The question then becomes whether the coercer chooses to sanction. Given the status quo of the quantum computing landscape between the United States and China, this seems to be the crossroads that we currently find ourselves in. As discussed before, the United States has the incentive to sanction Chinese quantum computing firms for the purposes of both mitigating their technological capacity and military capacity. Quantum computing represents not only a technological development on its own, but it is also inherently tied to military strategy as literature suggests that it has major repercussions for traditional warfare, and that it may also represent a new sort of warfare with its ability to decrypt massive amounts of information. Moreover, the supply chain of quantum computing, which relies heavily on Helium-3, already represents a contentious arena of international trade and is subjected to sanctions from its nuclear sourcing.

The United States has recently imposed export controls on advanced chips, as well as Biden's August 2023 Executive Order on "Addressing United States Investments in Certain National Security Technologies and Products in Countries of Concern" that regulates American investments in Chinese quantum information systems. Other legislative efforts like the White House National Security Memorandum regarding the need to increase U.S. presence in quantum computing, and the National Quantum Initiative, all highlight a moving direction of foreign economic and technological policy moving to address the increasing needs of quantum. Kevin Klyman, a technology researcher at Harvard's Belfer Center, predicts that "export controls on quantum computing hardware, error correction software, and the provision of cloud services to Chinese entities are poised to become the next front in the U.S.-China tech war" (Klyman, 2024).

Given all this analysis, it seems unlikely that the United States would push the pedals on sanctioning Chinese quantum computing. This means that scenario five, in which sanctions do not occur, seems to be the least probable. The questions that then remain are (1) whether these punitive economic measures will continue to escalate or if some consensus can be reached, and (2) what their escalation necessarily entails. Given the CCP's control of private industry, could it be a likely scenario that the United States increasingly outlaws American private involvement? Would this be feasible given the coupling of the two economies? Lacy and Niou (2004) contend that it may not be this worst-case scenario, given that the "differences in the sanction behavior of a coercer may be rooted in its preferences, not its capabilities" (Lacy & Niou, 2004, p. 39). It is this latter question about what sanction escalation entails that may bridge the gap between scenarios three and four, and whether the target capitulates or not.

CONCLUSION

The links between quantum computing and sanctions are clear. On the one hand, quantum computing directly empowers a country's defense and economic sectors, which may be reason enough to curb their advancement. Additionally, the uniquely scarce and finite supply chain of quantum computers makes the additional case for sanction consideration. Importantly, the United States and China are actively engaged in semiconductor and rare earth mineral sanction wars, which will continue to get worse in a world where these goods are increasingly needed in quantum computing. Moreover, quantum computers also require Helium; with one option being He-3, a nuclear byproduct which is already heavily regulated, contested, and subjected to immense export control measures, and the other option being He-4, a naturally occurring element that is finite, and is becoming embedded in the Great Power Conflict as China has sought to mine for it on the moon.

Given the race for quantum supremacy and breaking encryption, the debate between realism and liberalism remains. From the perspective of the United States, is it in their best interest to collaborate with China? From a realist perspective, the race between the United States and China is really a zero-sum game in which there is a clear winner, a clear loser, and both states will act out of pure self-interest. Indeed, this perspective is largely supported when you consider the real applications of quantum computing in the military space, and the fact that President Xi Jinping has made the outspoken stance that China strives to be the strongest military in the world by 2049. The CCP is known to have fostered one of the most politically unfree nations in the world, with media freedom rates on par with those in North Korea, as well as the clear persecution of minority groups like Uyghur Muslims who are forced into labor camps. Of course, then, the United States should do everything it can to protect the ideals of democracy, and to prevent the chaos that would ensue across the world if the balance of power shifted to a new state leader, and one that is quite authoritarian, at that.

However, there is more nuance to this idea of collaboration, and it is not totally unprecedented. This is where the liberalism argument comes in. Indeed, China and the United States have come to the discussion table on topics regarding climate change, economic growth, and various other issues that are the in the interest of both countries to collaborate on. Moreover, China continues to urge nuclear-countries to adopt a no-first use policy, which is suggestive of the idea that countries ought to sacrifice some of their own military interests to work together towards a shared goal, and the common interest of international security.

One thing that remains clear is that sanctions have failed, time and time again. Even in the specific context of the United States and Chinese sanctions around quantum computing, the impact calculus is so muddied and obscured by the fact that there has never been a precedent for two very evenly matched economies and militaries to engage in hostilities to this scale against one another. Moreover, if one buys the analysis that sanctions are only effective at the threat stage when they are not leveraged, then American sanctions against China have failed. This failure creates a vacuum where new possibilities and new outcomes are needed.

Perhaps some of this paper is meta as it deals with the large, daunting concepts of quantum computing, trade wars, game theory, and various outcomes in the quantum race that have impacts so wide-ranging that we can barely predict them. As I conclude, I want to bring in more tangible analysis about the narratives around quantum technologies and how they are perceived by the public. Indeed, the differences between quantum communications, sensing and computing tend to be simplified under one umbrella. This means that there is a lack of nuanced dialogue, insofar as all quantum technologies have unique applications and arrival timeframes. For example, quantum sensor technologies have already been deployed in the public sector, while quantum computing may still be years away. In a December 2023 commentary for the Brookings Institute, Joseph B. Keller extrapolates the impact of a lack of quantum education. He explains that “meaningful public awareness,” which can be achieved through “more formal education and general literacy initiatives,” is crucial when it comes to “ensuring the responsible development, adoption, and support of this groundbreaking technology in the United States” (Keller, 2023).

Alexei Grinbaum, the director of research at The French Alternative Energies and Atomic Energy Commission, discusses the systemic causes behind the lack of knowledge on quantum technologies. When it comes to the narratives used to explain quantum technologies to lay audiences, Grinbaum argues that they tend to follow pragmatic approaches that leverage logic and simplicity. He explains, however, that these narratives also perpetuate the idea of a black box, in which certain processes are purposely not publicized but assumed to work. While he concedes that these narratives may be effective in explaining these technologies, they may come at the expense of hindering public trust and make quantum something that is meta and intangible. He concludes that narratives should incorporate “scientific content” and provoke a “feeling of beauty.” He cites specific examples - like how entanglement could be complemented by mythological stories. Overall, he sees a great beauty in the strange, yet confusing properties of quantum, and argues that these should not be left out, but leaned into (Grinbaum, 2017). Even Einstein was willing to put words to the indescribable aspects of quantum by calling them “spooky.”

Narratives and perceptions aside, quantum technologies have proven their historical relevance and are going to be increasingly embedded into our future as they continue to advance. Past discoveries have blended into current innovation, and time and time again, emerging technologies have been proven to be malleable by humans. The final question of this paper then remains: what role will you, as an individual, an academic, a scientist, and an innovator play in shaping the outcome of arguably the most important technological development that we will see in our lifetime?

References

Abughris, N. (n.d.). *A Brief History of Economic Sanctions*. Carter-Ruck. Retrieved October 6, 2023, from https://www.carter-ruck.com/insight/a-brief-history-of-economic-sanctions/

Alaminos, D., Salas, M. B., & Fernández-Gámez, M. A. (2022). Quantum Computing and Deep Learning Methods for GDP Growth Forecasting. *Computational Economics*, *59*(2), 803–829. https://doi.org/10.1007/s10614-021-10110-z

Applied Quantum Computing for Today's Military. (2021, May). Advanced Technology Academic Research Center. https://atarc.org/wp-content/uploads/2021/05/ATARC-Military-Paper-by-Quantum-Working-Group.pdf

Baran. (2022, April 22). What is the International Law on Unilateral Sanctions?: Examining the Case of Unilateral Sanctions Imposed on Russia. *Al Sharq Strategic Research*. https://research.sharqforum.org/2022/04/22/unilateral-sanctions/

Bapat, N. A., Heinrich, T., Kobayashi, Y., & Morgan, T. C. (2013). Determinants of Sanctions Effectiveness: Sensitivity Analysis Using New Data. *International Interactions*, *39*(1), 79–98. https://doi.org/10.1080/03050629.2013.751298

Blinova, E. (, 20230714T1856). *Future Technologies Forum: Russia Races Against Time Pushing Quantum Computing*. Sputnik International. https://sputnikglobe.com/20230714/future-technologies-forum-russia-races-against-time-pushing-quantum-computing-1111878551.html

Biersteker, T., & van Bergeijk, Peter A.G. (2015). *I. HOW AND WHEN DO SANCTIONS WORK? THE EVIDENCE*. https://doi.org/10.2815/710375

Brezinski, M. E. (2006). 9 - ADJUVANT TECHNIQUES: ABSORPTION SPECTROSCOPY, CONTRAST PROBES, PHASE CONTRAST, ELASTOGRAPHY, AND ENTANGLED PHOTONS. In M. E. Brezinski (Ed.), *Optical Coherence Tomography* (pp. 245–275b). Academic Press. https://doi.org/10.1016/B978-012133570-0/50011-1

Caudevilla, O. (2023, September 18). *Opinion: A single currency is not the best way for Brics to de-dollarise*. South China Morning Post. https://www.scmp.com/comment/opinion/article/3234729/brics-has-better-way-de-dollarise-creating-single-currency

Cao, S., Wu, B., Chen, F., Gong, M., Wu, Y., Ye, Y., Zha, C., Qian, H., Ying, C., Guo, S., Zhu, Q., Huang, H.-L., Zhao, Y., Li, S., Wang, S., Yu, J., Fan, D., Wu, D., Su, H., … Pan, J.-W. (2023). Generation of genuine entanglement up to 51 superconducting qubits. *Nature*, *619*(7971), 738–742. https://doi.org/10.1038/s41586-023-06195-1

Center for Security and Emerging Technology, Fedasiuk, R., & Weinstein, E. (2020). *Universities and the Chinese Defense Technology Workforce*. Center for Security and Emerging Technology. https://doi.org/10.51593/20200043

China to impose sanctions on two U.S. companies over Taiwan arms sales_英语频道_央视网(cctv.com). (n.d.). Retrieved September 25, 2023, from https://english.cctv.com/2023/09/16/ARTIo6oxnkR4fM9IeOanrVXg230916.shtml?spm=C69523.PREmHITS7XIG.MaHyxoHRqIrX.3

China to step up quantum computing, AI in tech self-sufficiency drive. (2024, March 5). *Reuters*. https://www.reuters.com/technology/china-step-up-quantum-computing-ai-efforts-its-aims-tech-self-sufficiency-2024-03-05/

China: U.S. Economic Sanctions. (1997). *Congressional Research Service, Library of Congress*. https://www.everycrsreport.com/files/19971001_96-272_f3b51f9f7428f4d9c3024100b02ffef52aabd6fd.pdf

China's Baidu reveals its first quantum computer called Qianshi. (2022, August 25). *Reuters*. https://www.reuters.com/technology/chinas-baidu-reveals-its-first-quantum-computer-called-qianshi-2022-08-25/

China's gallium, germanium exports drop to zero as tech war simmers | CNN Business. (n.d.). Retrieved September 21, 2023, from https://www.cnn.com/2023/09/21/economy/china-chip-material-exports-drop-intl-hnk/index.html

China: Xi Jinping's Third Term Will Mean Dwindling Freedom for 1.4 Billion People. (2022, November 14). Freedom House. https://freedomhouse.org/article/china-xi-jinpings-third-term-will-mean-dwindling-freedom-14-billion-people

Chinese Threats in the Quantum Era. (n.d.). Retrieved March 31, 2024, from https://www.boozallen.com/expertise/analytics/quantum-computing/chinese-cyber-threats-in-the-quantum-era.html

Choi, D. (2023, September 6). Quantum Technology and the Military – Revolution or Hype? The Impact of Emerging Quantum Technologies on Future Warfare. *Marine Corps University*. https://doi.org/10.36304/ExpwMCUP.2023.11.

Cimpanu, C. (2021, November 25). *US sanctions 28 quantum computing entities in China, Russia, Pakistan, Japan*. https://therecord.media/us-sanctions-28-quantum-computing-entities-in-china-russia-pakistan-japan

Davis, R. (2021, September 29). Cutting Through the Hype of Quantum Optimization. *Qiskit*. https://medium.com/qiskit/cutting-through-the-hype-of-quantum-optimization-6d4b5c95e377

DelViscio, M. T., Andrea Gawrylewski,Jeffery. (2021, July 7). *How Does a Quantum Computer Work?* Scientific American. Retrieved September 8, 2023, from https://www.scientificamerican.com/video/how-does-a-quantum-computer-work/

DOE Explains...Quantum Mechanics. (n.d.). Energy.Gov. Retrieved September 8, 2023, from https://www.energy.gov/science/doe-explainsquantum-mechanics

Exclusive: Sanctions lead to scientific collaboration between Russia and China. (2023, July 22). South China Morning Post. https://www.scmp.com/news/china/science/article/3228292/quantum-entanglement-how-us-led-sanctions-are-turning-russias-genius-scientists-china-collaboration

Exploring quantum computing use cases for logistics. (2022, August 21). IBM. https://www.ibm.com/thought-leadership/institute-business-value/en-us/report/quantum-logistics

Faye, J. (2019). Copenhagen Interpretation of Quantum Mechanics. In E. N. Zalta (Ed.), *The Stanford Encyclopedia of Philosophy* (Winter 2019). Metaphysics Research Lab, Stanford University. https://plato.stanford.edu/archives/win2019/entries/qm-copenhagen/

Felden, E., & Petersmann, S. (2023, June 6). *China's quantum leap—Made in Germany – DW – 06/13/2023*. Dw.Com. https://www.dw.com/en/chinas-quantum-leap-made-in-germany/a-65890662

Fernando, J. (2024, March 11). *What Are Public Goods? Definition, How They Work, and Example*. Investopedia. https://www.investopedia.com/terms/p/public-good.asp

Freedman, S. J., & Clauser, J. F. (1972). Experimental Test of Local Hidden-Variable Theories. *Physical Review Letters*, *28*(14), 938–941. https://doi.org/10.1103/PhysRevLett.28.938

Freifeld, K., Shalal, A., & Shepardson, D. (2023, August 10). Biden orders ban on certain US tech investments in China. *Reuters*. https://www.reuters.com/world/white-house-detail-plans-restricting-some-us-investments-china-source-2023-08-09/

Freddy, H. J. (2022, December 9). *Sanctions as a Weapon of War: The European Experience*. ORF. Retrieved October 5, 2023, from https://www.orfonline.org/research/sanctions-as-a-weapon-of-war/

Garamore, J. (2023, October 19). *DOD Report Details Chinese Efforts to Build Military Power*. U.S. Department of Defense. https://www.defense.gov/News/News-Stories/Article/Article/3562442/dod-report-details-chinese-efforts-to-build-military-power/https%3A%2F%2Fwww.defense.gov%2FNews%2FNews-Stories%2FArticle%2FArticle%2F3562442%2Fdod-report-details-chinese-efforts-to-build-military-power%2F

Garfinkel, S. (2022, June 27). *Quantum Sensors—Unlike Quantum Computers—Are Already Here*. Defense One. https://www.defenseone.com/ideas/2022/06/quantum-sensorsunlike-quantum-computersare-already-here/368634/

Giles, M. (2019). *Explainer: What is quantum communication?* MIT Technology Review. https://www.technologyreview.com/2019/02/14/103409/what-is-quantum-communications/

Gilsinan, K. (2019, May 3). A Boom Time for U.S. Sanctions. *The Atlantic*. https://www.theatlantic.com/politics/archive/2019/05/why-united-states-uses-sanctions-so-much/588625/

Giumelli, F. (2015). Understanding United Nations targeted sanctions: An empirical analysis. *International Affairs*, *91*(6), 1351–1368. https://doi.org/10.1111/1468-2346.12448

Global Quantum Computing Market Size To Grow USD 143.44 Billion By 2032 | CAGR of 26.5%. (2023, June 12). GlobeNewswire News Room. https://www.globenewswire.com/en/news-release/2023/06/12/2686201/0/en/Global-Quantum-Computing-Market-Size-To-Grow-USD-143-44-Billion-By-2032-CAGR-of-26-5.html

Grinbaum, A. (2017). Narratives of quantum theory in the age of quantum technologies. *Ethics and Information Technology*, *19*(4), 295–306. https://doi.org/10.1007/s10676-017-9424-6

Hart, B., Lin, B., Lu, S., Price, H., Liao, G., & Slade, M. (2023, August 14). Is China a Leader in Quantum Technologies? *ChinaPower Project*. https://chinapower.csis.org/china-quantum-technology/

He, L. (2023, September 21). *China just stopped exporting two minerals the world's chipmakers need | CNN Business*. CNN. https://www.cnn.com/2023/09/21/economy/china-chip-material-exports-drop-intl-hnk/index.html

Helium | NIDC: National Isotope Development Center. (n.d.). Retrieved November 28, 2023, from https://www.isotopes.gov/products/helium

Helium Shortages and Quantum Computing. (n.d.). *Inside Quantum Technology*. Retrieved November 28, 2023, from https://www.insidequantumtechnology.com/news-archive/helium-shortages-quantum-computing/

'He's had a bad summer': Xi faces calls to loosen grip as China's crises mount | Xi Jinping | The Guardian. (n.d.). Retrieved September 25, 2023, from https://www.theguardian.com/world/2023/sep/17/hes-had-a-bad-summer-xi-faces-calls-to-loosen-grip-as-chinas-crises-mount

Howell, S. (2023, January 13). *The China-US Quantum Race*. The Diplomat. https://thediplomat.com/2023/01/the-china-us-quantum-race/

How Does a Dilution Refrigerator Work? (2023, February 13). *Bluefors.Com*. https://bluefors.com/stories/how-does-a-dilution-refrigerator-work/

Jian, C. (2019, November). *From Mao to Deng: China's Changing Relations with the United States | Wilson Center*. https://www.wilsoncenter.org/publication/mao-to-deng-chinas-changing-relations-the-united-states

Joske, A. (2019, November 25). *The China Defence Universities Tracker*. Retrieved September 7, 2023, from http://www.aspi.org.au/report/china-defence-universities-tracker

Kapustina, L., Lipková, Ľ., Silin, Y., & Drevalev, A. (2020). US-China Trade War: Causes and Outcomes. *SHS Web of Conferences*, *73*, 01012. https://doi.org/10.1051/shsconf/20207301012

Keller, J. (2023, December 5). *U.S. quantum leadership may hinge on public perceptions*. Brookings. Retrieved January 31, 2024, from https://www.brookings.edu/articles/u-s-quantum-leadership-may-hinge-on-public-perceptions/

Krelina, M. (2021). Quantum technology for military applications. *EPJ Quantum Technology*, *8*(1), Article 1. https://doi.org/10.1140/epjqt/s40507-021-00113-y

Klyman, K. (2023, March 31). The U.S. Wants to Make Sure China Can't Catch Up on Quantum Computing. *Foreign Policy*. https://foreignpolicy.com/2023/03/31/us-china-competition-quantum-computing/

Kurek, M. (2020, September 8). New record looms in VC funding of quantum startups. *Le Lab Quantique*. https://medium.com/le-lab-quantique/new-record-looms-in-vc-funding-of-quantum-startups-484b82541004

Lacy, D., & Niou, E. M. S. (2004). A Theory of Economic Sanctions and Issue Linkage: The Roles of Preferences, Information, and Threats. *The Journal of Politics*, *66*(1), 25–42. https://doi.org/10.1046/j.1468-2508.2004.00140.x

Lague, D. (2023, December 14). U.S. and China race to shield secrets from quantum computers. *Reuters*. https://www.reuters.com/investigates/special-report/us-china-tech-quantum/

Lewis, J. A., & Wood, G. (2023). *Quantum Technology: Applications and Implications*. https://www.csis.org/analysis/quantum-technology-applications-and-implications

Levy, P. I. (1999). Sanctions on South Africa: What Did They Do? *The American Economic Review*, *89*(2), 415–420.

Li, J. (2019, September 13). *A US official says tech giants Alibaba and Tencent present similar risks as Huawei*. Quartz. https://qz.com/1708662/chinese-tech-giants-tools-of-the-communist-party-us-official

Masters, J. (2019, August 12). *What Are Economic Sanctions?* Council on Foreign Relations. https://www.cfr.org/backgrounder/what-are-economic-sanctions

Mulder, N. (2022, February 24). The History of Economic Sanctions as a Tool of War. *Yale University Press*. https://yalebooks.yale.edu/2022/02/24/the-history-of-economic-sanctions-as-a-tool-of-war/

Moloo, N. (2021, February 28). *Understanding Quantum Superposition Through the Schrödinger's Cat Thought Experiment*. Medium. https://studentsxstudents.com/understanding-quantum-superposition-through-the-schr%C3%B6dingers-cat-thought-experiment-d0cea6e13063

Monroe, C., Raymer, M. G., & Taylor, J. (2019). The U.S. National Quantum Initiative: From Act to action. *Science*, *364*(6439), 440–442. https://doi.org/10.1126/science.aax0578

Morin, D. (n.d.). Introduction to quantum mechanics. . . *INTRODUCTION TO QUANTUM MECHANICS*.

National Quantum Coordination Office (NQCO). (n.d.). National Quantum Initiative. Retrieved September 3, 2023, from https://www.quantum.gov/

National Security Memorandum on Promoting United States Leadership in Quantum Computing While Mitigating Risks to Vulnerable Cryptographic Systems. (2022, May 4). The White House. 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/

NTT Research (Director). (2021, September 12). *Quantum Computers Explained in a Way Anyone Can Understand*. https://www.youtube.com/watch?v=zhQItO6_WoI

Nagashybayeva, G. (n.d.). *Research Guides: U.S. Trade with China: Selected Resources: Chinese State-Owned Enterprises* [Research guide]. Retrieved March 8, 2024, from https://guides.loc.gov/us-trade-with-china/state-owned-enterprises

Hufbauer, G. C., & Oegg, B. (2016, March 2). *Targeted Sanctions: A Policy Alternative? | PIIE*. https://www.piie.com/commentary/speeches-papers/targeted-sanctions-policy-alternative

Reinsch, W. A. (2022). *Weaponizing Trade*. https://www.csis.org/analysis/weaponizing-trade-0

Report for Selected Countries and Subjects. (n.d.). IMF. Retrieved October 27, 2023, from https://www.imf.org/en/Publications/WEO/weo-database/2021/April/weo-report

Rose, D. (2020). *Why has the UK handed the world's new most powerful weapon to China? | Daily Mail Online*. Retrieved November 13, 2023, from https://www.dailymail.co.uk/news/article-9044843/Why-UK-handed-worlds-new-powerful-weapon-China.html

Robertson, N. (2023, October 25). China calls US 'disruptor' of peace after reported Beijing military buildup [Text]. *The Hill*. https://thehill.com/policy/international/4274876-china-calls-us-disruptor-of-peace/

Rummler, T. (2023, February 9). *Securing supply chains with quantum computing*. LabNews. Retrieved November 28, 2023, from https://www.sandia.gov/labnews/2023/02/09/securing-supply-chains-with-quantum-computing/

Pii, J. (2023, April 13). *Chinese Quantum Companies and National Strategy 2023*. The Quantum Insider. https://thequantuminsider.com/2023/04/13/chinese-quantum-companies-and-national-strategy-2023/

Potter, J. (2023, November 1). *Quantum Slated to Better Maneuver Missiles*. Quantum Business News. https://www.quantumbusinessnews.com/applications/quantum-slated-to-better-maneuver-missiles-

Quantum Dragon Report—Strider Intel. (2019). Retrieved September 8, 2023, from https://erebor.striderintel.com/resources/quantum-dragon-report/

Quantum Consulting—Amazon Quantum Solutions Lab—AWS. (n.d.). Amazon Web Services, Inc. Retrieved November 20, 2023, from https://aws.amazon.com/quantum-solutions-lab/

Roberson, T., Leach, J., & Raman, S. (2021). Talking about public good for the second quantum revolution: Analysing quantum technology narratives in the context of national strategies. *Quantum Science and Technology*, *6*(2), 025001. https://doi.org/10.1088/2058-9565/abc5ab

Ruwitch, J. (2020, July 9). U.S. Sanctions Chinese Officials, Including Politburo Member, For Xinjiang Abuses. *NPR*. https://www.npr.org/2020/07/09/889406296/u-s-sanctions-chinese-officials-including-politburo-member-for-xinjiang-abuses

Sanders, C. (2021, November 25). China criticizes U.S. for putting Chinese firms on trade blacklist. *Reuters*. https://www.reuters.com/business/us-restricts-exports-dozen-more-chinese-companies-2021-11-24/

Salerno-Garthwaite, A. (2023, August 9). Quantum interceptor technology showcased for missile defence. *Army Technology*. https://www.army-technology.com/news/quantum-interceptor-technology-showcased-for-missile-defence/

Seskir, Z. C., Umbrello, S., Coenen, C., & Vermaas, P. E. (2023). Democratization of Quantum Technologies. *Quantum Science and Technology*, *8*(2), 024005. https://doi.org/10.1088/2058-9565/acb6ae

Stadermann, H. K. E., Van Den Berg, E., & Goedhart, M. J. (2019). Analysis of secondary school quantum physics curricula of 15 different countries: Different perspectives on a challenging topic. *Physical Review Physics Education Research*, *15*(1), 010130. https://doi.org/10.1103/PhysRevPhysEducRes.15.010130

Stambaugh, C. (n.d.). *THE ROLE OF INTERNATIONAL TALENT IN QUANTUM INFORMATION SCIENCE.*

Swayne, M. (2023a, February 28). *Top Quantum Spenders Based on GDP -- List Offers Surprising Changes in Leadership Status*. The Quantum Insider. https://thequantuminsider.com/2023/02/28/top-quantum-spenders-based-on-gdp-list-offers-surprising-changes-in-leadership-status/

Swayne, M. (2023b, August 10). *Executive Order Halts American Investment in Chinese Quantum Technology*. The Quantum Insider. https://thequantuminsider.com/2023/08/10/executive-order-halts-american-investment-in-chinese-quantum-technology/

Taskinsoy, J. (2020). *Diminishing American Power: The US - China Trade War, Sanctions, and Coronavirus* (SSRN Scholarly Paper 3677841). https://doi.org/10.2139/ssrn.3677841

Tellez, A. (2023, February 8). *Here Are All The U.S. Sanctions Against China*. Forbes. Retrieved September 22, 2023, from https://www.forbes.com/sites/anthonytellez/2023/02/08/here-are-all-the-us-sanctions-against-china/

The White House. (2023, August 9). *Executive Order on Addressing United States Investments in Certain National Security Technologies and Products in Countries of Concern*. The White House. https://www.whitehouse.gov/briefing-room/presidential-actions/2023/08/09/executive-order-on-addressing-united-states-investments-in-certain-national-security-technologies-and-products-in-countries-of-concern/

The US-China Trade War: Who Dominates Global Trade? (n.d.). Lowy Institute – Charts & Interactives. Retrieved October 27, 2023, from https://interactives.lowyinstitute.org/charts/china-us-trade-dominance/us-china-competition/

Tiffert, G. “Global Engagement: Rethinking Risk in the Research Enterprise.” https://www.hoover.org/sites/default/files/research/docs/tiffert_globalengagement_full_0818.pdf.

Tretkoff, E. (2005). This Month in Physics History. *American Physical Society*, *14*(10). http://www.aps.org/publications/apsnews/200511/history.cfm

Varanasi, L. (2023, December 17). *Brace yourself for “Q-Day,” a global cybersecurity event that could expose our most important secrets*. Business Insider. Retrieved March 31, 2024, from https://www.businessinsider.com/q-day-2025-cybersecurity-quantum-computing-data-security-privacy-china-2023-12

Venegas-Gomez, A. (2020). The Quantum Ecosystem and Its Future Workforce. *PhotonicsViews*, *17*(6), 34–38. https://doi.org/10.1002/phvs.202000044

Walsh, B. (2022, May 24). *This year's physics Nobel Prize went to pioneers in quantum tech. Here's how their work could change the world.* Vox. https://www.vox.com/23132776/quantum-computers-ibm-google-cybersecurity-artificial-intelligence-white-house

Why Quantum Tech Will Change Our Future: Big Brains podcast | University of Chicago News. (n.d.). Retrieved October 28, 2023, from https://news.uchicago.edu/why-quantum-tech-will-change-our-future-day-tomorrow-began

Whittington, M. (2022, September 18). *China has returned helium-3 from the moon, opening door to future technology | The Hill*. https://thehill.com/opinion/technology/3647216-china-has-returned-helium-3-from-the-moon-opening-door-to-future-technology/

Yamamoto, Y., Sasaki, M., & Takesue, H. (2019). Quantum information science and technology in Japan. *Quantum Science and Technology*, *4*(2), 020502. https://doi.org/10.1088/2058-9565/ab0077

Yang, J., Askari, H., Forrer, J., & Teegen, H. (2004). US Economic Sanctions Against China: Who Gets Hurt? *The World Economy*, *27*(7), 1047–1081. https://doi.org/10.1111/j.1467-9701.2004.00640.x

York, S. L. in N., Thornhill, J., Joiner, S., & London, I. de la T. A. in. (2023, May 3). *Quantum computing could break the internet. This is how*. https://ig.ft.com/quantum-computing/