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Outside the Atom:

The Factors Governing the Five Eyes' Quantum Innovation

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Introduction

The hot button issue of quantum technology has been at the forefront of recent global defence conversations. Members of the Five Eyes alliance — Australia, Canada, New Zealand, the United Kingdom, and the United States — have developed dual-use quantum programs for defence and commercialization purposes (Government of Canada 2022; Department of Science, Innovation, and Technology 2023b; Commonwealth of Australia 2023; Ministry of Business, Innovation, and Employment 2022; The Quantum Consortium 2020). These programs are funded by grants and research alliances between public and private industry and similar considerations have guided innovation and funding across Five Eyes nations.

Issues such as climate change, defence usage, commercialization and economic benefit, supply chains, and international competition have surfaced as influences on how the Five Eyes are approaching innovation within their programs and alliances. These common considerations can be discerned from documentation related to quantum programs and strategies released by the Five Eyes. To better position the 5 considerations listed above, we must first understand how the Five Eyes hav him e positioned themselves within this quantum race. The following section details each nation's strategy towards quantum development. Each nation is discussed within its own subsection, organized by nominal GDP.

United States

The United States has taken a broad approach to their national quantum strategy, focusing on multiple domains (National Quantum Initiative Advisory Committee 2023). Following the establishment of the *National Quantum Initiative Act* in 2018, the US allocated roughly $2 billion towards quantum through 2021 (Congressional Research Service, 2023). One focus of these efforts has been to establish partnerships with industry leaders to bolster the US economy (The Quantum Consortium 2020; National Quantum Initiative Advisory Committee 2023). Further efforts to establish a secure domestic quantum economy have been concentrated in workforce development and talent acquisition, starting as early as primary and secondary school (Subcommittee on Quantum Information Science

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2022). The US has also begun to shift its attention towards commercialization, quantum internet, and migration to post-quantum cryptographic systems (National Quantum Initiative Advisory Committee 2023; US Department of Energy 2018; The White House 2022). These goals, while encouraging economic growth, are part of the US national defence strategy to counteract potential 'malign actors' and to encourage increased international cooperation in NATO, AUKUS, and the Five Eyes (The White House 2023; National Quantum Initiative Advisory Committee 2023). The United States continues to strive towards quantum leadership and protecting American quantum in all sectors (The White House 2022; House of Representatives 2023; National Quantum Initiative Advisory Committee 2023).

United Kingdom

The United Kingdom has the most mature quantum strategy, with the establishment of the National Quantum Technologies Programme in 2013 (NQTP 2013). The program features four research hubs with a funding plan of £214 million (NQTP 2013), and the UK has already been able to feast on the fruits of its labour by attaching an atomic clock to one of their Navy ships (Royal Navy 2022). Through research hubs and specialized centres, the United Kingdom has been able to create a robust UK-based quantum supply chain secure from adversaries (NQTP 2013). Also notable are the extensive alliance and research agreements established with countries including the USA, Canada, and Australia (Innovation and Technology 2023; Innovation and Technology 2021; Department of Science, Innovation and Technology 2023b). The United Kingdom's influence also stretches into NATO; one of the headquarters of the Defence Innovation Accelerator for the North Atlantic (DIANA) is in London (Ministry of Defence 2023). British quantum strategy also considers the impact of quantum on the economy and the environment. The industry is expected to bolster thousands of pounds in social value and sensors are predicted to directly benefit the British public beyond a defence lens (Government of the United Kingdom 2023).

Canada

Canada's quantum strategy has been linked to the Department of National Defence and the Canadian Armed Forces (DND/CAF). Canada's strategy is described throughout Canada's *Quantum Science and Technology Strategy, National Quantum Strategy,* and *Quantum 2030* plan (Government of Canada 2020; Government of Canada 2022; Government of Canada 2023). Canada's strategy is focused on sensing technologies related to the changing climate and charting the Arctic (Government of Canada 2020). Canada has taken a stance that views quantum technology as a limitless opportunity, but also as a present danger if harnessed by adversaries (Government of Canada 2023; Bindel and Csenky 2021; Murphy et. al 2024). This has shifted Canada's perspective towards a defence-focused direction, with its alliances concentrating on quantum-safe cryptography and sensing (Innovation and Technology 2023; Bindel and Csenky 2021; Bindel in Csenky 2020). Canada also holds another DIANA headquarters in Halifax, allowing it some leverage and safety (Department of National Defence 2022). Canada has leaned into some commercialization of its quantum technology, with a predicted 3% increase in the nation's GDP by 2045 (Government of Canada 2022). More so, research and development into the security of the Canadian supply chain has proven to be a priority with extensive funding dedicated to private industry and secure communications and transport (Government of Canada 2023). The Canadian approach

is one of the most in-depth dual-use approaches tied directly to alliances with increasing international cooperation in defence sectors.

Australia

Australia's quantum strategy seeks to leverage both its geopolitical position and alliances (Commonwealth of Australia 2023). Thus far, NATO, the Quadrilateral Security Dialogue (QUAD), AUKUS, and the Five Eyes have been Australia's primary sources of international cooperation (Science and Resources - Department of Industry 2023). Considering its geopolitical position close to China, the primary quantum adversary, and collaboration efforts with NATO, QUAD, AUKUS, and the Five Eyes, it is no surprise that Australia's national quantum strategy has targeted quantum through a defence lens (CSIRO 2020). To further research efforts, Australia's quantum team has visited labs in the UK, US, Japan, and South Korea, in addition to sharing research with India (Commonwealth of Australia 2023; Science and Resources - Department of Industry 2023). Similar to Canada, Australia aims to establish a niche expertise in sensing. However, they have approached the problem through private industry developments to encourage the commercialization of Australian quantum technology (Commonwealth of Australia 2023; Anderson 2021). The hope of this commercialization is to establish a AUD$6 billion quantum industry and create 19,400 jobs by 2045 via increased efforts towards advancing STEM capabilities in youth and underrepresented groups (Commonwealth of Australia 2023). Eventually, the nation aims to have these industries make up 9% of the Australian market (CSIRO 2022).

New Zealand

New Zealand, despite having no national quantum strategy, has targeted quantum efforts towards computing, sensing, and communication technologies via the Dodd-Walls Centre for Photonic and Quantum Technologies (Dodd-Walls Centre 2022). In 2022, the centre allocated NZ$814,038 towards various projects within these three domains (Dodd-Walls Centre 2022). It has become clear that New Zealand's quantum strategy is focused on environmental, defence, and commercial applications (Dodd-Walls Centre 2022; Ministry of Business, Innovation, and Employment 2022; New Zealand Government 2023b). Within the defence field, the focus has been on ensuring data protection and secure communications (New Zealand Government 2023b). To achieve these goals, the nation has emphasized the importance of workforce development and international cooperation (Ministry of Business, Innovation, and Employment 2022; Dodd-Walls 2022; New Zealand Government 2023a). New Zealand aims to increase its collaboration within the Five Eyes agreement; however the nation is also looking towards increasing bilateral cooperation with Germany, Australia, the US, and the UK (New Zealand Government 2023a; New Zealand Government 2023b). Through these efforts, New Zealand seeks to emerge as a vital quantum ally and increase its research and development efforts to 2% of the nation's GDP by 2030, ensuring the country benefits from quantum (Ministry of Business, Innovation, and Employment 2022; New Zealand Government 2023b).

With each nation's national strategy outlined, we can see that each nation has emphasized the importance of security, the economy, and leadership within the quantum space. These national strategies have overlooked a few key areas. This project, focusing on the Five Eyes alliance and Quantum technology, has determined several opportunities for potential

improvement within the Five Eyes alliance (Murphy et. al 2024) via these key considerations. The following section details these considerations and what they mean for the Five Eyes.

Recommendations

The project has prioritized analyzing the resilience against climate change provided by quantum technology with a variety of applications that would improve a state's ability to be climate conscious. Quantum sensors have been proposed as a method of reducing greenhouse gasses and carbon emissions, which benefits all states in meeting emissions targets (Department of Science, Innovation, and Technology 2023a; Department of State 2023). Overall, the hope is for quantum to replace more damaging technology with hybrid approaches and aid in the discovery of further green strategies as well as provide better measurements of the current environment.

The most commonly mentioned consideration outside defence is the commercialization and economic benefit of quantum. All Five Eyes provide extensive economic evaluations of the contribution of quantum to GDP, industry, and the development of supply chains (Government of Canada 2022; Department of Science, Innovation, and Technology 2023b; Commonwealth of Australia 2023; Ministry of Business, Innovation, and Employment 2022; The Quantum Consortium 2020). Part of industrial development includes a conversation around talent production and retention. When it comes to this consideration, the Five Eyes are not collaborating, but instead actively competing for members of the same international talent pool (Government of Canada 2023; NQTP 2013; Dodd-Walls Centre 2022). The establishment of an economically fruitful quantum industry in Five Eyes nations remains both a cooperative and deeply competitive process.

Tightly related to the development of an economic industry and supply chain is collaboration with private industry. Five Eyes states have already collaborated with many quantum innovation companies (Kung and Fancy 2021; Anderson 2022). An advantage of this collaboration is the commercialization of developing technologies, however, there are also concerns about the need to control developing technology via cooperation between private industry and government. Without cooperation, corporations may take their headquarters abroad or sell technologies to competitors. When nationally controlled, states can ensure all quantum technologies are dual-use and control the defence usage of new innovations.

This leads to the final consideration of the project which is the collaboration of the Five Eyes within the ongoing quantum arms race. The Five Eyes have reached outside the alliance and collaborated with other organizations such as the North Atlantic Treaty Organization (NATO) (Kung and Fancy 2021; Government of Canada 2023; Commonwealth of Australia 2023; NQTP, 2013; The White House 2022; Ministry of Business, Innovation, and Employment 2023). Perhaps more intuitively, the project also addresses the possibility of Five Eyes adversaries and how the alliance has responded to their developments. The natural example is the People's Republic of China and their rapid development of quantum technology (CSIRO Futures 2022). The Five Eyes maintain a complicated balancing act in which they are collaborating towards quantum development to gain leadership, while simultaneously competing against adversaries and each other for the position (Murphy 2024).

Quantum is a complex issue with both economic and defence considerations at the forefront. Militaries and academics alike are concerned with dual-use aspects of quantum; it is one of the top recommendations of the authors that benefits to the environment are also explored. Quantum is an opportunity to either adjust research and efforts towards climate-conscious science, or to take advantage of quantum technology for extensive resource extraction and environmental damage. In particular, sensing technology has been at the forefront of the resilience and climate conversation (CSIRO 2022). These conversations include that for quantum technology to function well, the climate needs to be stable. However, Canada's capabilities in detecting environmental anomalies and pollution levels are also directly credited to quantum (National Research Council Canada 2023; Government of Canada 2020). Thus, quantum technology is necessary for advancing environmental monitoring technologies but is, itself, vulnerable to our shifting climate. To utilize quantum technology is a step towards a more resilient future, and to limit quantum technology to commercial and defence uses is a waste of potential. The opportunity to limit future damage from previous and current methods of environmental engagement, through either resource extraction or inaccurate estimations of natural disasters, should be taken without hesitation.

There can be no doubt that the development of quantum technology offers a unique chance for nations to bolster their economies. Both industry and national leaders have recognized this chance for growth, and it is the second recommendation of the authors to seize this opportunity for increased public-private partnership to develop domestic economies. With estimations from all Five Eyes expecting quantum to be a multi-million dollar industry that will bolster GDP by several percentiles, the development of domestic economies is crucial for maintaining global leadership (Quantum Initiative Advisory Committee 2023; Government of the United Kingdom 2023; Government of Canada 2022; Commonwealth of Australia 2023; Ministry of Business, Innovation, and Employment 2022). To ensure the efficient development of domestic economies, national efforts should be centered on increased collaboration between public and private developers, and dual-use quantum technologies wherever possible. Targeting dual-use quantum technology ensures that Canada is able to promote development on multiple fronts. Further, public-private partnerships are critical for increasing the speed of quantum development and protecting domestic economies. Should nations completely ignore privately-developed technologies, it is possible that competitors will purchase them and undermine national security efforts.

Furthermore, the importance of workforce development cannot go unrecognized. Several nations have already committed to building programs to promote workforce development (Commonwealth of Australia 2023; Subcommittee on Quantum Information Science 2022). In addition, many nations have emphasized the importance of attracting international talent (Subcommittee on Quantum Information Science 2022; Government of Canada 2022b). However, it must be noted that all nations will be competing for the same international talent. Therefore, it is the authors' recommendation that increased effort be applied to the development and maintenance of domestic quantum talent. This is not to say that international talent should not be pursued — in fact, talent acquisition is invaluable to success on the international stage. However, this aspect of workforce development should not overshadow domestic development efforts, as creating and maintaining talent already within the nation is vital to ensuring a resilient quantum economy of scale.

The third recommendation made in this project is increasing communication within the Five Eyes and with their adversaries respectively. Currently, cooperative efforts between all five of the Eyes on quantum are few and far between. While there exists collaboration within separate alliances, these efforts leave out one or more of the Eyes (Kung and Fancy 2021; Government of Canada 2023; Commonwealth of Australia 2023; NQTP 2013; The White House 2022; Ministry of Business, Innovation, and Employment 2023). Perhaps the best example of this is New Zealand's position within the alliance. Despite being located in a key geographic region relative to Australia, New Zealand's collaboration with the Five Eyes outside of bilateral and trilateral agreements is limited (Dodd-Walls Centre 2022; New Zealand Government 2023a; New Zealand Government 2023b). While other members of the Five Eyes strive for increased cooperation, there has yet to be a clear consensus on how the Five Eyes alliance as a whole should approach quantum. Without clear communication and collaboration within the alliance, adversaries have an increased chance of pulling ahead in quantum. To further discourage adversary leadership in quantum, it is vital to maintain clear and open communications with these adversaries. Communication and cooperation, even if limited in nature, ensures that there is a clear understanding of an adversary's developmental progress. This would allow Canada and other Five Eyes to better prepare their own quantum efforts to counter nations like China. Without these open communication channels, quantum competition becomes a guessing game with global leadership and national security at stake.

The last recommendation made by this project is the collaboration of Five Eyes militaries in joint exercises with field-ready technology. Each Five Eyes ally has considered what quantum technology will look like when applied to their military ecosystem, however none have directly addressed how their defence-ready technology will be shared with allies. British research hubs have been at the forefront of quantum development with a first-of-its-kind atomic clock already attached to a UK Navy ship, but there has been no word as to whether one of these clocks will be shared with allies (NQTP 2013; Royal Navy 2022). With geopolitical adversaries a growing threat and conscious concern of the Five Eyes, utilizing the alliance to its fullest is paramount to the success of quantum development. Canada noted in their *Quantum 2030* plan that collaboration with allies will be the only way to ensure quantum-safe communications, as potential adversaries like China have boasted of the superiority of their own quantum communications system (Government of Canada 2023). Joint exercises should not be limited to quantum-safe communications, but be extended to all quantum technologies, such as the United Kingdom's promising National Quantum Computing Centre (Department of Science, Innovation, and Technology 2023a). Collaboration tilts the scales in the favour of the allies and increases the literacy of all armed forces, a goal that appears consistently across all Five Eyes states.

Factors contributing to the pace of quantum technology development are not limited to technical challenges. Quantum technology's irreversible advances indicate a larger politico-socio-economic shift in how international politics and their subsequent defence strategies operate. It is expected that the Five Eyes nations will collaborate towards a strong economic front and protected supply chain. Similarly, collaboration on defence protections for post-quantum communications is natural. Quantum technology's effect on alliances and adversaries, however, has heightened tensions that are already strung thin. In addition to these politico-socio-economic shifts, how we interact with the environment is expected

to shift, potentially impacting individuals across the globe. The intricacies of quantum technology's effect on the fragile nature of the environment and climate change must be at the forefront of any innovative decisions henceforth. The potential consequences of quantum development on the environment have yet to be fully explored and to ignore the effect that these consequences could have on an already delicate planet is to ignore the essential human security of all who live on it. The considerations presented will directly impact the usages for future quantum technologies and paying attention to the goals for its

To aid in the secure development of quantum technology, this project has outlined four primary recommendations. First, the authors recommend that the environmental benefits of quantum technology be explored and taken advantage of. These benefits, such as more accurate and time-sensitive sensors, can be harnessed to counter ongoing climate challenges. Second, the project recommends increased public-private partnerships to ensure the secure development and exchange of quantum technologies produced domestically, with particular emphasis placed on domestic workforce development. Third, we recommend increasing clear and open communication between the Five Eyes on quantum development efforts, as well as the establishment of a clear consensus on how the alliance should approach quantum. In addition, the project recommends that some communication with traditional adversaries, such as China, be established and maintained to ensure accurate and controlled flows of information regarding the competitive nature of quantum development. Finally, this paper recommends that the Five Eyes engage in field-ready joint exercises. The collaborative potential of field-ready quantum technology has yet to be explored, despite the critical nature of cooperation within current military alliances such as NATO. Collaboration on this front will ensure the Five Eyes maintain a vital edge in the quantum development game.

To understand any kind of policy or research development, it is essential to understand the context in which it operates. The considerations and recommendations presented in this article articulate the exact factors that have greatly influenced the ability of the Five Eyes to develop their quantum programs. The path that they take will be altered and adjusted by new considerations and threats that appear with time. Any further research should not take this list of considerations as exhaustive. It is imperative that the context of any review take into account the current state of the Five Eyes. Technology as rapidly developing as quantum deserves an equivalently developed analysis of the changes to come.

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