Combined Forecast and Technology Assessment for Quantum Computing Technologies

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ABSTRACT
Quantum computing, which utilizes quantum mechanical phenomena to streamline the ways in which information is managed, processed, and exchanged, has been a primary research focus for decades. The development of quantum computing, however, is still in its earliest stages. Greater investments in this research by private companies, public corporations, and governments alike will yield more and more progress. The research presented in this report surrounds four technology forecasting and assessment techniques including trends, monitoring, scenarios, and assessments. This report details the past, future and present trends of quantum computing; recent hardware and software advancements, potential use cases, scenarios, assessments and projected market growth. It is intended for decision makers, technology investors, manufacturers, government agencies, educational institutes, research and consultancy firms and provides recommendations for how to maximize the potential of the quantum computing revolution.

Keywords
Quantum computing, quantum computing forecast, quantum computing trends, quantum computing monitoring, quantum computing scenario, quantum computing assessment

1. INTRODUCTION
Classical computation has revolutionized essentially every industry in the modern world, allowing us to solve new problems and manage highly complex systems. However, limitations still exist. In order to continue expanding the scope of computation's problem solving capabilities, a new level of computational power is necessary, one that scales exponentially alongside the data systems its managing [29].

Quantum computing is emerging as that new form of computation after decades of research. Utilizing quantum mechanical phenomena to accelerate the rate of data processing, the hardware and software capabilities of the technology are just now approaching a functional model [30].

Much like the bit of classical computing, the basic unit of information in a quantum computer is a quantum bit, or "qubit". Qubits represent standard 1s and 0s much like a standard bit, but have the distinctive property of "superposition", in which two qubits can become "entangled" and can instantaneously affect one another. This allows quantum computers to utilize algorithms that go beyond 0s and 1s to process massive amounts of data at unforeseen speeds by using entangled qubits. This capability makes quantum algorithms infinitely more powerful than their classical counterparts. Recent forecasts predict that quantum computing will be able to disrupt many industries, with the ability to crack modern encryption methods and solve massive scale problems within an instant. It's important to note that these projections have not yet become reality. However, they are theoretically possible, and are well within the scope of current research [31].

This report examines the past and future trends of quantum computing; recent hardware and software advancements, potential use cases, scenarios, assessments and projected market growth. Accordingly, the purpose of this forecast is to provide a detailed analysis of the quantum market along with forecasts and assessments of quantum computing performance for decision makers, technology investors, manufacturers, government agencies, educational institutes, and research and consultancy firms.

2. TRENDS FORECAST
2.1 Methodology
A trend forecast consists of the collection of data on past patterns of change to project future technological developments. Technological developments can be predicted through "Moore's Law" using mathematical formulas and extrapolation methods to follow past trends into the future. Moore's Law holds that the number of transistors that can be contained in a silicon microchip doubles roughly every two years. There are signs, however, that this growth is slowing.

Martino outlines three assumptions regarding growth curves: the upper limit to the growth curve is a known factor, the chosen growth curve fits the historical data, and the historical data gives the coefficients of the curve formula [1]. Due to these assumptions, growth curves follow an "S-curve" pattern. New technological advancements are intrinsically slow to be adopted and this slow growth is represented in the beginning small-sloped portion of the curve. Soon, the curve exponentially slopes upward, reflecting the rapid growth and implementation of the technology. Once technical limitations and upper limits have been reached, the growth of the curve slows and rounds out to form an 'S' shape.

As with any forecasting method, there are strengths and weaknesses to using this approach. Past trends and mathematical reasoning are the best method of predicting growth with quantifiable parameters over a short time frame. However, when choosing the appropriate growth curve, trend forecasts can neglect to consider the factors driving the technological change in addition to the mathematical considerations in place and user biases. A significant amount of data is required, and it works only for quantifiable parameters, is vulnerable to discontinuities, and does not address causal mechanisms.

Trend data was acquired through several internet queries using key words and phrases including, but not limited to, "quantum computing trends", "quantum computing forecast" and "quantum computing Moore's law". These searches yielded a wide variety of results that were compiled into a more concrete, succinct data set used for this forecast. This data was used to create trend charts and project quantifiable parameters to analyze adoption and substitution of technologies.

2.2 Trends

In looking at future trends in quantum computing, it is important to first consider the past advancements made in physics, mathematics, and computing that led to the development of quantum computers. As far back as the 1920's physicists were developing quantum theory. By 1970, the phrase "quantum information theory" was first used and proposed as a means of computation [2]. Soon, quantum computers as we know them today were being described and designed.

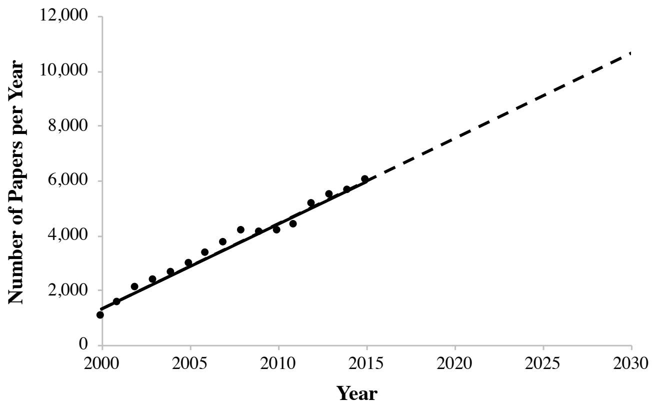

Figure 1: A Google Scholar search for publications containing the terms "quantum computing" illustrates how the field has grown in recent years [3]

Research partnerships between big technology companies and elite universities began to form by the early 2000s; Google and University of California Santa Barbara, Lockheed Martin and University of Maryland, Intel and Delft University of Technology [4]. In Figure 1, a Google Scholar search for publications containing the terms "quantum computing" yielded results with a positive linear trend from 2000 to 2015 [3]. Several competitive start-ups emerged in the early 2000's as well, including D-Wave Systems and Rigetti Quantum Cloud Services. In fact, today, IBM, D-Wave, and Rigetti are the three companies with commercial quantum computing products on the market in 2019. Google, Intel, and Microsoft are also in the race, with products in development and soon to be released [5].

Governments are launching quantum computing initiatives as well. In 2016, the Australian government invested AUD $25 million over a five year period toward silicon quantum integrated circuit research and development [4]. The same year, Canada committed $76 million to the University of Waterloo's Transformative Quantum Technologies program [4]. The United States devoted $1.275 billion over five years in the National Quantum Initiative Act of 2018. Europe recently launched a Quantum Technologies Flagship project lasting 10 years and costing $1.1 billion. Perhaps the most cutting edge country in quantum is China. The number of Chinese patents in quantum has far surpassed those registered anywhere else. The country is also building a $1 billion National Laboratory for Quantum Information Sciences projected to open in 2020 [4].

This hype surrounding quantum computing and the race to develop the technology is justified. Quantum devices have potential applications in materials and drug discovery, optimization of complex systems, artificial intelligence, the energy crisis, chemistry, cryptography, machine learning, optimization and many other industries.

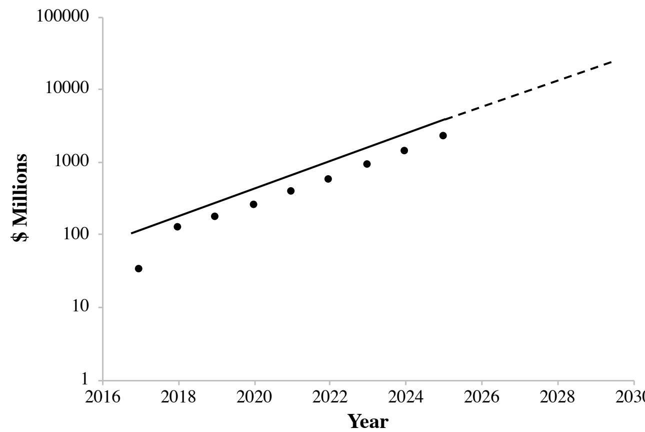

Figure 2: Enterprise quantum computing market to reach $2.2 billion by 2025 [6]

According to a report from Tractica, while the market for enterprise quantum computing is nascent, total market revenue will begin to accelerate in the next several years, rising from $39.2 million in 2017 to $2.2 billion annually by 2025 at a 23% CAGR. This trend can be seen in Figure 2 [6]. A competing report by Market Research Futures expects the market to grow at a 24% CAGR to $2.464 billion by 2022 [7]. These studies, while slightly differing, indicate that the major driving factor for the quantum computing market is the increasing performance capability of supercomputing.

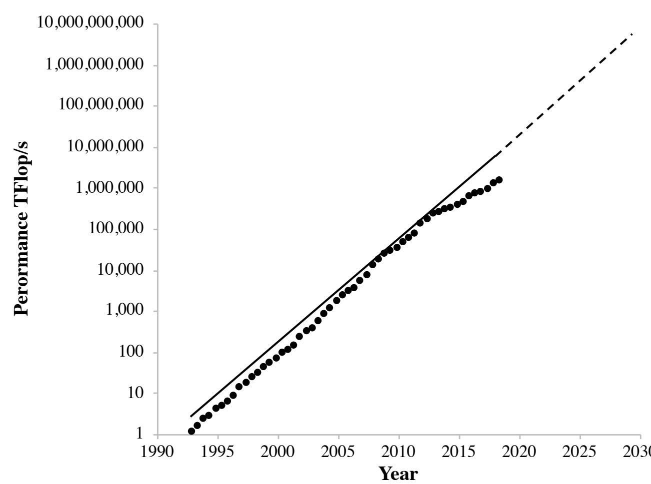

Figure 3: The performance capacity of computers has increased exponentially since the 1990s and is projected to reach 1.0E9 TFlop/s by 2030 [8]

The performance capabilities of supercomputers are expressed using a standard rate for indicating the number of floating point operations per second (Flop/s). For example, a 1 TFlop/s computer system is capable of performing 1 trillion floating-point operations per second. In other words, in order to match what a 1 TFlop/s computer system can do in just one second, one would have to perform one calculation every second for 31,688.77 years [9]. According to Figure 3, the performance capacity of computers has increased exponentially since the 1990s and is projected to reach 1.0E9 TFlop/s by 2030 [8]. Quantum computing is the technology that will continue this exponential trend in computing power.

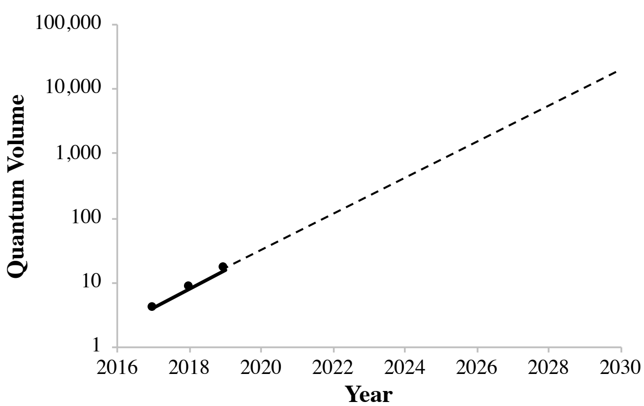

Figure 4: IBM hopes to double quantum computer performance annually, progress that shows as a straight line on this chart [10]

This is a standard way of measuring conventional computing, but what happens when quantum surpasses the levels at which this assessment is accurate and applicable? IBM has proposed a new method of measuring the progress of quantum computers, claiming it is an equivalent to the Moore's Law of conventional computing. By using "quantum volume" as a measure of progress, metrics like error rates and the quality of connectivity between qubits will be included and factored in, in addition to the conventional qubit count. IBM revealed that quantum volume on its machines doubled from 4 in 2017 to 8 in 2018 and its recently unveiled Q System One machine has a volume of 16 [12]. If the trend continues, by 2030, quantum volume will reach 10,000, illustrated in Figure 4 [10].

The doubling of this method is undoubtedly parallel to that of Moore's Law. While Moore's Law has held true for decades since its inception, the miniaturizing of processor circuitry has grown more difficult, reaching an asymptote of efficiency. For this reason, many argue that quantum computing is the only way to continue progress in this industry [11].

2.3 Results of Trends Forecast

These trends illustrate that, although quantum computing has been theorized for half a century, it is still in its earliest stages and the field will see exponential growth within the next decade. Greater investments in this research by private companies, public corporations, and governments alike will yield more and more progress [4]. As evidenced by the growing number of publications on quantum computing in Figure 1, by 2030, one can predict that these numbers will increase twofold [2]. The market revenue for quantum computing will begin to accelerate in the next several years, rising from a recorded $39.2 million in 2017 to $2.2 billion annually by 2025 at a 23% CAGR according to one report [6]. This growth is propelled by the technical advancements made in the performance capacity of supercomputers which is projected to reach 1.0E9 TFlop/s by 2030 [8]. IBM revealed that the quantum volume on its machines has been doubling yearly. If the trends continue, by 2030 the quantum volume will reach 10,000 [10]. This growth trend has been compared to that of Moore's Law, and many argue that quantum computing is the only way to make advancements past the apparent asymptote science has reached [11].

As with any forecast, limitations do exist. Although there is much historical data regarding developments leading to the quantum computers of today, quantum computing as a field is still very young. Very few quantum computing services are on the market as of 2019, and even fewer quantum computers are available for purchase. Cost is undoubtedly a huge limitation, yet because this industry is so young, there is little data available on this factor.

The research available and presented in this report suggests remarkable growth in quantum computing through the next decade. In the last five years, hardware and software capability have moved out of university labs and into real-world business products. Still, the technology needs to mature to become fully enterprise-ready and deliver meaningful, cost-effective results.

3. MONITORING FORECAST

3.1 Methodology

A monitoring forecast is a systematic means for identifying precursors for breakthrough technologies and using them to provide advance warning for decision makers. A breakthrough technology is defined as "an advance in the level of performance of some class of devices or techniques that significantly transcends the limits of prior devices or techniques."

On a trend chart, this is identifiable by a move to a new growth curve with an upper limit higher than that of the old growth curve. Monitoring is aimed at predicting the breakthroughs. Indications of these precursors can present in many ways, but the most obvious are predictable by the development performance of a supporting or complementary technology to that being predicted. Actionable information can be gathered and technological developments can be predicted through a procedure of data analyzation and conclusion formation.

Martino outlines a four step process for a monitoring forecast: collection, screening, evaluating, and threshold setting. First, information is collected on a technology. Once sources have been selected to be monitored, the information is screened, catalogued, and coded. This step ensure that only relevant information is included in the forecast. Items allowed into the system are then evaluated for their significance. A set of hypotheses is developed as a part of the evaluation, noting patterns and confirming or disconfirming expected evidence. As evaluation continues, the evidence for one or more hypotheses naturally grows stronger. Of course, a hypothesis can not be confirmed until an outcome is present. Therefore, the forecaster must set a threshold for each hypothesis, so that when a hypothesis passes a threshold, it will trigger action from decision makers [1].

As with any forecasting method, there are strengths and weaknesses to using this approach. Threshold setting is a largely subjective process. The thresholds set will vary depending upon the needs of the organization creating the forecast and the individuals consulted and responsible for the success of an organization. In addition, because monitoring only formally involves one forecaster, it is likely that information may be overlooked and not included.

Monitoring data was acquired through several internet queries using key words and. These searches yielded a wide variety of results that were compiled into a more concrete, succinct data set used for this forecast.

3.2 Current Events

3.2.1 Quantum Computers

D-Wave Systems released the first commercially available quantum computer in 2017, the D-Wave 2000Q as seen in Figure 5. It is a quantum processing unit with 2000 qubits, the most of its kind. D-Wave projects to double this number in its next quantum computer release in 2019 [13]. D-Wave machines have been installed at Google, NASA, Lockheed Martin, University of Southern California, United States Government agencies, Los Alamos National Labs, Oak Ridge National Lab, Toyota Tsusho, and Temporal Defense Systems, making it the most widely used commercially available quantum computer on the market [13].

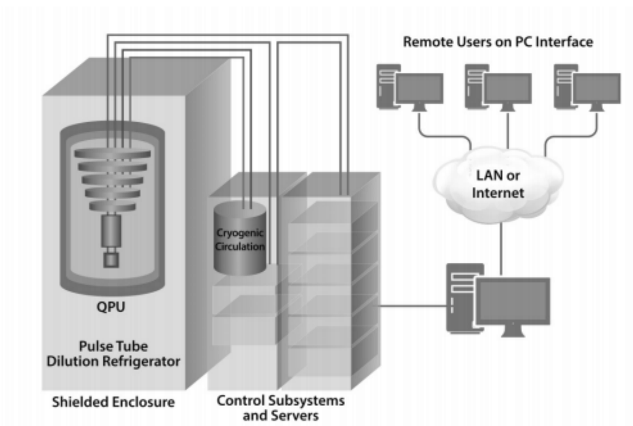

Figure 5: The D-Wave 2000Q System [13]

In January of 2019, IBM released the Q System One, which is claims is "the world's first integrated universal quantum computing system for commercial applications" [14]. The Q System One, unlike the systems used by Rigetti, Intel and Google, does not use superconducting circuit loops [15]. Instead, it is a single, tightly integrated system enclosed in an airtight case nine feet (2.7 meters) tall shown in Figure 6. The Q System One is encased in half-inch-thick glass to eliminate external disturbances. The system also uses a combination of metal supports to keep the cooling chamber, electronics, and casing separate, which has been a huge limitation to quantum computer system technology [17].

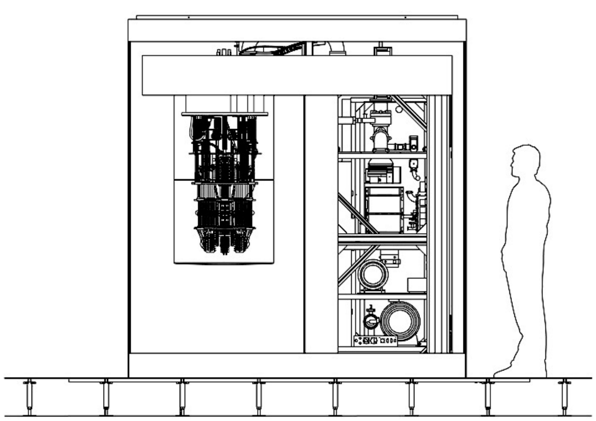

Figure 6: IBM Q System One [17]

Google, along with Rigetti Computing, and Intel, rely on chips specially designed to have quantum properties by virtue of the superconducting circuit loops they contain [18][19]. In February 2019, Google researchers announced a key control circuit in CMOS that will work at cryogenic temperatures. The circuit is a high-performance, low-power, pulse modulator that will program the qubits and is the first CMOS cryogenic quantum control IC to have a working interaction with qubits [20]. In Figure 7, a schematic of the Google cryogenic-CMOS qubit controller mounted on the 3 kelvin stage of dilution refrigerator and connected to a qubit.

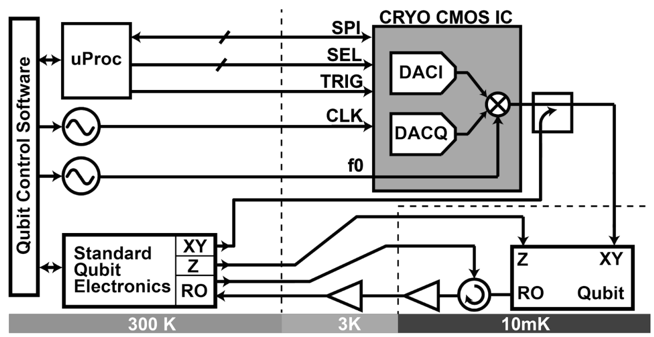

Figure 7: Schematic of the Google cryogenic-CMOS qubit [19]

Another approach to quantum hardware architecture consists of a quantum particle suspended in a system running at room temperature. IonQ is known to be working on this method [20]. In a more recent development, in February 2019, the United States Military filed a patent for a room-temperature superconductor, seen in Figure 8. This invention consists of a metal coated wire over an insulator core. An electromagnetic coil surrounds the wire, and when activated by a pulsed current, this coil vibrates. The vibration is what allows the wire to act as a superconductor at room temperature [21].

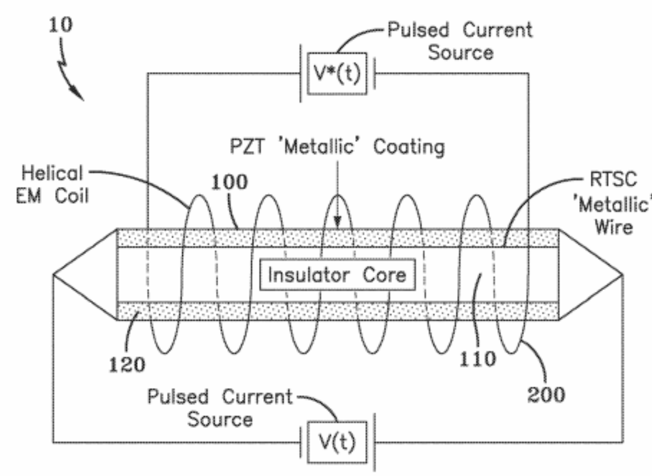

Figure 8: Room temperature superconductor proposed by the United States Navy [21]

Microsoft is pursuing a third strategy called topological quantum computing, which at this point is completely theoretical and has no working hardware. Microsoft is hoping to encode its qubits in a kind of "quasiparticle." This method is promising because it would make the computer extremely resistant to outside interference [22].

3.2.2 *Quantum Cloud*

IBM's Q Experience is a novice-friendly gateway that offers developers the ability to experiment with quantum computing. The platform offers user guides, an open-source SDK, and interactive quantum demonstrations. Their most advanced quantum machine is restricted to preapproved researchers, but its older 5- and 16-qubit devices are accessible to all [14].

Rigetti offers Quantum Cloud Services (QCS), a cloud computing platform and SDK that tightly integrates its 16-qubit quantum processor with classical computing infrastructure. The company has promised a $1 million prize to the first organization to demonstrate a "quantum advantage"—where a quantum computer is proven to be more effective than a classical computer. A 128-qubit processor, promised for next year, will likely be necessary for the prize to be awarded [18].

In 2018, D-Wave Systems Inc. launched Leap, a real-time online quantum computing environment. Leap is the latest addition to the quantum cloud—a set of services that make quantum computing accessible to almost anyone with a computer and a broadband connection. Leap allows anyone to sign up, giving them one minute of time on a cloud-connected 2000Q each month. In addition to providing access to a 2000Q computer housed at D-Wave's headquarters in the Vancouver suburbs, Leap provides documentation, videos, training materials, and a community for developers of all skillsets to learn and discus. D-Wave is also offering an open-source software development kit (SDK) called Ocean that can be used to build applications and solve problems on the 2000Q [20].

The real prize in quantum computing, of course, awaits the company that becomes the default software and hardware provider for the rapidly expanding quantum cloud. The prospect of becoming the Windows or Intel of computing's next great leap is enough to persuade any organization to give away access to their most innovative technology today [23].

3.3 Results of Monitoring Forecast

These products and events illustrate that, although quantum computing has been theorized for half a century, it is still in its earliest stages and the field will see exponential growth within the next decade. Greater investments in this research by private companies, public corporations, and governments alike will yield more and more progress.

The superconducting strategy led by Google and Rigetti appears to be the leading technology, but it's unclear what form of hardware will ultimately prove the most advantageous, or if all three approaches might end up coexisting [15] [19].

IBM's Q System One has been touted as "the world's first fully integrated universal quantum computing system designed for scientific and commercial use." While this system is designed for commercial use, it is still an experimental device that is intended as a research tool meant for program development and testing for future technological developments. It is only accessible via the cloud, just like Rigetti's systems. D-wave is the only commercial quantum computer, and even so it is extremely inaccessible [14][17].

As with any forecast, limitations do exist. Although there is much historical data regarding developments leading to the quantum computers of today, quantum computing as a field is still very young. Very few quantum computing services are on the market as of 2019, and even fewer quantum computers are available for purchase. Cost is undoubtedly a huge limitation, yet because this industry is so young, there is little data available on this factor. The research available and presented in this report suggests remarkable growth in quantum computing through the next decade.

The research available and presented in this report suggests remarkable growth in quantum computing through the next decade. In the last five years, hardware and software capability have moved out of university labs and into real-world business products. Still, the technology needs to mature to become fully enterprise-ready and deliver meaningful, cost-effective results.

4. QUANTUM COMPUTING SCENARIOS

4.1 Methodology

A scenario is a snapshot of some aspect of the future and/or paths leading from the present to the future. A set of scenarios can encompass the plausible range of possibilities for some aspect of the future with the assumption that the richness of future possibilities can be incorporated into a set of imaginative descriptions.

Scenarios have three purposes: To display the interactions among several relevant external forces in order to provide a vision of alternate, plausible futures. To depict future situations in a way readily understandable by the non-specialist in the subject area. To provide specific, actionable recommendations to decision-makers.

There are five steps of a scenario-based action. First, two external factors must be identified and ranked by impact and variance. These factors could include but are not limited to economic, political, intellectual, competitive, technological, ecological, religious-ethical, managerial, and sociocultural factors. Then two levels for each factor are identified and four scenarios are created according to these outcomes. For one scenario, a SWOT matrix is created. Beginning with the external environment, threats and opportunities are identified and related to organizational capabilities. Identified strengths and weaknesses reveal promising opportunities and critical threats respectively. With these findings in mind, strategies can now be developed. Threats and opportunities are mapped against strengths and weaknesses to produce a matrix of strategies. All of this information is then presented in an action plan presenting a prioritized list of specific, actionable recommendations that restate and summarize these findings to a decision maker.

As with any forecasting method, there are strengths and weaknesses to using this approach. Scenarios can present complex portraits of possible futures and incorporate a wide range of information from other forecasting techniques. However, they may be more fantasy than forecast unless a firm basis in reality is maintained.

4.2 Key Environmental Factors

The two most critical factors in the development and diffusion of quantum computing are technology and competition. Significant technical barriers must be surmounted before quantum computing achieves its potential. This will require the development of more stable hardware, commercial platforms for software development, and the development of cloud computing capabilities for the distribution and access of quantum computing resources.

Competition is the second most important environmental factor affecting quantum computing. With so many technology companies, government agencies, educational institutions, and start ups in the race for quantum supremacy, development is going to be significantly impacted by this factor. Funding will be divided and intellectual property will be heavily monitored. It is also possible that a lack of competition could have equally as much impact. With less competition, an oligopoly is possible, as well as no further development at all.

4.3 Scenario Matrix

Technology

Competition		**Inhibit**	**Promote**
	Low	***No further development*** • Many technological barriers • Competition leaves the market • Quantum computing is no longer pursued	***Technological oligopoly*** • Technology advances quickly • Too few competitors in market • Declining competitive pressure • Increase in price • Reduction in output
	High	***Competition for development*** • Highly concentrated competition • Funding too divided • Many technological barriers	***Optimal development*** • Technology advances quickly • Many competitors in market • Huge strides made in the field leading to great discovery

Figure 9. Quantum computing scenario matrix

4.4 Scenarios

4.4.1 No further development

The first of four potential scenarios identified results from a lack of competition and huge technological barriers. Funding from government agencies for research and development would come to an end and the pursuit of quantum computing would be completely abandoned This is rare, but has occurred in emerging technologies of the past.

4.4.2 Technological oligopoly

In this scenario, a slowdown in business dynamism means that entrenched technology firms working towards quantum supremacy have less to fear from startups. As a result, the economy suffers as innovation slows and job growth stalls. The decline in dynamism in the quantum computing could originate as the number of companies starting up and dying off plunges and the industry becomes more productive. The impact of the giant tech companies not only affects the efficiency of its industry but on the entire U.S. economy and it portends slower productivity growth. High and rising profits in an increasingly concentrated market are typically a sign of lessening competition and increased market power by dominant companies as well. That's good for shareholders, of course, but not good for consumers or the overall economy.

4.4.3 Competition for development

This scenario is most similar to that of the present, 2019. This industry is seeing the beginnings of a battle between tech giants such as Google, IBM and Microsoft, which are vying with each other to attract developers onto their respective quantum platforms. Government agencies have been dividing funding for research and development initiatives across the globe as well. China has announced plans to spend more than $10 billion to build a national laboratory for quantum science, to open in 2020. This has triggered efforts in Washington, DC, to create a "National Quantum Initiative." The European Union launched a quantum-research initiative in 2016 and backed it with more than $1 billion. These efforts are very divided and are not the best in the face of great technological barriers.

4.4.4 Key Scenario: Optimal Development

The following is an excerpt from a hypothetical story published in *The New York Times* on April 20, 2025 based upon the Optimal Development scenario identified.

BOSTON, MA— For years, and for all the mounting scientific evidence, time travel has remained marooned in the imaginations of artists and movies like Back to the Future." Now, and by accident, it is more real than ever. Physicists announced on Wednesday that at last they had accidentally discovered what science fiction writers, movie directors, and Albert Einstein alike have dreamed up: time travel.

"We have done what we thought was impossible," said Edward Farhi, a physicist at the Massachusetts Institute of Technology Center for Theoretical Physics (MIT CTP) and director of the quantum computing research conducted there, during a Wednesday news conference in Boston.

This miracle was accomplished by violating the second law of thermodynamics. That law is closely related to the notion of the arrow of time that posits the one-way direction of time from the past to the future."We have artificially created a state that evolves in a direction opposite to that of the thermodynamic arrow of time," said Farhi.

Quantum physicists from MIT CTP decided to see if time could spontaneously reverse itself at least for an individual particle and for a tiny fraction of a second. The physicists explained that the electron state evolution is governed by Schrödinger's equation. Although it makes no distinction between the future and the past, the region of space containing the electron will spread out very quickly. That is, the system tends to become more chaotic. The uncertainty of the electron's position is growing.

The results were announced simultaneously at news conferences in Boston, and five other places around the world. In March 2019, Researchers from the Moscow Institute of Physics and Technology teamed up with colleagues from the U.S. and Switzerland and returned the state of a quantum computer a fraction of a second into the past. In the past five years, no advancements have been made. "We hit a wall," said Liu. " We were unable to replicate what was done."

Wednesday's discovery is groundbreaking. Time can be reversed, and the increments can be set by quantum computers. Seth Llyod, director of the center for extreme quantum theory at MIT, said, "What a time to be alive."

4.5 Results of Scenarios

By investigating various scenarios pertaining to the future of quantum computing technology, it is clear that the future is quite unpredictable and could result in many different circumstances. Though historical and current trends suggest that the two key factors, technological and competitive, will both promote this technology over the coming decades, preparing for other outcomes is critical.

5. QUANTUM COMPUTING ASSESSMENTS

5.1 Methodology

Technology assessment is "the systematic study of the effects on society, that may occur when a technology is introduced, extended, or modified, with emphasis on the impacts that are unintended, indirect, or delayed" [24]. Rogers suggests classifying these assessments as desirable versus undesirable, direct versus indirect, anticipated versus unanticipated, and as increasing or decreasing equality [25]. It particularly important to examine the undesirable, indirect, unanticipated consequences, which decrease equality because they are often over looked by decision makers.

5.2 Desirable, Direct, and Anticipated Consequences

Quantum computing's most anticipated and desirable future will likely be in augmenting subroutines of classical algorithms that can be efficiently run on quantum computers to tackle specific business problems. Theoretically, a quantum computer could be used to identify the highest efficiency routes with extremely high processing speeds.

Quantum computing is also becoming vital in the cyber security industry, which is projected to grow to 248.26 billion U.S. dollars by 2023 [26]. Part of this growth may be attributed to society's increasing reliance on the Internet of Things (IoT). As everything become digitally accessible, every person should be more concerned about cyber security. As we continue to see advancements in quantum computing technologies, more governments, businesses and households will have access to these protective tools.

5.3 Undesirable, Indirect, and Unanticipated Consequences

While cyber security has the potential to be improved by quantum computing, the advent of the quantum computer could make the hacking process easier and faster. Some researchers assert that no encryption existing today would be able to hold against from the processing power of a functioning quantum computer [27]. Citing the fact that nuclear technology was primarily developed as a destructive tool, many argue that similarly quantum computers could be used for a purpose other than intended. After the war, many more positive applications were found for nuclear technology, having great impact on many other fields. Quantum computers' potential application in relation to encryption could be used for good or for malicious purposes and therefore requires monitoring for these undesirable consequences.

5.4 Changes in Equality

The richest 1 percent of the United States population has 34 percent of the accumulated wealth; the top 0.1 percent has some 15 percent [38]. The biggest causing factor in this disparity is that the technology-driven economy greatly favors the wealthy. Quantum computing will join the ranks of technologies before that drive this inequality. In addition, quantum technology is largely inaccessible due to its cost. While the cost of quantum computers will likely decrease as the technology becomes more developed, much like conventional computers, use and purchase very dependent upon socioeconomic status.

5.5 Results of Assessments

These assessments illustrate that, although quantum computing has been theorized for half a century, it is still in its earliest stages and the field will see exponential growth within the next decade. Greater investments in this research by private companies, public corporations, and governments alike will yield more and more progress. Similarly, establishing the aforementioned unanticipated, indirect, and undesirable consequences helps to adequately prepare to handle them.

6. CONCLUSIONS

Using trend forecasting method, it was determined that the development of quantum computing, however, is still in its earliest stages. Greater investments in this research by private companies, public corporations, and governments alike will yield more and more progress. Because of this, total market revenue will begin to accelerate in the next several years, growing to an approximate $2.2 billion by 2025, propelled by the technical advancements made in the performance capacity of supercomputers, which is projected to reach 1.0E9 TFlop/s by 2030, and about 10,000 in quantum volume. The research and historical evidence presented in this report suggest remarkable growth in quantum computing through much of the next decade.

Evidence from the monitoring forecast shows that in the last five years, hardware and software capability have moved out of university labs and into real-world business products. Still, the technology needs to mature to become fully enterprise-ready and deliver meaningful, cost-effective results. Google and Rigetti are leading a super conducting strategy that appears to be the leading technology. IBM's Q System One and D-Wave's 2000Q are the only commercially available quantum computers. Quantum Cloud services that provide user guides, open-source SDKs, and interactive quantum demonstrations include IBM's Q Experience, Rigetti's Quantum Cloud Experience, D-Wave Systems' Leap.

Four different scenarios for the development of quantum computing technology were described based on different configurations of the two most critical environmental factors affecting the technology—the level of competition and the level of technological progress—and a scenario illustrating the potential of the technology with maximal technological progress was expanded upon.

Using technology assessment, desirable, direct, and anticipated consequences as well as undesirable, indirect, and unanticipated consequences of quantum computing were then assessed, as were the effects quantum computers may have on equality. Desirable consequences of quantum technology include use as a method of large data processing and cyber security. Undesirable consequences include hacking and other cyber crimes. Quantum computing will likely widen the socioeconomic gap by easing and expediting the upper class's use of technology, giving them greater access to information, and improving their decision-making and cyber security.

There is no doubt that the quantum revolution is coming. It is essential for decision makers, technology investors, manufacturers, government agencies, educational institutes, and research and consultancy firms to make sure that they are ready for this cutting edge of technology innovation. Enterprises can begin learning more about the fast-evolving market by identifying where quantum will have the greatest impact and preparing with quantum-ready applications. By identifying areas where today's quantum computers can make a difference and testing initial use cases, these decision makers can best position themselves for success in a quantum world. Those that begin experimentation and innovation in these early stages of quantum computing will be best prepared to maximize the potential that the quantum revolution is bound to bring.

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