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The Rise of the Quantum Computing Industry – Identifying the key barriers of adoption of QC-technology as a service

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The authors declare that they are the sole authors of this thesis and that they have not used any sources other than those listed in the bibliography and identified as references. They further declare that they have not submitted this thesis at any other institution to obtain a degree.

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Abstract

The future is here. New digital, disruptive innovations are changing and affecting industries across society. And the emerging Quantum Computing (QC) industry is not an exception. Billions of dollars have been invested by actors such as governments, large enterprises like IBM and AWS, and by smaller to medium firms towards achieving a fully working QC-technology. Therefore, firms who are looking to adopt it must address the barriers that come with it.

This thesis therefore explores what barriers, with the objective on key ones, that exist when firms are adopting QC-technology as a service into their business strategy. The geographical scope of this study is the European and North American industries. The applied method is qualitative and based on the methodology of grounded theory where six semi-structured interviews are carried out with key experts in the field . Furthermore, the analytical PESTLE-framework was used to systemically code and categorize the barriers found from the interviews to analyze the political, economic, social, technological, legal, and environmental factors connected to the research question. By using key experts from different parts of the industry and this framework, it resulted in a holistic view of the industry's barriers.

The findings of this study are that the QC-industry is still in its early era with 34 barriers of adoption identified and eight of them deemed to be the key ones because of their significance and frequency of mentions. The eight key barriers are QC-technology is costly, impatient investors, funding issues, lack of consistent revenue streams, lack of awareness from top management, insufficient ecosystem, lack of skilled labor and immature technology. The most important minor barriers of the other 26 include lack of standardization and benchmarks, lack of collaboration between certain geographical parties, misinformation from vendors and not using external advisors. Nonetheless, the QC-technology is on the up-rise and is projected to affect industries across the world. Firms in these industries must therefore learn to adopt to the dynamic changes that come with what the QC industry brings. Therefore again, it is the intention of this thesis to explore the key barriers and mitigation strategies to overcome them.

Keywords: Quantum Computing technology, barriers, servitization, disruptive innovation, mitigation strategies

Sammanfattning

Framtiden är här. Nya digitala, disruptiva innovationer håller just nu på att förändra och påverka industrier över hela samhället. Den växande kvantdatorindustrin är inte ett undantagsfall. Flertalet miljarder dollar med målet att uppnå en fullt funktionell kvantdator har investerats av aktörer som stater, stora företag som IBM och AWS samt små till medelstora företag. Därför bör företag som kommer att påverkas av effekterna adressera barriärerna som finns.

Den här uppsatsen undersöker därför vilka barriärer, med fokus på de essentiella, som existerar för företag när de ska adaptera kvantdatorteknologi som en service i deras affärsstrategi. Den geografiska omfattningen berör den nordamerikanska samt den europeiska marknaden. Metodiken som användes var ”Grounded theory”-metodologin där sex semi-strukturerade intervjuer utfördes med nyckelexperter i industrin. Fortsättningsvis så användes PESTLE-ramverket för att systematiskt koda samt kategorisera de identifierade barriärerna utifrån politiska-, ekonomiska-, sociala-, teknologiska-, legala- samt miljöaspekterna. Genom att ha erhållit data från nyckelexperter från olika delar av industrin samt använt ramverket så gav det en holistisk bild av industrins barriärer.

Resultatet av studien är att kvantdatorindustrin är i ett tidigt skede med 34 barriärer identifierade och åtta av dem som anses vara de mest essentiella på grund av deras signifikans samt frekvens av omnämnanden. De åtta nyckelbarriärerna inkluderar att kvantdatorteknologin är dyr att investera i, otåliga finansiella investerare, finansieringsproblem, brist på konsistenta intäktsflöden, brist på medvetenhet av ledningen, bristfällande ekosystem, brist på kompetent personal och icke-mogen teknologi. De viktigaste mindre barriärerna utav de 26 inkluderar brist på standardisering samt riktmärken, brist på samarbete mellan vissa geografiska områden, felaktig information från industrin till köparna, samt att inte ta hjälp av externa rådgivare. Vidare, så är kvantdatorteknologin samt industrin i helhet i en uppgång och förväntat att förändra industrier över hela världen. Företagen i dessa industrier bör därför lära sig redan idag att adaptera sig till de dynamiska förändringarna som kvantdator industrin medför. Därför är syftet för det här examensarbetet att utforska nyckelbarriärerna och strategierna som i syfte för att överkomma dem.

Nyckelord: Kvantdatorteknologi, barriärer, servitisering, disruptiva innovationer, riskreduceringsstrategier.

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Chapter 1

Introduction

1.1 Background

Quantum Computing hereby referred to as "QC", is at the initial stage of technological evolution and has a high potential of generating disruptive innovations. These innovations are the different application areas for QC and if successful could support competitive advantage of firms and nations by faster calculations, for certain problems. Therefore, further research and development of QC is important [41]. *Do note that an example definition of what a quantum computer is can be read in sub-chapter 2.1.*

The projected outlook for the QC industry is that by the end of 2023, the market will be worth about $1.9 billion and to grow and hit $8 billion by 2027. Future global research and development are expected to take place to commercialize QC. The leading contributing countries or regions are the US, EU, Australia as well as China. To support this growth, the need for identifying potential barriers of adoption is necessary [23].

The state of the QC industry is now in a situation where a few big tech firms are in a race for developing a fully functional Quantum Computer. Some of the leading firms are IBM, Google, Rigetti Computing, Microsoft, and D-wave [2]. IBM released back in 2016 a quantum computer called IBM Quantum Experience with a five-qubit system, although that is not considered a fully working quantum computer [23]. Even if IBM is one of the leaders in the development of QC, Rigetti Computing also has a similar cloud-based QC system. Cloud-based means the delivery of hosted services via the internet, which in this instance could be accessing a Quantum Computer online. The name of the platform is called Forest which is based on a 36-qubit system where the Python programming language can be used. In contrary to most other quantum computers which need the most basic programming language called Assembly, to code the algorithms [23]. Furthermore, at the end of 2022, IBM released a 433-qubit system, which is also a cloud-based system [12].

According to Awan et al. [2] there are a few main challenges with QC adoption. The barriers they have identified are a lack of technical expertise, information inaccuracy as well as organizational interest in adopting the new process. Also mentioned in the article is that future empirical research needs to be done to gain deeper knowledge on the adoption of QC. Deeper knowledge is needed to see how it compares to traditional computational hardware and investigate the advantages [2]. The near-term challenges with QC have also been identified within previous research. A few examples of challenges are the interplay between hardware, hardware access,

software, benchmarking, applications, and error mitigation [13].

1.1.1 The possibilities and adoption of quantum computing technology

While the technology of a fully functioning quantum computer is still in development [21], there are future societal applications in several industries [41]. These industries include the aircraft industry, space industry, communication technology, medicine, finance, and so forth. Furthermore, concrete applications in the aircraft industry include a shorter period when developing robust and efficient aircraft with low CO2 emissions because of faster optimization and modeling, using QC. Moreover, an application in the medical industry with the help of quantum computing simulation includes lowering the time of developing new generations of drugs [41]. According to Bayerstadler [51], other industry applications to which quantum computing could contribute are cybersecurity, the energy sector, artificial intelligence, machine learning, and process innovation.

As the development of quantum computing technology progresses, the attention from the academia and industry and financial support are simultaneously increased. In the coming years, the European Commission is planning to launch a one billion Euro initiative on QC-technology alongside companies like Intel, investing at least 50 million USD in research on QC [41]. With this in mind, Quantum Computing technology may be needed to be adopted by the companies and organizations in a way that all its possibilities are captured. The quantum computer is moreover considered to be a "disruptive" technology [53].

Danneels [16] defines disruptive technology as "... a technology that changes the bases of competition by changing the performance metrics along which firms compete." Another description of QC is that it is a technology based on the development of a radical innovation [64]. The article mentions that radical product innovation are defined as "new products that are based on substantially new technology and deliver substantially better customer benefits relative to previous products" [16].

Moreover, the adoption of a radical innovation or a disruptive technology may face challenges when adopting a new product or service by the firm, i.e., QC-technology. The process of implementing a high technology (high-tech) that is radically different from its predecessor is a more complex task [68].

1.2 Defining the scope

With the brief introduction above in mind, a research topic and its significance can be outlined. This thesis will explore the quantum computing industry, more specifically identifying the barriers which exists for a company when implementing quantum computing technology as a service. Especially on how these key potential barriers are related to a firm's business strategy.

1.2.1 Research area

In general, this disruptive technology is emerging and has potential to transform business and industries by delivering solutions that can overcome computational limitations that regular computers and high performance computers have [51].

As the QC-technology is viewed as a disruptive technology and potentially a radical innovation, a firm looking to adopt this technology in their business strategy may face challenges or opportunities that comes with barriers. Moreover, barriers may occur when a firm implement QC-technology as a service in their business strategy. These barriers could by themselves be divided in areas such as political, economic to social factors. From a firm's perspective, by understanding the barriers which exist when implementing QC as a service in its business strategy, the findings of this thesis could be helpful. The findings can simultaneously help policymakers and other businesses to make informed decisions on when and how to invest in Quantum Computing technology. Knowing when, how and why to invest in QC is relevant from the perspective of the technology's potential impact on industries, such as the energy sector and artificial intelligence.

A research study and objective in this area is therefore beneficial for firms when identifying the strategies to overcome the identified barriers when adopting this technology in their business strategy. This in turn may imply an acceleration of the pace of innovation and adoption of this disruptive technology for industries and society thus reaching the potential applications of QC faster.

1.2.2 Research question

From the scope of the research area, our research question is:

- What are the key barriers to adopting Quantum Computing technology as a service to a firm's business strategy?

1.2.3 Scope

This thesis's scope is dependent on the industry's community of researchers and experts including finding a relevant number of research (interviewee) participants. These participants are also interviewed in a semi-structured manner with four preset main questions with individual follow-up questions dependent on each interviewees' answers to follow a semi-structured standardization. Furthermore, the types of firm representatives (alas representing with their own opinions) include participants from the private sector, non-profit organizations, consulting firms and governmental organizations.

The geographical areas to be focused on are only firms and organizations in the European and the North American markets. About the research question itself and the term "key barriers", key barriers are in this context the main barriers that have been identified from the interviews' raw data and qualitative methodology called "Ground Theory". More specifically, according to the PESTLE-analysis, each key barrier will be categorized into one of the sections of either the Political, Economic, Social, Technological, Legal or Environmental category.

Moreover, as the industry is constantly developing more and more articles and findings may be found during the writing of this thesis. However, the authors take this into the account and have iterated this thesis wherever applicable when new information from the industry have been released.

Lastly, the barriers analyzed will be presented and further discussed from a buyer and/or seller perspective. What this means is that a barrier could be only relevant from the vendor or seller side and not from the buyer side and vice versa. This is important to point out in order to give relevancy and context to which actor in the industry should take the (key) barrier into account when adopting QC-technology.

1.2.4 Limitations of scope

Limitations in this thesis include limited resources and standardization, the complexity of the subject, access to information, generalizability, and ethical considerations. Resources are limited because of several factors, one could be limited sample size because of the low availability of participants. Private firms or similar institutions may have regulations that exclude them from being interviewed about the research question's topic. These players may therefore be reluctant to share their thoughts or discussions because of company rules. This could lead to weaker generalizability if the sample size is insufficient. The number of interviews in this study is six, which is not too few nor too many, considering the varying roles of the interviewees.

Another limitation is that access to information, like the availability of data, could occur because of the lack of public data on the implementation of QC or business strategies in the field. Furthermore, another limitation is the potential lack of diversity in the sample regarding the low representativeness of women in the industry. This lack of diversity leads to weaker generalizability.

The choice of method for a qualitative study by semi-structured interviews may also risk affecting the wording of the responses possibly resulting in not as descriptive answers as other methods, due to the nature of the live interviews. Other limitations are ethical considerations and the changing dynamic of the industry. Ethical considerations may arise due to the nature of the study. If the respondents refuse or cannot answer a question due to a conflict of interest or similar factors, they may be excluded from the data thus making the data less complete. As the landscape of the QC-industry constantly changes due to the inherent nature of research-based knowledge and level of development stage, this study's findings may become less relevant.

1.3 Outline

The outline of this thesis will include chapters in the following order: Related Work, Method, Result and Analysis, Discussion, and lastly, Conclusion. It is essential to explore followed by examining the existing research in all relevant fields such as disruptive innovations and high tech.

Chapter 2

Related Work

To gain an overall understanding of the Quantum Computing industry and the challenges and opportunities that come with it, a broad literature review is performed down below. Peer-reviewed articles, dissertations and other relevant, and other credible sources are reviewed in four main categories: QC industry, technical diffusion/disruptive innovation, business strategies and servitization, and lastly adoption barriers.

2.1 QC industry

One definition of a quantum computer is that it is a type of computing device, or computer, which uses quantum mechanics to perform multiple computations at the same time and consists essentially of a single memory register. Practically speaking, this means that a Quantum Computer is never on or off, but rather in an intermediary stage, or "superposition". Superposition is when inputs of information can be processed in multiple stages simultaneously, making a quantum computer much more efficient than today's computers, for several application areas [41].

A Quantum Computer has two "base-states" for the qubits for which it obtains the values 0 and 1 both at the same time. It can be represented as a vector according to the figure 1 below. A qubit is the minimum unit of information that we can store in a Quantum Computer. Traditional computers uses a minimum unit of information called a "bit" which can only obtain the value 0 or 1, at one time [60].

$$\textit{State 0: } \begin{pmatrix} 1 \\ 0 \end{pmatrix} \textit{ State 1: } \begin{pmatrix} 0 \\ 1 \end{pmatrix}$$

Figure 1. The two base states for a QC

Not only, can a qubit be in the two states described in the above image, but also in a state of "superposition" where it is a linear combination of the two which means that it can be in both states at the same time [60].

Another important part of Quantum Computers is a concept called "entanglement", which is also unique to Quantum Computing. The concept refers to when one qubit is dependent on the state of another qubit. Therefore, if two qubits are entangled, if any flip or rotation is made to one of the qubits, it would result in the other qubit having the same change. The advantage of entanglement is that all qubits, that are entangled will work in tandem to arrive at a certain result at the same time, which results in faster calculations [53].

Several scientific articles and research work in the field of quantum computers mention several business and technological opportunities with the invention, for instance faster calculations in the medical- and financial industries [28], [41]. Quantum mechanics within the computer industry has thus become a hot topic at an academic level. Even to the extent that building a functional Quantum Computer is seen as a challenge as big as "the new race to the moon". Mature Quantum Computer technology can have "significant and potentially disruptive impact on our society" [41].

Looking at the previous research done within QC, the focus of research articles have changed. From a period of 1990—2020, the focus of the research has changed from mainly hardware to software-related subjects. The new research area focus of software accelerated the revolution of technological pathways. The new pathways could be summarized with three main areas: quantum image processing, quantum machine learning, and quantum sensors. There is very limited research done on barriers or identifying economic factors for the QC-industry, which is an issue of information for the industry [11].

There does exist some research that looks at the challenges for QC within the software industry. Among them are Coccia et al. [11], which found that the software needed to develop the algorithms is a challenge. One solution that has the potential to be great is to opt for a heavily user-oriented approach, which some firms have adopted with open cloud-based systems. It is the industry consensus that the full scope of the near-term quantum systems is presently unknown. No fundamental roadblocks have been identified, currently for the industry. Furthermore, there is a possibility that the application range lacks some of the enthusiastic expectations [11].

2.2 Technical diffusion and disruptive innovation

When facing emerging technologies, such as disruptive innovations, firms of all sizes will have to gain a thorough understanding of technical adoption and technical diffusion. Kee [30] defines *adoption*, in the context of innovation, as the decision of accepting or rejecting the technology and the subsequent implementation process, discontinuance, or modification of said technology by an organization or individual.

By adopting a disruptive or radically high-tech innovation, a systemic process may follow in the form of diffusion. *Technological diffusion* can be defined as the communication process by which an innovation spreads through channels from an organization, individual or any other unit of adoption to another part of society over time. Moreover, also mentioned that studies of adoption may focus more on the adopters' perspectives whereas studies on diffusion tend to instead analyze the whole perspective of a market or society [30].

In the diffusion process itself, there are several perspectives on factors that determine the level of adoption of a radical and high-tech innovation from a business-to-business view. Furthermore, according to Vowles et al. [68], differences exist between the determinants of an early adopter, late adopter or an unaware one. Their main findings show how firms' internal traits particularly influence determinants and levels of adoption. Examples are technological knowledge and the ability to sense and respond to radical innovations from a customer's point of view. Moreover, from a manager's perspective, it is relevant to understand the importance of empower-

ing employees to seek out recent technology by innovation and opportunism and to network with the users and producers of the innovation [68].

A multi-level framework is displayed by Si and Chen [58] where networking with different actors in the supply chain and several external and internal factors are pointed out to influence the adoption of disruptive innovation.

Furthermore, from the perspectives of the firms, the direct factors influencing the level of adoption of disruptive innovations are the firm's strategy, organization, marketing, and resources. This includes, for instance, the firm's business model, strategic road mapping, disruptive vision, adoption time, market position, customer orientation, resource allocation, knowledge embeddedness, and intellectual assets [58].

With the adoption of disruptive innovations comes unexpected challenges in for instance the software industry and especially the Quantum Computing industry. The main challenges that have been found when adopting or implementing QC include management, software development, institutional and organizational aspects. One key potential challenge is the lack of resource understanding for the adoption itself when it comes to education and implementation. Other key challenges are the overall lack of necessary technology and competencies skills, lack of awareness for a new ecosystem for QC and lack of information collaborations with institutions, academic community, and government [2]. The authors also implied that these challenges are more intensive for SME's (Smaller and Medium Enterprises) compared to larger corporations [2].

However, there do exist ways to enable easier implementation and adoption of disruptive innovation and technology (QC). Awan et al. [2] suggest that there is a need for organizational documents of all the processes, requirements, and rules to redefine and align the firm's infrastructure to ease the enabling of QC. Firms may also benefit from seeking out R&D and other educational collaborations with stakeholders. For instance, academic-based research groups and individual scholars could facilitate a shared understanding of the usage, implementation, and show, to reap benefits of QC applications to ensure technological skills across the organization and community and thus create a new ecosystem [2].

2.3 Business strategies and servitization

2.3.1 Business strategies

As a perceived disruptive technology, QC is expected to impact some businesses and its organization's core business both in the short and long term [6]. Moreover, along with the future of commercial use of QC-technology [61], companies looking to adopt and integrate quantum computing technology in their business strategy in some way or another may face consequential challenges [2].

Bhasin and Tripathi [6] states that while adopting innovative technology, such as QC, an organization's concurrent main objective is to increase the revenue and/or reduce cost [6]. However, from a long-term perspective, an innovative business model and new business strategies needs to be developed from the firm's side to gain a stronger market position and to sustain the long-term impact of said technology [6].

Moreover, one of the barriers found to adopt QC is thus understanding the current absence of business strategies. Organizations who adopt early to QC may create competitive entry barriers [40]

In a case study from 2022, the co-founder of a leading Quantum Computing company implied that by offering services that satisfy the customers' needs, a firm can strengthen, or create, their market position in the industry [61]. A key strategy for easing adoption mentioned is to hire strong competencies outside of the core QC-industry, i.e., expertise in Artificial Intelligence and Machine Learning, thus balancing the competencies of the team.

Furthermore, other factors are to satisfy current and future clients' needs by building platforms that enable easier integration of QC, in the future and engage with early adopters. Another factor is to focus on financially valuable business problems, applicable problems with large market potential, prototyping at a relevant time, and raising venture capital [61].

According to Jenkins et al. [27], the challenges which Quantum applications are facing lie within the Quantum Computing business ecosystem, a system that requires commercially viable software, hardware, and infrastructure. Therefore, firms should approach accordingly to that ecosystem through one (or more) of the identified generic contemporary business strategies: conventional, options, discovery and adversarial. The Conventional QC strategy of approach is done through traditional problem-solving but with superior performance. The Options strategy explores QC-technology's capabilities by positioning the firm through pilot projects and focusing on employees developing knowledge. The Development Discovery strategy is defined as the process of performing research and development with the hopes of identifying and navigating a problem space of extraordinary scope. And the Adversarial strategy, is the real-time competitive decision making which is a strategy that could be used by firms that anticipate gaining advantages in a certain area of competition [27].

According to Zach et al. [72] all firms who were late adopters of the disruptive innovation Airbnb, saw negative effects of their market values. The study shows that if firms do not move quickly and adopt the disruptive innovation, they will see negative responses from their investors which will negatively impact stock prices. Furthermore, Benzida et al. [4] also analyses the interplay between the business strategies for firms when it comes to the adoption of a disruptive technology. The authors of the study explain that the only way disruptive innovation has a possibility of being successful with the broad scale adoption is when firms have a clear strategy for gaining market share.

2.3.2 Servitization

Servitization as a concept was first introduced by Vandermerwe and Rada back in 1988 [66]. According to these authors, servitization is the transformation from being a manufacturer of physical products to becoming a service provider. There are other definitions and characterizations of servitization. For example, Wang et al. [70] define servitization as the process of transforming present business strategies to a more service-oriented business logic. The concept of servitization is often described as a transition. The transition is from stand-alone products and add-on services to maintenance contracts, operational services and performance-based offerings. Therefore,

this thesis intents to explore the concept of servitization to see if the QC industry can learn and implement it to gain a competitive advantage and to look for potential barriers [34], [47].

According to Wang et al. [35] the theoretical studies constructed on the topic of servitization mostly focus on either the connotation, driving factors or future research. The methods used for the research papers written on servitization vary a bit, for example three studies [47], [9], [52] all use a qualitative method where they do case studies on firms and interview key employees. Moreover, some other use a quantitative method where for instance, in study [33] they use a survey-based approach and in [35] they used a meta-analysis method of analyzing articles.

By analyzing different research within servitization and looking at their findings the authors can compare outcomes and see how that relates to potential barriers within QC. Exploring the area of which ways of working with servitization is the most effective, study [47] found that using a Bottom-up methodology instead of a Top-Down approach is more effective, which contradicts previous research on servitization. Palo et al. [47] also concluded that the change to servitization does not mean that the firm should only focus on selling and developing services. Rather, the best approach is to develop a duality of business models with both selling the products and services parallel to each other. Cenamor et al. [9] explored adopting a platform approach to servitization and found that firms use servitization to gain a competitive advantage and meet the heterogeneous customer demand. They also found that there are risks of excessive costs and undercutting profits. The paper suggests that there could be immense potential for a new type of architecture of platform within servitization that is a hybrid of a simple product platform and an ecosystem of platforms.

Another study investigated the relationship between the interaction of digitalization and servitization relative to the financial performance of a firm. The conclusions were that there is a U-shaped relationship between the interaction of digitalization and servitization with the financial performance of the firm. From low to moderate levels the relationship is negative and significant. From moderate to elevated levels of digitalization and servitization the relationship is positive and significant. Another finding is that if high servitization and digitalization is desired, then huge investments are needed [33].

Furthermore, Rabetino et al. [52] found that the sources of servitization-driven competitive advantages and the link between strategic choices and performance logic for successful servitization, often take place simultaneously. Companies often look at product life-cycles, cost reductions or productivity increases, to highlight the value of innovative solutions. By co-developing new offerings together with the customers, firms can achieve higher customer loyalty and develop revenue-generating mechanisms that could also be extended to new customers [52].

Looking at the more strategic or managerial perspective on servitization, a study concluded that the profitability of servitization is highly dependent on the efficient support of operating management methods. A manufacturing firm should start with a traditional basic service model and then when further capabilities develop, they can implement a customer-oriented service strategy. Traditional manufacturing firms require continuous improvement of technology innovation capabilities before they can utilize servitization to enhance their performance while safeguarding core competencies. Manufacturing firms in developing areas can adopt the techniques used by firms

located in developed areas to improve short-term benefits [35].

Shleha et al. [57] looked at the role that servitization played for entry mode diversity for high-tech manufacturing firms. With entry mode diversity the authors defined it as when a firm wants to enter a new market or industry, and there exists few different entry strategies for doing so. Therefore, entry mode diversity is that a firm uses multiple of these strategies simultaneously. The findings of the study were that servitization manufacturers who used the entry mode diversity strategy were found to be greatly more likely for a successful entry. It was also found that for firms offering advanced servitization increased the likelihood of a successful sale by over 12%, in markets when the diversified entry mode had been implemented.

2.4 Adoption barriers

There are different definitions and viewpoints on barriers. According to Oduro [46], the concept of barriers is defined as potential obstacles to innovation. That is the factor negatively impacting the adoption rate of innovation within a firm. Wilkening [71] defines innovation adoption as: "the [voluntary and/or coercive] process through which [an organization] passes from first knowledge of an innovation to forming an attitude towards the innovation, to a decision to adopt or reject, to implementation of the new idea, and confirmation of this decision." There are different definitions and viewpoints on barriers. Therefore, innovation adoption is viewed as a process within the organization that follows the steps of knowledge about the innovation, attitude formation, decision-making of adoption/rejection, and the implementation method if adoption is chosen [71].

The five main factors that have been observed that may potentially affect the adoption are relative advantage, compatibility, trialability, complexity and observability [71]. Other barriers that have been found are collaboration issues, organizational issues, knowledge issues, trust-related issues, risk issues, strategy issues, and financial issues according to several previous studies [18], [25], [65], [62], [67], [10], [36], [7].

According to study [2], the key barriers they have identified within the adoption of QC are lack of technical expertise, information accuracy as well as organizational interest in adopting the new process. The barriers are conceptualized into a few primary areas financial, collaboration, organizational, technical and knowledge.

2.4.1 Financial barriers

Access to financial aid for high-tech firms is a key determinant of the firm's success. It is also seen as a challenging task to secure adequate financing to meet rapid business needs, at the different development stages of the firm [1]. According to a study done on the barriers to innovating firms, they found that all firms they investigated implied that the cost-related barriers are important. Non-innovating firms rated market and knowledge barriers as more important, than financial barriers [24].

Testa et al. [63], looked at the effects of R&D grants for varying sizes of firms and found that there was robust empirical evidence for the positive impact on the scale-up of employment. They also found the average employee increase ranged from 7 to

16 per granted firm. Also concluded was that some of the grant programs evaluated saw a doubling in the number of employees, compared to the non-granted firms [63]. According to Fanelli [20] most SME's that were interviewed established the lack of financial resources for adoption, as the most important barrier, which was also found by North et al. [44].

2.4.2 Collaboration barriers

One study [48] examined the effects on collaboration within high-tech firms by looking at a method called CPFR. CPFR stands for collaborative planning, forecasting and replenishment [48]. It is used to improve collaboration to serve customers better and forecast demand more precisely. It was found that it is an effective method for high-tech firms. From the model used for analysis, they could see that strategic enablers were ranked extremely low. They also found that education and training was the second most impactful enabler [48].

Another study [45], looked at joint decision making and found that there are two main represented drivers of joint decision-making. The two drivers are the need to access the resources and capacity of another firm, and the need to adapt to market developments/maintain client base. The first set of co-occurrences is more apparent in buyers, whereas the second set is more apparent in suppliers. Moreover, the perceived value of joint decision-making is predicted to be greater than the value of individual decisions [45].

2.4.3 Organization barriers

A few studies have identified organizational barriers. Wang and Lestari [69] identified three key firm competences related to organizational barriers, R&D partnerships, inter-organizational networks, and government relationships (guanxi). Guanxi is a Chinese saying for social business networks as well as contacts, but the word is still used by the west since the translations does not incorporate all, given the circumstances [69]. The study found that business networks yield an indirect effect on new product development (NPD) and marketing management. Business networks, surprisingly, according to the authors of the study, do not have a direct effect on market entry success. NPD was found to have an indirect effect on the market entry success [69].

According to Berry [5] who did a study on strategic planning found that technological entrepreneurs often do not implement strategic planning. The consequences are that they miss a crucial factor to have long term growth and development. R&D grants by themselves will not sustain the further development of the firms since the management issues persist, which could affect the survival of these firms if not addressed. Governments and practitioners must place equal weight on developing the general management and marketing skill-base of small high-tech firms to ensure continued economic regeneration, innovation, and international competitiveness [5].

Another study, Senaratne & Wang [56], looked at organizational ambidexterity, which is a firm's ability to develop its core business while simultaneously exploring new industries to enter, e.g., adopting an innovative technology. The study looked at high-tech firms, both large firms and SME's. The authors of the study concluded that

ambidexterity could be divided into two approaches for firms to take, exploration- and exploitation-oriented approaches. Exploration-oriented means that a firm uses a wide range of strategies such as Mergers & Acquisitions (M&A) to gain knowledge and diverse resources. A Merger is where two firms combine into one new legal entity while an Acquisition is when one firm buys another outright [56]. Exploitation-oriented on the other hand is the same as exploration but the difference is that the motivation behind it is to gain more operational advantages. Exploitation-oriented could be economies of scale and scope as well as more control of their supply chain with vertical or horizontal integration. The study found that high-tech SME's must avoid focusing on either exploration or exploitation because that could lead to long term failure- or success traps. For larger firms it was found that they are fully able to adopt an organizational ambidexterity strategy with minimum risk, given their abundance of resources [56].

2.4.4 Technical barriers

One study done on the key challenges within the software industry to the adoption of QC found a few main challenges. One of them was deemed a technical barrier and related to the lack of engineering and design methodologies for software development and verification [2]. Another study [23] found that entanglement and superposition will play a vital role for QC´s future and therefore need to be further researched on.

Another potential technical barrier is that because of the quantum characteristics of QC, it is not capable of fully replacing classical HPC's, in all areas. Quantum decoherence and qubit interconnectivity are two major challenges to achieve quantum advantage[1] within the present era that the QC industry is in, called the NISQ-era. Qubit interconnectivity means that two or more qubits are connected. Quantum decoherence means that quantum coherence has been lost. Quantum coherence in turn, means that the process of how a system behaves changes from being able to be explained by quantum mechanics to being explained by classical mechanics. Finally, NISQ stands for Noisy Intermediate-scale Quantum era and is defined as the best quantum computer currently developed has between 50-100 qubits and that does not have an error correction[2] that is good enough for quantum superiority [23].

2.4.5 Knowledge barriers

According to Erden et al. [19], high-tech firms compete for valuable research-based knowledge when performing R&D, and therefore the firms expect sufficient returns from the investments. Since these investments in R&D are deemed to be elevated risk, Pittaway et al. [49] suggests that partnering with other high-tech firms is beneficial. Partnering can mitigate the cost, decrease risk, and gain more strategic benefits as well as share the newfound knowledge between the firms [49]. A study done on the impact quantum literacy has on the industry from an educational point of view found

[1]Quantum advantage: A quantum computer attains computational advantage when outperforming the best classical computers running the best-known algorithms on well-defned tasks [37]

[2]Error correction: procedure where the quantum state of a system is protected against a known type of noise through adding redundancy to that state, preemptively [15]

that hierarchical bounded knowledge and complex mathematics as a barrier to the adoption of QC [2].

2.5 Summary

For the QC industry overall, the research has historically been focusing on hardware but is transitioning to focusing on software and technological pathways for the adoption of QC. Moreover, the technical adoption of a disruptive innovation such as QC faces different challenges in terms of management, software development, and institutional and organizational aspects. These adoption challenges may be mitigated through using business strategies (when implementing QC-technology) such as servitization. Implementing knowledge development and understanding customer orientation in business strategies are also important.

For servitization the previous research presented that gradual change to develop services as well as a duality of business model is more appropriate than only focusing on creating services. For the barriers to adoption concept, the authors of this thesis concluded it was appropriate to group the barriers into five main categories: financial, collaboration, organizational, technical and knowledge. To test the concepts and conclusions made by these studies, this thesis is sought to perform a qualitative study. The method of how that is planned is described in the coming chapter, which is about the study's methodology.

Chapter 3

Method

This chapter explains the methodology chosen by the authors to answer the research question and fulfill the purpose of this paper. The concepts explained in this chapter are research design, description of research method as well as validity and reliability. The our main phases of the methodology are systematic literature review, data collection, data analysis and discussion of the results and literature. The aim of the concepts is to give the reader an understanding of what, why and how the strategies and approaches are used for each consecutive phase of the methodology.

3.1 Research design

The main purpose of the methodology is to form guidelines and principles for the research. For this study, a suitable method needs to be chosen and directly connected with the issue at hand [26]. Therefore, a qualitative study was chosen with the analysis method called "grounded theory" with inductive reasoning. The qualitative study allows practitioners to use a small sample to collect analytically generalizable data. The reason a quantitative method was not chosen is that it requires a vast amount of numerical data, which does not exist. Therefore, the authors of this study concluded it would not be possible to attain, given the time constraint [55]. Inductive reasoning is where data is collected to build a theory rather than to test it.

Furthermore, based upon the methodology used, the data collected forms the basis for which generalizable inferences are drawn [8]. Grounded theory is applied with inductive reasoning where grounded theory is a predefined set of steps to execute for analyzing the data. It is often referred to as an iterative process where the data collection, analysis and theory, stand in close relationship to each other [8]. The alternative to inductive reasoning is deductive reasoning which is the logical process of obtaining a conclusion from a premise that is known or something known as true, ahead of time. The reason deductive reasoning is not a great method for this thesis is that no statements or hypothesizes are being tested but instead an explanation is made for the concept of the key barriers [22].

3.2 Description of research method

The research method is divided into four phases as seen in Figure 2 on the next page: Systematic literature review, data collection, data analysis and discussion of the results and literature.

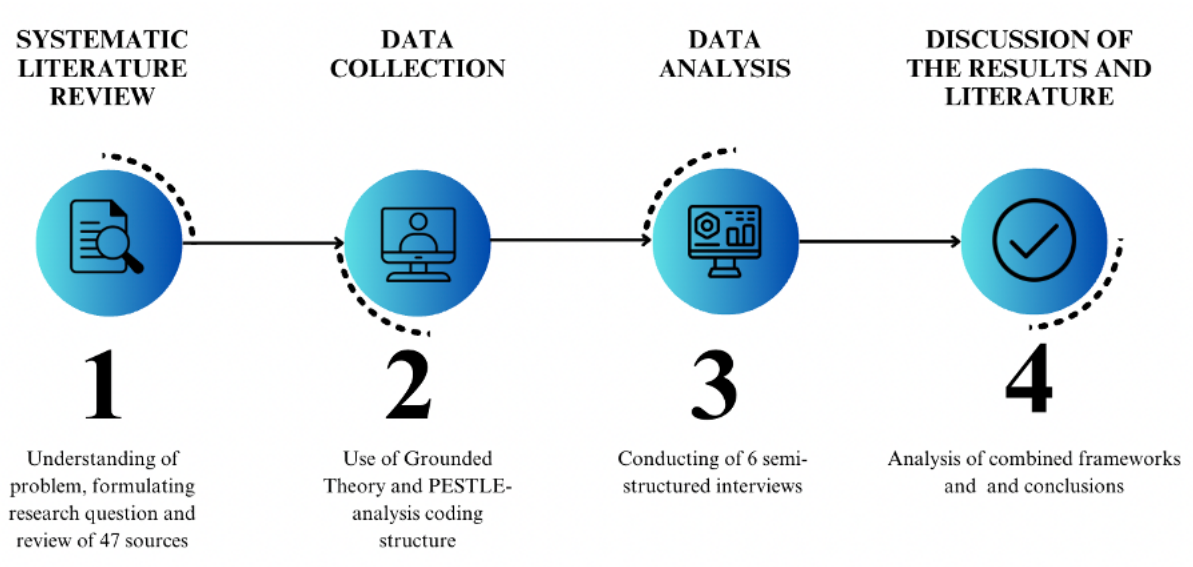

Figure 3.1: The four research phases

3.2.1 Phase 1: Systematic literature review

Firstly, to gain an understanding of the field of this study, an extensive literature review of the previous research done. According to Snyder [59] the literature review acts as a cornerstone of the thesis and is an essential aspect of a well-developed and thought-out scientific methodology. Also mentioned in the article, is that the goal of a literature review should be to give a detailed representation of what is currently known about the subject.

The articles were accessed from the database "Summon" which fulfills the requirements needed for it to have credibility, since it is managed by a governmental or academic institution [54]. The motivation for a literature review was to gain a deeper understanding of the terminology and to find gaps in the research where this thesis fits in. The findings of the previous literature will act as a reference point when we compare it to our results in chapter 6. The previous literature was also helpful when the interview guide was constructed, for the semi-structured interviews. It was helpful because a broad overview of the topics was gained which resulted in knowing more of what to look out for and model the interviews accordingly. Furthermore, the four main questions asked in the interview derived from the four topics chosen for the literature review. The topics that were deemed to be relevant, and therefore explored for the thesis were: The Quantum Computer industry overall, Tech diffusion and adoption, Business strategies with an emphasis on servitization as well as Adoption barriers.

A selection of keywords was used to find articles on the topics above that was relevant to the QC industry. The keywords used were Quantum Computing industry, adoption curve, tech diffusion, tech adoption, disruptive innovation, business strategies, servitization, barriers, financial barriers, barriers of adoption and high-tech. Important to note is that keywords were oftentimes used in duos or even more where

the use of an "AND" operator was used for the search to look for articles with all keywords specified. Primarily the keywords high-tech, Quantum Computing industry and disruptive innovation were used in addition with another keyword. This was done to look for concepts in the relevant industries. The way of combining and using multiple keywords for searches is similar to one of the methods also used, which is called building blocks. Building blocks is where you start with searching with just the concept you want to explore, then you extend it by using synonyms or related terms. This way a comprehensive set of documents is retrieved through a systematic standardized method [54].

In the first screening of the literature, it was intended to have at least 20 articles, which was found. In the second screening it was concluded that more sources were needed. A few more sources were then added. Finally, for the last screening and completion of the literature review a total of 47 articles were used.

3.2.2 Phase 2: Data collection

For the data collection part of the method for this thesis semi-structured interviews were chosen. Interviews are a great way to collect primary data in the simplest way where questions are asked directly face-to-face between two people, digitally or in person. Primary data was chosen because it is important for the thesis to develop a deep understanding of the QC industry, to identify key barriers. The literature review, acts as a foundation for the research on the barriers of adoption for QC. Since the purpose of the thesis is to explore and explain open-ended barriers, it was deemed to be the best option [26].

The other methods for interviews are structured or unstructured. Structured interviews are where a standard format for the interviews is predetermined which means that all questions are decided beforehand. The reason this method is not as advantageous is that follow-up questions are not allowed which create a deeper understanding of the topics. Unstructured on the other hand is a fully unrestricted interview within a certain topic where the interviewee can talk freely. The interviewer's role is mostly to be there and guide and record what the person says. The motivation behind why this was not chosen is that no direct follow-up questions are asked and just guidance is done for the topic discussed which does not paint as great of a picture as semi-structured interviews [22].

Table 1: The response and the acceptance rates.

	Contacted	**Accepted**	**Response rate (%)**	**Acceptance rate (%)**
Email	6	0	67	0
LinkedIn	38	6	37	16
Total	44	6	41	14

The above table 1 details the number of people contacted, responses and accepted, for the different contact methods. The response rate is also displayed and was calculated by dividing the number of responses with the number of total people contacted. The acceptance rate was similarly calculated but with the number of people who accepted to partake in the interviews divided by the total number of people contacted.

Table 2: The Interviewees' information.

Person	**Role**	**Type of firm**	**Years of experience**	**Location**
A	Senior consulting associate with specialization in QC	Consulting	5+	Switzerland
B	Head of Machine Learning and QC	Private sector	5+	UK
C	Innovation and commercialization of quantum technologies	Government	10+	UK
D	President, CEO, COO	Non-profit, Private sector	15+	USA
E	Worldwide business development and Go-To-Market strategy specialist in QC	Private sector	10+	USA
F	CEO, leader, advisory board member	Consulting, Non-profit, Private firm	15+	USA

In table 2 above a description of the interviewees' current duties are represented and what geographic location they are conducting their business. The names of the interviewees will remain undisclosed which will be motivated a bit more in-depth in the validity and reliability sub-chapter.[3] The different interviewees will instead be referenced as Interviewees A-F.

Person A has several years of experience in consulting for one of the top three consulting firms. Furthermore, he specializes in Quantum Computing where he has a PhD in physics at a prestigious university. The next Interviewee B has experience of working in a division focused on Quantum Computing from one of the leading universities in the UK. Their current role is head of Machine Learning and QC algorithms at one of the leading QC firms. Interviewee C has a PhD in Quantum Information and is currently working for a government entity focused on innovation and commercialization of quantum technologies. The next Interviewee D is the only woman that was interviewed. According to her, there is very few women working in the QC industry. She has vast experience from two of the leading QC firms in the industry and is currently CEO and COO for consulting firm and a start-up. She is also president for a non-profit organization called "Women in Quantum" which promotes women getting into the industry. The next person Interviewee E, has over 10 years of experience in the industry. He is working for one of the leading firms in R&D for QC, Amazon Web Services. He also has experience working for a few other QC firms previously. The final Interviewee F has a great deal of experience with QC, with over 15 years in the industry. He has several current obligations such as CEO of his own consulting firm and leader of a non-profit organization. He is also an advisor to several other firms that are both within and outside the QC industry.

Regarding sampling, it is not associated with qualitative studies but rather quantitative ones. For the quantitative studies, a statistically significant result must be achieved for conclusions to arise. For qualitative on the other hand, the purpose is rarely to draw any statistically sound conclusions but to understand and gain insight to topics. Sampling is still an important concept to consider and adopt the methodology for. What is important for sampling in qualitative studies is instead who and how many people should be involved [22].

With the sampling theoretical framework specifically for qualitative studies in mind, the researchers of this thesis decided on interviewing at least one expert from each type of firm/organization, to give their expert opinion. The types of firms/organizations were chosen for the full scope of the industry. With the various parts of the industry being represented a variety of opinions could be established. It could be established since theoretically a person that is working at a firm in the private sector does not have the same view on the industry as someone working for a governmental entity. Furthermore, regarding the quantity of people to interview, overall, there is no true guidance on the quantity. What is most important when the issue of number of participants is the credibility of those people, which is called "purposeful sampling." If the people interviewed are credible and have vast experience within the topic you are studying just a few participants could be enough for valid conclusions to be drawn [22].

[3] All data collected from the interviews and quotes are according to the interviewees' thoughts and views and not of the firm/organization they are associated with.

The decision of who to contact and how to go about it, demanded a great deal of thought. Firstly, an understanding of what information was needed to answer the research question was obtained. Secondly, the analysis of who could provide that information was conducted. What was concluded by the authors was that people working in the QC industry with a more business or managerial role were the best suited for an interview, preferably someone higher-up in the organization. The motivation behind why they are more suited is that for instance a physics researcher working on the actual QC and further developing it does not have the expertise on business topics. After the targeted audience was selected a continuous search was conducted primarily on LinkedIn but also on government websites for individuals.

A list of people that were to be contacted was established. Afterwards, paragraph for the request to participate in the interview was constructed. Points of considerations were length of interview, reward for the recipient, recording method, interview medium and the general purpose of the thesis. The length of the interview was decided to be 30-45 min since it was hypothesized that the acceptance rate would increase if the interviews were shorter. According to Ghauri et al. [22] an interview should not be more than an hour and a half, which was complied with. Furthermore, the interviews were not to short where insufficient answers would be obtained. For the reward of the recipient, it was chosen that we would send them a copy of the thesis after completion which could potentially help them gain more insight. The recording method was chosen to be both from the software used for the interview (Zoom and Microsoft Teams) as well as from both the authors phones to create redundancy [8]. After the text was constructed, it was sent out mostly through LinkedIn but also email, with varying response- and acceptance rates, which can be observed in the table below.

Table 3: Main interview questions

Topic	**Question**
QC industry overall	What is your view on the current state of the QC-industry with regards to technical and economic perspective?
Technical adoption	What would it take for firms in general to accelerate an adoption of QC?
Barriers	Which barriers do you think exist for you or firms in general when adopting QC?
Business strategies with a focus on servitization	What role do you think servitization plays for QC-business strategies?

The above table 3 lists the main questions asked in the interviews. The follow-up questions were then written down while the interviewees gave their answers. After the interviewees had initially answered each main question then all the follow-up questions were asked as well as even more follow-up questions if needed. The main questions were chosen based on the primary areas explored in the related work chapter. The intention of the questions was that they would be quite broad for the interviewee to give a lengthy answer and therefore it would be easier to produce follow-up questions.

3.2.3 Phase 3: Data analysis

Phase three is all about data analysis. The method utilized to transcribe and code the raw data from the interviews was done by a thematic model, an analytical framework, called the PESTLE analysis with the help of three levels of coding, derived from the Grounded theory [17].

According to Robèrt et al. [29] one approach to conduct an analysis, in this case for the QC-industry, is through mapping the external trends by precisely the factors of PESTLE. The name stems from an acronym for the Political, Economic, Social, Technological, Legal and Environmental factors of external trends and gives context to the organization or industry both in the present and certain future.

Moreover, derived from the Grounded theory, there are three preferred types of coding: open coding, axial coding, and selective coding [17]. Open coding structure refers to the analysis of data by which codes (or sub-codes) are attached to data-points such as a phenomenon, quote, event and so forth. It aims to initiate the unrestricted attachment of labelling of all data points with representational coding. Axial coding follows open coding by identifying the relationships between groups of the initial open codes. Its purpose is to develop major core codes from each group of interrelated or overlapping open codes. Lastly, selective coding is the selection of the central concept that emerged as the focal phenomenon from the process of axial coding. These codes are classified as representing conditions, context, interaction, actions, and outcomes. Doing this, a list of these codes are obtained, which in this case is represented as barriers to adoption within the QC-industry [17].

An important thing to point out is the flaw with this type of coding. Bryman and Bell [8] mentions that one of the common criticisms of this coding approach is the "possible problem of losing the context of what is said". Another criticism is the result of fragmentation of data where the narrative flow of what the interviewee says is lost. Moreover, some other limitations could be that the analysis only looks at the macro-level of the barriers and not perhaps on the micro- or meso-level, along with that the results of a PESTLE-analysis is on a static, snapshot, level meaning that the barriers could change over time [31].

However, the PESTLE-analysis along with the Ground theory approach was chosen because it enables and allows a systematic and strategic evaluation of risks, opportunities, and prospects in a disruptive or unfamiliar environment, again like the QC-industry. These barriers may also change how businesses act in their industry, i.e., changing their business strategies with these factors in mind.

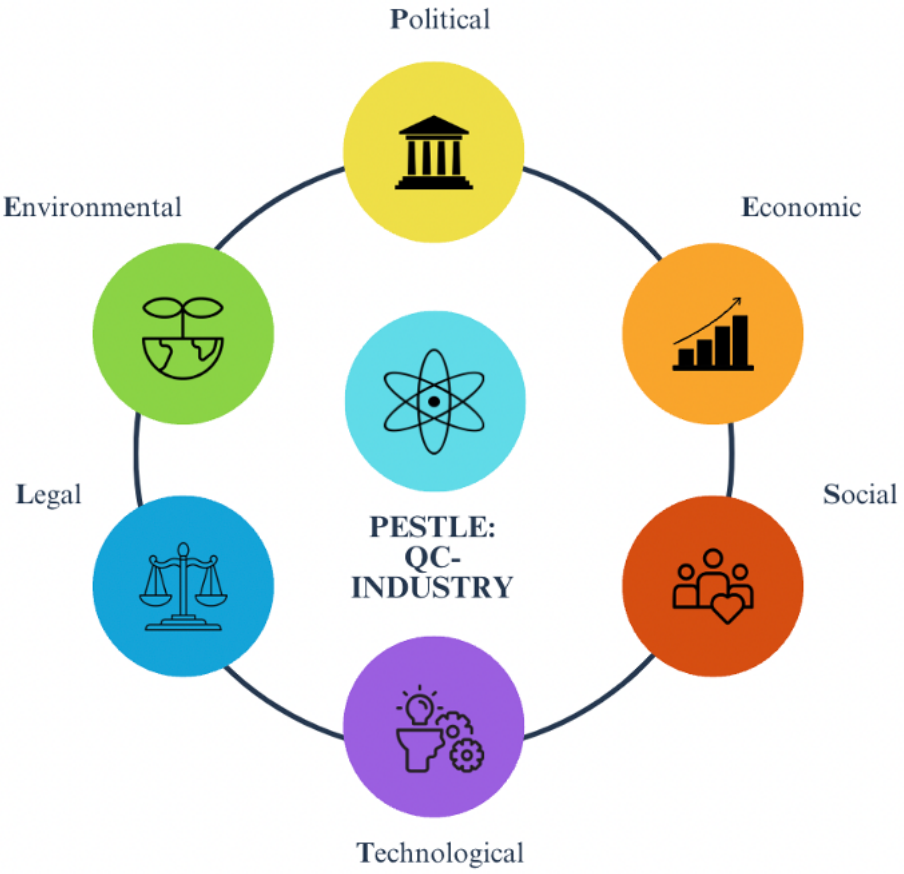

Figure 3.2: PESTLE-framework

Each sub-code, or sub-barriers, is derived from the received data from the six conducted interviews through clustering. Therefore, each factor and barrier are deconstructed individually by the subcodes and their frequency (times mentioned or discussed) with relevant quotes. An important addition is that each barrier will be analyzed from a seller and/or buyer perspective as previously mentioned.

Onto the five categories of the framework, each barrier is explained down below [32]. See the Results and Analysis chapter for additional subcodes in detail.

Political factors (barriers) determine the extent to which legal agency or government influence and control the economy or/of an industry, like the Quantum Computing industry, through policies and legislations et cetera.

Economic factors (barriers) determine the economics performance's direct impacts on a firm's long-term prospects in the market. These determinants include economic rates, growth patterns, market models, and so on, and could affect how a firm act given the barriers.

Social factors (barriers) scrutinize the industries or market's social environment and benchmark the determinants like cultural trends, population analytics, and demographics. These factors are vital when understanding how and when customers act and engage with products and services.

Technological factors (barriers) relate to the innovation of technology and its complexity which directly or indirectly affect operations of the industry and the market. Factors include technological development and awareness, and research and development, etc.

Legal factors (barriers), including legislation, relegation, and such, affect both the firm internally but also the market and industry externally. Firms may adapt their strategy depending on the different laws and other legal aspects.

Environmental factors (barriers) include all the barriers that are determined or influence the physical surrounding physical environment of the firm and industry.

3.2.4 Phase 4: Discussion of the results and literature

The last phase will be about performing a comparison of the findings from the literature review and the findings from the results of this thesis. Its purpose is to identify any similarities and /or differences between the two parts. Moreover, this phase is concluded with the implications the combined analysis of framework has on firms' adoption of QC-technology as a service in their business strategy. Mitigation strategies for overcoming the barriers will also be presented in this phase. All phases are summarized in figure 3 above.

3.3 Validity and reliability

It is essential to ensure credibility in this master thesis by drawing well supported conclusions that are relevant to the subject. Therefore, according to Björklund and Paulsson [38] three categories will be analyzed to ensure credibility: validity, reliability and objectivity. In short, the validity of a study could be defined as the degree to which the implications and findings accurately represent the investigated phenomenon [26]. The phenomenon (research question) in this thesis, again, is the investigating and thus identifying of the key barriers of adopting and implementing quantum computing technology as a product or a service in a firm's business strategy.

This thesis's validity will be evaluated via triangulation to gain a holistic view [43] which is the comparison of findings from diverse sources, i.e., like the Related work-part in Chapter 2, the semi-structured interviews (the questions asked) and the PESTLE-analysis (result). Transcribing the interviews, looking for key words from the PESTLE-analysis, cross-linking with the theory and reflecting with peer-reviewed articles is the method used to ensure high validity. Therefore, by ensuring that each aspect in the research question is analyzed through this triangulation, the validity of this thesis is strengthened.

Reliability is the consistency and stability of the findings over the time aspect across independent settings and environments [39], i.e., a study or experiment by a researcher with high reliability should have the same or comparable results if performed with the same specification by other researchers in different periods. High reliability usually means standardized and well-performed data collection and analysis. In the case with this thesis, semi-structured interviews were used (standardized) along with the PESTLE-analysis for transcription and decoding with subcodes.

Moreover, high reliability relies on coherent data from the collection of data [39]. Through estimating and cross-checking between the interviewees for any eventual outliers, a high reliability will be ensured [39]. Objectivity deals with the absence of bias in the research process and of its reporting of findings [39]. It is important to point out that the raw data from the interviewees are their own private opinions rather than their company's. However, as the interviewees are true key experts in their field with extensive experience across platforms from the whole QC-industry, their thoughts are still considered to be relevant and valid enough to be highly credible. With all the above in mind the results will be presented next.

Chapter 4

Results and Analysis

This chapter displays and analyzes the barriers of adoption found from the six interviews. Each main area deriving from the PESTLE analysis will be analyzed and the sub-barriers relating to that area will be presented. The tables display the sub-barrier[4], id, the total number of mentions for all interviews, number of interviewees that mentioned it, and buy or sell side perspective. The reason the distinction is made between the sell- and buy-side perspective is that during the interviews both perspectives were mentioned and therefore a holistic view could be obtained for the results.

4.1 Political barriers

Table 4: Sub-barriers related to political barriers.

ID	Sub-barrier	Number of mentions overall	Number of interviewee mentions	Buyer or seller side perspective
1.1	Exporting concerns	3	1	Seller
1.2	Geopolitical issues	3	2	Seller
	Total	6		

Regarding the political barriers, which can be observed in the table above, only two sub-barriers were found. Furthermore, the total number of mentions of the two barriers was six, which is insignificant compared to the other main barriers. Therefore, the political barriers could be concluded to be minor barrier. The first sub-barrier

[4]See appendix 8.1 for an explanation and direct quotes of each sub-barrier.

1.1 was only mentioned by one of the interviewees, Interviewee F. The interviewee mentioned he had observed that the US was worried about the QC technology that is being developed by US firms being accessed by other countries. The reason they were worried is that the US does not want certain countries' firms to be involved in the supply chains of US firms. Although the interviewee does not mention any country by name. Another issue discussed related to the sub-barrier is that hiring people from non-western countries as a US-based firm has some limitations to it. The result of the limitation further amplifies the existing shortage of skilled labor discussed more thoroughly in chapter 5.3. For the future, sub-barrier 1.1 could be an issue, it all depends on how the US government decides to restrict the industry moving forward.

The second sub-barrier 1.2 which is about geopolitical issues, was mentioned by Interviewees A and D. The main gist discussed during the interviews was about the collaborative issues which might be a result of the geopolitical issues between certain countries. Interviewee A mentioned that the current situation between Russia and Ukraine has resulted in some Russian research have been "left out to dry" with not being able to work with any QC firms outside of Russia. Furthermore, collaborations with China have been divisive with the US being very restrictive and not wanting any collaboration at all while the EU is more open to it, according to Interviewee D. The results of the varying opinions become problematic for the US since EU firms doing business with US firms might want to collaborate with China.

4.2 Economic barriers

Table 5: Sub-barriers related to economic barriers.

ID	Sub-barrier	Number of mentions overall	Number of interviewee mentions	Buyer or seller side perspective
2.1	QC is costly	9	4	Buyer
2.2	Impatient investors	16	5	Seller
2.3	Price to performance	2	1	Buyer
2.4	Insufficient supply chain	4	3	Seller
2.5	Funding issues	16	6	Seller
2.6	Customer segmentation	7	2	Seller
2.7	Lack of consistent revenue streams	13	4	Seller
	Total	67		

Economic barriers are among the most prevalent barriers mentioned in the interviews. Seven sub-barriers were identified and conceptualized, where 67 mentions were in total.

The first sub-barrier 2.1 within the economic barriers is that QC is costly. Firstly, what was mentioned by Interviewee B is that the QC as a service business model such as AWS bracket and Microsoft Azure Quantum are immensely helpful for creating an infrastructure. That said, they are currently expensive to use and there is no guarantee of outcome. A few interviewees mentioned that QC is very costly to develop which is why only a few big tech firms are doing it alongside some start-ups. Furthermore, interesting discussion points relating to QC being costly were made by Interviewees D and F where they discussed willingness to pay (WTP). The arguments they made were that although QC is very costly to develop and to run some calculations on the existing services available, the customers are willing to pay a premium if a quantum advantage exists. The reason for this is that traditional computers might not be able to do these calculations now being realized by QC technology. Therefore, unfamiliar problems could be solved, which might be worth the big price tag for these firms. The sales strategy mentioned by Interviewee D is that the focus of sales was on the big tech corporations since they have bigger budgets and are more willing to invest in QC than SME's.

One of the major barriers identified by all but one of the interviewees is the sub-barrier of "Impatient investors" 2.2. It was deemed the current biggest issue facing the industry by Interviewees A and F. They discussed that investors are getting more impatient with their investments and want to see a return. This issue was described to be present in a multitude type of investors. Firstly, the most mentioned argument was for private investors such as venture capitalists, private equity, and so on. Secondly, the top management of the big tech firms has also been getting more impatient with these huge investments in QC and wants to see more of a return in the short term. This ties a little bit into the sub-barrier about top management not being aware or not understanding the impact QC might have. The CEO's of firms need to balance the investments in R&D that bring long-term returns, by trying to maximize short-term gains. Thirdly, what was mentioned by Interviewee A was that this phenomenon of investors getting increasingly impatient and demanding to see returns could be seen in the stock market as well. What he mentioned was that five main firms only work with QC that have gone public in the last few years. All these firms' stock prices have gone down by approximately 70%. A caveat to the impatience that he mentions is that the stock prices do not correlate with the technology they are developing.

The next sub-barrier 2.3 identified was only mentioned by Interviewee E. The main discussion was about what needs to be present for a widespread adoption to take place. And what he mentioned is that QC need to be better than classical computing on a price-to-performance basis. This could be related to other sub-barriers as well, but this interviewee was the only one to mention this exactly, which is at the core of the explanation for the adoption of QC.

Another identified barrier 2.4 for QC adoption is that the industry supply chain is not sufficient. This was discussed by Interviewees A, C, and F. They explained that the industry is scattered since it is still in its early phase. There is no structure on which the suppliers, customers, regulators, and so on. What the industry looks at

currently is that most firms are a combination of a multitude of roles and collaborate with similar firms. It could be the case that one firm could be a supplier for one firm and then a customer for another. This non-structured supply chain development is an issue from a collaboration and optimization standpoint. This is because firms are not focusing on working on improving that but instead have a multitude of roles within the supply chain. Interviewee F also explicitly said that "the supply chain doesn't exist today." What was also mentioned about the supply chain was that it is more related to the issues that have been present in the last few years regarding the chip shortage.

One of the most talked about barriers 2.5 is funding issues, with all interviewees mentioning it. The concepts or areas discussed relating to this include lack of funding, quantum winter, government grants, R&D, big tech having bigger budgets, and continued investments. Starting with the concept of lack of funding it relates a bit to the impatient investor barrier. To explain a bit further, getting access to capital is a more challenging task. Previously, a few years ago, investors were not as strict and did not have the same demands as they have now. This slowdown in investments and difficulty in getting firms on board with investing in QC is what the industry calls quantum winter. Quantum winter was mentioned quite a few times by the interviewees but most of them said that we are not fully there yet, the industry is at a "quantum fall"-stage, meaning that the situation is worse than before but not terrible yet. This lack of capital was presented not only in the view of investments into new start-ups but also continued investments in firms that are working on developing QC's. Continued investments are deemed to be a crucial part of the success of further development and ensure that the firms do not run out of capital.

A mitigation strategy for partially solving this funding issue is the need for government grants. Some interviewees said that it is currently a necessity for the further development of QC and not having the risk of start-ups going out of business. Also discussed regarding government grants by Interviewee A is that the best use of these grants is for smaller firms or start-ups. The reason for that is the big firms already have a lot of capital and are possibly already conglomerates dominating a few industries and therefore subsidizing these huge tech firms is not the best use of public capital. Another interesting point relating to funding issues is that these big tech firms can afford to be more long-term since they usually have backing from the top management. For the SME's on the other hand the whole firm is reliant on the access of capital and if QC advantage does not get realized they will go bankrupt. The big tech firms have a lot more solid revenue streams and therefore may not risk bankruptcy if QC fails.

Continuing, the next barrier identified of customer segmentation, 2.6, is a minor barrier with only two interviews mentioning it. The gist of the arguments made regarding this sub-barrier is that proper customer segmentation is not clear and that understanding customer wants and needs is essential for the industry. Interviewee E was the one who talked the most about this. What he discussed was that currently, the firm he works for (Amazon Web Services) is mostly working towards understanding the customer's wants and needs and not so much with generating huge returns in the short term. He goes on to explain that most customers do not really care about how QC works or the technicality of it but instead only about what it can do for them and what kind of value it brings. Also mentioned was that they have identified

three different customers, universities, scientists, and private firms.

Finally, sub-barrier 2.7 of consistent revenue streams has been categorized. This barrier is deemed a major barrier with 4 interviewees mentioning it and 13 mentions. Mentioned in the interviews is that having solid consistent revenue streams is next to non-existent today. The revenue streams mentioned in the interviews which exist today are sales of hardware, sales of software, servitization, consulting, and education. The revenue stream closest to a sustainable one, currently, and in the future is the servitization business model. Servitization brings access to firms and organizations that do not have the means or skill to develop a QC themselves but can still run their simulations and algorithms on a system.

Moreover sub-barrier 2.7, also mentioned about servitization of QC is that investors like these models since they can see this consistent, although not huge, sales and potential profits in the quarterly reports. Therefore, the servitization strategy might be a good way for QC firms to please impatient investors and deal with the access to capital struggles in the short term. And therefore address the lack of consistent revenue streams in the industry. Another insight into why the servitization of QC could be a great revenue stream and business model is that the interviewees see that customers prefer a package deal where all things are included. The customers are also willing to pay a premium for this since they are paying for the convenience of having all things with QC on one platform. Regarding the sales of pure hardware, what was mentioned is that it is not a sustainable revenue stream, since oftentimes it is a one-off sale to a university for instance and the demand for hardware is lacking. With the sales of software revenue stream, it is also not deemed to be consistent, although a bit better than hardware. The reason that it is better is because additional services could be sold with it and when improvements are being made that could also be sold directly to the customer.

4.3 Social barriers

Table 6: Sub-barriers related to social barriers.

ID	Sub-barrier	Number of mentions overall	Number of interviewee mentions	Buyer or seller side perspective
3.1	Misinformation	10	4	Buyer
3.2	Lack of awareness from top management	15	5	Seller, Buyer
3.3	Insufficient ecosystem	8	4	Seller, Buyer
3.4	Lack of understanding the technology	8	4	Seller, Buyer
3.5	Lack of skilled labor	18	6	Seller
3.6	Not using an external advisor	1	1	Seller, Buyer
3.7	Collaboration issues	11	5	Seller, Buyer
3.8	Gender diversity	3	2	Seller
	Total	74		

Eight social barriers were identified after the six interviews with 74 mentions overall, which shows high significance given the rest of the tables of the PESTLE-analysis. The social barriers mentioned by most of the interviewees were all but sub-barriers 3.6 and 3.8.

In sub-barrier 3.1, misinformation, the interviewees talk about the hype and misrepresentation of information between the buyer and seller side and between sellers themselves in the overall ecosystem of the QC industry. Interviewee F states that "There's been a lot of drama and there's been a lot of hype", Interviewee D says that "There has been a lot of hype in the industry. So, there are a lot of false promises and a lot of projections that are not true and so a naïve customer has to wade through, ..., all these exaggerations". Interviewee D further mentions that a company in Thailand has shared their profits with their customers which they suggest, as a seller strategy, will become more prevalent as the computers become more powerful and as the software as a service solution becomes more turnkey.

Moving on with sub-barrier 3.2, the lack of awareness from top management. According to Interviewee A, to propagate the idea of QC organizationally downwards in a firm, the executive board or higher senior management should initiate and be on board first. They also mention that leaders in a company not understanding what QC is or what its benefits are is a barrier. One reason is that QC is in its early stage and the barrier of risk aversion is there. Following that, Interviewee F mentions an example where one of the four biggest banks in the US getting a competitive advantage over their competitors in the industry because they are already investing in QC technology right now. This interviewee fills out that it is postulated that the advantages will be bigger in the future as well as the pain and the gap for those who do not invest and similarly to the technology of AI. This is as those who embraced AI early will have a big advantage.

Onward to sub-barrier 3.3, the insufficient ecosystem is in this case explained as the ecosystem in which QC resides, involving all societal pillars of society in the system such as customers, vendors, the public, government agencies, logistics, economics, and so on. For example, buyers do not have the necessary infrastructure to incorporate quantum computation in their existing processes and workflows says Interviewee A. And the primary barrier, according to Interviewee E, "is to make it work, ..., we need to make the hardware, the software, the distribution all work together."

Sub-barrier 3.4, the lack of understanding the technology, refers to this early stage of QC that there is a "very high" entry barrier to understanding the technology and making the most of it. Interviewee B views this sub-barrier from the buyer's or customer's side by suggesting that at this point in the industry, buyers struggle to identify what they want in a partnership and figure out what the deliverables and value that QC can bring. Aside from not understanding the business aspects of the QC technology, there is also "lack of technical knowledge on the technology" says Interviewee C. Furthermore, this interviewee suggests that a solution to this sub-barrier is to democratize the knowledge of QC so that everyone who wants to adopt the technology, whether that is an end customer or supplier, can have access to the knowledge available.

Continuing with sub-barrier 3.5, the lack of skilled labor refers to the shortage of experienced or QC-educated people in businesses and academia overall. The biggest

challenge is to get people, organizations, and companies, access to immense talent with experience in the field alleges Interviewee E. Interviewee A agrees with this as they state "Generally, people who can do QC-related work are in short supply." Moreover, Interviewee B implies that niche knowledge and being able to evaluate the various aspects of the advantages, from realizing and building hardware to software and full tolerance is the toughest barrier to overcome by companies and others wanting to engage in the QC field. And strategies to overcome this sub-barrier, by Interviewee D, is to involve all parts of the ecosystem in sharing knowledge and educating academia.

Sub-barrier 3.7 of Collaboration issues deal with the conflicting interests between different players in the industry, such as competing companies. Interviewee B affirms that there are conflicts of interest, i.e., when it comes to the fact that no two QC companies are identical or have a shared agenda. Moreover, Interviewee C explains that there is a barrier to networking, in the sense that there is a challenge to reach end customers. And to solve that, end buyers alike suppliers, companies, and organizations need to network and build relationships between each other and QC developers or QC-companies. Interviewee C fills out that the QC technology is at the early level in which "the only way to make it useful" is to offer the technology as a service where there are a centralized unit and people can access it through the internet or external modules.

Lastly, the two other barriers which were not mentioned by most of the interviewees, sub-barrier 3.6 and 3.8, could be minor barriers as of now but could be potential uprising barriers in the future. Sub-barrier 3.6 of not using an external advisor refers to Interviewee F asserting that there are two-fold internal barriers. For context, there is a need for having experienced people that can be added to your staff and secondly have specific advisors or third-party consultancies that can help one adapt to quantum-like people knowing the quantum commercialization space. The interviewee continues by stating that "this is going to be one of the biggest growth areas in quantum." Moreover, regarding sub-barrier 3.8 of gender diversity, Interviewee D states that the QC industry is very male-dominated and that a diverse team makes more effective decisions than a non-diverse team. Interviewee E claimed that "like any tech-centric thing, your diversity and inclusion is challenging". This future challenge of making a team more effective through diversity and inclusion can be discussed further.

4.4 Technological barriers

Table 7A: Sub-barriers related to technological barriers.

ID	Sub-barrier	Number of mentions overall	Number of interviewee mentions	Buyer or seller side perspective
4.1	Immature technology	25	6	Seller, Buyer
4.2	Too many technologies	2	2	Seller, Buyer
4.3	Fault tolerant QC not existing	2	1	Seller
4.4	Lack of benchmarks	4	3	Seller, Buyer
4.5	Too fast technological development	5	3	Seller, Buyer
4.6	Lack of quality management	3	1	Seller, Buyer
4.7	Hybrid technology	1	1	Seller, Buyer
4.8	Cooling issue	5	2	Seller, Buyer

Table 7B: Sub-barriers related to technological barriers.

ID	Sub-barrier	Number of mentions overall	Number of interviewee mentions	Buyer or seller side perspective
4.9	Software uncertainty	3	1	Seller, Buyer
4.10	Complex technology	1	1	Buyer
4.11	Lack of standardization	5	2	Seller
	Total	56		

Eleven sub-barriers of technological barriers were identified from the interviews, with 56 mentions overall.

The most frequently mentioned one was sub-barrier 4.1 of immature technology, with 25 mentions, representing 44.6 % of all technological barriers. Moreover, there were several areas mentioned by two or more interviewees; scalability issues, that the QC industry is in the NISQ-era and quantum advantage not being present. Simply put by Interviewee A, from a technical point, QC is bluntly not mature yet, like Interviewee B pointing out that QC is brittle and in its early stage. The current challenges of miniaturizing millions of qubits into a small space and at the same time keeping the functionality of the trapped ions and figuring out how a dilution fridge should work in hand adds more contributes to the immaturity of the technology. Interviewee A continues by claiming that QC does not outperform classical and high-performance computers as of now, in a broad consensus, as they see that there are no real production use cases today which Interviewee B also claims. Other specific areas that are immature, according to Interviewee C are quantum error correction, fidelity[5], and resilience to noise[6].

Moreover, according to Interviewee E, the primary barrier of QC is just "making it work." As acknowledged by Interviewees E and F the quantum advantage is thus not there, or realized, yet. Another issue that all interviewees talked about was the challenge of commercialization. Although all but one Interviewee (F) acknowledged that commercialization is not present in QC today, they all implied that commercial-

[5]Fidelity: expresses the probability that one state will pass a test to identify as another [50].
[6]Noise: factors that can affect the accuracy of calculation for a Quantum Computer [3].

ization is an important milestone, and issue today, for the industry to reach before the technology can be seen as mature.

Onto sub-barrier 4.2 of "too many technologies," Interviewees A and F talked about the multiple complex technologies and modalities competing, i.e., superconducting technology, on who will be the most successful. Both sellers and buyers have choices to make on which technology/modularity to research and develop, despite when there is not an obvious choice on which modularity will turn out to be the successful one(s). According to Interviewee A, this is specifically regarding handling increased qubits and then scaling it to fault tolerance which leads to the next sub-barrier.

The "fault-tolerant QC not existing today", or sub-barrier 4.3., is a challenge from the seller's side. Interviewee F states that the "whole fault tolerant thing is 8 to 10 years away, . . . , you're looking at 2030 and beyond for fault tolerance" and that this fault tolerance is needed for different firms of quantum computing to function. This especially regards blind computing as firms adopting QC may be dependent on QC being fault-tolerant to fully utilize it.

Furthermore, three interviewees discussed the lack of benchmarks, sub-barrier 4.4. Interviewee B points out from both sides that the validity of hardware in the QC-industry is scarce. And more from a buyer side, this interviewee suggests that buyers must be able to evaluate vendors (sellers) in a systematic way, which there is a lack of in the industry as of now. Moreover, Interviewee D brings up that although there is a lack of benchmarks, one that does exist is quantum volume[7]. The interviewee anticipates that the benchmarks will change soon, but that quantum volume is an especially important metric as of now.

Continuing to the sub-barrier 4.5, "too fast technological development", Interviewee A states that "the industry has grown a lot faster than, let's call it, talent supply". Interviewee D adds that for instance the hardware part of the industry is constantly evolving, a buyer purchasing a specific hardware version this year might be outdated just the following year as "what's good this year may not be good next year." Furthermore, Interviewee C mentions that the QC-technology itself is disruptive and thus if it would become widely available tomorrow that would bring adaptation problems in its application areas, such as encryption.

Lack of Quality management, or sub-barrier 4.6., Interviewee E is the only interviewee discussing this matter. They explain that while QC needs to show a better performance than a high-performance computer, see appendix 8.1, performance is not only the faster calculation by the speed to the solution. But it is also the availability, reliability, maintainability, and explainability as "the big customers are not going to adopt this technology (QC) until it's reliable and available and explainable as a solution".

Hybrid technology, or sub-barrier 4.7, was mentioned by only Interviewee E. He mentions that there are very few large companies in the QC industry that offer hybrid high-performance computing alongside their quantum processors, thus limiting the choices for customers who only desire hybrid technology.

The cooling issue, sub-barrier 4.8, was mentioned five times by two interviewees.

[7]Quantum Volume: a way to measure and compare progress toward improved system-wide gate error rates for near-term quantum computation and error-correction experiments [14].

According to Interviewee A, when scaling the number of qubits on a constrained surface, the problem of keeping it cooled down will appear. Interviewee E dives into this further. As the dilution refrigerators may require human, physical, maintenance and repair, it will be a problem if kept in physical data centers like what many cloud companies are doing with their servers today.

Software uncertainty, sub-barrier 4.9, was discussed by Interviewee B. According to the interviewee, there is a lot of uncertainty regarding how much industry and academia can do with the software in the short term. There are issues regarding near-term quantum algorithms not being part of the standard academic knowledge as it is difficult to assess the software's impact before the research is carried out. Therefore, from the buyer's side, it is hard to choose which software to rely on.

Moreover, on sub-barrier 4.10 of complex technology, Interviewee B points out that QC itself is an extremely high entry barrier subject. This is in the sense that the industry is a complex interdisciplinary field, with certain academic niches where even pioneers of the field have different visions of "what works." This barrier is connected to the lack of skilled labor in the field, both from the buyer's (private companies) side and the suppliers of the quantum computers themselves.

The last sub-barrier of 4.11, lack of standardization, was mentioned by two Interviewees B, and C. Interviewee C acknowledges that since QC is in its early stage, there are no standardizations on which QC technology to allocate the R&D as companies are working on different technologies to choose and agendas. This makes it hard for QC developers to which technology to focus on, and for customers to choose which technology to buy. Interviewee C further points out that as of now there is only one standard that the companies can rely on which is fidelity, or quantum volume.

4.5 Legal barriers

Table 8: Sub-barriers related to legal barriers.

ID	Sub-barrier	Number of mentions overall	Number of interviewee mentions	Buyer or seller side perspective
5.1	Restricting export in the US	1	1	Seller, Buyer
5.2	IP	7	3	Seller
5.3	Regulation framework by government	1	1	Seller
	Total	9		

The barriers found relating to legal issues from the interviews were threefold. The total number of mentions for all legal sub-barriers is nine which indicates a low significance. The first sub-barrier 5.1 is related to 1.1 although the main difference is that this sub-barrier is legal restrictions that the US has implemented. What was mentioned relating to this is only from Interviewee F where he explains that firms from "certain" countries are not legally allowed to either invest or buy out US companies. What will happen then is that transaction will potentially be blocked by the government. Also mentioned in the interview is that similar things might be present in the EU, although according to Interviewee D, the EU is more open to working with these countries.

For the next sub-barrier 5.2 regarding Intellectual Property (IP), it is mentioned that IP's are a valuable way of increasing the valuation of a firm, particularly start-ups. Also mentioned is that both hardware and software could be patented so the firms working with developing QC algorithms are also protected. Governments can potentially subsidize the partnerships between academia and the private sector by having the academic institutions develop some IP's that the firms can use, according to Interviewee B. Interviewee C further mention that there exist some IP issues when firms across different countries are developing QC technology together. The issues are that each country has its IP regulations and therefore it could be an inconvenient

process of filing a patent with the international development of QC technology. The most critical issue regarding the IP sub-barrier is what Interviewee F mentions, which is that the patent office in the US is not working functioning well. What specifically is not working is that firstly, many patents relating to QC are being filed with the influx of organizations working with the development. Therefore, the patent office is currently overwhelmed.

Secondly, there are not enough workers in the patent office that have the knowledge needed on QC to be able to approve or deny patents. Therefore, the result is that "bad" patents are being accepted which is currently a big issue and could be in the future as well. Why it's bad is well explained by Interviewee F where he says: "If bad patents get through and get issued, then you still have to take someone to court, sort of invalidate that patent which can be very expensive and they can hold up trade, which is not good."

For the last sub-barrier relating to legal issues 5.3 regulation framework by government, only Interviewee C mentioned this and therefore makes it a minor issue. What the interviewee pointed out is the need for standardization in the industry with the different technologies and ways of working as such, which is also explained by sub-barrier 4.11. Governments need to step in and create this legal framework on which standardization can be modeled. The reason the government needs to step in and create this regulation is that firms cannot collectively decide on the standards since they all have their narratives and biases. They have these biases to model the standards to be beneficial for their gain. For the QC industry's future, this barrier might be a major issue if not addressed soon.

4.6 Environmental barriers

Table 9: Sub-barriers related to environmental barriers.

ID	**Sub-barrier**	**Number of mentions overall**	**Number of interviewee mentions**	**Buyer or seller side perspective**
6.1	Extraction of material	2	2	Seller
6.2	Power consumption	3	2	Buyer
6.3	Scarce material	2	2	Seller
	Total	7		

Environmental barriers were mentioned seven times, with none of them being mentioned by most of the interviewees, implying a minor significance. Although the environmental barriers were only discussed six times, it does not necessarily mean that the environmental aspect of QC is unimportant. A future increased visibility and importance of this aspect could arise as the technology matures.

Moreover, sub-barrier 6.1. of "extraction of material" was mentioned twice by two separate Interviewees C and F. Interviewee C emphasizes that the whole extraction process, refining and disposing of phases of quantum computing materials requires some type of impact on the environment. Interviewee F follows up by pointing out that parts of this technology are produced in "non-like-minded countries", compared to the West, and that the materials are "exotic" which itself brings an environmental impact.

Sub-barrier 6.2 of "power consumption" was the most frequently mentioned in Table 9. Interviewee C discusses this sub-barrier twice and Interviewee D once, for instance, while running quantum computation you also require control through classic computer power, and with that comes "a lot of power consumption". Furthermore, Interviewee C follows up by stating that at the end of the day to have a quantum computer, you need a high-performance computer on top of it just to control the program. QC is also, according to this interviewee, not very sustainable because "it has very little power for the amount of energy that it consumes." Furthermore, Interviewee D mentions that regarding the adoption of QC, there is a concern, especially from Europe around the power consumption of quantum computers. Although Interviewee D points out that quantum computers use less power than high-performance computers, looking over the aspect of power consumption will help the adoption of servitized QC eventually.

Lastly, with sub-barrier 6.3. of scarce material, Interviewee C discusses the idea that quantum computing technologies rely on materials that might be difficult to come by which Interviewee E continues to discuss. Interviewee E mentions the challenge with the dilution refrigerators used to cool the whole quantum computer system. There are two diverse types of isotopes of Helium used in these refrigerators which by themselves are in "very scarce supply," therefore it could be a long-term challenge to just get the helium to scale the up QC and the adoption of it.

Conclusively, 34 different barriers were identified and categorized into the six categories derived from the PESTLE analysis. The key barriers are discussed in the following Chapter 5.

Chapter 5

Discussion

Chapter 5 interprets and discusses the key findings and barriers of the study in a holistic way. Moreover, this section dives deeper into the abyss of how the findings compare to the previous work and ends with our implications and recommendations on how firms, both on the buyer and seller side, can mitigate and overcome these key barriers and what we add to the academia. Again, the research question is about identifying the key barriers for firms when adopting quantum computing technology as a service (servitization) in their business strategy. Nevertheless, this chapter highlights that the key barriers impact each other and are connected as they reflect the complex and interdependent nature of the QC industry when firms and society adopt it in a servitized way.

5.1 Summary of findings

After the analysis of the resulting barriers derived from the coded interview scripts, a conclusion was made that the key barriers were focused on the Economic, Social, and Technological areas. For Political, Environmental, and Legal areas no key barriers were found. The reason that no key barriers were found is that the interviewees did not mention any barrier enough times as well as from our analysis they were deemed to not be a key barrier currently.

Furthermore, in the future, some of these areas could be major or key barriers. For instance, the environmental barriers could face issues with the high energy consumption for running and cooling the quantum computers.

Another potential huge issue in the future might be related to political barriers. As mentioned in the interviews the US is very much concerned with the exporting and investments of the industry, especially with China. These political tensions might increase for the QC industry, in the future, when technology becomes more powerful and mainstream adoption takes place. For the legal barriers, the most prominent issue is regarding Intellectual Property (IP). As explained in the analysis section patent offices are not capable of meeting this demand with the high number of patents being filed. The potential outcome for the future is that legal disputes will have to take place between firms regarding patents, which in turn costs capital and time which hinders the adoption. A discussion on each barrier deemed a key barrier is presented below.

5.1.1 QC-technology is costly

The first barrier deemed to be a key barrier to the adoption of servitized QC technology is related to the fact that the QC technology is costly. The reason for it being deemed a key barrier is the high number of mentions as well as the importance of it. The high price tag to not only develop and buy a QC for a firm but also the servitization of QC through the platforms offered by a few firms is likely why a lot of firms are not using QC. Another aspect of the excessive cost of QC is that the risks involved are also currently high. As previously mentioned, there is no guarantee of outcome from the algorithms run or even that a fault-tolerant quantum computer can be developed. Therefore, many firms are hesitant to invest and bank a lot of capital and resources on this technology. The smaller firms and start-ups that are only working on QC are at an even greater risk because they are risking their entire business that QC will come to fruition.

The reasoning for why quantum computers are so expensive to develop and use is related to sub-barrier 4.1 immature technology. Currently, no fully developed product exists, which in turn makes it so that economies of scale cannot be achieved. The consequences that will follow if this barrier is not addressed are that firstly customers will find the technology too expensive and will therefore not implement it. The firms who develop and sell it will also not invest and use the technology since an attractive ROI does not exist due to excessive costs.

5.1.2 Impatient investors

The second barrier that is a major barrier and in turn a key barrier of adoption is the increase in the lack of patience for the investors of QC. The extent of this barrier is quite severe. The reason for that is that all but one interviewee mentioned it and those who did said it was a major issue. The extent of the barrier is impactful since the industry is in its earlier phase, therefore the investors are the most important stakeholder at this current stage. They are the ones funding this continuous development of technology and without them the QC industry would not be at the stage it is today or even exist. The consensus on the concept of impatient investors was that it is a pressing issue that has been evolving for the last few years. The underlying reason for the barrier has a few potential explanations.

The first is that the economic state globally has worsened quite a bit over the last few years according to the interviewees hence investors are demanding stricter criteria and tougher promises of returns and development if they were to invest. Another explanation given by one of the interviewees was that the pandemic was a factor. What he saw was that after the pandemic hit it, potentially, became increasingly harder to please investors.

The last explanation of the rise in impatience for the investors could be that they are educating themselves more and gaining a better picture of QC. Therefore, they can more precisely dictate the demands on where they want the development to be in a few years or the exact financial returns. The consequences of this barrier could be that investors will be hesitant to further invest in QC firms. This in turn will hinder the whole industry since the industry is not profitable. Therefore, the industry is heavily reliant on outside capital to fund the development.

5.1.3 Funding issues

One of the biggest barriers found by the results is the funding issue barrier as all interviewees mention it and based upon the consequences it might lead to if not addressed. The extent of the barrier is also quite large since a name has even been given to this concept called "quantum winter," as previously mentioned. That said, varying opinions exist on how severe the issue is, and the consensus is that it is an issue currently that needs to be addressed. It has not yet come to full quantum winter where extremely limited funding is being directed for the industry. The potential reasons for why it currently exists are similar to the barrier of impatient investors as explained above. Furthermore, other reasons could be that banks and investors do not believe in the technology and therefore are more hesitant to fund start-ups and bigger firms.

From our analysis, this barrier is also related to the sub-barrier regarding top management's lacking awareness of QC. What happens if the top management does not have great awareness and knowledge of the technology is that they are not as positive towards the continued investments within the development. It results in tougher justification from the head of the department from, for instance, a big tech firm. They must argue why the firm should continuously invest in this technology that only costs massive amounts of capital.

The direct consequence of this barrier if not addressed could be like the "impatient investor" barrier described above, in that the whole industry will suffer. The way it will suffer from lack of funding is that both the number of new start-ups within QC will decrease as well as the number of big tech firms who are investing in QC will decrease. The consequence will also be that a lot of firms possibly will go bankrupt, especially the smaller firms that are heavily reliant on VCs and other forms of funding.

5.1.4 Lack of consistent revenue streams

The final barrier that is related to economic factors and deemed a major barrier is the lack of consistent revenue streams for the QC industry. The barrier could also be related to the lacking ecosystem and supply chain that exists in the industry. How it relates is that firms do not have a clear vision of the customer, suppliers et cetera, which makes it hard to fully develop solid precise business models and in turn revenue streams. A few different revenue streams have been developed and are being used now, with servitization being mentioned the most and seems to be a great business model for a solid revenue stream. The extent of this barrier is broad where all firms are fighting this issue and some are more successful than others.

A potential reason for the barrier being present is that since the industry is in such an early phase, clear business models and strategies have not emerged. Another reason could be that clear supply chains and ecosystems have not evolved which in turn makes it hard for firms to develop a clear consistent revenue stream. The consequence, if this barrier persists, is that firms focused on selling QC will not enter the market. And the reason being that they cannot develop a solid business plan is because solid consistent revenue streams do not exist.

Another consequence is that the firms that are in the industry will not have

longevity. Furthermore, they will not have longevity since outside investments can only take a firm so far until the investors become impatient because they are not seeing a return as discussed above, which is already partially present in the industry.

5.1.5 Lack of awareness from top management

The social barrier of lack of awareness from executives and top management was mentioned 15 times spread across five interviewees, which indicates a quantitative argument that a lack of awareness is indeed a key barrier. Though it was not covered by all interviewees this does not necessarily undermine the importance of this topic. Moreover, the influence of the executive/senior management on the whole organizational mindset is essential and, in the end, affects the firm's competitive advantage.

One analogy, for example, from Interviewee F is that invested firms in QC such as JP Morgan Chase have leaders with expertise in the commercialization aspect of it. Though the leaders might not know when the advantage of QC or when fault-tolerant QC will get realized when it does the company will have an "unfair competitive advantage because our competitors are not investing, they are not aggressive, they are just sitting on the sidelines". What is postulated is that the gaps are going to be greater between those who invest in QC early, in general, and those who do not or do it later. Therefore, having the executive management envision the actual commercial benefits of this QC technology is thus essential for the adoption of the technology to be initiated.

There are moreover potential explanations as to why this barrier exists. One is that QC technology might not be profitable enough for the executive board/-management to invest in as of now and thus for the management to change their business strategy. The executives need to see the long-term view, not just short-term prioritizing. And to live with the risk that comes with investing in QC until the competitive advantages are realized, much like the JP Morgan Chase example. Interviewee A further strengthens this by pointing out that companies, especially the public, might not have the long-term incentives to take on the risk that comes with precisely investing a budget in developing or adopting QC technology.

Other explanations could be the lack of business cases and limited exposure to QC technology, in a sense the lack of networking, and management resistance to change the status quo. The senior management might perceive the technology as not (yet) mature enough for them to see the momentous benefits it could bring to the business, or they do not see clear business applications. Moreover, the lack of exposure to QC technology can make it complicated for them to understand the potential implications and thus, again, the benefits it can bring. Interviewee C explains this well by saying that there is a need for raising quantum literacy and a lack of networking between the end users (buyers) and the quantum computing developers (sellers). Both reasons can be explained by the lack of understanding of the technology, which is precisely sub-barrier 3.4, or lack of experience with emerging technologies.

If firms looking to adopt QC technology do not address this barrier, then consequences will follow. In general, as with all (key) barriers, the adoption of the technology will be slowed or harder to overcome especially when the technology is offered as a service. In specific, it could be difficult for the research and development

team to get funding for innovating or researching the subject of quantum computing. This in turn leaves the firm at a competitive disadvantage, compared to other firms investing and implementing this technology early.

Lastly, not addressing the lack of awareness from the senior/executive management could lead to a lack of internal support for necessary, needed, education or programs to learn the expertise that is required to handle future QC technology effectively. Also, if any unknown barrier will come up in the future, then the skill may not be present to address this. This could potentially add to the shortage of skilled talents and missing to utilize all the service's functionalities.

5.1.6 Insufficient ecosystem

The second social barrier deemed a key barrier is the insufficient ecosystem existing in the QC industry. With eight mentions distributed amongst most interviewees, the insufficient ecosystem also has quantitative arguments as to why it is a key barrier for both the seller and buyer sides. The prevalence of this barrier on a firm's adoption of QC technology and its business strategy is extensive. For the development to scale up, and thus also the adoption of servitized QC, there is a need to make the software, hardware, and the entire distribution work altogether. This inherently implies the need for the end-users, suppliers, industry partners, and society to partner up and cooperate towards realizing the advantages of QC and thus far accelerating the adoption of it. As said by Interviewee F, "partnership is not happening enough in the ecosystem" and like sub-barrier 3.7 of collaboration issues. It is therefore important that the current ecosystem is robust and developed enough, standardized in other words, and democratized through being available for all so that the potential of QC can be supported and realized.

Furthermore, the lack of a developed ecosystem also makes it difficult for firms to offer QC as a service. If a firm, a seller, wants to servitize QC it requires QC software, - hardware, and other tools along with talent supply to properly develop and deliver this service. Interviewee B also indicates that if there were availability to access hardware and such "in one package", the risks of adopting the current QC technology would reduce. Moreover, with an underdeveloped ecosystem sellers may struggle to offer their customers high-quality QC services and deliver them. Due to the lack of partnership and that servitization relies on trust and long-term relationships as mentioned before, customers (buyers) could be estranged from wanting to adopt QC services because of the current system's lack of reliability or compatibility. An insufficient ecosystem makes it therefore difficult for companies to easily adapt to QC especially when it comes to servitization of the technology, from both seller and buyer sides.

Underlying reasons why this barrier exists are plenty. Other than the lack of standardization, some other reasons could be regulatory challenges (sub-barrier 5.2. and 5.3), security concerns, excessive costs (sub-barrier 2.1), and the level of expertise needed to develop the ecosystem (sub-barrier 3.5). Regulatory-wise, there are rules and legal barriers that hinder the global market by countries not cooperating with other countries due to different agendas, i.e., regarding knowledge or hardware trading of QC technology. Another aspect is the data privacy and security one, some applications or use cases for instance Big Pharma may involve confidential informa-

tion which limits the available information and knowledge to other industry players and thus potential partnerships. Furthermore, the supply of advanced level of knowledge required to develop a functional ecosystem is in shortage, as described before and in chapter 5.1.7. down below.

Regarding the consequences of this barrier, one consequence is the increased costs and time spent for implementation, thus damaging the ability of the firm to fully utilize the service because of a lack of infrastructure from their own (buyer) part. Another consequence could be increased difficulty in creating and sustaining long-term relationships and collaborations with buyers (if the firm is a seller) and with other sellers in the industry.

5.1.7 Lack of skilled labor

The next key barrier is the lack of skilled labor. This barrier was also the one mentioned the most amongst all other social sub-barriers with 18 mentions by all six of the interviewees, which shows a high significance. To realize an actual fault-tolerant quantum computer, it is required to have enough knowledge and expertise. Some expertise that is in shortage are for instance mathematicians, physicists, and software engineers with a niche in QC according to Interviewee D. And from the results, all interviewees agree that there is a shortage of skilled expertise, and without that, there will not be a thriving industry nor concretized competitive advantages nor commercialization. The more skilled people there are the faster barriers can be overcome, especially when aiming to make commercial money.

With the above in mind, the lack of skilled labor, i.e., the knowledge itself, is therefore indeed prevalent. As Interviewee B stated, "Knowledge and being able to evaluate all the various proposals for quantum advantage, for realizing and building hardware, for realizing full tolerance, ..., is probably the toughest barrier to overcome for companies and the ones who probes this fields."

This barrier can also be connected to the aspect of servitization. Servitization involves integrating different technologies and several types of people (buyer-side, society, and so forth) which in turn could incentivize the seller side of firms to have the forefront, complete, solution, compared to their competitors. Lack of skilled labor, therefore, limits a company's ability to integrate all the types of technologies in their overall service offering hence also limiting the deep level of long-term relationships with their desired customers. Conclusively, companies strategizing to servitize their offerings must ensure that they have the capacity of the necessary expertise to deliver high-quality QC-technology services. Otherwise, its service will be deficient

The potential underlying reasons why there is a lack of skilled labor are many. One main explanation is that companies investing in the QC- field are signing up relevant talents, P.h.D. students/post-doctorates, et cetera., early in their education which limits the supply of talent even further and increases the competitiveness of attracting talents early.

Moreover, it is hard to find people with years of experience in the field. Both explanations can be validated by, for instance, Interviewees A; "they tend to sign up other Ph.D. students, and E; "it's hard to find someone with 20 years' experience of programming a quantum computer". Furthermore, as the industry is in the NISQ era shown in the results, the industry is also in a complex early stage. This could

mean that there are not enough curricula or educational courses where the "right" knowledge is taught, i.e., quantum physics. Moreover, there is, again, a tendency to not co-operate with other countries due to different agendas which in turn leads to a talent shortage as trading knowledge may be prohibited due to legalities as aforementioned.

There are several potential consequences to the lack of skilled labor for the firm when they adopt the servitized QC technology. Firstly, the learning curve will be longer probably leading to increased costs because of the prolonged implementation of the technology. Secondly, there will be a gap in knowledge between companies with the talents and companies and the rest of the society thus contributing further to the limited available information of QC within the industry and hindering the development of it. Thirdly, due to a higher competition to attract the short supply of talent, firms may want to spend more on attracting and retaining these people.

5.1.8 Immature technology

The barrier that was mentioned the most was, again, sub-barrier 4.1 of the current immature technology. With 25 mentions spread out on all six interviewees the significance and prevalence of this barrier is rigorous, making it a key barrier. Its effect on a firm's adoption of QC technology by servitization should therefore be great. The overall goal of the industry is to have a Quantum Computer that is not only fault-tolerant and resistant to external noise but also that it is mature enough, as with many underdeveloped disruptive innovations. This is to perform better in real life than that in high-performance and classical computers. From the results and in a broad consensus according to at least Interviewees B and C, the QC industry is simply not there yet, therefore nor are the quantum advantage or functioning scalability. Moreover, as the technology is immature, firms may not see the actual benefits or applications of this technology and thus hesitate to adopt and invest economic capital. This makes this potential key barrier connected to a sub-barrier of 2.5 of funding issues.

Furthermore, due to the lack of maturity, meaning that today's practical applications are limited, there are uncertain risks and unknowns on how the technology will perform when realized. This could make it hard for firms to assess benefits and risks to accurately allocate resources to the right technology when looking to adopt QC technology, further strengthening the prevalence of the barrier.

Possible specific reasons why this barrier exists are vast. Main reasons could be that the QC industry lacks a clear but primarily common roadmap (related to sub-barrier 4.4), an absence of industry standards (sub-barrier 4.11), lack of networking between interdisciplinary fields and industries (3.7), and the complexity (4.10) and resource intensiveness of the technology. All these explanations require some type of open partnerships within the industry which also leads to the consequences if the technology continues to be immature for a long time.

Regarding the consequences of immature technology, some consequences are underdeveloped hard- and software, potential performance inconsistencies, and security concerns for firms when wanting to achieve scalability, commercialization, and interoperability. Therefore, potentially harming the firm's reputation or keeping customers.

On servitization, immature technology can be connected to it in multiple ways. Without a mature technology to offer as a service, firms may be reserved to invest or adopt this technology as with other barriers as aforementioned. More specifically regarding the immature technology, though the product goal is a stable and fault-tolerant QC technology, offering it as a service is the whole business strategy. But without a performing technology, the service will under-deliver.

5.2 Comparison with previous research

This thesis is a qualitative study to which the research question is "What are the key barriers to adopting Quantum Computing technology as a service to a firm's business strategy? ". This comparison is guided around the research question, findings of the study, and existing literature. The comparison therefore primarily explains the findings of the study with Business strategies and Servitization (Chapter 2.4) and Adoption Barriers (chapter 2.5) leading to a concise but also focused discussion. Moreover, this chapter is divided into two parts, separating the findings of the study into two individual comparisons. The first one is how the findings of the study are directly related to the chapter on related work through the adoption of QC technology. And the second one is how they are indirectly related to each other in the context of disruptive innovations rather than QC directly itself.

5.2.1 Adoption of QC

By comparing Chapter 2.5 with the findings of the study, there are two key barriers and three minor barriers that are mentioned in both the findings of the results and previous research in a direct or indirect related way. These two key barriers mentioned are the lack of skilled labor and the lack of awareness from top management.

All six interviewees pointed out the key barrier of lack of skilled labor, as well as Awan et al. [2] who also pointed out that one of the barriers when adopting QC is the lack of technical expertise. In this context, lack of technical expertise implies the niche knowledge that only skilled labor can bring hence strengthening the prevalence and the significance of this key barrier 3.2.

Another barrier that Awan et al. [2] mentioned was the "organizational interest in adopting new processes" which is similar to the potential key barrier of lack of awareness from top management. As aforementioned it is difficult for a firm's or organization's innovation budget to get funding unless the executive management is on board alas if there is any interest from them to adopt QC. This increases the relevance and, again, the significance of this key issue when firms are entering the quantum computing industry and are adopting QC as a service. Therefore, Awan et al imply that both barriers of lack of skilled labor and lack of awareness from top management are indeed key barriers.

Moreover, Awan et al. [2] also mentioned the information accuracy as a key barrier that firms need to overcome. The minor sub-barrier 3.1. of misinformation could bring that barrier into the spotlight. Though it is not considered a key barrier as of now, firms may want to address this barrier in the coming future when the supply of different technologies and suppliers/sellers increases to get the most accurate information available. Therefore, this minor barrier could become key in

the certain future. The last similar barriers, compared to the findings of the study that was directly mentioned by Awan et al. are the minor technical barriers of lack of benchmarks, 4.4, and lack of standardization, 4.11. They acknowledge that a technical barrier is the "lack of engineering and design methodologies for software development and verification" implying that there is a lack of standardized way of developing and verifying, nonetheless benchmarking and software related to QC. Because each of these sub-barriers was mentioned a total of four times by three interviewees and respectively five times by two interviewees, they were not deemed to be key barriers. However, as previous studies have highlighted these two sub-barriers, they might become more significant when for instance the ecosystem of QC matures.

The last barriers directly related to adopting QC, but not necessarily in a servitized way, were the major challenges of error mitigation, quantum decoherence, and qubit interconnectivity. These three technical challenges are a result of the immature technology and the NISQ era that the QC industry is currently in, thus implying the significance of the third key barrier of the immature technology, 4.1. With this key barrier being the most mentioned it may also indicate that immature technology is the biggest key barrier for firms when adopting QC technology as a service.

Moving on and comparing the differences between the results of this study and the previous research that was presented in Chapter 2 relating to the adoption of QC directly, some interesting points can be made. Firstly, as previously discussed the research that has been done on the barriers or hindrances to QC adoption in the industry is limited. Therefore, the number of differing barriers and in turn, key barriers is quite larger. Our study found a total of 34 barriers where eight are deemed to be key barriers, whereas previous research found in total of 10 barriers.

Starting with analyzing the difference in the key barriers that were found for this study and the related work, every key barrier except lack of skilled labor and lack of awareness from top management differed. That means QC technology is a costly, impatient investor, funding issues, lack of consistent revenue streams, insufficient ecosystem and immature technology are differing. Moreover, why these six other key barriers could be found in this study but not in the previous research can be explained in a few ways. Firstly, the quantum computing industry is in its early phase called the NISQ phase, as mentioned previously [41]. With this early phase, the industry is growing at a rapid pace, with projections of growing from $1.9 billion in 2023 to $8 billion by 2027 [23]. Therefore, the challenges and barriers that the industry is facing at any given time could change rapidly. The key barriers identified in this study could be completely different in just a few years.

Furthermore, the studies used for comparison are a few years old, which could be an explanation. Another possible explanation for the differing results is that the method used for the other studies was not qualitative semi-structured interviews, which is the case for this thesis. The depth of the results that were retrieved from the interviews might be a reason for the nature of the result. As explained earlier, the interviewees were experts in the field, and since they all have varying roles in different organizations, combined with the use of the PESTLE framework, a holistic view could be obtained.

Moreover, some important examples of differing barriers are firstly collaboration issues. With collaboration issues, the issue is not that firms do not wish to collaborate but rather that the need for networking and collaboration is extremely high for a QC

vendor or buyer to succeed. This in turn leads to a hindrance for the industry.

The second minor barrier which differed and is deemed to still be quite important is the lack of standardization. The barrier is currently not that big of a hindrance to the industry, although in the future it might be. The reason it might be a major issue in the future is that if scalability is to be achieved in the industry all suppliers, vendors, hardware providers, etc. need to be on the same page. If they are not in compliance with each other there will be a huge variety of technologies, cooling solutions, etc., resulting in a fragmented market, which is the case currently.

Another important but not key barrier is intellectual property. Currently, this hindrance is not extensive, although this could also be a major issue in the future, similar, to the lack of standardization. Bad IPs and conflicts within the QC industry between major players are not advantageous for any stakeholder.

Lastly, the insufficient supply chain is also an important barrier that differed. The issue that exists to a certain degree but might be to a great extent in the future is that the differentiation on where organizations are within the supply chain leads again, to a fragmented market. A great quote from Interviewee F summarizes this issue quite bluntly "The supply chain does not exist today."

5.2.2 Similarities and gaps with adoption of disruptive innovation

Comparing the findings from previous studies presented in Chapter 2 on the adoption of disruptive innovation for high-tech firms, it is an important step to further position the findings of this study within the body of knowledge. Considering QC as a disruptive innovation has been stated in this study and therefore is the comparison of QC and other disruptive innovations academically plausible.

Firstly, looking into the similarities of the previous studies relating to the adoption of disruptive innovation and comparing it to the results of this study, three main concepts can be outlined. The first area is regarding the top management of firms understanding the technology and its potential impact on the industry. This concept was also found in previous work relating to the adoption of disruptive innovations; therefore, it can be concluded that disruptive innovations and QC have some similar barriers to adoption. From previous research, the viewpoint was more so to do with the top management encouraging and enabling its employees to seek the new technologies, and in turn the employees then need to convince their bosses to adoption [68].

The next concept that was found to be similar is a collaboration barrier relating to networking with actors in the supply chain, collaboration with high-tech firms, and R&D partnerships. For the QC industry, the supply chain is not well established, as previously explained. Furthermore, since that is the case the need for collaboration is increased since the supply chain synergies do not exist as well. The previous studies found similarly that collaboration within R&D and knowledge sharing within high-tech firms is a detrimental factor for the success of a firm.

Lastly, funding issues are also a concept that was similarly found. For this thesis, the results showed that the funding issue is among the biggest issues currently with the industry seeing a harder time justifying and attracting investors. The previous research further confirms this where one study found that all the innovating firms

involved in the study indicated that cost-related barriers are important [24]. Another two studies found that for SMEs, the lack of financial resources is the most important barrier to adoption [20], [44].

Looking at the differences on the other hand, two main concepts were mentioned in the literature that were not found in this study. Firstly, governmental relationships were identified as an organizational barrier by Wang and Lestari [69]. They explained it by using the Chinese term guanxi, which means business networks and, in this case, related to the government. They argued that having a strong relationship with the government is detrimental to the adoption of disruptive innovation [69]. If a good relationship with the government is achieved, a higher chance of receiving a grant for your research and development is possible.

Furthermore, what they also found was that the size of the business network a firm or person has does not have a direct effect on the success of market entry [69]. Therefore, it can be concluded that other factors come into play when the success of a market entry is to be evaluated.

Lastly, the literature stated, not found in this study, that planning and more specifically strategic planning is an important part of the adoption of a disruptive innovation. They argued that strategic planning is an essential part of an entrepreneur's long-term growth. Furthermore, if not implemented the survival of the SMEs becomes a point of concern, and it becomes a barrier to adoption [5]. Therefore, smaller firms need to have thorough planning and development of the general management for the direction of the firm. They also need to plan the necessary steps that the firm needs to take for the vision of the entrepreneurs to come to fruition, and for the adoption of the technology to take place.

5.3 Implications

The eight key barriers found are central to firms when adopting QC technology as a service. Therefore, firms need to address the barriers and overcome them to accelerate the adoption of the servitized technology and thus advance the industry as a whole. These barriers can be addressed by both the players who already are in the industry but also those who are about to enter it. This section consequently addresses the key-, and the minor barriers through mitigation strategies and thus show what we add to the currently known research.

5.3.1 Mitigation strategies

To enable coming firms and already existing actors in the industry to overcome these key barriers when adopting QC technology as a service, we must further discuss the mitigation strategies derived from the findings of the study and the related work part. It is essential for adopting firms of QC to find and apply successful mitigation strategies on the key (and minor) barriers to accelerate the development of the whole industry. The mitigation strategies for each barrier (both key and some minor) are furthermore elaborated more in Appendix A.2 and A.3. They are elaborated further on the aspects of why they are important and how and if they are related to the previous research, the results and potential challenges to appear when applying the

relevant strategy, whereas in this section the mitigation strategies for the key barriers will only be mentioned.

To remind the reader again, here are the eight (8) key barriers found, not necessarily in order of their importance: QC-technology is costly, Impatient investors, Funding issues, Lack of consistent revenue streams, Lack of awareness from top management, Insufficient ecosystem, Lack of skilled labor and Immature technology.

Do note that all other (minor) barriers must be overcome to ease the adoption of QC technology as a service, such as the sub-barriers of geopolitical issues, misinformation from the industry, and the lack of standardization et cetera. What these categories of strategies have in common, however, is that the QC industry, as an ecosystem, needs to come together collectively to create a functioning ecosystem where these key barriers can be overcome. This means that all pillars of society, from the government or legal agencies to the academia, the buyers such as SME's and large enterprises, and the seller side need to cooperate to achieve a non-fault tolerant QC technology and functional ecosystem.

We also want to point out that some of the mitigation strategies found from the results are also found in previous studies, i.e., the related work, further strengthening the significance of those strategies. And likewise, there are additional strategies from the findings that are not found in the related work. These mitigation strategies may not be optimal for all adopting buyers or sellers albeit they are indeed relevant to address.

1. QC-technology is costly

   • Partner or collab with QC-companies in R&D to share costs and reduce economic risks.

2. Impatient investors

   • Be realistic on expectations and educate on long-term benefits.

3. Funding Issues

   • Seek out grants from governmental, non-profit, and private funds to enable fundamental science to bring QC to a commercial threshold.

4. Lack of consistent revenue streams

   • Utilize servitization.
   • Create more diverse revenue streams.

5. Lack of awareness from top management

   • Expose the leaders and executive management to QC-technology's use cases and benefits.
   • Quantum engagement through networking with potential long-term partners.

6. Insufficient ecosystem

   • Large actors should advocate for increased economic and regulatory support from the government.
   • Develop and collaborate on investing in standardized hardware and software infrastructure to support full-service packages.

7. Lack of skilled labor

   • Partner and support academic institutions who upskill their programs to increase the QC-fundamental knowledge of graduates in adjacent fields to narrow the talent gap.

8. Immature technology

   • Increase the overall investments in R&D to accelerate the realization of achieving a fully functioning quantum computer.

These strategies are just examples of mitigation strategies that the seller and buyer sides of firms could partake in when adopting servitized QC technology. However, with the background of Chapter 2 of Related Work and the results and findings of the study, these 11 key mitigation strategies are deemed to be the most relevant and significant as of now and should be explored further. The other strategies for the minor barriers could be up-and-coming key barriers in the future and should be viewed as such by the industry through constant attention to its development.

5.3.2 Research contribution

The contribution that this thesis brings to the body of knowledge is quite extensive, partially explained by the lack of previous research on the barriers to the adoption of Quantum Computing. The first and most important contribution is regarding the key barriers that have been identified and discussed. Eight key barriers have been found and are deemed to be key barriers. The previous research has found two similar barriers and therefore what this study contributes is the other six barriers. The six barriers that differed are QC-technology is costly, impatient investors, funding issues, lack of consistent revenue streams, insufficient ecosystem, and immature technology is differing. What was also captured from this study is trends that exist within the QC industry, currently. One of the barriers that could be deemed to be a trend within the industry is the funding issue. As indicated by the interviewees the last few years there has been an increase in the difficulty of accessing capital with a lot of talks with the term coined in the industry "quantum winter".

Moreover, the mitigation strategies that were found by this study but not described in previous research to combat the barriers also add to the literature. A total of 10 mitigation strategies were found for all eight key barriers. The most important mitigation strategy that was found is the servitization strategy. This solves, or at least limits several of the key barriers found in this paper. The reason for that is it decreases the barrier of adoption to a lot of firms as well as pleases the investors

by showing a consistent revenue stream, which is favorable.

Lastly, how this study adds to the literature and body of knowledge is the methodology used. The limited number of previous studies done on the subject has not used the same methodology. The results gained by using this method are a holistic view and deep knowledge from the answers from the interviews which is a better method compared to the other studies. The studies in question have used a literature review of previous research as well as quantitative methods. We argue that the quantitative methodologies do not capture the complexity of the area of this thesis as great as the qualitative ones. Therefore, this study complements a methodology that captures and explains what the barriers to adoption are for QC, in a better way.

Chapter 6

Conclusion

Chapter 6 summarizes and concludes the key findings of the study aligned with addressing the main focus of the thesis thereafter emphasizing why this work is important and how it could contribute to the academia of quantum computing. The chapter ends with the limitations of the study and what future research could focus on to even further accelerate the adoption of servitized QC-technology.

6.1 Conclusion

Modern society with all its complexities encounters numerous obstacles in its pursuit of realizing the benefits of disruptive technologies, and with it faces a legion of challenges, or so-called barriers. A currently emerging field is the Quantum Computing industry. The reasons it is an emerging field are its potential huge benefits over classical high-performance computing, therefore potentially disrupting industries across our society. Industries to be drastically impacted include the Financial, Medicinal, Logistical, Cybersecurity, Energy and Environmental to name a few. If firms in these industries, no matter the size, are looking to gain competitive advantages if and when fully working quantum computer gets realized they have to adopt the QC-technology in their business strategies . This thesis is thus designed with the purpose of identifying and addressing all relevant barriers by primarily focusing on the key barriers that occur when firms are looking to adopt QC in a servitized way. Therefore, our research question is: "Which are the key barriers to adopting Quantum Computing technology as a service to a firm's business strategy? ".

The findings of this study resulted in 34 barriers with eight barriers deemed to be significant enough to be considered the key ones where the economic, social, and technological barriers were found to be the biggest spheres. These eight key barriers are: QC-technology is costly, impatient investors, funding issues, lack of consistent revenue streams, lack of awareness from top management, insufficient ecosystem, lack of skilled labor and immature technology.

These results were able to be identified through using the methodology of Ground Theory by semi-structured interviews with key experts from different roles in the industry thereafter categorized with the PESTLE-framework. Moreover, the analysis provided a holistic view of the QC-industry with all the barriers and mitigation strategies. In this way, six of the eight key barriers were found to be new to the academia with the use of servitization being the most significant mitigation strategy.

As the disruptive quantum computing technology emerges, firms must be aware of the barriers when adopting it in a servitized way. Otherwise, they will not be able

to capture all the benefits nor the competitive advantages that comes with it. Our eight identified key barriers with their respective mitigation strategies is a tool to visualize a clear roadmap on how firms can navigate in the landscape of quantum computing.

The limitations identified for this thesis are the interviewees' background, subjectivity of the coding method and geographical limitation.

Firstly, regarding the interviewees background, it has been argued in Chapter 3 that a broad selection of interviewees that results in a holistic view of the industry is obtained for this study. What could be a limitation though with that is one area of competence that none of the interviewees had. That area is the legal or regulatory area where we were in contact with one person with this competence but unfortunately was unable to participate. Such person could give a better insight into what regulations and laws need to be uphold both for accelerating the adoption but also controlling it within certain limits so it will not harm society.

Secondly, the objective that we have had when doing the coding of the qualitative data and categorizing the statements of the interviewees into codes and thereafter barriers, could come into question. Also, an issue with the coding method is that the open answers become overly simplified since a whole paragraph is to be categorized within one concept.

Lastly, the geographical limitation that is present within the paper and therefore the location of residence of the interviewees was a concept which was addressed at the start of the study. Primarily, the geographical locations that we feel would be good to explore are China and the Asian market overall. We have decided not to explore these geographical locations since we do not have the access to the data or people in these areas. Furthermore, this could be an interesting area for future researchers.

6.2 Recommendations for future research

What the future researchers within the field of Quantum Computing and specifically barriers of adoption such as in this thesis could focus on are fourfold. The concepts of which could be further explored upon are business models, enablers, China, and the Asian market as well as sustainability.

With the future research focus of business models, we imply that this thesis does not delve deep enough into this area. The reason for that is another focus was chosen with the business strategies instead which was deemed to be a better exploration of previous studies completed. For the business models concept, what could be interesting to look at is testing different models with pricing strategies. The reason being that currently there exist a difficulty of two parties working with QC agreeing on a price for the services.

Furthermore, enablers of quantum computing could also be an interesting research subject and give further insights for the firms interested in QC. With enablers we imply that it is the opposite of barriers where future researchers could investigate which factors help firms drive success. Research on enablers could result in firms interested in adopting QC or firms already in the industry, being able to identify and implement factors and strategies used by successful firms.

Moreover, the most important area of future research is the inclusion of the Asian,

especially Chinese and Japanese, market but also the Australian market. The reason why it is so important is because, for instance, China is the government which has invested the most in QC ($15.3 Billion) [42]. As mentioned in the limitations, the Asian market was not explored by us but researchers residing or having access to the information or the people working with QC in these areas could add insightful conclusions. It would therefore be interesting to explore whether our conclusions are only applicable for the European and US/North American market or if they differ and if so how.

The final area of future research is sustainability. From the results of this thesis, it was found that environmental barriers were not deemed to be major once. However, in the future we hypothesis that sustainability will be an important subject within the QC industry. Therefore, future research is needed on this subject to further align research knowledge with the progression of the industry. More specifically on the process when extraction raw, rare, materials for the development of hardware and addressing the energy consumption, i.e., electricity, required when using quantum computers .

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Appendix A

Supplemental Information

A.1 Quotes and definitions of sub-barriers

Table 10: Quotes and definitions of political barriers.

Barrier	Definitions	Quotes
Exporting concerns	The US government expressing concerns with exporting and collaboration QC with "certain countries"	"The US government is very paranoid about various countries, you know, being in the supply chain." - Interviewee F
Geopolitical issues	Issues arising between countries for firms based upon the governing bodies.	"So many European countries were likely to collaborate with China which causes a problem for the US companies"- Interviewee D

Table 11: Quotes and definitions of economic barriers.

Barrier	**Definitions**	**Quotes**
QC-technology is costly	The Quantum Computer having a big price tag.	"...the risks are still quite high, which overall with a pretty high price tag or in case of failure they could be put back by quite substantial financial loss, which is what nobody wants, not even from the supplier's point of view wants that to happen. – Interviewee B
Impatient investors	The investors of QC having a smaller patience with their investments showing a return.	"OK, so right now quantum computing I would say the biggest challenge is in patience from the investing public." – Interviewee A
Price to performance	Quantum Computers does not have lower cost than regular computers related to the computation time.	"...so we need to cross that threshold on performance where there is a commercial quantum advantage where a quantum computer outperforms the classical alternative on a price and performance basis." – Interviewee E
Insufficient supply chain	The supply chain within the industry is underdeveloped.	"...the supply chain does not exist today" - Interviewee F

Table 12: Quotes and definitions of economic barriers continuation.

Barrier	**Definitions**	**Quotes**
Funding issues	Trouble raising new or receiving continued funding.	"So what I talk about when I talk about sales of quantum computers is what I call the appetite for innovation. I should trademark that phrase. That's my phrase." –Interviewee D
Customer segmentation	Issues with identifying customer demands and grouping the into varying categories.	"...there will be customers that want access to the most detailed parts of each computer and at the lowest level. There'll be other customers that want nothing to do with quantum information science itself and just want to run high performance financial applications" – Interviewee E
Lack of consistent revenue streams	The QC industry does not have a multitude of consistent revenue streams for firms.	"It's just that these revenues are not substantial enough to sustain the business part, maybe in certain cases where hardware transactions between company and government really could matter." – Interviewee B

Table 13: Quotes and definitions of social barriers.

Barrier	**Definitions**	**Quotes**
Misinformation	The hyperbole, sometimes false, of information regarding potential benefits, performance etc. from vendors or others in the industry to potential buyers	"There's this misrepresentation of the information of the capabilities of the current state. That is, for lack of understanding technology, ..." – Interviewee C
Lack of awareness from top management	The limited recognition that the benefits of QC-technology get by those in top positions	"It does help when a senior executive is on board with QC from the start. Because they have the organizational kind of power to propagate this downward" – Interviewee A
Insufficient ecosystem	The absence of a comprehensive interplay between resources, support, and infrastructure necessary to develop, deploy and use QC-technology	"The primary barrier is to make it work, ..., we need to make the hardware, the software, the distribution all work together". – Interviewee E
Lack of understanding of the technology	Actors in the industry not understanding the potential benefits and the science behind the technology	"There's still a very high entry barrier to, ..., understanding quantum computing and making the most out of it"- Interviewee B

Table 14: Quotes and definitions of social barriers continuation.

Barrier	**Definitions**	**Quotes**
Lack of skilled labor	Limited supply of people with key competencies on QC-technology	"The biggest challenge is people getting access to great talent with experience" - Interviewee E
Not using an external advisor	Lack of utilizing a third-party for strategic guidance	"You need to have specific advisors, . . . , third-party consultancies to help you adapt quantum, . . . , people who really know the commercialization space. I think this is going to be one of the biggest growth areas in quantum" – Interviewee F
Collaboration issues	Actors in the industry not sharing knowledge with each other	"There is some conflict of interest from the point of the vendor, . . . , there are no two QC-companies that look alike or have a shared agenda, – Interviewee B
Gender diversity	Lack of representation of women in the industry	"Right now, in QC, it's a very male dominated industry, . . . , there's a lot of quotes where you can see that a diverse team generally makes better decisions than a non-diverse team – Interviewee D

Table 15: Quotes and definitions of technological barriers.

Barrier	**Definitions**	**Quotes**
Immature technology	No fully working quantum computer yet	"... this technology is very brittle and it's at a very early stage" –Interviewee B
Too many technologies	Vast range of available technologies to invest in as a firm or vendor	"There's eight modalities out, ..., and we don't know which player in a technical approach who might not make it or make it" – Interviewee F
Fault tolerant QC not existing	Today's QC-technology is vulnerable to failures, disturbances, and malfunctions	"I think that the whole fault tolerant thing is 10 years away, 8 to 10 years away. So, you know, you're looking at 2030 and beyond for full tolerance" – Interviewee F
Lack of benchmarks	The limited availability of models or measures to evaluate the performance and capabilities of one's QC-technology	"The validity of hardware is very scarce" – Interviewee B
Too fast technological development	Customers and society alike not advancing in their knowledge of QC at the same pace as the technology is evolving	"But it is a fact that the industry has grown faster than the, let's call it talent supply" – Interviewee A

Table 16: Quotes and definitions of technological barriers continuation.

Barrier	**Definitions**	**Quotes**
Too fast technological development	Customers and society alike not advancing in their knowledge of QC at the same pace as the technology is evolving	"But it is a fact that the industry has grown faster than the, let's call it talent supply" – Interviewee A
Lack of quality management	The absence of processes and systems to ensure the technology meets the quality standard and performance	"Performance is not just your speed to solution, it is also availability and reliability, maintainability, explainability" – Interviewee E
Hybrid technology	The idea of using a quantum computer and a classical computer to solve a problem	"Hybrid high performance compute at scale, that's where AWS has got something to offer" – Interviewee E
Cooling issue	The problem of keeping the quantum computer close to 0 Kelvin (-273.15 °C) to ensure the stable state of the atoms	"If you scale that [number of qubits] to a million, there's a lot of surface to cover, especially if you want to cool it down" – Interviewee A
Software uncertainty	The unpredictability in the behavior and performance of the software	"There's a little bit of uncertainty from the software and algorithms, especially from the algorithm perspective on what people really would be doing" – Interviewee B

Table 17: Quotes and definitions of technological barriers continuation.

Barrier	**Definitions**	**Quotes**
Complex technology	The advance niche of nature that the technology possesses	"I think that quantum computing is still a very high entry barrier subject, . . . , it's an interdisciplinary field" – Interviewee B
Lack of Standardization	The lack of standardized methodologies, specifications, protocols, etc. for firms to follow in their development, deployment, and utilization	"There is this need of some level of standardization. Currently there is no real standard for quantum computing in a level." – Interviewee C

Table 18: Quotes and definitions of legal barriers.

Barrier	**Definitions**	**Quotes**
Restricting export in the US	Legally restricting investments and exporting QC	"But if you're a company, say you guys want to do a startup and you want to raise money and you're based in the US, and let's say certain people from certain countries want to invest in your company, they won't be allowed to do that." – Interviewee F
IP	Intellectual Property issue with regards to patents etc.	"..., if bad patents get through and get issued, then you still have to take someone to court, sort of invalidate that patent which can be very expensive and they can hold up trade, which is not good." – Interviewee F
Regulation framework by government	A framework does not exist that standardizes the concepts and ways of working within QC by the governments.	"So in that sense it may be necessary that at least initially, government or public agency try to not impose but come up or set a standard that might be a more general and benefit" – Interviewee C

Table 19: Quotes and definitions of environmental barriers.

Barrier	Definitions	Quotes
Extraction of material	The environmental impacts when extracting exotic materials from biological spheres	"... there's some exotic materials that are being used in various aspects that of course have an environmental impact" – Interviewee F
Power consumption	The non-sustainable consumption of electricity when powering quantum computers	"..., quantum computing by itself is still not very sustainable because it has very little power for the amount of energy that is consumes" – Interviewee C
Scarce material	The limited supply of raw materials or elements to produce or power a quantum computer	"..., a long-term challenge to scale is just getting the supply of helium" – Interviewee E

A.2 Mitigation strategies for key barriers

1. QC-technology is costly

• Partner or collab with QC-companies in R&D to share costs and reduce economic risks. Both previous studies and our findings of the study have found that seeking partnerships or collaborations on R&D to gain knowledge and strategic benefits is a significant mitigation strategy for this key barrier. This especially targets SME's or Independent software vendors who may not have the economic capacity to diversify or heavily invest in R&D. What sets this thesis's findings from the previous studies aside is that we have found that large enterprises may want to invest in non-quantum work to minimize the financial risks of QC in case it gets too costly.

2. Impatient investors
As the key barrier of Impatient investors was not mentioned in the Related work, this barrier may be an emerging one in the field. A trait of impatient investors that we have seen from the findings from the study is that they tend to get more satisfied

when they see servitization due to factors such as a stronger cash flow. Moreover, this key barrier can be connected to another sub-barrier found from the findings, social sub-barrier of Misinformation.

• Be realistic on expectations and educate on long-term benefits. With the Misinformation in the industry in mind, it is essential for buyers and investors to get educated on the realistic expectations and state of the QC-industry, preferably by the vendors themselves. To provide continuous updates and reports, set realistic goals, be open about financial key data and educate on the long-term benefits and potential returns could pro-long the patience of the investors.

3. Funding Issues
As mentioned before, a lot of the investments for QC-startups right now comes from venture capitalists. However, other actor(s) that should be involved are the governmental, legal or non-profit/national funding agencies. And what they can do to short-circuit the adoption of servitized QC-technology for the vendors and firms is plenty. Previous research may not have brought this up before, and although the legal and political barriers were considered minor, some mitigation strategies for the key barrier of funding issues that these body of actors include:

• Seek out grants from governmental, non-profit, and private funds in order to enable fundamental science to bring QC to a commercial threshold. The grants-part is something that both the previous research found and what we did from the results which strengthens the importance of this mitigation strategy even further. However, the part of using the grants to fund fundamental science with the goal of commercialization is additional from our side. An important notice is that these grants by the legal bodies should mainly be given out to QC-focused SME's and institutions of academia instead of large enterprise vendors, according to for instance Interviewee A. Another important point to bring up is that, again, all but one interviewee said that commercialization of QC is not here yet, which is a heated discussion in the industry. But continuous governmental and non-profit investments into the basic and applied sciences of quantum, i.e., seeking out Moore's Law's problem or error mitigation could ease the adaption of the industry in general.

4. Lack of consistent revenue streams

• Utilize servitization. From the findings of the study, additional mitigation strategies that were implied by the absolute majority of the interviewees is that the use of servitized framework when offering the product of QC-technology as a service is a solid revenue stream from a vendor/seller view as of now. Moreover, using servitization means gaining competitive advantages and could reach heterogeneous customer demand which is a point that both the related work and the findings of study have mentioned.

Though other business strategies exist and servitization is not optimal for all vendors or sellers, it is by far the most frequently positively mentioned from an economic standpoint from the interviewees. The service itself could reduce the intrinsic costs of doing business for both the sellers and the buyers of the service. Additionally,

the previous research did also point out that by using a platform-based servitization strategy it may streamline and limit the effects of the service paradox.
a. Examples of applied servitization in the QC-industry are through running and deploying algorithms or releasing access to all the hardware and software infrastructure with capacity enough to simulate small business cases in one package, seemingly leading to risk reduction. Interviewee A called this type of servitization as a "software development interface or educators" implying that the technology should be interactive and educative at the same time using services.
b. A similar example is the package by Amazon Web Services, the AWS Braket, aforementioned by some interviewees which is doing similar practice However, without enough competence such as the AWS Enterprise; maintaining, operating and offering this service could bring an economic challenge. Therefore, larger to medium enterprise with diversified activities should be more inclined to use servitization as a business strategy rather than smaller and newer QC-startups on the seller/vendor side.

• Create more diverse revenue streams. Derived from mitigation strategy III, smaller or medium firms with financial capacity could consider offering consulting services and other types of partnerships or collaborations to potentially generate more revenue and thus overcome the lack of (consistent) revenue streams. As Interviewee F said, these types of third-party consultancies could generate more revenue than the actual technology service itself.

5. Lack of awareness from top management
These mitigation strategies were not mentioned in the related work/previous studies but several times in the findings of the study.

• Expose the leaders and executive management to QC-technology's use cases and benefits. By "simply" exposing the feasibility and potential return of QC for the top management in their daily life through i.e., workshops, courses, conferences and reports by educative QC-organizations and firms, it could entail a clearer vision of what the management could benefit from this technology. Other mechanisms could be hiring a third-party consultant or agency with expertise in the selected relevant field of QC for guiding and advising the executive management.

• Quantum engagement through networking with potential long-term partners. If the executive management can identify potential long-term partners in terms of both venture capitalists and strategic investors, this could be used as a proxy for the adoption of the QC-technology in a servitized way through validation of its maturity and advancement.

And it is essential to point out that one challenge that exist when overcoming this key barrier is the potential resistance to change from the stakeholders overall (from employees to the executive board/management) if the current product usage is working. This may require more invested capital to incline the actors to completely embrace and adopt the technology.

6. Insufficient ecosystem
This key barrier entails that all pillars of the QC-system need to function together, alas other barriers could be viewed as a sub-part of this key barrier. However, to distinct these parts, specific mitigation strategies only for this specific barrier are discussed here.

• Large actors should advocate for increased economic and regulatory support from the government. If larger corporations or vendors and buyers would come together and publicly advocate for more governmental support for QC-technological adoption for SMEs it could benefit the adoption as the system as a whole.

• Develop and collaborate on investing in standardized hardware and software infrastructure to support full-service packages. This mitigation strategy is found both in previous studies and our findings which increases the significance of this barrier but also strategy. By partnering on developing standardized benchmarks the general ecosystem could lead to a clearer roadmap, and vision on how QC-technology should be advanced.

7. Lack of skilled labor
Two mitigation strategies to address the lack of skilled labor and talent were found in the findings. A relevant challenge that comes with overcoming the lack of skilled labor to accelerate the adoption of servitized QC is the expertise required to recruit and train employees in the niche labor market that the QC-industry is.

• Partner and support academic institutions who up-skill their programs to increase the QC-fundamental knowledge of graduates in adjacent fields to narrow the talent gap. This entails providing curricula for quantum computing and its relevant science, i.e., standardizing the development of variational and near-term algorithms and the actual physics itself.

8. Immature technology

• Increase the overall investments in R&D to accelerate the realization of achieving a fully functioning quantum computer.

The NISQ- and early stage of the QC-technology come from the fact that the technology is simply put not mature yet. And this key barrier is connected to all other barriers as well as minor ones through the argument that the immaturity stems from all other aspects not being developed enough and barriers not being overcome. That is also why before identifying the technology as fault-tolerant and "mature", all barriers from the findings need optimally to be addressed before the adoption of QC-technology as a service is finally here.

The following mitigation strategies are aimed to be used to overcome the minor barriers. Although it is not our focus in the research question, we deem it to be interesting for the reader on how the potential emerging barriers can be overcome. Therefore, these other mitigation strategies can be seen in Appendix A.3.

A.3 Mitigation strategies for minor barriers

Regarding barrier of not having IP, firms no matter the size should focus on being IP-rich in order to create competitiveness and thus force the industry to advance.

On collaboration issues, previous research has found that the CPFR-method is a great way of improving collaboration issues. Moreover, this barrier is also connected to the sub-barrier of not using external advisors. Alike other mitigation strategies, it is highly relevant for an adopting firm of servitized QC to hire a third-party consultancy or advisor to gain external feedback on the organization. What one can also do is to collaborate with service and infrastructure providers (vendors) for network and relationship purposes. Furthermore, what a vendor can do, despite not having a fully functional QC-technology service, is to now sign up and establish relationships to start the commercial conversations

Another mitigation strategy on the barrier of not having gender diversity is to simply put hire diverse competent talents to gain a broader perspective on the subject.

The lack of standardization in the field can be mitigated by establishing long-term relationships with specific interdisciplinary academics that are approaching quantum computing from different viewpoints and technological approaches. Moreover, another mitigation strategy, for the government and public agencies to act on, is to not impose on QC but rather set up a national agenda and vision standard that is beneficial for all. Interviewee B also alludes that there should be help of government, to impose multiple ways of partnerships and platforms for collaboration between the academia, industry, and buyer side.

A long-term solution for the barrier of a small customer segment is to expand the customer base, and thus market share, to i.e., Independent Solution Vendors and other tech start-ups. The barrier of Hybrid technology can be mitigated by viewing Quantum Computing as a hybrid performance technology rather than just the technology itself.

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