QUANTUM COMPUTING AND INTELLECTUAL PROPERTY LAW

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ABSTRACT

What types of intellectual property (IP) rights can be vested in the components of a scalable quantum computer? Are there sufficient market-set innovation incentives for the development and dissemination of quantum software and hardware structures? Or is there a need for open-source ecosystems, enrichment of the public domain, and even democratization of quantum technology? This Article explores possible answers to these tantalizing questions.

This Article demonstrates that strategically using a mixture of IP rights to maximize the value of a quantum computer owner's IP portfolio potentially leads to IP protection in perpetuity. Overlapping IP protection regimes can result in an unlimited duration of global exclusive exploitation rights for first movers, who are very often a handful of universities and large corporations. The ensuing IP overprotection in the field of quantum computing leads to an unwanted concentration of market power. Overprotection of information causes market barriers and hinders both healthy competition and industry-specific innovation. In this case, it slows down progress in an important application area of quantum technology, namely quantum computing.

In general, our current IP framework is not written with quantum technology in mind. IP should be an exception—limited in time and scope—to the rule that information goods can be used for the common good without restraint. IP law cannot incentivize creation, prevent market failure, fix winner-takes-all effects, eliminate free riding, and prohibit predatory market behavior at the same time. To encourage fair competition and correct market skewness, antitrust law is the instrument of choice.

This Article proposes a solution tailored to the exponential pace of innovation in the Quantum Age, by introducing shorter IP protection durations of 3 to 10 years for quantum- and AI-infused creations and inventions. These shorter terms could be made applicable to both software and hardware. Clarity about the recommended limited durations of exclusive rights—in combination with compulsory licenses or fixed prized statutory licenses—

DOI: https://doi.org/10.15779/Z38R785Q1G

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encourages legal certainty, knowledge dissemination, and follow-on innovation within the quantum domain. In this light, policymakers should build an innovation architecture that mixes freedom (e.g., access and public domain) and control (e.g., incentive and reward mechanisms).

This Article concludes that anticipating spectacular advancements in quantum technology, the time is now ripe for governments, research institutions, and the markets to prepare regulatory and IP strategies that strike the right balance between safeguarding our fundamental rights and freedoms, our democratic norms and standards, and pursued policy goals that include rapid technology transfer, the free flow of information, and the creation of a thriving global quantum ecosystem, while encouraging healthy competition and incentivizing sustainable innovation.

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Quantum computing derives its constituent elements from principles of quantum mechanics (superposition, entanglement, and tunnelling), the theory of the very small. Quantum mechanics describes the interaction between matter and energy and the building blocks of atoms at the subatomic level, beyond classical physics, including subatomic particles such as protons, neutrons, and electrons. On the other hand, Einstein's theory of relativity is the theory of the very large, describing the operation of laws of physics such as gravity, speed of light, time, space, mass and energy ($E = mc^2$).[1] Quantum mechanics and general relativity are yet to be unified in an all-compassing mathematical model that explains the behavior of nature both at the micro and the macro level.

Quantum bits or qubits are the quantum version of classic (binary) bits.[2] A qubit can be a 1 or a 0, or both. We call this superposition,[3] with a qubit

1. *See* Albert Einstein, *Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig?*, 18 ANNALEN DER PHYSIK 639, 641 (1905) (denoting "E" as energy, "m" as mass, "c" as the speed of light).

2. *See, e.g.*, XIANG FU, QUANTUM CONTROL ARCHITECTURE 9 (2018).

3. *See id.*

representing a quantum particle in superposition of all possible quantum states.[4] In addition to exhibiting superposition, quantum particles can be in several places at the same time while remaining "aware" of each other. This is known as entanglement.[5] Finally, quantum tunnelling refers to the observable fact in which subatomic particles penetrate a potential energy barrier that is higher in energy, such as a steel door. For humans, these are counterintuitive quantum states.

A. WHAT CAN WE DO WITH A QUANTUM COMPUTER?

In general, quantum computing is ideally suited for solving mathematical optimization problems, some of the computationally hard problems on which we build current cryptography,[6] and for simulating the behavior of atoms and elementary particles. Quantum computers are useful when modelling nature[7] or searching large amounts of data using parallel quantum query algorithms.[8] These computers excel at simulating complex systems. However, quantum machines also have limits. For example, quantum computers can help find approximate solutions to computationally complex NP-hard and NP-complete problems, such as the travelling salesman problem,[9] but they cannot deliver exact answers to these problems.

B. QUANTUM & ARTIFICIAL INTELLIGENCE HYBRIDS

The combination of artificial intelligence (AI), machine learning, and functioning quantum computers and simulators can theoretically solve mathematical, physical, and chemical optimization problems. Technological synergies can disentangle problems that are currently not solvable with the help of binary computers. Such synergies may include AI and quantum computing hybrids consisting of bits, neurons, and qubits. Combining powerful AI

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4. *See Understanding Quantum Computing*, MICROSOFT (Nov. 2, 2021), https://docs.microsoft.com/en-us/quantum/overview/understanding-quantum-computing [https://perma.cc/XCT7-CU2K].

5. FU, *supra* note 2, at 11.

6. *See Cybersecurity by Quantum-Safe Crypto*, TNO, https://www.tno.nl/en/focus-areas/information-communication-technology/roadmaps/trusted-ict/quantum/quantum-safe-crypto/ [https://perma.cc/4FK6-WT3L] (last visited Nov. 11, 2021) (describing quantum-safe cryptography using an advanced security proxy).

7. *See* Andris Ambainis, *What Can We Do with a Quantum Computer?*, INST. ADVANCED STUDY (2014), https://www.ias.edu/ideas/2014/ambainis-quantum-computing [https://perma.cc/B5BG-CQLH] (suggesting quantum information may lead to a better understanding of the principles of quantum systems).

8. *See* Stacey Jeffery, Frederic Magniez & Ronald de Wolf, *Optimal Parallel Quantum Query Algorithms*, 79 ALGORITHMICA 509 (2017).

9. *See, e.g.*, Richard H. Warren, *Solving the Traveling Salesman Problem on a Quantum Annealer*, 2 SN APPLIED SCI. 75, 75 (2020).

algorithms using classical computers with quantum algorithms that utilize quantum mechanical principles has the potential to revolutionize bio engineering, including in the areas of synthetic cells[10] and nano-engineering. Furthermore, quantum computing will enhance AI. In the coming years, interaction between quantum technology and AI will give the world a new perspective on science itself. Techno-optimists expect that practical, fault-tolerant quantum computation, quantum software, and quantum data will play an important role in the development of autonomous artificial beings and in the awakening of Artificial Super Intelligence (ASI)—a downright paradigm shift.

II. IP ON THE COMPONENTS OF QUANTUM COMPUTERS

Let us now link quantum computing to intellectual property law. Quantum computers can be protected by different types of intellectual and industrial property rights, such as chip rights (semi-conductor topography protection), patents, copyrights, trade secrets, design rights, and trademarks. We discuss which IP rights can be established per component of these machines, be it software or hardware. We also discuss whether there are gaps/loopholes in protection and whether there are overlaps. Although IP rights are territorial rights, we make these qualifications as much as possible from the perspective of an international IP *acquis*.[11] There may be regional differences in formal and material requirements, flexibilities, scope, and term of protection in the EU, China, India, or the United States.

A. THE COMPONENTS

Quantum computers, depending on their specific application in the domains listed above and on their precise implementation method, may contain the following layers of components:[12] the technology building blocks (qubits), quantum gates and multipliers, quantum integrated circuit chips, the various types of quantum processors such as spin qubits and

10. *See Synthetic Biology*, NAT'L HUM. GENOME RSCH. INST., https://www.genome.gov/about-genomics/policy-issues/Synthetic-Biology [https://perma.cc/C2LB-73RK] (Aug. 14, 2019).

11. *See, e.g.*, Paul Goldstein & Bernt Hugenholtz, INTERNATIONAL COPYRIGHT: PRINCIPLES, LAW, AND PRACTICE (4th ed. 2019); Maciej Szpunar, *Territoriality of Union Law in The Era of Globalisation*, *in* EVOLUTION DES RAPPORTS ENTRE LES ORDRES JURIDIQUES DE L'UNION EUROPÉENNE, INTERNATIONAL ET NATIONAUX: LIBER AMICORUM JIŘÍ MALENOVSKÝ 149 (2020).

12. NAT'L ACADS. SCIS., ENG'G, & MED., QUANTUM COMPUTING: PROGRESS AND PROSPECTS 113 (Emily Grumbling & Mark Horowitz eds., 2019).

superconducting[13] transmon qubits,[14] quantum interference devices,[15] compiler engines (i.e., optimizers, translators, mappers),[16] decoders, the simulator and the emulator, the circuit drawer, the microarchitecture (quantum execution (QEX) block and quantum error (QEC) block), the quantum-classical interface, the quantum instruction set architecture, quantum memory, quantum software,[17] smart quantum algorithms,[18] the application programming interface (APIs),[19] quantum arithmetic units (quantum addition, subtraction, multiplication, and exponentiation), runtime assertion and configuration, quantum computing platforms, program paradigms and languages, the Bacon-Shor stabilization code, three dimensional color codes,[20] and surface codes.

Furthermore, the actual casing (the dilution refrigerator or "fridge") of a quantum computer contains, *inter alia*, a cryoperm shield, quantum amplifiers, cryogenic isolators, a mixing chamber, a modular wiring architecture, superconducting coaxial lines,[21] input microwave lines, and a qubit signal amplifier.

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13. For further reading on superconductivity, see Glennda Chui, *Stanford physicist's quest for the perfect keys to unlock the mysteries of superconductivity*, STANFORD NEWS (Sept. 10, 2020) https://news.stanford.edu/2020/09/10/unlocking-mysteries-superconductivity/ [https://perma.cc/72DE-DFW7].

14. *See Demonstrators*, QUTECH, https://qutech.nl/demonstrators/ [https://perma.cc/5FNU-2YYB] (last visited Nov. 11, 2021).

15. *See* Niels Jakob Søe Loft, Morten Kjaergaard, Lasse Bjørn Kristensen, Christian Kraglund Andersen, Thorvald W. Larsen, Simon Gustavsson, William D. Oliver & Nikolaj T. Zinner, *Quantum interference device for controlled two-qubit operations*, 6 NPJ QUANTUM INFO. 47 (2020).

16. *See* Epiqc, University of Chicago, *New compiler makes quantum computers two times faster*, PHYS.ORG (Oct. 11, 2019), https://phys.org/news/2019-10-quantum-faster.html [https://perma.cc/5N6K-S24D].

17. *See* NAT'L ACADS. SCIS., ENG'G, & MED., *supra* note 12, at 135.

18. *See* Ashley Montanaro, *Quantum algorithms: an overview*, 2 NPJ QUANTUM INFO. 15023 (2016).

19. *See, e.g.*, *What are the Q# programming language and Quantum Development Kit (QDK)?*, MICROSOFT (Nov. 10, 2021), https://docs.microsoft.com/en-us/azure/quantum/overview-what-is-qsharp-and-qdk#the-quantum-programming-language-q [https://perma.cc/2WDR-UD9B].

20. *See* Aleksander Kubica, Michael E. Beverland, Fernando Brandão, John Preskill & Krysta M. Svore, *Three-Dimensional Color Code Thresholds via Statistical-Mechanical Mapping*, 120 PHYS. REV. LETT. 180501 (2018).

21. *Cf.* Yufan Li, Xiaoying Xu, M.-H. Lee, M.-W. Chu & C. L. Chien, *Observation of Half-Quantum Flux in the Unconventional Superconductor β-Bi_2Pd*, 366 SCIENCE 238 (2019); Johns Hopkins Univ., *New Superconducting Material Discovered That Could Power Quantum Computers of the Future*, SCITECHDAILY (October 11, 2019), https://scitechdaily.com/new-superconducting-material-discovered-that-could-power-quantum-computers-of-the-future/ [https://perma.cc/GVN8-SEHW].

In addition, a conventional computer is used to access the output of the quantum computer in human and machine-readable formats. This means there is a certain amount of "classical control," through the quantum-classical interface. In case we are dealing with quantum and AI hybrids (or hybrid quantum-classical co-processing systems), we have to add all the parts of the AI system to this list of components, including the inference engine that processes the rules.[22]

B. Creations & Inventions

Only novel, useful, inventive, and non-obvious inventions made by a human inventor can be patented. Meanwhile, copyrights generally require a minimum of creativity, originality, and a human author.[23]

Technical discoveries that have been developed and embedded into hardware can be patented. Software can be copyrighted. From the perspective of IP rights, we can group the components of a quantum computer by hardware (chip rights, design, and utility patents), software (copyrights and creative commons), and algorithms (open source[24] or public domain). The protection term for patents is 20 years, compared to life of the author plus 70 years for software. One of the reasons for this difference is that the copyright system and the patent system both have distinct objectives.[25] In general, quantum computing hardware is much more difficult to develop and replicate than the accompanying software and algorithms. It requires more investments to make the hardware than to write the code. As a result, computer chips—including the knowledge, cleanroom facilities, and lithographic devices necessary to fabricate them—can become subject to geopolitical conflicts and export control reforms,[26] as observed in today's trade war between the United States and China.[27]

22. *See* Mauritz Kop, *AI & Intellectual Property: Towards an Articulated Public Domain*, 28 TEX. INTELL. PROP. L.J. 297, 318 (2020).

23. *See id.* at 303–04.

24. *See, e.g.*, QISKIT, Open-Source Quantum Development, https://qiskit.org/ [https://perma.cc/TQX3-KY7F] (stating Qiskit is an open source SDK for working with quantum computers at the level of pulses, circuits and algorithms).

25. *See* PETER S. MENELL, MARK A. LEMLEY, ROBERT P. MERGES & SHYAMKRISHNA BALGANESH, INTELLECTUAL PROPERTY IN THE NEW TECHNOLOGICAL AGE: 2020 35 (2020).

26. *See* Noah Barkin, *Export controls and the US-China tech war*, MERICS (Mar. 18, 2020), https://merics.org/en/report/export-controls-and-us-china-tech-war [https://perma.cc/24PR-JKGW]; Eleni Lazarou, *United States: Export Control Reform Act (ECRA)*, EUR. PARLIAMENT THINK TANK, (Nov. 22, 2019), https://www.europarl.europa.eu/thinktank/en/document.html?reference=EPRS_BRI%282019%29644187 [https://perma.cc/JN5N-CELF].

27. *See, e.g.*, *A quick guide to the US-China trade war*, BBC NEWS (Jan. 16, 2020), https://www.bbc.com/news/business-45899310 [https://perma.cc/24XZ-CXB7].

C. PATENTS

The patent system aims to incentivize inventors to disclose, produce, and market their invention with the prospect of return on investment.[28] It intends to encourage the detailed disclosure of innovative ideas and optimize the allocation of research and development (R&D) capacity by granting exclusive rights to the inventor. At the same time, it incentivizes inventors to improve and build upon earlier patents.[29] Generally, processes, machines, manufactures and compositions of matter can be patented. In contrast, laws of nature, physical phenomena, and abstract ideas are excluded from patentable subject matter.

The following components are eligible for patent protection: the technology building blocks (qubits), quantum gates and multipliers, quantum integrated circuit chips, the various types of quantum processors such as spin qubits and superconducting transmon qubits, quantum interference devices, compiler engines (i.e., optimizers, translators, mappers), decoders, the simulator and the emulator, the circuit drawer, the microarchitecture (QEX block and QEC block), the quantum-classical interface, the quantum instruction set architecture, and quantum memory. The "quantum computing process" can be protected by patent as well. The dilution refrigerator, including its individual cryoperm shield, quantum amplifiers, cryogenic isolators, mixing chamber, superconducting coaxial lines, input microwave lines, and qubit signal amplifier component, is also eligible for patenting—provided it crosses the thresholds of novelty, usefulness, and non-obviousness in order to be an invention susceptible of industrial application.

D. COPYRIGHTS

Copyright intends to incentivize and maximize creativity, cultural diversity, technological progress, and freedom of expression. An important objective of copyright is to stimulate creation and dissemination of diverse cultural expression by enabling successive generations of authors to draw freely on the works of their predecessors.

According to the World Trade Organization (WTO) Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPs) and the World Intellectual Property Organization (WIPO) Copyright Treaty (WTC), creative aspects of software source code and firmware can be protected by copyright, as if they are literary works. Specifically, the expression of computer software

28. MENELL ET AL., *supra* note 25, at 34.
29. Kop, *supra* note 22, at 312.

is protected, not its functionality.[30] The idea/expression dichotomy prescribes that expression is protected by copyright. On the other hand, algorithms, functionality, principles, and ideas are not protected.[31] The latter are part of the public domain. Before the expression of an idea is captured in a tangible medium, it can be time-stamped by an i-Depot. Ideas can also be protected contractually by a non-disclosure agreement (NDA).

The following components are eligible for copyright protection: quantum software, the APIs, quantum arithmetic unit (quantum addition, subtraction, multiplication, and exponentiation), runtime assertion and configuration, quantum computing platforms, program paradigm and languages, the Bacon-Shor stabilization code, color codes, and surface codes. These components fall within the scope of copyrightable subject matter, provided these are original works of creative human authorship and fixed in a tangible medium of expression.

It is possible that certain applied programming languages useful for quantum computing will be open sourced instead of copyright protected,[32] or licensed for use via Creative Commons.[33] As with classical computing, it is expected that both commercial and open-source operating systems will come into the market.

A few uncrystallized areas require specific attention and perhaps some legal pioneering. Functionality, for instance, is not protected by copyright.[34] This raises the question of whether software and API functionality should be protected by patents. Arguments for and against patentability of software functionality and computer implemented inventions can be made.[35] Legal

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30. *See, e.g.*, Directive 2009/24/EC, of the European Parliament and of the Council of 23 April 2009 on the Legal Protection of Computer Programs, 2009 O.J. (L 111) 16.

31. *See* Daniel Gervais & Estelle Derclaye, *The Scope of Computer Program Protection After* SAS*: Are We Closer to Answers?*, 34 EUR. INTELL. PROP. REV. 565 (2012).

32. Such as eDSL in Python. *See generally edsl*, GITHUB, https://github.com/topics/edsl [https://perma.cc/3FP6-HQ59] (last visited Oct. 28, 2021); *see also* Damian S. Steiger, Thomas Häner & Matthias Troyer, *ProjectQ: An Open Source Software Framework for Quantum Computing*, 2 QUANTUM 49, 49 (2018) (introducing an open source software for quantum computing).

33. *See generally* CREATIVE COMMONS, https://creativecommons.org/ [https://perma.cc/NB6T-2K5Y] (last visited Oct. 28, 2021).

34. Pamela Samuelson, *Functionality and Expression in Computer Programs: Refining the Tests for Software Copyright Infringement*, 31 BERKELEY TECH. L.J. 1215, 1215 (2016); Peter S. Menell, *Rise of the API Copyright Dead?: An Updated Epitaph for Copyright Protection of Network and Functional Features of Computer Software*, 31 HARV. J. L. & TECH. 305, 447 (2018).

35. *See generally* PÉTER MEZEI, DÓRA HAJDÚ, LUIS JAVIER CAPOTE-PÉREZ & JIE QIN, COMPARATIVE DIGITAL COPYRIGHT LAW (2020).

uncertainty about IP protection, whether concerning copyrights or patents, usually results in a shift to trade secrets, which generally stifles innovation.[36]

E. INPUT & OUTPUT DATA

Depending on the application area, current quantum computing systems input consists of problem definitions. It is also possible to feed input data from a classical computing device into a quantum circuit, via the quantum-classical interface.

In case of AI hybrids that utilize machine learning training datasets, clearance of the input information is needed in the event this data represents IP subject matter.[37] Besides a rainbow of potential IP rights potentially vested in the data that need to be licensed under current law, including a *sui generis* database right on the training corpus itself (in Europe), the main roadblocks for the uptake of AI and data are privacy, General Data Protection Regulation (GDPR) concerns, and uncertainty about ownership of data.[38] There is a lack of trust in the existing rules because they are complex, abstract, and not written specifically for AI and machine learning training data. As for AI, there needs to be a broad exemption, or even a superior right to process data for quantum computing purposes, that respects privacy and other fundamental rights.[39]

In case quantum computing output represents IP subject matter, this output is eligible for IP protection. It can then be licensed or sold. If desired, IP rights on the output can also be waived and pushed into the public domain.

F. IP OWNERSHIP: LEGAL SUBJECTIVITY AND PUBLIC DOMAIN

Output created or invented by autonomous quantum/AI systems without human upstream or downstream intervention should be public domain. The output lacks human creativity and inventiveness, and society benefits from a

36. *See, e.g.*, Kop, *supra* note 22, at 318.

37. *See* Mauritz Kop, *Machine Learning & EU Data Sharing Practices*, TRANSATL. ANTITRUST & IPR DEVS. (Stanford-Vienna Transatl. Tech. L. F., Stanford, CA), Mar. 19, 2020, at 9, https://www-cdn.law.stanford.edu/wp-content/uploads/2015/04/2020-1.pdf [https://perma.cc/KQ4D-7AXR][hereinafter Kop, *Machine Learning*]; *cf.* Kop, *supra* note 22, at 320–22.

38. *See* Kop, *Machine Learning*, *supra* note 37, at 8, 18.

39. Mauritz Kop*, The Right to Process Data for Machine Learning Purposes in the EU*, 34 HARV. J. L. & TECH. ONLINE DIGEST, at 1 (2021), https://jolt.law.harvard.edu/digest/the-right-to-process-data-for-machine-learning-purposes-in-the-eu [https://perma.cc/4ZLA-E3JW]; *cf.* CHRISTOPHE GEIGER, GIANCARLO FROSIO & OLEKSANDR BULAYENKO, CTR. INT'L INTELL. PROP. STUD. (CEIPI), THE EXCEPTION FOR TEXT AND DATA MINING (TDM) IN THE PROPOSED DIRECTIVE ON COPYRIGHT IN THE DIGITAL SINGLE MARKET—LEGAL ASPECTS 4 (2018); Sean Flynn, Christophe Geiger, João Quintais, Thomas Margoni, Matthew Sag, Lucie Guibault & Michael W. Carroll, *Implementing User Rights for Research in the Field of Artificial Intelligence: A Call for International Action*, 42 EUR. INTELL. PROP. REV. 393 (2020).

robust public domain. Additionally, IP rights can only be owned by legal subjects, such as people, universities, or corporations. Autonomous systems lack legal subjectivity or legal personhood needed to own rights and carry responsibilities. Machine generated quantum/AI creations and inventions should be *Res Publicae ex Machina*.[40] These belong in an articulated public domain.

G. TRADE SECRETS & TRADEMARKS

On top of copyrights and patents, virtually every component of a quantum computer can contain continuously renewable trademarks (and in some circumstances trade dress) and trade secrets[41] with potentially unlimited duration of IP protection. Further, cybersecurity law and national security considerations could, beyond the scope of the IP toolkit, play a role in keeping technological breakthroughs a state secret.[42] As is the case with AI systems, legal uncertainty about the patentability of quantum computing systems, together with the unlimited duration of trade secret rights, could ultimately cause a shift towards trade secrets to protect assets and commodify quantum computing applications and quantum data. This trend might impede disclosure of ideas, dissemination of information, technology transfer to the market,[43] and follow-on innovation.[44]

Note that a trade secret right does not protect against reverse engineering. This IP loophole can be filled by concluding contracts that prohibit unwanted reverse engineering.[45]

Additionally, a quantum computer's looks, brands, and functional design can be protected. Product design, artwork, logos, software interfaces, layouts, and hardware modelling can—depending on the territory for which protection is sought—be protected by an arrangement of IP instruments such as design rights, tradename rights, and trade dress.

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40. Kop, *supra* note 22, at 323–329.

41. *See, e.g.*, Josef Drexl, *Designing Competitive Markets for Industrial Data—Between Propertisation and Access*, 8 J. INTELL. PROP., INFO. TECH. & E-COMMERCE L. 257 (2017).

42. For a discussion of quantum technology IP protections in the national security context, see Mauritz Kop & Mark Brongersma, *Integrating Bespoke IP Regimes for Quantum Technology into National Security Policy*, (forthcoming Feb. 2022), https://law.stanford.edu/publications/integrating-bespoke-ip-regimes-for-quantum-technology-into-national-security-policy/ [https://perma.cc/98TC-VF9R].

43. *See, e.g.*, *Tech Transfer*, TNO, https://www.tno.nl/en/focus-areas/techtransfer/ [https://perma.cc/URD3-6EXR] (last visited Jan. 15, 2022).

44. *See, e.g.*, ORG. FOR ECON. COOP. & DEV., OECD SCIENCE, TECHNOLOGY, AND INDUSTRY OUTLOOK 2012, at 195 (2012).

45. Kop, *supra* note 22, at 318.

H. IP OVERLAP & OVERPROTECTION

Strategically using a mixture of IP rights to maximize and protect the value of the IP portfolio of the quantum computer's owner can result in an unlimited duration of global exclusive exploitation rights for first movers absent compulsory licensing of standard essential patents (SEPs) in certain territories. Thus, there are no consequential loopholes in IP protection possibilities. Far from it. Instead, there is an overlap of IP protection regimes.[46] At this time, new layers of rights do not seem appropriate.

Other quantum technologies—such as quantum sensing, quantum simulation, and the quantum internet—are equally eligible for IP protection using the same amalgam of IP rights. From a (beyond IP) innovation law perspective, future quantum internet functionality[47] ought to be public domain and net neutrality should exist. Its constituting and enabling components, however, could theoretically be protected by an array of IP rights, with each right protecting something different. The same applies to quantum sensors, quantum simulation, engineered/synthesized plants, and novel materials and devices invented with the help of quantum technology.

In general, our current intellectual property framework is not written with quantum technology in mind. Intellectual property should be an exception—limited in time and scope—to the rule that information goods can be used for the common good without restraint. Perhaps, essential overarching concepts underpinning certain categories of applied quantum technologies should be democratized to enable equitable access. From a dogmatic and sustainable innovation policy perspective, IP rights holders should not be legally entitled to internalize the full social benefits of their creations and inventions.[48] It is unnecessary to limit uncompensated positive externalities in a well-structured quantum technology marketplace. It is equally unnecessary to internalize such positive spillovers in intellectual property after initial investment costs have been retrieved.[49] Positive quantum technology creation and invention externalities do not need to be remedied by IP regulations, taxes, or subsidies beyond the break-even-point. Furthermore, there is no tragedy of the

46. *Id.*; *cf.* Jean-Marc Deltorn & Franck Macrez, *Authorship in the Age of Machine learning and Artificial Intelligence* (Ctr. Int'l Intell. Prop. Stud., Research Paper No. 2018-10), https://ssrn.com/abstract=3261329.

47. *Cf. Quantum technologies and the Advent of the Quantum Internet in the European Union*, EUR. UNION, https://digital-strategy.ec.europa.eu/en/library/quantum-technologies-and-advent-quantum-internet-european-union-brochure [https://perma.cc/3UHJ-FUXC].

48. *Cf.* Mark A. Lemley, *Property, Intellectual Property, and Free Riding*, 83 TEX. L. REV. 1031, 1032 (2005).

49. *Id.* at 1072.

commons in IP on quantum technology knowledge goods.[50] Information cannot be overused.

Intellectual property cannot incentivize creation, prevent market failure, fix winner-takes-all effects, eliminate free riding, and prohibit predatory market behaviour at the same time. To encourage fair competition and correct market skewness, antitrust law is the instrument of choice.[51]

The question is whether the identified overlap in regimes benefits business dynamism and accelerated innovation. The subsequent IP overprotection may create barriers for market entrants and raise concerns regarding fair competition, freedom of expression, and the creation of new jobs.[52] Overprotection might hinder industry-specific innovation. In this case, it slows progress in an important application area of quantum technology, namely, quantum computing.

A solution tailored to the exponential pace of innovation in the Quantum Age is to introduce shorter IP protection durations of 3 to 10 years for quantum- and AI-infused creations and inventions. These shorter terms could apply to both software and hardware. Clarity about the proposed limited durations of exclusive rights—in combination with compulsory licenses or fixed-prized statutory licenses—encourages legal certainty, knowledge dissemination, and follow-on innovation within the quantum domain.[53] In this light, policymakers should build an innovation architecture that mixes freedom (e.g., access and public domain) and control (e.g., incentive and reward mechanisms).

On November 25, 2020, the European Commission (EC) presented its IP Action Plan, which promises an "overhaul [of the] intellectual property system to strengthen Europe's ability to develop next generation technologies [and]

50. Kop, *supra* note 22, at 324.

51. To ensure, among other things, that dominant online platforms can be challenged by new market entrants and existing competitors, so that consumers have the widest choice and the Single Market remains competitive and open to innovations, the European Commission recently introduced the Digital Services Act package, as part of the European Digital Strategy. *See The Digital Services Act Package*, EUR. COMM'N (Oct. 21, 2021), https://ec.europa.eu/digital-single-market/en/digital-services-act-package [https://perma.cc/A496-5WVR].

52. Kop, *supra* note 22, at 325.

53. *Id.* at 314, 329.

reflect advances in data and AI."[54] The EC aims to set global standards in IP. The Action Plan announced measures in five key areas:[55]

1. Improve the protection of IP
2. Boost the uptake of IP by small and medium-sized companies (SMEs)
3. Facilitate the sharing of IP
4. Fight counterfeiting and improve enforcement of IP rights
5. Promote a global level playing field

I. IP ALTERNATIVES

Regarding innovation incentives and allocation mechanisms, IP rights are not the only answer—and not automatically the best answer. Policymakers could apply innovation policy pluralism (i.e., mix, match, and layer IP alternatives such as antitrust law, contract law, consumer privacy protection, tax law, and standardization and certification, as well as prizes, subsidies, public-private funding, competitions, penalties, and fines) to enable fair-trading conditions, remedy externalities, and balance the effects of exponential innovation within the markets.[56] Because innovation incentive and reward mechanisms, externalities, and safety/security risks vary per industry and per technology, policymakers should differentiate more unequivocally between economic sectors when designing regulatory solutions. Further, IP rights might be less important in a quantum- and AI-driven world where creation, reproduction, and distribution have become inexpensive.[57]

III. CONCLUSION

Our current intellectual property framework is not written with quantum technology in mind. Anticipating spectacular advancements in quantum

54. *See Commission Adopts Action Plan on Intellectual Property to Strengthen EU's Economic Resilience and Recovery*, EUR. UNION (NOV. 25, 2020), https://ec.europa.eu/commission/presscorner/detail/en/IP_20_2187 [https://perma.cc/Z4ZX-SNB5].

55. *Intellectual Property Action Plan Implementation*, EUR. UNION (Sept. 6, 2021), https://ec.europa.eu/growth/industry/strategy/intellectual-property/intellectual-property-action-plan-implementation_en [https://perma.cc/6VMU-9RFF].

56. *See* Daniel J. Hemel & Lisa Larrimore Ouellette, *Innovation Policy Pluralism*, 128 YALE L.J. 545 (2019); Mauritz Kop, *Beyond AI & Intellectual Property: Regulating Disruptive Innovation in Europe and the United States—A Comparative Analysis*, STANFORD L. SCH., https://law.stanford.edu/projects/beyond-ai-intellectual-property-regulating-disruptive-innovation-in-europe-and-the-united-states-a-comparative-analysis/ [https://perma.cc/9PPA-FH3K] (last visited Jan. 15, 2022).

57. *See* Mark A. Lemley, *IP in a World Without Scarcity* (Stanford Pub. L. Working Paper No. 2413974, 2014), https://ssrn.com/abstract=2413974.

computing, quantum sensing, and quantum communication, the time is now ripe for governments, research institutions, and the markets to prepare new regulatory[58] and intellectual property strategies that encourage healthy competition and incentivize sustainable innovation.[59] These strategies, however, must strike the right balance between competing priorities: quantum IP rights should facilitate rapid technology transfer, information sharing, national security policy objectives, and the creation of a thriving global quantum ecosystem, while safeguarding fundamental rights and freedoms and reinforcing our democratic values.

58. *See* CHRIS JAY HOOFNAGLE & SIMSON GARFINKEL, LAW AND POLICY FOR THE QUANTUM AGE (2021).

59. For a detailed description of ethical, legal and social guiding principles for quantum technology, see Mauritz Kop, *Establishing a Legal-Ethical Framework for Quantum Technology*, YALE J. L. & TECH.: THE RECORD (2021), https://yjolt.org/blog/establishing-legal-ethical-framework-quantum-technology [https://perma.cc/AW8B-F5FK]; *see also* Mauritz Kop, *Ethics in the Quantum Age*, PHYSICS WORLD, Dec. 1, 2021, https://physicsworld.com/a/why-we-need-to-consider-the-ethical-implications-of-quantum-technologies/.