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The Quantum Market and Its Potential - October 2023

Quantum Computing (QC) is in its infancy but may grow up fast. The current market for quantum computing is small - approximately $2.5 billion annual revenue. Today's commercial quantum products and services center around: [1]

- Shared quantum hardware,
- Cloud and AI accelerators (for Machine Learning and Large Language Models),
- Optimization and supply chains,
- Simulation (molecular biology and pharmacology), and
- Cryptography and Cybersecurity

Commercial funding for quantum computing is heavily subsidized. Government funding from China, the United States, and the European Union, much of it related to cryptography, cybersecurity, and optimization,[2] reached $23.5 Billion in 2022.

Analysts believe QC's market will grow quickly.- a Cumulative Average Growth Rate near 31% over the next five years, and an eventual $1.0 trillion market. Whether that translates to investment opportunity probably depends on timing.

If QC follows the path several other high-tech, high-capital markets have followed: a lengthy period of slow price appreciation gives way to a rapid (and largely irrational) bubble (up and down) followed by a lengthy recovery that reflects rational investment assumptions.[3]

The Quantum Computing investment-ecosystem encompasses academic and government institutions, literally dozens of privately held companies, and a number of public companies, thus, affording a variety of portfolio allocation options.

Diversification options among public companies are limited. Virtually all the public companies occupy the Technical or Information sectors - primarily computer hardware, software,

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[1] The list implies that quantum computer capabilities are best applied to multi-variate, multi-objective problems that take advantage of QC's massive scalability and parallelism. That impression may be more attributable to our lack of imagination than it is to QC's capabilities. As the technology matures, additional paradigms may emerge.

[2] DARPA, for example, has supported optimization, data security, and encryption studies. Like many things involving DARPA, this support has both a bright and a dark side. Optimization, for example, can be applied to assure a steady supply of needed product at least cost. With minimal changes to the algorithm and a different set of environmental sensors, it can be weaponized to facilitate target identification, selection, prioritization, and execution. The virtues of the latter scenario depend on what is being targeted, by whom, and why.

[3] See for example, the dot com bubble, the most recent 5-8 years of electric vehicle stock history, and where we at Cambyses believe the AI securities market is headed.

components (semi-conductors), data services (Cloud and AI), and mission-critical support services.

Don't hold your breath or save your allowance for consumer versions of quantum machines. Current and foreseeable QC-tech is too expensive, complex, bulky, and balky for home applications. Instead, we expect some variation on Quantum as a Service (QaaS) to emerge in the consumer market. Commercial offerings along similar lines have already entered the market.

The Quantum Ecosystem and Players

Publicly traded companies in the quantum ecosystem provide a range of services and products that mirrors, with some stark exceptions, the standard computer economy:

Full Spectrum Quantum Products and Services

- The primary players in the full spectrum market {Amazon (AMZN), Apple (AAPL), Alibaba (BABA), International Business Machines (IBM), Alphabet (GOOGL), and Microsoft (MSFT)} provide a range of quantum services as part of their broad product offer. These companies lead the quantum industry but are not quantum centric. For example, each of them has launched cloud services based on quantum platforms that supplement their existing cloud offer. They are the safest options for investors who want a presence in the segment, but want to avoid many of the major risks.

- While Amazon and Friends play for headlines, Honeywell (HON) subsidiary Quantinuum has quietly become the largest globally integrated quantum computing entity.

- D-Wave Quantum (QBTS) has the distinction of being the only full spectrum and quantum centric company in Cambyses' Quantum initiative. Their product/service offer is solely based on quantum, to the exclusion of "computer classics."

Software

- Standalone quantum-software developers are numerous. They constitute roughly half of Cambyses Initiative's fifty-two companies.

- Many of these companies suffer a bad case of the "Toos." They are too volatile. They are making too little money (or losing too much). Their price is too low. (Over-valued penny stocks) And finally, they are too dependent on equity infusions. (Low sales volume and minimal cash from operations) Thus, while Cambyses follows and studies these companies, we consider most of them unsuitable for our investors.

- Quantum Computing, Inc. (QUBT), a provider of quantum-based finance, healthcare, and supply chain management software is archetypical.

Data Security

- Depending on who and when you ask, quantum computing is either the best thing that ever happened to data security and privacy or the final death knell for both.

- Both arguments are readily supportable. Several quantum computing capabilities,[4] give rise to new, and virtually unbreakable, data encryption/exfiltration techniques. At the same time, those characteristics threaten to overwhelm existing data defenses. The U.S. Government Accountability Office and the European Data Protection Supervisor consider the latter possibility so acute that they have sponsored software development "competitions" that emphasize solutions to the encryption issue.[5]

- Arqit Quantum (ARQQ) and Quantum Corporation (QMCO) are developing data security responses tailored to both structured and unstructured quantum data.

Hardware

- For most of the last 25 years, IonQ (IONQ), a trapped-ion quantum computer developer, was the sole stand-alone quantum computer manufacturer.

- Rigetti Computing's (RGTI) 2021 IPO added an additional market participant.

- With the exception of these two companies, government, academic, or "Full Spectrum" companies have developed most quantum computer platforms.

Semiconductors and Superconductors

- The list of quantum semiconductor suppliers reads like The Usual Suspects: Nvidia (NVDA) and Intel (INTC) lead the development effort, followed by Advanced Microdevices (AMD) in a manufacturing role.

- Literally all of the current quantum computing paradigms support their Quantum Processing Unit (QPU) with low-temperature superconductor technology, In-house

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[4] Quantum computers are particularly suited to vector-tensor analysis, and, by extension, to prime factorization. QCs are so good at prime factoring that one leading researcher quipped; "So far, we have spent about two billion dollars to prove that 15 = 3 x 5." Since virtually all public/private key encryption and RSA algorithms rely on prime factorization, the algorithms and the data they protect are extremely vulnerable to attack by quantum systems. The speed at which quantum computers can perform these calculations allows communications and stored data to be compromised in real time, thus weaponizing quantum computers.

[5] These "quantum proofing" exercises have been less than stunningly successful. In one notorious instance, a "quantum-proof" encryption algorithm (certified as such by the U.S. Government Accountability Office) was "hacked and broken" in under one hour using an off the shelf $500 laptop, without quantum assistance.

development - with each of the full-spectrum, hardware, and semiconductor manufacturers developing their own proprietary approach - accounts for most of the progress to date. Cambyses is not convinced that is the most efficient development route.

ETFs and Mutual Funds

- We are aware of only one quantum-focused ETF, Defiance Quantum ETF (QTUM). We note, however, that most (if not all) NASDAQ and Large Cap funds include the large-cap companies we include in our "Full Spectrum," "Hardware," and "Semiconductor-Superconductor" lists.

Update 12/2023, The Future for Quantum Computing.

Quantum Computing presents a muddled outlook and high risk future.

When will Quantum go commercial? Maybe tomorrow, maybe 2040, maybe never! Several trends affect commercialization and investment opportunity.

1. _Investor Expectations:_ Pure play quantum is not a fast payoff and is very risky. Private opportunities are available only to Qualified Investors with high risk tolerance and a long planning horizon. Public Quantum securities divide along three lines:

    a. _"The Big Kids"_ The Big Kids (e.g., META, IBM, GOOGL, MSFT) have multiple product/service lines and revenue streams. This removes some of the performance and timing risks associated with Quantum.
    b. Stand-alone (quantum only) and private quantum efforts assume all of the risks inherent in long-term deployment and uncertain or volatile outcomes.
    c. Stand-alone efforts that have already entered public the market have already descended into purgatory. For many of them, their only hope is that someone acquires them).

2. _Geopolitical influences:_ Historically, quantum has been an international collaborative effort. That "tradition" is being impinged upon by international competition for markets and influence. The final outcome may be affected by 2024 election rhetoric and outcomes. The geo-meltdown revolves around defense, the AI/Quantum nexus, cybersecurity, and prestige.

3. _Coordination:_ Whereas international cooperation seems to be receding, coordination between government, academia, and commercial interests on a national level is emerging. In the US, Government support comes primarily from Defense [DARPA], Commerce, DOL, and the State Department. Commercial/Academic coordination is evident in e.g., Boeing's multimillion-dollar support for UCLA's Center for Quantum Science and Engineering, and MIT's alliances with – well… nearly everybody. Coordination takes on a slightly different flavor/emphasis depending on who is coordinating:

Commercial/academic coordination focuses on practical applications and use in AI. Government coordination focuses on preventive measures, AI assisted defense, and cybersecurity.

4. *Quantum Noise:* Historically, Qubits were (and remain) fragile – changing state on the slightest pretext. When Quantum was young, this "quantum noise" was tolerable. As quantum machines grew larger and their applications became more focused on real world problems, the noise (errors occurred in about one in 100 qubits) became overwhelming. This, in turn has led to abandonment of Noisy Intermediate Scale Quantum (NISQ) in favor of systems that deploy correction qubits to maintain data integrity. Until recently, quantum noise reduction was inefficient: In some cases, the noise/correction qubits outnumbered the computational qubits by as much as eight to one. A recent breakthrough (that employs single, whole, atoms instead of the ionized electrons used previously) may reduce the system overhead that supports most of the current noise reduction model.[6]

5. *Multiple Smaller Processors:* As the industry matures, it seems to be moving away from "mine is the biggest" and toward "mine talks to more of its colleagues." IBM and MIT, in particular, have become enamored with the concept. So far, communication speed and bandwidth is the major impediment to the approach. Right now, communication between quantum machines is conducted via standard electronic means – not specifically quantum. Recently, quantum entanglement has been demonstrated at up to 1,500 miles – so perhaps a faster communication method is on the horizon.

6. *Software and Programmers:* More sophisticated software and trained programmers is more an imperative than a trend. This is partly a question of adaptation and experience – programmers who are willing to move away from circuit-based programming and into more flexible modes that produce innately quantum software. Integration of QC and AI may accelerate this as well as expose the need for more of it. It may also require manufacturers to establish industrywide standards – for the moment system compatibility is low and, along with programming complexities, limits applications to those that solve "quantum problems" rather than "real world problems." Quantum will otherwise remain in an invidious position: "The impossible they can do immediately – The ordinary takes a bit longer."

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[6] Teams at Oxford, Cal Tech, and Harvard have reported favorable error rates, in the range of one error per million, using the technique. Cf: https://www.caltech.edu/about/news/a-new-way-to-erase-quantum-computer-errors or https://news.harvard.edu/gazette/story/2023/10/self-correcting-quantum-computers-within-reach-error-correction-entanglement/

Disclaimers

This article is an outgrowth of Cambyses Financial Advisor's Quantum Computing Initiative. Our Initiatives cover immature, high risk, or speculative industry segments we believe offer future business and investment opportunities but are not yet, with some exceptions, suitable for many investors. Our Quantum Computing Initiative monitors or evaluates fifty-one public and private companies that are involved in quantum activities.

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