Once Upon a Time in Quantum Computing: A Grounded Theory Study on Hardware Purchasing

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Abstract

Quantum computing is a potentially disruptive field, and a significant amount of resources are invested in technology advancements. The business-related research, however, is a relatively unexplored area. This master's thesis explores the key factors that buyers consider when purchasing quantum computing hardware, the perception towards start-ups versus established quantum computing companies, and the elements that influence the make-or-buy decision.

To investigate these themes, a grounded theory approach was used. The empirical data was collected through a total of 13 interviews, involving buyers, sellers, and industry experts from Europe and North America.

The study found that performance, price, and trust were the most important purchasing criteria. The buyers perceived start-ups as more innovative and open to customization, whereas larger players were more attractive in terms of stability and track record. The make-or-buy decision was influenced by the trade-off between knowledge, time, budget, and customization, with the mindset of key individuals being a potentially underlying element. A theoretical model based on the make-or-buy findings was also proposed.

The insights from this thesis offer valuable information for both sellers and buyers in the quantum computing market, and open up avenues for continuing research on the industry's business dynamics.

Keywords: quantum computing, hardware, supplier selection, start-ups, make-or-buy, trust, grounded theory.

Glossary

Academic buyer: University lab or government-owned research institute.

AI: Artificial intelligence.

B2B: Business-to-business.

Bits: The smallest piece of data a classical computer can store. Each bit represents a single state of either one or zero.

Commercial buyer: Private company.

Fault tolerance: The framework of allowing qubits to be protected from quantum errors introduced by poor control or environmental interaction.

Fidelity: A measure of how close the final quantum state of the real-life qubits is to the ideal case. The threshold for building fault-tolerant quantum computers is considered to be 99 percent fidelity, implying a one percent error rate.

ISO 9000: A set of five quality management systems standards that help organizations ensure they meet customer and other stakeholder needs.

MEAT: Most economically advantageous tender.

NISQ: Noisy, intermediate scale quantum.

Noise: The multiple factors that can affect the accuracy of the calculations that a quantum computer performs.

OECD: The Organisation for Economic Co-operation and Development.

Order qualifier: Criteria an organization must meet for a buyer to consider it a possible supplier.

Order winner: Criteria that win the order for a supplier.

Quantum advantage: A stage when a quantum computer can solve certain problems cheaper, faster, and more accurately than classical computers.

Quantum winter: A period of reduced funding and interest in quantum computing research. Analogous with the concept of an AI winter.

Qubits: The basic unit of quantum information. Unlike the binarity of bits, a qubit is a superposition of zero and one.

Shor's algorithm: A quantum computer algorithm for finding the prime factors of an integer developed by the mathematician Peter Shor in 1994.

SME: Small and medium-sized enterprises.

SOGI: Societies, organizations, groups, or individuals.

von Neumann architecture: A computer architecture based on a description by John von Neumann and others in 1945.

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1 Introduction

The chapter introduces the background of the master's thesis, followed by its research objectives and research questions. Then, the chosen delimitations and the overall structure of the thesis are presented.

1.1 Background

In today's world, it is hard to imagine a time without the presence of classical computers. The technology has revolutionized society in terms of how people work, communicate, and access information. Behind the zeros and ones (bits) of our everyday lives however lies a history of tremendous technological advancements. A part of this success saga can be attributed to an extraordinarily productive interplay of funded academic and industrial research as well as entrepreneurial companies that were founded and staffed by people who moved back and forth between universities and industry (National Research Council, 1999). In the related field of classical supercomputing, when exploring an alternative to the traditional von Neumann architecture, a large increase in firms developing parallel solutions emerged. Once a dominant parallel computer design was established, the number of firms proceeded to decline as the market converged to the winning solution (MacQuarrie et al., 2020).

Quantum computing is a technology which can process data at an exponential rate, which is faster than any classical (super)computer. Since the technology has the property to perform large scale simulations, potential industry applications include technology, industrial goods, and finance (Chamola et al., 2020). The quantum technology thus has similarities to classical computing in the sense that it can prove to be a disruptive innovation. In fact, the Nobel Prize in Physics 2022 was awarded to a group of individuals who, through their experiments, have contributed in shaping the way from theory to technology in the quantum landscape (The Royal Swedish Academy of Sciences, 2022). The laureates' groundbreaking work used entangled quantum states, a technique that was also utilized in 2021 when a Japanese research center announced a further breakthrough in entangling qubits which could improve error correction in quantum systems, and hence potentially make large-scale quantum computers possible (Biondi et al., 2021).

Given the expectations that quantum computing is set to be a breakthrough technology, it is anticipated that billions of dollars will be invested in the technology to make it commonplace, thus drawing further similarities to the rise of classical computing. Further, projections imply a 50.9 percent cumulative annual growth rate of customer spend within the worldwide quantum computing market over the forecast period 2021 to 2027, going from $412 million in 2020 to $8.6 billion in 2027 (IDC, 2021). Quantum technology start-up investment activity more than doubled in 2021 as more and more start-ups are entering the quantum computing landscape (Masiowski et al., 2022). Many of the start-ups in the quantum computing market can be characterized as university spin-offs, as they often commercialize hardware solutions originating from previous research at a parent university. The management of these start-ups usually consists of academics, researchers, and PhD students in the specialized field, and funding is generally provided by the university or venture funds with close connections to said university (Dargan, 2020). Apart from academia and start-ups, the race towards quantum computing also involves technological powerhouses such as IBM, Google, and Microsoft (Himes, 2023).

Despite the huge promises of the field, it is worth noting that over 40 years has passed since Richard Feynman showed that quantum mechanics seemingly cannot be imitated by a classic computer, which some people attribute to be the crystallization of the idea of a quantum computer (Nature Reviews Physics, 2022). Thus far however, quantum computers have yet to demonstrate their quantum advantage (World Economic Forum, 2022). In a nutshell, the exponential promise of quantum computing is conditional on the ability to scale up the number of qubits while achieving a sufficient level of fidelity. Given that technical noise is present in every single quantum computing operation, the ongoing pursuit to reach fault tolerance involves the development of different quantum computing hardware platforms. The two most advanced approaches, superconducting circuits and trapped ions, are expected to require about 1,000 and a few dozen physical qubits, respectively, per actual logic qubit (Biondi et al., 2021). For quantum computers based on superconductors, this would translate to around one million qubits being needed to operate at scale; the most promising roadmap for 2023 is IBM's quest to build a computer containing one thousand qubits (Cho, 2020).

Although quantum advantage is unlikely to be just around the corner, countries around the world are planning for a future which involves quantum computers. If a country were to foresee investing in the field, not only does it risk losing out on many of the promises of the technology, but it would also expose itself to great risk. For instance, a quantum computer that has a sufficient number of qubits without succumbing to various decoherence phenomena could use Shor's algorithm to break encryption schemes that are in place to protect credit cards, state secrets, and other confidential data (Chu, 2016). This decryption threat is taken seriously, as exemplified by the US congress passing the "Quantum Computing Cybersecurity Preparedness Act" in 2022, addressing the needs of having encryption solutions that are resilient to attacks from quantum computers in the future (Khanna, 2022). The race towards fault-tolerant quantum computers involves the biggest economies in the world, with the total announced planned government funding well exceeding $30 billion (Masiowski et al., 2022).

As the technology of quantum computing is still under development, and it is unclear whether several or any of today's hardware platform approaches will be able to demonstrate a quantum advantage, it is perhaps reasonable that the academic literature has been primarily focused around exploring the promises of the technology itself. However, given the recent changes in the market dynamics, with the influx of start-ups entering the industry with in-house solutions to compete with larger players, it also ought to be topical to investigate the purchasing decisions along with their related trade-offs for buyers of quantum computing hardware. Areas of interest for this purpose include what criteria these buyers use to select among the different suppliers, if they perceive the start-ups differently from the established companies, and what the driving factors are for an organization deciding between developing the hardware in-house or sourcing it. Based on the past experience from the development of classical computers, a fruitful collaboration between academia, larger incumbents, and the many new start-up companies might prove to be ever so important for reducing the risk of a stagnation in the funding of quantum computing technology, a scenario commonly referred to as "quantum winter". In light of this, it is of high value to foster the academic knowledge in the quantum computing hardware procurement needs and preferences.

1.2 Research Objective

The objective of this thesis is to explore decision-making factors for buyers of quantum computing hardware, with a focus on mapping the relative importance of purchasing criteria, understanding the perception of buying from start-ups versus larger companies, and investigating the factors that drive the make-or-buy decision.

1.3 Research Questions

- What criteria are currently used in the procurement of quantum computing hardware?
- Which of these criteria are considered order winners?
- What is the perception of buying from start-ups versus established companies?
- What influences the make-or-buy decision for an organization?

1.4 Scope and Delimitations

The thesis explores hardware procurement in the quantum computing industry. More specifically, it is limited to European and North American market participants. Further, the interviews were limited to employees of academic buyers, commercial buyers, and sellers, complemented with industry experts, all having direct insight into the purchasing decisions but from different perspectives.

1.5 Structure of the Thesis

Chapter 1

The chapter introduces the background of the master's thesis, followed by its research objectives and research questions. Then, the chosen delimitations and the overall structure of the thesis are presented.

Chapter 2

The chapter begins with describing the thesis' research strategy and design. Then, a detailed overview of the grounded theory approach, including the data collection, data analysis, and literature review is presented. After follows a discussion of the reliability, replicability, and validity of the thesis, as well as the ethical considerations.

Chapter 3

The chapter presents the literature review related to the thesis in accordance with the grounded theory approach. That is, it begins with the initial literature review, followed by the ongoing literature review, and ends with the final literature review.

Chapter 4

The chapter sets the scene for the interview section by giving a further overview of the quantum computing industry. The described categories are, in order, the current hardware approaches, the quantum computing market ecosystem, the quantum geopolitical landscape, and the concept of a quantum winter.

Chapter 5

The chapter presents the results from the interviews held with academic buyers, commercial buyers, sellers, and industry experts. The findings are conveyed based on one research question at a time, with each research question section being subcategorized into the different interview groups.

Chapter 6

The chapter discusses and interprets the empirical findings from the interviews, one research question at a time. Further, comparisons are made with relevant literature.

Chapter 7

The chapter provides the concluding remarks of the thesis by summarizing the key findings, and notes the research and managerial implications. Then, the limitations are addressed and future research directions are proposed.

2 Methodology

The chapter begins with describing the thesis' research strategy and design. Then, a detailed overview of the grounded theory approach, including the data collection, data analysis, and literature review is presented. After follows a discussion of the reliability, replicability, and validity of the thesis, as well as the ethical considerations.

2.1 Research Strategies

There exists a multitude of ways to form a research strategy; Cresswell (2009) proposed three types: qualitative, quantitative, and mixed methods. Numerous authors on methodological theory differentiates between quantitative and qualitative research (Bell & Bryman, 2011).

Qualitative research is an approach that typically places greater emphasis on words rather than numerical quantification when gathering and interpreting the data. Bell & Bryman (2011) suggested that there exists three significant characteristics that are particularly noteworthy for qualitative research: (1) it has an inductive view of theory and research, meaning that the theory is generated out of the research; (2) there is an epistemological position of interpretivism, which emphasizes the understanding of the social world through participant interpretation; and (3) it holds an ontological position described as constructionism, which suggests that social properties are results of interactions among individuals.

Quantitative research is a strategy that, contrary to qualitative research, highlights the collection and analysis of numerical data. Bell & Bryman

(2011) further suggested that quantitative research holds the following three properties: (1) follows a deductive approach in the link between theory and research, where the purpose is to test the theory; (2) follows practices and norms of the natural scientific model; and (3) holds an objectivist ontological position of the social reality, meaning that social phenomena exists independently of social actors.

The mixed methods research design is a combination of a qualitative and a quantitative approach that utilizes both approaches to reach a stronger conclusion than either of them alone (Creswell, 2009).

Qualitative and quantitative methods are distinct from each other and possess different strengths, logics, and address different types of questions and goals. The strength of employing a qualitative research methodology originates from the process-oriented and inductive approach, which mainly focuses on the specific situations or individuals, and its emphasis on descriptive data. This allows for a more detailed exploration of experiences and insights that might be missed with a quantitative approach (Maxwell, 2012).

Further, Höst et al. (2006) described the following four different methodologies based on the aim and character of the study:

- *descriptive* studies primarily aim to comprehend and depict how a process or system works or is executed;
- *exploratory* studies are focused on achieving a deep understanding of how a process or system works or is executed;
- *explanatory* studies are aimed at establishing causation and explanation for how a process or system functions or is executed;

- and *problem-solving* studies aim to find a solution to a specific identified problem.

Worth noting is that a study does not have to be limited to being one or the other; rather, it can be a combination of them as well (Höst et al., 2006).

2.1.1 Chosen Research Strategy

Given the small number of actors and limited available information of the quantum computing hardware market, it was considered that a qualitative research approach was the best suitable option to answer the research questions. Furthermore, the research strategy was of an exploratory character given the limited research of the subject in the context of quantum computing hardware.

2.2 Research Design

The research design refers to the overall structure for conducting the collection of data and subsequently the analysis of this data. Hence, the research design is a framework for evidence that is appropriate for the research questions and the criteria used to evaluate its quality. Reliability, replication, and validity is commonly used criteria to the quality of business research and is further explained in chapter 2.4 and 2.5 (Bell & Bryman, 2011).

Bell & Bryman (2011) presented five different research designs commonly used in business and management research:

- *Classic experimental design*: Two groups are established and participants are randomly selected in either the control group or the experimental group. Pre-testing of the two groups is conducted and afterwards the experimental group receives the experimental treatment. The difference between the two groups' measurements are then tested and the experimental effect is measured.
- *Cross-sectional design*: Involves the gathering of data on multiple cases at a single point in time. The aim of the cross-sectional design is to collect a set of measurable data related to chosen variables in order to identify patterns of correlation or association.
- *Longitudinal design*: Similar to cross-sectional design but measures the data at least two times and has the objective to analyze the change in variables during the chosen timeframe.
- *Case study design*: Through a case study, the subject matter itself is studied and the researcher seeks to answer a comprehensive and detailed explanation of one or more cases. Typical cases are organizations, people, locations, or events.
- *Comparative design*: Two or more study objects are observed and the aim is to through comparison find knowledge within existing theories or improve the knowledge within a field through suggesting concepts for a new theory.

To avoid misinterpretation of the data in business research, Bell & Bryman (2011) emphasized the importance on what level the analysis is with respect to the SOGI (societies, organizations, groups, or individuals) model. The risk of cross-level misattribution occurs when data derived from one level is used to draw conclusions about another level. To avoid this, it is important to clarify what level in the SOGI model that is being researched.

2.2.1 Chosen Research Design

Given that the purpose of this thesis is to explore purchasing decision factors and preferences in the quantum computing hardware market, it was concluded that a comparative design was the most suitable research design to achieve this objective. The comparative design is similar to a case study but with the extension that multiple cases are being examined and compared to derive findings across the cases (Bell & Bryman, 2011). Considering the limited knowledge within procurement in this field, the employment of a comparative design was deemed appropriate to form emerging theoretical knowledge within this research area. The decision to include multiple cases allows for variations in the results and increases the possibility for the researcher to identify the conditions under which a theory may or may not be applicable (Bell & Bryman, 2011). Moreover, the research concerns academic and commercial actors such that the level of analysis will be on an organizational level.

2.3 Grounded Theory

Grounded theory is a common analysis tool within qualitative research, and is particularly well-suited for research within an organizational setting. Some of its strengths are that it is advantageous in areas where there is a dearth of existing literature or theoretical frameworks, and that it provides a deeper understanding of the situation among members within an organization, hence acting as a springboard for linking theory to practice. The data analysis technique involves systematically collecting and analyzing data during the research process to ultimately develop a theory based on this data. The technique is iterative and recursive in its nature and the data collection and analysis is performed simultaneously and developed during the research process (Bell & Bryman, 2011). The approach comprises several distinct features, including theoretical sampling, constant comparison, and the use of coding (Bell, 2010).

Since there is a lack of literature regarding the purchasing decision within the quantum computing hardware market, grounded theory was deemed to be the most relevant analytical framework for the thesis, as it allows for inductively developing theories from the research data.

2.3.1 Data Collection

The data was collected through semi-structured interviews with both academic and commercial organizations. The academic organizations were buyers of hardware, whereas both commercial buyers and sellers were interviewed, along with industry experts working in the field of quantum computing with vast experience.

2.3.1.1 Sampling

A study can be either fixed or flexible in its nature. Fixed studies are studies that have a predominantly defined approach, whilst a flexible study can continuously be adapted to changed conditions during the research process (Höst et al., 2006). In the context of grounded theory, the data collection and analysis are two intertwined processes that are not to be completely separated. The sampling process changes dynamically based on the development of the research (Bryant & Charmaz, 2007). Within grounded theory research, the most common way of sampling is to start with purposive sampling and, as the theory is being constructed, continue with theoretical sampling (Korstjens & Moser, 2018). Hence, the sampling strategy chosen was purposive sampling and theoretical sampling.

Purposive sampling is a non-probabilistic sampling technique, where sought participants are sampled in a way such that they are deliberately selected based on the scope of the study and the research question. Theoretical sampling is a type of purposive sampling where the researcher generates data through samples that enables the discovery of categories and their characteristics to subsequently generate theories. This means that the researcher collects and analyzes the data simultaneously, and the researcher determines what to sample next based on what is relevant for the emerging theory to be formed (Bell & Bryman, 2011).

The interview sampling was conducted in two phases, initially through purposive sampling and later by theoretical sampling. In the first phase, the aim was to find interview objects based on the following two criteria: (1) their organization is purchasing hardware for quantum computing applications and (2) they are involved in the purchasing of those products. Also, the search included industry experts, defined as having direct experience within the two mentioned criteria. The organizations and experts were found through various participation lists of quantum computing industry events, quantum computing-focused websites, and keyword searches using Google. If the organization owned or were in the process of developing a quantum computer, or if it explicitly stated they worked with the development of quantum computing hardware, the organization advanced through the first filtration stage. Subsequently, contact information on the organizations' websites for preferably individuals were sought. In search of relevant individuals who were deemed to have either the experience themselves to fulfill the second filtration criterion or could refer to an individual with the required expertise, job titles such as the following were sought: "Head of

Lab”, “Principal Investigator”, “CEO”, “COO”, “CTO”, and “Research Scientist”. If no direct contact information to an individual was found, the organization was contacted either through a general email, or in some cases, when the potential interview object had an open LinkedIn profile, they were approached directly through LinkedIn. 50 interview requests were sent out to academic buyers, commercial buyers, and industry experts during the initial phase, out of which 8 individuals accepted the request, representing a conversion rate of 16 percent. To ensure that each interview subject was relevant with regards to the two criteria, the participants were screened both in the correspondence before and during the actual interview.

In the second phase of the sampling process, it was identified that there was a lack of interview objects from the commercial buyers, and that including the sellers’ point of views would provide further insights in the procurement process. The emerging hypothesis was that there would be a discrepancy between the purchasing criteria valued by academic and commercial buyers, partly driven by the fact that academic actors are funded by public money. Further, including the sellers’ perspective was deemed to provide a valuable comparison to the buyers’ perception of the procurement decision. After discussions with the supervisor, it was concluded that future interview requests were to be sent to these actors to allow for theoretical saturation across different groups. Through theoretical sampling, potential interviewees were identified through the same method as in the purposive sampling, but with the additional criteria that they are a commercial buyer, or that (1) their organization is selling hardware for quantum computing applications and (2) they are involved in the sales process of those products. In the second phase, 27 interview requests were sent, out of which 5 were accepted and took part in the study, representing a conversion rate of approximately 19 percent. In summary, a total of 77 requests for interviews were sent out with 13 interviewees accepting, meaning a total conversion rate of circa 17 percent.

2.3.1.2 Semi-Structured Interviews

Semi-structured interviews are interviews with the aim to understand the interviewee's experience within the research subject. It can have a mix of structured questions and questions with a set of alternative answers with the purpose to describe and explain the research subject (Höst et al., 2006). Interviewing in qualitative research generally differs vastly from interviews in quantitative research in the tendency of being much less structured in its approach, such that the interviewee's perception of the research subject is obtained during the interview (Bell & Bryman, 2011).

In a semi-structured interview, the subjects of interest for the researcher should be covered in an interview guide with a list of questions. Despite having an interview guide, the interviewer retains the discretion to deviate from its sequence of questions. Additionally, the interviewer may ask follow-up questions not originally included in the interview guide either to extract more information from the interviewee, or because the interviewer encountered a compelling aspect that aligns with the research and the interviewee's experience (Bell & Bryman, 2011).

The interviews were structured as semi-structured interviews and conducted over 31 days between March and April 2023. Buyers, sellers, and industry experts were interviewed and three interview guides (see appendix A, B, and C, respectively) were tailored for each group. The themes discussed in the interviews were the same, but they were approached from different perspectives based on the knowledge of the interviewee. Due to the long distance between the researchers and interviewees, the interviews were conducted digitally on either Zoom or Microsoft Teams. It would not have been possible to conduct the interviews in-person due to distance and cost constraints. There are also additional advantages of digital interviews; Archibald et al. (2019) points out that digital interviews also could be perceived as more time-efficient, flexible, and yielding the possibility to reach a greater population than for traditional in-person interviews.

Due to the nature of grounded theory, the interview guides developed slightly during the interview process as more knowledge was acquired. Two changes that were made were (1) adding a question about describing the public procurement process for academic buyers and sellers, and (2) rearranging questions to facilitate better flow in the interviews. All interviews except two were performed in English, with the other two being in Swedish. For those interviews, the English interview guides were translated to Swedish ahead of the interview. During the interviews, both researchers asked questions to the interviewee and one always took notes.

2.3.2 Data Analysis

The steps within the adapted grounded theory are:

1. Forming general research questions
2. Relevant interview objects are sampled through purposive and theoretical sampling (as described in section 2.3.1.1)
3. Data is collected through semi-structured interviews (as described in section 2.3.1.2)
4. Coding of the data
5. Constant comparison

6. Saturate categories
7. When categories are saturated, formalization of the grounded theory

Steps 2 through 6 are iteratively done throughout the research process such that data collection and analysis is performed simultaneously and relevant interview objects are found; Figure 1 illustrates the adapted model used for grounded theory. According to Charmaz (2006), grounded theory represents a set of principles that can be adapted to the specific research objective; it does not consist of methodological rules that researchers must strictly adhere to. However, Hood (2007) argued that all grounded theory should include theoretical sampling, constant comparison, and developing theory through saturation of categories. Thus, the adapted grounded theory model used is a simplification of the grounded theory model presented by Bell & Bryman (2011).

Coding is a key process within grounded theory, and it is through coding the data that the researcher can convert the raw data into more manageable concepts that explains what the data indicates (Bryant & Charmaz, 2007). This is in contrast with quantitative research strategy which entails analyzing predetermined codes to the collected data. In grounded theory the codes are defined based on what is found in the data, and a consequence of this is that new areas and research questions can emerge during the process. Hence, the research questions presented in this thesis are a result of the grounded theory process.

Thereafter, in step 5, the constant comparison is conducted to analyze the newly acquired data and its frequency of occurrence within the category (Bryant & Charmaz, 2007). Constant comparison allows the researcher to develop inductive theories through categorizing, coding, and describing and connecting the categories. Theoretical sampling is closely related to this process (Boeije, 2002). If the category is not saturated during step 6, a new iteration of sampling is conducted and the process continues. Theoretical saturation is said to be achieved when there are no new insights emerging from the data within one category. Theoretical sampling is considered a sampling technique used within exploratory research, and since it is primarily used to generate or suggest theories, not confirm theories, it is possible to declare that theoretical saturation is reached without having to formally prove it (Bryant & Charmaz, 2007).

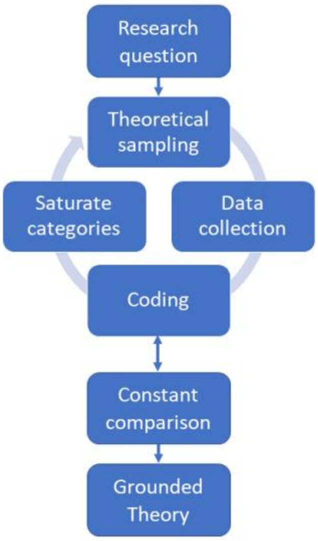

Figure 1: Adapted grounded theory framework.

Constant comparison is the foundation of the analysis in this research and *the constant comparative analysis procedure*, as suggested by Boeije (2002), was adopted for the analysis (see table 1). This is a three-step procedure that initially starts with open coding within a single interview. During the first step, every response given during the interview is examined to identify its meaning and assign it a code. Further, fragments are identified and compared if they share the same codes, and categories are formed between related codes. As soon as there exists more than one interview within any of the four groups, new interviews within that group are compared to the existing interviews. Axial coding is performed in this step with the aim to find common themes between the interviews and compare them to find characteristics of each category. In the final and third step, interviews across different groups are performed to attain a broader knowledge of the issue and give the data triangulation (Boeije, 2002).

Table 1: Different steps of the constant comparative analysis procedure in keywords (Boeije, 2002).

Type of comparison	**Analysis activities**	**Aim**	**Questions**	**Results**
1. Comparison within a single interview	Open coding; summarizing core of the interview; finding consensus on interpretation of fragments	Develop categories understanding	What are the core messages? How are different fragments related? What do fragments with the same code have in common?	Summary of the interview; Provisional codes
2. Comparison between interviews within the same group	Axial coding; formulation criteria for comparing interviews; hypothesizing about patterns and types	Conceptualization of the subject produce a typology	Is A talking about the same as B? What do both interviews reveal about the category? What combinations of concepts occur? What interpretations exist for this? What are the similarities and differences between interview A, B, C …? What criteria underlie this comparison?	Expansion of code words until all relevant themes are covered; Description of concepts; Criteria for comparing interviews; Clusters of interviews
3. Comparison of interviews from groups with different perspectives	Triangulating data sources	Complete the picture and enrich the information	What does group 1 say about certain themes and what does group 2 have to say about the same themes? What themes appear in group 1 but not in group 2 and vice versa? Why do they see things similarly or differently? What nuances, details or new information does group 2 supply about group 1?	Verification of provisional knowledge of interviewees from group 1; Additional information

2.3.3 Literature Review

When conducting a research study, the majority of studies begin with a review of literature before going to the data collection and analysis stage. In grounded theory, it is generally discouraged to perform an extensive literature review before these stages due to the risk of constraining the research to previous theoretical ideas (Adams et al., 2015). However, Dunne & Thornberg (2019) stated that the literature review can be divided in three phases. They proposed that during the first phase, prior to the data collection, the researcher starts with an initial literature review to understand the research subject in a broad perspective, but refrain from adopting any theoretical frameworks to their research. During the data collection phase, the researcher may conduct an ongoing literature review to seek existing research which relates to what has been found during the data collection. The third phase is the final literature review, which is performed when the researcher compares the findings with current research, with the purpose to integrate the findings with other fields and situate the theory with existing theoretical ideas. In the course of this phase, the researcher has the opportunity to demonstrate the relation of their findings to existing literature, as well as the contribution the research has within its research domain. Further, they proposed that the researcher is open about their pre-existing knowledge that influences the study. As an understanding of the quantum computing landscape was considered a prerequisite to identify relevant research areas, the authors began the study by conducting market research. An industry overview that covers the knowledge gained about the actors, hardware platforms, and projected growth and challenges connected to the quantum computing market is presented in chapter 4.

The three different phases of the literature review mainly consisted of a mix between peer-reviewed articles and academic books. In the ongoing literature review, research from OECD (The Organisation for Economic Co-operation and Development) was presented, as the material of interest pertained to OECD countries. To find peer-reviewed articles relevant for the objective of the master's thesis, keyword searches within the three search engines LUBsearch (collective entry point for all of Lund University's libraries), JSTOR, and Google Scholar were used. The books presented in the reference section were mostly found in the same manner as the journal articles. However, used literature that was not accessible online was instead borrowed from Lund University libraries. Finally, more general facts relating to the quantum industry and similar, either of interest for the preparation of the interview guide or after having been mentioned by an interviewee, were found through Google.

2.4 Reliability and Replicability

Reliability concerns the dependability of both the data collection and analysis with respect to variations within the sample. Through an accurate depiction of the research methodology, the reader can more easily make an informed assessment of the reliability of the study (Höst et. al, 2006). Goetz & LeCompte (1982) made the distinction between internal reliability and external reliability within business research. Internal reliability concerns the agreement in perception of the data and to which degree other researchers are likely to perceive and analyze the information in a similar manner as the original researcher. External reliability refers to the level of reproducibility of a study, which is a large concern within qualitative studies. This pertains to the fact that the social setting and circumstances during the study could be hard to replicate, even though the method could be easily replicable (Bell & Bryman, 2011).

To mitigate the risks associated with internal and external reliability, several actions were taken during the research process. For the internal reliability, both authors were present during all interviews, and the interviews were recorded and transcribed shortly after in all but two cases. Additionally, notes were taken and reviewed immediately after the interview to address any discrepancies in responses and ensure that there was alignment in the interpretation of the data. In case of any disagreements, the audio recording of the interviews was available to resolve such matters among the researchers. Goetz & LeCompte (1982) argued that the most effective protection against risks linked to internal reliability in studies could be the involvement of multiple researchers discussing until a consensus has been reached.

With regards to the external reliability, the methodology and work process is thoroughly documented and presented in such a way that external researchers can replicate the methodology. In the case of quantum computing however, the industry is developing quickly and the future requirements within quantum technology is uncertain. This decreases the probability of obtaining replicable results even though the same methodology is used due to changes in the context of the industry.

2.5 Validity

The notion of validity is divided in two parts: internal validity and external validity. Internal validity refers to the extent to which measured data accurately represents what was intended to be measured. To increase the internal validity of a study, one can use multiple methods to study the same process or object, a technique called triangulation. External validity refers to the degree the study can be applied to other settings and groups (Höst et al., 2006; Goetz & LeCompte, 1982).

The study is of exploratory character and the research subject is novel within this industry; it was hence deemed required to get perspectives of the procurement process from a range of actors. The internal validity was ensured through the initial sampling criteria: (1) their organization is purchasing hardware for quantum computing applications and (2) they are involved in the purchasing of those products. This ensured that relevant individuals within relevant organizations were interviewed in the data collection process. Further, the researchers regularly monitored the collection of data and the analysis of it through constant comparison to ensure consistency with the methodology.

2.6 Ethical Considerations

Bell & Bryman (2011) described four principles—harm to participants, lack of informed consent, invasion of privacy, and deception—that should be considered when conducting business research.

Harm to participants can relate to either physical harm, emotional harm or professional harm (Bell & Bryman, 2011). It was assessed that the risk of physical harm was low in this study since the participants involved in the study were at no physical risk during the interview process. However, the emotional and professional harm was addressed and primarily related to the anonymity of the participant. To ensure anonymity, the participant was informed that their involvement in the research would be anonymized, and that if the interview was recorded, this would be solely for transcription purposes. Due to the small number of actors within the quantum computing industry, incorporating the country of origin of the organization was deemed infeasible, as it poses a significant threat to breaching the participant's anonymity. Thus, only the continent that the organization is headquartered in will be presented.

Lack of informed consent is primarily focused on providing participants with sufficient information about the project to enable them to make an educated decision on whether to participate or not (Bell & Bryman, 2011). To guarantee informed consent, participants received information about the research in the interview request, along with a query about their interest in additional details on the themes to be discussed during the interview. Further, an introduction about the research topic and its themes were presented in the beginning of each interview.

During qualitative studies that incorporate interviewing, the interviewee might reject to answer one or more of the questions asked due to privacy reasons. The researcher may encounter challenges in which questions that may be sensitive for the interviewee, thus it is imperative that the respondents are not forced to answer (Bell & Bryman, 2011). The option to decline to provide an answer during the interview helped address the ethical concern of *invasion of privacy*. Lastly, *deception* occurs when researchers present their research as something that it is not (Bell & Bryman, 2011). This was addressed through informing the participants about the research motives, both in the request for participation correspondence and during the interview.

3 Literature Review

The chapter presents the literature review related to the thesis in accordance with the grounded theory approach. That is, it begins with the initial literature review, followed by the ongoing literature review, and ends with the final literature review.

3.1 Initial Literature Review

3.1.1 Order Qualifiers and Order Winners

A buyer typically needs to do trade-offs between different desired attributes when selecting a supplier. For instance, a buyer of quantum computing hardware is likely to have to pay more for superior performance characteristics. As a way to distinguish between these differences in a manufacturer's strategy formulation, Terry Hill introduced the concept of order qualifiers and order winners (Bamford et al., 2018). According to Hill (2000), companies that fail to differentiate between order qualifiers and winners are consequently posed to be unable to develop coherent strategies that support their markets. In the long run, adhering to said strategic provision might be at the root of an organization's overall success or failure.

Order qualifiers are defined as criteria that must be met for a buyer to even consider the supplier (Hill, 2000). Owing to the fact that failing to meet the set of order qualifying criteria disqualifies the supplier from being considered for the bid, and that providing these criteria are not enough to actually win orders, order qualifiers can also be interpreted as order losers. For instance, the research discussed that organizations at the time tended to increasingly scan for suppliers that were registered under the ISO 9000 series. If a buyer did assess this aspect as an order qualifier, a supplier who was registered would simply stay on the shortlist for the bid, whereas a supplier who was not registered would immediately lose it.

Order winners are then defined as criteria that buyers use to determine which supplier wins the bid (Hill, 2000). To identify what constitutes qualifiers and what constitutes winners in a given market, recognizing the essential differences between the two is a must. Delivering on an order qualifier means that a competing supplier only needs to be as good as the competitors; delivering on an order winner means that the supplier outperforms the competition in the category.

Lastly, Hill (2000) underscored that order qualifiers and order winners are different, but that one of the two is not more or less important than the other, as both are essential for a company to maintain existing market shares and grow. Further, criteria that are considered order winners for a primary supplier might very well differ from those of other supplier categories. Since contractual demands and opportunities are different when a buyer is dealing with a primary supplier as opposed to a secondary one, the order winners in the respective cases should reflect this dynamic.

3.1.2 Institutional and Industrial Purchasing

Laios & Xideas (1994) undertook an empirical study involving 46 organizations, comprising 21 industrial enterprises and 25 institutions to explore differences in the purchasing function. They found that in the articulation of requirements, industrial enterprises have a complex process including different functions within the firm. In contrast, institutions tend to rely on the individual that needs the equipment to form the technical requirements. In the selection of suppliers however, institutions tend to have a more structured process in the form of, e.g., competitive bidding. For industrial enterprises the selection process is less structured, as the thorough requirement process yields a limited number of qualified suppliers.

Gravier et al. (2011) also found a difference between private and public buying behaviors when comparing the for-profit and the not-for-profit sector through survey procurement data sent out to both segments. In the for-profit sector, more experienced buyers tended to be in charge of the most important purchases. For the not-for-profit sector on the other hand, there were no indications of the same strategic allocation of resources to manage heterogeneous types of spend. Hence, the survey data suggested that the not-for-profit organizations did not use a purchasing portfolio model to segment their spending. Additionally, as the leaders of the not-for-profit organizations were found to be more opportunistic than their for-profit counterparts, the authors implied that efficiency-related outcomes of integrated supply chain management may not be as achievable for not-for-profit actors, partly due to the possibility of senior procurement leaders in this sector seeking out to advance their personal goals rather than the efficiency of the organization.

Based on previous literature in public procurement and supply chain management, Larson (2009) tested two hypotheses, each implying differences between what procurement professionals in the public sector view as important vis-à-vis their private sector counterparts. Through analyzing over 2,000 received questionnaires covering 54 topics related to supply chain management, the study found support for both hypotheses. Firstly, the public sector was significantly more inclined to have a narrow view on the supply chain, regarding it as a proxy for purchasing instead of a strategic cross-functional effort. Secondly, the relative importance of different elements within the procurement process was weighted differently, with the largest discrepancies arising from the public sector assigning significantly higher importance to public procurement and requests for proposals, and the private sector being much more focused on, e.g., global purchasing and import (export) processes. However, the most similar element between the groups was the implied importance of supplier selection evaluation.

3.2 Ongoing Literature Review

3.2.1 Public Procurement

Public procurement is a complex government activity that accounts for approximately 12 percent of the gross domestic product of OECD countries. The guiding principle for public procurement is that the process is conducted in a fair and open manner, but each government takes their own decision with regards to how the public procurement is to be carried out. The decisions taken (and not taken) by governments can significantly impact their economic and social development, for instance by either strengthening or weakening the capacity of SMEs (small and medium-sized enterprises) to win public contracts (OECD, 2018). According to the EU, evaluations based on MEAT (most economically advantageous tender), as opposed to price, yields an advantage for SMEs since these firms are viewed as sources of innovation. However, the support for this claim has been challenged in the literature. Stake (2016) found that the policy was counterproductive in Sweden; SMEs probability of winning public bids decreased significantly when MEAT was used as the evaluation criterion.

The intricacies surrounding public procurement and what the optimal evaluation technique ought to be was further investigated by Lorentziadis (2020), who examined whether a particular supplier can be favored in the evaluation process or not with MEAT as a public procurement framework. The study found that contracting authorities in this case can influence the bidding behavior by manipulating the score function, thus either magnifying or downplaying certain criteria. On the other hand, when using price as the decisive (or only) factor, either higher quality bidders will be discouraged from participating, or lower quality bidders will be disqualified and thus unable to compete.

3.3 Final Literature Review

3.3.1 Supplier Selection in High-Technology Markets

In order to attain success in B2B-markets, it is vital for suppliers to understand the purchasing behavior of their potential customers (Anić et. al, 2017). Marketing research has historically focused on low-technology products (Heide & Weiss, 1993). Kar & Pani (2014) delineated over 60 different purchasing criteria used in various contexts when studying supplier selection. However, research within organizational purchasing often neglects the technical complexity of the product when studying the purchasing decision (Donthu & Lewin, 2005). When studying purchasing behavior for radical software innovations, Iyer & Jayasimha (2020) acknowledged that the research in this area was very general and the existing models did not consider the adoption of radical technology innovations. In an effort to address this issue, a grounded theory study was conducted to examine the dynamics within the buying and adoption process. By doing so, the authors found evidence that the buying process of radical software innovations differed from the general organizational buying models.

The high-technology market distinguishes itself from industrial markets in four distinct dimensions (Abratt, 1986):

1. The elevated degree of innovation in these products increases the risk that their historical performance is limited or non-existent.
2. Buyers must assess various technological approaches taken to solve a problem to identify which aligns with their specific needs.
3. Post-sales technical and application support offered by the supplier constitutes a crucial element for success.
4. It is typically a requisite for sales representatives to exhibit a comprehensive understanding within their technological field.

For procurement of laboratory instruments in South Africa, Abratt (1986) found that: (1) in most cases there is more than one individual involved in the procurement process from the purchasing side; (2) price is not the primary factor for selection; instead, it is a combination of criteria where service, reliability, and after-sales support are the most important; (3) contacts with the supplier serves as the most valuable source of information about the solutions; and (4) technical personnel play a crucial role in the purchasing decision process.

Further, research by Franses et al. (2001) found that, in the market for technology intensive products, vendors and buyers are integrated in an interfirm network. The study suggested that buyers tend to favor vendors they have a strong relationship with, as well as vendors that have strong ties with their component manufacturers, which then can be shared. This is in line with the literature review on general supplier selection criteria conducted by Abdolshah (2013), who emphasized that organizations of the time were increasingly looking to establish longer-term working relationships with suppliers. The article found that quality, delivery, and performance history were evaluated as *extremely important* criteria through the general supplier selection literature, with quality standing out as the most important.

Leasing is an alternative option of purchasing an item or hardware. Richardson & Wang (2020) found that if a research institution maintains an instrument replacement rate that keeps pace with technological advancements, it can gain a competitive advantage. A lease becomes more attractive as the pace of technological advancement increases. Further, research institutions often have a restricted budget with competition for internal funds, leading to longer equipment refresh cycles. Procurement through leasing is a desirable option for organizations with conservative budgets since it can offer a predictable and consistent cost structure year after year.

3.3.2 Start-Ups and Trust

The perception of buying from start-ups was studied by Konya-Baumbach et al. (2019) in the context of digital innovation adoption. The study found that initial trust perceptions from customers were of high importance for adoption intentions, and further demonstrated that managing the perceived level of trust can be a make-or-break for the survival of the start-up. Also, it was shown that innovations are typically surrounded by a level of ambiguity, and that signaling trustworthiness is particularly critical in the early stages of adoption.

House et al. (1986) continued previous research by psychologist Arthur Stinchcombe on the topic of *liability of newness* by exploring whether external legitimacy or internal coordination was the main driver behind the higher propensity of younger organizations to die. The argument for the former is that older organizations are more likely to develop fruitful relationships with other organizations and have their solutions supported by powerful actors within the industry. Thus, more mature organizations are more likely to be regarded as legitimate than younger ones. In fact, the study found the most support for the argument of external legitimation decreasing the chances of survival for organizations in the start-up phase.

A literature review of 175 papers on the topic of supplier selection revealed that the perceived trust of the supplier was not being used as a major criterion at the time (Janjua et al., 2021). The researchers noted that most buying situations involve the value proposition as the buyer's primary concern, but argued that excluding supplier trustworthiness from the criteria in high-risk situations was concerning. In these cases, buyers tend to place a larger emphasis on the actual supplier, evaluating dimensions such as capabilities, reputation, and relationships, since these better indicate whether the supplier can be a reliable partner or not. As such, new literature ought to accommodate the fact that transactions which carry greater risks often involve the question "Can I trust you?".

The element of trust in information technology artifacts was examined in a paper by Elie-Dit-Cosaque et al. (2008). Their research showed that culture can affect the degree to which customers perceive trust, as the findings in differences between France and the US were consistent with the previously documented lower trust French culture as opposed to the higher trust US culture. Hence, the way this technology was perceived was not culturally neutral.

3.3.3 Make-or-Buy Decision

Apart from sourcing or leasing, a potential hardware buyer also has the option to manufacture the components in-house. Many firms view the make-or-buy decision as an economical one, where the organization weighs cost of producing and cost of purchasing (Porter, 1980). When researching the make-or-buy decision at Ericsson within semiconductors, a highly technological field, Bratt et al. (2010) found that the decision process was not dominated by the economical view; rather it focused on a broad range of factors such as control of innovation and the rate of technological advancement.

Venkatesan (1992) explored strategic sourcing with regards to the make-or-buy decision in the context of highly engineered products. The recommendations brought forward by Venkatesan were based on the notion that the manufacturing focus should be learning how *not* to make things. As such, three principles for a manufacturer in the high engineering field were presented: (1) focus on components that are critical to the product and that the organization is distinctively good at making; (2) outsource components to suppliers that have a comparative advantage (e.g., greater scale, lower costs, or stronger performance incentives); and (3) utilize the prospect of outsourcing as a means to generate employee commitment to improve the manufacturing performance.

Moschuris (2008) discussed the outsourcing decision as among the most strategic ones that an organization can make, since it addresses the organizational choice of what expertise to develop internally and what to purchase. Hence, the research set out to provide practical contributions to the field regarding which organizational participants are involved in the make-or-buy decision. The study found that the process usually involves the technical function, the production function, the financial function, as well as a designated make-or-buy committee. Further, the paper showed that what organizational participants are involved, and to which extent they influence the final decision, varied significantly depending on both the organization characteristics and the characteristics of the investigated solution.

4 Industry Overview

The chapter sets the scene for the interview section by giving a further overview of the quantum computing industry. The described categories are, in order, the current hardware approaches, the quantum computing market ecosystem, the quantum geopolitical landscape, and the concept of a quantum winter.

4.1 Hardware Solutions

Quantum computing is a rapidly evolving high-technology field of study, characterized by a significant discrepancy between what applications are desired to run on it and the current limitations regarding the technical capabilities of the hardware (Baker & Chong, 2021). There exist several competing hardware platform solutions that are currently being developed, utilizing various physical interactions (electrical, optical, and magnetic) to define qubits. These domains require different conditions and hardware for the generation and control of the qubits. Some of the most common platforms are superconducting qubits, trapped ions, neutral atoms, photonic simulators, spin systems, nitrogen-vacancy centers, and T-cells (National Academies of Sciences, Engineering, and Medicine, 2019). Today, no existing hardware platform has achieved the necessary scale, speed, and quality to demonstrate an advantage over classical computers in real-world problems, however the furthest developed are superconducting qubits and trapped ions (World Economic Forum, 2022).

A major bottleneck in the pursuit of reaching quantum advantage is overcoming the critical challenge that noise poses on the error rates in the qubit gates. To effectively eliminate the errors to a state that can be considered fault tolerant, engineers need to develop advanced error-correction algorithms. However, this requires bigger processors than what are available today. The current state of quantum computing is often referred to as the NISQ (noisy, intermediate scale quantum) era; engineers are not able to completely eliminate noise in the systems, but techniques to reduce it are being developed. Although the real commercial promise of quantum computing lies within the fault-tolerant era, a few commercially viable applications are expected to be produced with NISQ-level quantum computers (Finke, 2022).

4.2 Market Ecosystem

The quantum computing market comprises start-ups, larger commercial players, public organizations, and academic groups. In 2022, there were 248 start-ups, 17 larger players, 57 public organizations, and 180 academic groups within the quantum computing industry. Attention towards start-ups has grown significantly in recent years, as over two thirds of the total quantum start-up investments since 2001 occurred between 2021 and 2022 (Masiowski et al., 2023). The start-ups are often spin-offs from university research groups where they continue to work in close collaboration with their former university to get access to their research facilities and knowledge (Potter, 2023). To support the ecosystem of quantum start-ups in the pursuit of quantum advantage, large tech companies, private investors, and governments have invested billions of dollars into the field (Bova et al., 2023). Further, the majority of quantum computing start-up investments are directed towards hardware manufacturers. Technology improvements in hardware components are needed to enable scaling to fault-tolerant quantum computing, and due to the high complexity, hardware players require significant capital and highly specialized knowledge (Masiowski et al., 2023).

4.3 Geopolitical Landscape

The last few years have seen a proliferation around the world of national initiatives related to quantum research, with major players such as China, the US, the EU, and Russia aiming to position themselves in the race towards a new quantum revolution. Governmental interest is partly driven by the economic prospects, but also by the significant security implications of quantum technologies. It is believed that a fully functioning quantum computer can allow a country, or even a non-state actor, to break any public encryption key. Thus, information and data security likely need to be reimagined with the presence of fault-tolerant quantum computers, making it a highly geopolitically sensitive field (Fancy & Kung, 2021). The tendency for international collaboration within this potentially transformative technology is low among the two leading countries China and the US (Shen et al., 2021).

4.4 Quantum Winter

In 1973, reports were highly critical of the failure of AI research to live up to its grand objectives, eventually leading to a complete cessation of British research in the field for over a decade, and a wave of funding cuts across Europe (De Spiegeleire et al., 2017). Inflated expectations and long expected timelines to commercialization means that the quantum computing field possesses similar characteristics to the earlier stages of AI research, thus making it vulnerable to experiencing a similar winter (Verdict, 2022). For instance, three quantum computing companies that had their initial public offerings between 2021 and 2022—IonQ, Rigetti Computing, and D-Wave—have all lost above 50 percent of their initial valuation as of May 3, 2023, with Rigetti and D-Wave both having trailed approximately 95 percent (Yahoo! Finance, 2023a; Yahoo! Finance, 2023b; Yahoo! Finance, 2023c). Biddle et al. (2019) suggested that if the NISQ-level quantum computers fail to reach commercial acceptance, countries or organizations that remain actively engaged in maturing the technology are likely to take leadership in the field. In order to avoid a technological surprise, the authors maintained the notion that a funding organization should avoid focusing on the current potential advantages of quantum computing at the expense of committing to the long-term research efforts needed to reach quantum advantage in truly impactful applications.

5 Empirical Findings

The chapter presents the results from the interviews held with academic buyers, commercial buyers, sellers, and industry experts. The findings are conveyed based on one research question at a time, with each research question section being subcategorized into the different interview groups.

5.1 Interview Participants

Table 2: Group categorization and role of each interviewee.

Group	**Role**	**Continent**
Academic Buyer 1	Head of Lab	North America
Academic Buyer 2	Postdoc	Europe
Academic Buyer 3	Postdoc	Europe
Academic Buyer 4	Head of Lab	North America
Academic Buyer 5	PhD student	Europe
Academic Buyer 6	Head of Lab	Europe
Commercial Buyer 1	CEO	Europe
Commercial Buyer 2	CEO	Europe
Seller 1	CTO	Europe
Seller 2	Account Manager	Europe
Seller 3	COO	Europe
Industry Expert 1	Consultant	North America
Industry Expert 2	CEO	North America

Table 2 gives an overview of the group categorization and role of each of the 13 interviewees, who were sampled according to process described in section 2.3.1.1. As can be seen, out of the 13 interviewee objects, six were classified as academic buyers, two as commercial buyers, three as sellers, and two as industry experts. Further, 9 of the interviewees operated from Europe, whereas two academic buyers and both industry experts were from North America. Among the academic buyers there was a mix between the level of seniority in the lab, ranging from PhD student to the actual head of the lab. Both commercial buyers were CEOs of their respective organization. The roles of the sellers were varied, but each of them had been involved in the selling process with both academic and commercial buyers. One of the industry experts possessed vast knowledge from working as a consultant within the industry, whereas the other one was the CEO of an organization within the quantum computing landscape. This interview subject had knowledge about—as well as experience in—the hardware procurement process from different actors' perspectives.

The respective buyers, sellers, and industry experts will be referred to in accordance with their labeling in table 2, meaning: Academic Buyer 1, 2, 3, 4, 5, 6; Commercial Buyer 1, 2; Seller 1, 2, 3; and Industry Expert 1, 2.

5.2 Purchasing Criteria

After asking the interviewees from the four different groups about what purchasing criteria were considered when a buyer is selecting a supplier for quantum computing hardware, the raw data was coded into a total of eight categories, as described in section 2.3.2. These included *performance*, *price*, *trust*, *ease-of-use*, *compatibility*, *time*, *service*, and *geography*. A brief summary of what each theoretical category entails is provided below.

- *Performance* covers the technical aspects and quality of the product.
- *Price* captures the nominal price itself as well as budget restrictions and perceived economic value.
- *Trust* encapsules the degree to which the supplier can be deemed reliable. Well-tested solutions, financial stability, and the buyer's perception of the supplier are common examples of trust factors.
- *Ease-of-use* implies a user-friendly solution.
- *Compatibility* refers to how compatible the hardware is with the rest of the system. The factor is concerned with the adaptability of the hardware and also encompasses the flexibility of the solution in the specific domain it is purchased for.
- *Time* includes lead times as well as potential time-savings (and losses) related to a purchasing decision.
- *Service* covers the functionality and speed of the support system a supplier has in terms of installing the hardware solution and resolving a customer's queries.
- *Geography* refers to preferences regarding the location of the supplier. Underlying factors include geopolitical risk, supply chain concerns, and associated bureaucracy.

5.2.1 Academic Buyers

Seven out of the eight identified purchasing criteria were mentioned by at least one academic buyer, with the three most prominently mentioned factors being *performance*, *price*, and *trust*. The findings in the group represented slightly more similarities than differences, with three out of the seven factors belonging to a single buyer. The considered purchasing criteria for Academic Buyer 1 through 6 are presented in table 3.

Table 3: Purchasing criteria for the academic buyers.

Category	**Buyer 1**	**Buyer 2**	**Buyer 3**	**Buyer 4**	**Buyer 5**	**Buyer 6**
Performance	x	x	x	x	x	x
Price	x	x	x	x	x	
Trust	x	x	x	x		x
Ease-of-use	x				x	
Compatibility	x					
Time			x			
Service		x				
Geography						

All academic buyers talked about *performance* as a purchasing criterion. Academic Buyer 2 and 5 had strict requirements regarding the noise, thus making the performance an important criterion. Academic Buyer 3 stated that they demand high performance since they are buying state-of-the art hardware. Given the complexity of what Academic Buyer 3 was sourcing, performance can sometimes simply refer to fulfilling all of the technical requirements, a view that was also shared by Academic Buyer 4. Academic Buyer 6 described performance as an essential factor.

All academic buyers except for Academic Buyer 6 mentioned *price* as a purchasing criterion, with Academic Buyer 6 even stating that price is of little interest. Academic Buyer 3 highlighted that they put in an effort to be aware of the market prices as a way to reduce the risk of purchasing the hardware to an inflated price. Academic Buyer 4 stressed that the budget is a constraint, thus making them price-sensitive.

Aside from Academic Buyer 5, all academic buyers discussed the element of *trust* as a purchasing criterion. Academic Buyer 1 explained that they are more comfortable buying hardware that colleagues have recommended, that has been used in a paper, or from a supplier that they have been involved with in the past. The point of colleagues' past experience is shared by Academic Buyer 4, who argued that the lack thereof raises concerns. Academic Buyer 3 stated that a proxy for the credibility of a company is for how long they have been delivering the equipment, and that buying from a new player is somewhat of a bet. Academic Buyer 6 explained that a personal feeling is often used to determine whether the supplier can be trusted or not.

Academic Buyer 1 and 5 both cited *ease-of-use* as a purchasing criterion. Academic Buyer 1 mentioned a preference towards solutions that are designed in a more comfortable and accessible way, whereas Academic Buyer 5 elaborated on the importance of a user-friendly manual.

The criteria *compatibility*, *service*, and *time* were each mentioned once by Academic Buyer 1, 2, and 3, respectively. Academic Buyer 1 explained that their quantum domain places an extra emphasis on compatible hardware equipment for the system to function properly. Academic Buyer 2 discussed their need for a well-functioning support and service system whenever encountering problems with the hardware in their experiments. Lastly, Academic Buyer 3 highlighted time as a valuable resource, concluding that it is preferable for them to purchase hardware that they expect to function well in order to minimize the risk of losing time later on.

5.2.2 Commercial Buyers

Four out of the eight identified purchasing criteria were mentioned by at least one commercial buyer, with the two most prominently mentioned factors being *performance* and *trust*. Thus, the findings within the group represented a balanced amount of similarities and discrepancies, with two out of four factors differing between the two buyers. The considered purchasing criteria for Commercial Buyer 1 and 2 are presented in table 4.

Table 4: Purchasing criteria for the commercial buyers.

Category	**Buyer 1**	**Buyer 2**
Performance	x	x
Price		x
Trust	x	x
Ease-of-use		
Compatibility		
Time		
Service		
Geography	x	

Both commercial buyers talked about *performance* as a purchasing criterion. Commercial Buyer 1 stated that even finding a supplier might be challenging due to the highly specific technical specifications. Commercial Buyer 2 went further by expressing that they almost exclusively consider the actual performance of the product.

Further, both commercial buyers discussed *trust* as a purchasing criterion. For Commercial Buyer 1, the trust was examined by evaluating the stability of the supplier. The hardware they purchase becomes a component of a larger system, so they need to feel confident that the supplier will be around long-term. Commercial Buyer 2 screened for what they consider to be serious suppliers, meaning a supplier that has a track record of successful deliveries.

Commercial Buyer 2 highlighted *price* as a purchasing criterion, but also noted that the level of price-sensitivity often is a function of the level of performance they are looking for. If the performance requirement on the hardware is of greater (lesser) importance than usual, then the pricing factor will be less (more) important.

Lastly, Commercial Buyer 1 also brought up *geography* as a purchasing criterion, and especially emphasized the element of political stability. Commercial Buyer 1 exemplified by mentioning a degree of caution towards sourcing from China due to uncertainties regarding the political developments in the future, and acknowledged that this represented a change in mindset likely to have occurred over the recent years.

5.2.3 Sellers

Six out of the eight identified purchasing criteria were mentioned by at least one seller, with the most prominently mentioned factor being *ease-of-use*. However, the findings within the group varied, with four out six factors being mentioned by a sole supplier. The considered purchasing criteria according to Seller 1 through 3 are presented in table 5.

Table 5: Purchasing criteria according to the sellers.

Category	**Seller 1**	**Seller 2**	**Seller 3**
Performance		x	x
Price		x	
Trust	x		
Ease-of-use	x	x	x
Compatibility			x
Time			x
Service			
Geography			

All sellers talked about *ease-of-use* as a purchasing criterion for the buyers. Seller 1 described that they provide reduced lab complexity with their hardware solutions. Seller 2 highlighted that no manual work is needed with their product during the first years, allowing for a fully automated and hence service-free usage. Seller 3 explained that saving time is a major reason for buyers purchasing their hardware. Therefore, delivering a user-friendly solution is of high importance.

The purchasing criterion *performance* was mentioned by both Seller 2 and Seller 3. However, Seller 2 provided nuance and explained that the funding of the buyer usually determined the level of performance that was sought after, with organizations operating on a stricter budget having to compromise on the performance requests. Seller 3 further elaborated on the performance factor, mentioning that their commercial buyers are more interested in increasing the performance of their systems, whereas academic buyers seek reproducibility in their experiments. To effectively communicate the hardware's performance characteristics and understand the specific technical needs of a potential buyer, both Seller 2 and Seller 3 mentioned the importance of introducing people with domain expertise to the buyer.

Seller 2 expressed *price* as a purchasing criterion, in accordance with the performance trade-off mentioned above. They argued that price is not an issue for well-funded organizations, whereas less funded organizations are price-sensitive in their hardware needs.

Seller 1 stated that *trust* was an important purchasing criterion, the argument being that when a customer has been convinced that they really want the hardware the deal is more likely to be won. They explained that exemptions from the role of trust include cases where the buyer is looking for a quick and cheap hardware solution.

Lastly, Seller 3 brought up both *compatibility* and *time* as purchasing criteria. The former is due to the fact that their product usually fits into the buyer's hardware setup, hence eliminating inconveniences such as having to change and adapt the system, and the latter being in line with the previously mentioned ease-of-use argument. A buyer who decides to purchase their product will partly do so to free up time resources.

5.2.4 Industry Experts

Seven out of the eight identified purchasing criteria were mentioned by at least one industry expert, with the four most prominently mentioned factors being *performance*, *price*, *trust*, and *geography*. Thus, the findings within the group represented slightly more similarities than differences, with three out of seven factors differing between the two experts. It is to be noted that all seven purchasing criteria discussed between the two were touched upon by Industry Expert 1, who described the sourcing process often being a multi-factor decision. Industry Expert 2 also highlighted the issue of overgeneralizing, but did not present the same depth of purchasing criteria that the buyer might have under consideration. The considered purchasing criteria according to Industry Expert 1 and 2 are presented in table 6.

Table 6: Purchasing criteria according to the industry experts.

Category	**Expert 1**	**Expert 2**
Performance	x	x
Price	x	x
Trust	x	x
Ease-of-use		
Compatibility	x	
Time	x	
Service	x	
Geography	x	x

Both industry experts talked about *performance* as a purchasing criterion. Industry Expert 1 stated that the performance is often of high importance, connecting it to several buyers being quality-driven as well as the supplier's ability to customize towards the buyer's demands being a success factor. Industry Expert 2 resonated in line with the latter part, and explained that the often heavily customized specifications lead to the technical aspects constituting a cornerstone to a competitive bid.

The *price* was also brought up as a purchasing criterion by the two experts. Industry Expert 1 claimed that the price is usually a secondary factor, albeit acknowledging that it is always dependent on the strategy of the individual organization. On a somewhat different note, Industry Expert 2 stated that the price is always an issue for buyers.

The two industry experts both discussed *trust* as a purchasing criterion. Industry Expert 1 and 2 both mentioned aspects related to the reliability of the supplier, with Industry Expert 2 especially highlighting the presence (or lack thereof) of financial reliability.

The fourth and last purchasing criterion mentioned by both experts was *geography*. Industry Expert 1 meant that there were lots of sensitivities with regards to geopolitical considerations, saying that buyers prefer to make business with companies located in countries they are friendly with. The industry expert exemplified this by stating that actors in the US do not want to buy from, for instance, China or Russia unless deemed absolutely necessary. Further, the expert declared that bureaucratic difficulties have arisen within Europe, bringing up the example of a lot more paperwork being needed nowadays when buyers in the UK source from the EU. Industry Expert 2 focused a lot on the geopolitical risk, bringing up the point that although a Western organization might be allowed to buy from a Chinese supplier they can still be reluctant to do so, since including this supplier in their supply chain can cause import or export problems with market participants in other countries later down the road.

Industry Expert 1 talked about *compatibility*, *time*, and *service* as important purchasing criteria. Compatibility was discussed with regards to hardware needing to fit well into the system. The time factor could often be troublesome, as the industry expert pointed out that lead times for hardware more often than not are extensive, requiring the buyer to carefully carry out the planning of their operations or experiments. Lastly, the argument for service being a purchasing criterion was because buyers want to be sure that they can get support when they are in need.

5.3 Order Winners

The eight purchasing criteria that were mentioned by the interviewees were then coded as either order qualifiers or order winners for the respective interviewee. For each interviewee group, each interview participant will be highlighted to more thoroughly cover the reasoning behind which factors (if any) constitute the order winner category.

5.3.1 Academic Buyers

Out of the seven identified purchasing criteria for the six academic buyers, *performance* and *trust* were brought up as order winners three times, and *price* was highlighted once. The order qualifiers and order winners for Academic Buyer 1 through 6 are presented in table 7.

Table 7: Order qualifiers (Q) and winners (W) for the academic buyers.

Category	**Buyer 1**	**Buyer 2**	**Buyer 3**	**Buyer 4**	**Buyer 5**	**Buyer 6**
Performance	Q	Q	W	Q	W	W
Price	Q	Q	W	Q	Q	
Trust	W	Q	Q	W		W
Ease-of-use	Q				Q	
Compatibility	Q					
Time			Q			
Service		Q				
Geography						

Academic Buyer 1

Academic Buyer 1 posited that if the suppliers' offerings are similar with respect to technical and economic aspects, then *trust* is the deciding factor. Knowledge about the hardware beforehand, be it from recommendations from colleagues or from having seen it being used in research, demonstrates a degree of reliability which is heavily factored into the purchasing decision.

Academic Buyer 2

Academic Buyer 2 noted that whenever they enter a tendering process, the research team is not able to influence the purchase order decision after the tendering document has been published. Thus, no one specific order winner is used. That being said, an optimization process in advance of the tender usually occurs, where the funds needed to allocate for the purchase is weighted against the parameters they are looking for.

Academic Buyer 3

Academic Buyer 3 commented a lot on the perceived credibility of the supplier, arguing that sourcing from a trustworthy supplier reduces the risk of the purchase. However, as this is a major qualifying factor, the actual order winners are often conditioned on the credibility being deemed good enough. Then, *performance* and *price* make the difference, the former especially in cases of more advanced experiments, and the latter to ensure that they avoid buying for inflated prices.

Academic Buyer 4

Academic Buyer 4 places the strongest emphasis on *trust*. The buyer interviews colleagues with experiences from the set of considered suppliers to determine the level of transparency associated with each possible supplier. Whenever the transparency can be questioned, then concerns are raised surrounding the supplier, and vice versa.

Academic Buyer 5

Academic Buyer 5 identified *performance* as the key purchasing criteria. The noise properties are of the utmost importance for them in their experiments, hence making the performance criterion a clear-cut area of interest.

Academic Buyer 6

Academic Buyer 6 discusses the interplay between quantitative factors (*performance*) and *trust* in the final decision of which supplier to source from. They select the supplier based on what opportunities the hardware seems to provide, but also based on a feeling about their trustworthiness. The latter comes from knowledge and experience, sometimes even through direct contact, with the potential suppliers.

5.3.2 Commercial Buyers

Out of the four identified purchasing criteria for the two commercial buyers, *performance* was the only one being brought up as an order winner and was also mentioned by both interviewees. The order qualifiers and order winners for Commercial Buyer 1 and 2 are presented in table 8.

Table 8: Order qualifiers (Q) and winners (W) for the commercial buyers.

Category	**Buyer 1**	**Buyer 2**
Performance	W	W
Price		Q
Trust	Q	Q
Ease-of-use		
Compatibility		
Time		
Service		
Geography	Q	

Commercial Buyer 1

Commercial Buyer 1 commented on *performance* as the key criteria for the purchasing decision. Given that the hardware they are sourcing is highly complex and specialized, a supplier might win the order simply by meeting their technical requirements. Further, given that the set of specifications are met, the expected depth of the performance is examined.

Commercial Buyer 2

Commercial Buyer 2 explained that the *performance* criterion stands out when selecting among suppliers of highly technological hardware, being the decisive factor in a majority of their purchases. However, they stressed that the notion that it is often a multi-factor decision, exemplifying that the purchase of high performing hardware might still not be justified if the price deviates too far from expectations.

5.3.3 Sellers

Out of the six identified purchasing criteria by the three sellers, *performance*, *price*, *trust*, and *compatibility* were each brought up once as the order winner. The order qualifiers and order winners according to Seller 1 through 3 are presented in table 9.

Table 9: Order qualifiers (Q) and winners (W) according to the sellers.

Category	**Seller 1**	**Seller 2**	**Seller 3**
Performance		W	Q
Price		W	
Trust	W		
Ease-of-use	Q	Q	Q
Compatibility			W
Time			Q
Service			
Geography			

Seller 1

Seller 1 posited that *trust* often is a main element when a buyer proceeds to choose a supplier, especially in the case of higher value hardware. They explained that a buyer who feels certain that the offered solution will provide the best value is more likely to pay for the solution.

Seller 2

Seller 2 meant that what constitutes the order winner largely depends on the categorization of the buying organization. They argued that most academic buyers are price-sensitive, thus leading to the *price* of the hardware being a key criterion. However, for more well-funded buyers within academia and commercial players, price was usually not an issue at all. Instead, the actual *performance* and overall quality of the hardware drives the purchase decision.

Seller 3

Seller 3 stated the *compatibility* of the hardware solution can be regarded as the order winner. They commented on the price aspect being of less importance since comparing two or more suppliers purely with this in mind would be like looking at apples and oranges. According to them, hardware that is flexible and adaptable to the built-up system that the buyer has in place is very valuable.

5.3.4 Industry Experts

Out of the seven identified purchasing criteria by the two industry experts, *performance*, *price*, and *trust* were each brought up once as the order winners. However, both interviewees stressed that it is hard to pin down the question to one general answer. The order qualifiers and order winners according to Industry Expert 1 and 2 are presented in table 10.

Table 10: Order qualifiers (Q) and winners (W) according to the industry experts.

Category	**Expert 1**	**Expert 2**
Performance	W	Q
Price	W	Q
Trust	Q	W
Ease-of-use		
Compatibility	Q	
Time	Q	
Service	Q	
Geography	Q	Q

Industry Expert 1

Industry Expert 1 discussed the heavy dependency on the situation at hand, but still brought up *performance* and *price* as the main elements for consideration for the final purchasing decision. The expert noted that some organizations are more driven by the quality of the hardware they wish to source, whereas others are sensitive to the prices.

Industry Expert 2

Industry Expert 2 highlighted *trust* as a key criterion in many purchasing decisions. The buyer's perception of the reliability of the supplier is often examined by evaluating, for instance, financial reliability and overall supply chain capabilities. The expert continued to state that these trust-related elements can become even more important in competitive bidding processes.

5.4 Buying from Start-Ups Versus Larger Players

Most interviewees expressed that there was a difference between sourcing their hardware from a start-up as compared to a larger, more established player. For each interviewee group, each interview participant will be highlighted to more thoroughly cover how their perception of a supplier differs—if applicable—depending on the size and age of the company.

5.4.1 Academic Buyers

All academic buyers except for Academic Buyer 5 noted differences between buying the quantum computing hardware from a start-up compared to a larger player. Academic Buyer 1 was the only one who conveyed strict preferences for one or the other.

Academic Buyer 1

Academic Buyer 1 was more hesitant to source from start-ups as compared to larger players, since start-ups are at a disadvantage in terms of previous success examples and expected stability, both being important trust elements. They described previously successful deliveries as something they actively scan for in the supplier selection; a criterion that is often difficult to meet for newly established companies. Further, given uncertainties regarding the financing situation of a start-up, they cannot know if the start-up will be able to meet their purchasing needs over a longer period of time, or if it will even be around at that point. In one case, although the price provided by the start-up was the most competitive, they proceeded with a larger player simply due to the perceived reliability factor.

Academic Buyer 2

Academic Buyer 2 described start-ups as attractive suppliers in many areas, although mentioning that their lack of funding makes them less competitive. According to the buyer, the core factor in the purchase is the quality of the hardware. As such, start-ups that can deliver on the required level of performance are often the preferred choice, since they more often pressure the price and provide customizable solutions as compared to the larger players. Nonetheless, until a start-up has started to scale up their production, the low levels of funding generally means that they cannot keep the necessary instruments on stock, thus leading to prolonged delivery times.

Academic Buyer 3

Academic Buyer 3 explained that they are open to buying from all kinds of actors in the market, but still elaborated on differences between working with start-ups as compared to larger players. They stated that an evaluation process of the supplier's merits, including whether they have feedback from other customers or not, always takes place. Here, a start-up is naturally put at a disadvantage. However, they mentioned symbiotic experiences in which the start-ups provided significant discounts on the hardware in exchange for receiving feedback on their solution. Through this process, start-ups can get around the problem of lacking merits, and simultaneously create a word-of-mouth effect within the community.

Academic Buyer 4

Academic Buyer 4 ascertained that the preference between the size of the supplier often depends on the hardware they are sourcing. For more specialized requirements, start-ups are usually the preferred supplier, as they offer more customization. On the other hand, the smaller size of a start-up is often associated with them having a limited sales network, which causes difficulties in the case of overseas purchases. Additionally, bureaucratic circumstances for the buyer meant that buying from a start-up was often a more time-demanding task.

Academic Buyer 5

Academic Buyer 5 stressed that they did not have any preconceived notions as to opting for a start-up or a well-established company. Instead, their key purchasing criteria is simply the performance, possibly followed by the price.

Academic Buyer 6

Academic Buyer 6 elaborated on multiple differences between buying from a start-up versus a larger player, the most important ones being that start-ups are more collaborative, whereas larger players provide more safety. As a start-up often needs to open a market, the experience of Academic Buyer 6 was that these actors were more interested in what was being sourced rather than how much they got paid, since a closed transaction opens up other potential revenue streams through word-of-mouth in the quantum computing community. This flexible nature in terms of price negotiations is also prevalent in the support process; start-ups are attractive because they tend to appreciate feedback on their customized solutions. As such, working with a start-up can almost feel like working with a colleague. Larger players on the other hand were preferred with regards to financial stability and administrative competence. Also, since larger players have scaled up and tested their standard hardware for a longer time, there is generally less risk of encountering unexpected problems with the product.

5.4.2 Commercial Buyers

Commercial Buyer 1 expressed a preference for buying the quantum computing hardware from larger players. Commercial Buyer 2 had exclusively sourced from larger players, but still briefly elaborated on conditions under which they would be open for buying from a start-up as well.

Commercial Buyer 1

Commercial Buyer 1 stated that a larger player is generally preferred, as a bigger leap of faith has to be taken when buying hardware from a start-up. The buyer maintained that they are open to source from a start-up if they believe that they can have a fruitful cooperation, but that there was always a larger risk of the newer, smaller company defaulting. This poses a threat to the buying party's operations; it is considered a tedious process to identify and replace a supplier once their hardware has been integrated into the overall system.

Commercial Buyer 2

Commercial Buyer 2 explained that buying from a start-up had not been relevant for their purposes, but that they would most likely be open to it conditional on the start-up being able to provide previous success examples.

5.4.3 Sellers

Both Seller 2 and Seller 3 described differences between buyers' perception of sourcing the quantum computing hardware from a start-up compared to a larger player. Due to time constraints, Seller 1 was unable to comment on the potential differences.

Seller 1

N/A.

Seller 2

Seller 2 described that buyers typically are interested in historical performance data, which tends to favor a larger player over a start-up, as larger players generally have a vast amount of customer references and a longer running track record. Nevertheless, Seller 2 still posited that a start-up can be at an advantage at times simply because a buyer is interested in testing something new.

Seller 3

Seller 3 argued that buyers of quantum computing hardware are likely more hesitant to source from start-ups because of the long-term perspective. Oftentimes, buyers want to be sure that the supplier will be around for maintenance and support for many years to come, which puts larger and more stable players at a favorable position. Also, the perceived risk of buying from the startup—or, equivalently, the lack of trust—increases if the start-up is unknown in the field and does not have any customer references. However, Seller 3 meant that start-ups can be preferred at times, since the buyers are aware that these players are more flexible than the larger ones that already have fixed structures.

5.4.4 Industry Experts

Industry Expert 1 stated that most market participants have an open mind to working with both start-ups and larger players. Industry Expert 2 on the other hand claimed that a strong size preference is present.

Industry Expert 1

Industry Expert 1 maintained that a vast majority of buyers are open towards working with both start-ups and larger players. Nonetheless, the expert noted that each type has its unique set of characteristics. For instance, start-ups provide more personal support, since establishing good relationships with the few customers they have is a crucial activity. Following the same reasoning, Industry Expert 1 claimed that larger players are not likely to provide the same level of help or customization.

Industry Expert 2

Industry Expert 2 argued that buyers prefer larger players when sourcing their quantum computing hardware, mostly due to the perceived lower level of risk. When working with a start-up, the buyer cannot be as certain that the supplier will exist in a few years' time, contrary to the case of a larger supplier which generally has much better financial backing. Further, Industry Expert 2 posited that start-ups backed by venture capital companies are a cause of extra concern, since the timing of new rounds of funding can be very uncertain. Despite start-ups losing a competitive edge in the purchasing process due to these preferences, the expert noted that some hardware solutions are so specialized that buying from start-ups will constitute the only relevant option.

5.5 Make-or-Buy Decision

After asking the interviewees from the four different groups about what was considered in a potential make-or-buy decision, the raw data was coded into a total of five categories, as described in section 2.3.2. These included *knowledge*, *time*, *budget*, *customization*, and *mindset*. A brief summary of what each theoretical category entails is provided below.

- *Knowledge* refers to whether the organization possesses the sufficient expertise to build and maintain the quantum computing hardware in-house or not.
- *Time* relates to the speed at which the solution can be developed, and also considers potential time-savings for aspects such as research.
- *Budget* encapsulates cost considerations and spending priorities for an organization.
- *Customization* captures the ability to tailor the hardware to adhere to specific requirements, as well as the complexity in defining—or even fully knowing—the desired attributes.
- *Mindset* refers to the attitudes and beliefs of key decision-makers within an organization.

Generally, the make-or-buy decision was described as an interplay between several of the factors, *mindset* being excluded. Hence, to highlight the close connection and the considered trade-offs, each interview participant will be highlighted within each interviewee group.

5.5.1 Academic Buyers

Four out of the five identified make-or-buy factors were mentioned by at least two academic buyers, with the two most prominent being *time* and *knowledge*. The findings in the group represented many similarities, yet a few differences, with the most obvious outlier being that Academic Buyer 1 did not mention any factors in the decision. The considered make-or-buy factors for Academic Buyer 1 through 6 are presented in table 11.

Table 11: Make-or-buy factors for the academic buyers.

Category	**Buyer 1**	**Buyer 2**	**Buyer 3**	**Buyer 4**	**Buyer 5**	**Buyer 6**
Knowledge		x	x		x	x
Time		x	x	x	x	x
Budget		x	x			
Customization				x		x
Mindset						

Academic Buyer 1

Academic Buyer 1 did not explicitly state any make-or-buy factors. They simply described that they buy hardware when setting up a new lab as well as when they deem it to be necessary.

Academic Buyer 2

Academic Buyer 2 discussed the interconnection of *knowledge, time,* and *budget*. They began by stating that the outsourcing decision often boils down to the expertise within the organization. If it is missing, it is preferable to buy the hardware, as it will take a long time to get everything working, and time is a scarce resource. On the other hand, if they do have the competence, it is significantly cheaper to build the hardware in-house and thus a more attractive option.

Academic Buyer 3

Academic Buyer 3 also described how *knowledge*, *time*, and *budget* are elements that determine the make-or-buy decision. They argued that lots of new players in the quantum industry possess superior expertise in certain applications, further stating that sourcing from them can save years in time for research groups. However, Academic Buyer 3 noted that groups with limited funding need to balance the price and the time they spend on a hardware solution. This was described as contrary to the case of well-funded research groups, since their main bottleneck is worker hours. Therefore, they are incentivized to purchase the hardware solution instead of building the whole set-up together for productivity purposes.

Academic Buyer 4

Academic Buyer 4 discussed the trade-off between *time* and *customization*. On the one hand, sourcing hardware yields a shortcut in time. On the other, there can be some uncertainty regarding whether the solution will meet their demands or not. Thus, they sometimes choose to develop in-house despite the time aspect because of flexibility purposes.

Academic Buyer 5

Academic Buyer 5 explained that whenever they face a make-or-buy decision, they tend to choose to purchase the hardware, describing it as a combination of *knowledge* and *time*. Firstly, they do not possess the experience required for efficient in-house production. Secondly, they favor the time-savings associated with the purchase as it allows them to study quantum physics instead of allocating time to build from scratch.

Academic Buyer 6

Academic Buyer 6 mentioned *knowledge*, *time*, and *customization* as factors at interplay in the make-or-buy decision. Oftentimes, they have seen hardware solutions in the quantum computing market developed by people with more experience. In these cases, they have decided that they do not need to reinvent the wheel, as it is much better to allocate the budget to purchasing the solution and thereby proceeding with the research in a few weeks rather than spending years trying to develop it in-house and thus losing research competitiveness. The exception to this buying rule was in cases where it has been difficult for the supplier to offer a solution that meets the needed requirements without heavily prolonged delivery times.

5.5.2 Commercial Buyers

Four out of the five identified make-or-buy factors were mentioned by at least one commercial buyer, with the two most prominent being *budget* and *customization*. Thus, the findings within the group represented a balanced amount of similarities and discrepancies, with two out of four make-or-buy factors differing between the two buyers. The considered make-or-buy factors for Commercial Buyer 1 and 2 are presented in table 4.

Table 12: Make-or-buy factors for the commercial buyers.

Category	**Buyer 1**	**Buyer 2**
Knowledge	x	
Time		x
Budget	x	x
Customization	x	x
Mindset		

Commercial Buyer 1

Commercial Buyer 1 stated that they might consider outsourcing a certain part of the hardware design in the future, corroborating that this would depend on the make-or-buy factors *knowledge*, *budget*, and *customization*. More specifically, they meant that a buy decision could be taken if the supplier was more knowledgeable in the field, and thus could deliver the solution more cost-efficiently while meeting the desired custom attributes.

Commercial Buyer 2

Commercial Buyer 2 discussed the make-or-buy factors *time*, *budget*, and *customization*. They stated that since they are in a quite pressured economic situation, it is often easier to juggle with the time than the budget, i.e., not choosing to outsource. However, they also noted that neither time nor money might necessarily be saved with this approach. Nonetheless, Commercial Buyer 2 continued with explaining that outsourcing can be a significant commitment the first time around due to uncertainties around which final product they are looking for as well as the time needed to communicate this information to the supplier. Therefore, when they cannot feel confident that outsourcing saves them time, they prefer to opt for making the hardware solution in-house.

5.5.3 Sellers

All five identified make-or-buy factors were mentioned by at least one seller, with the three most prominent being *knowledge*, *time*, and *budget*. Worth to note is that Seller 2 sold such complex hardware that their buyers do not possess the alternative to produce it in-house. Thus, Seller 2 was not asked to present their view on the topic. The findings between Seller 1 and Seller 3 represented more similarities than differences, with three out of the five factors being shared. The considered make-or-buy factors according to Seller 1 through 3 are presented in table 13.

Table 13: Make-or-buy factors according to the sellers.

Category	**Seller 1**	**Seller 2**	**Seller 3**
Knowledge	x		x
Time	x		x
Budget	x		x
Customization			x
Mindset	x		

Seller 1

Seller 1 elaborated on *knowledge*, *time*, *budget*, and *mindset* as make-or-buy factors for potential buyers. They described that academia usually allocates a large share of the budget on worker hours, thus meaning that they tend to have a workforce that builds the hardware solution in-house. Oftentimes a PhD student or similar builds the application and the expertise regarding it. Hence, when said student leaves, the lab is left without any support or knowledge about the specific hardware solution. Seller 1 stated further that the heads of the labs are becoming more and more aware of this phenomenon, meaning that more research groups are choosing the buy decision to speed up their work, dedicate more time to actual research, and also to offset some risk. However, they posited that some lab leaders simply want to do everything in-house, and that this sentiment is hard to change.

Seller 2

N/A.

Seller 3

Seller 3 described *knowledge*, *time*, *budget*, and *customization* as pillars to the make-or-buy decision for potential buyers. They presented the perspective that, in a sense, all that a university has is time, which can explain why so many labs decide to design the systems in-house. Further, they argued that choosing to make the design in-house is often significantly cheaper for an organization, especially in terms of hardware costs, but also when accounting for the associated time-costs from in-house production. Nonetheless, an organization that decides to outsource gains time to focus on the experiments with the quantum device itself. They can source from a more knowledgeable supplier, which saves them the trouble of customizing and the risk of getting stuck.

5.5.4 Industry Experts

All five identified make-or-buy factors were mentioned by both Industry Expert 1 and 2, thus representing full agreement between the two. The considered make-or-buy factors according to Industry Expert 1 and 2 are presented in table 14.

Table 14: Make-or-buy factors according to the industry experts.

Category	**Buyer 1**	**Buyer 2**
Knowledge	x	x
Time	x	x
Budget	x	x
Customization	x	x
Mindset	x	x

Industry Expert 1

Industry Expert 1 discussed all five identified theoretical make-or-buy categories. The expert argued that some organizations simply believe that they are better off designing the equipment themselves. For the organizations that do consider the make-or-buy option, they claimed that the make decision often originates from a perception that the organization either possesses better know-how than what is offered in the market, or due to cost considerations. Further, adhering to highly specific technical requirements can prove difficult for suppliers, leading an organization to proceed with building the solution in-house. Nevertheless, having the right expertise within an organization can always be a challenge. If an organization would forgo the option to source from a more experienced supplier, they need to set up an engineering team to develop the solution, a process that drains a lot of resources.

Industry Expert 2

Industry Expert 2 also touched upon all five make-or-buy factors. The expert argued that some organizations seemingly have the mindset that if something needs to be done, they better do it themselves. They maintained that time is of essence in developing hardware solutions, and that it can sometimes be difficult to find a supplier that meets all the needed specifications. Since the organization often knows exactly what it needs, it can therefore sometimes be easier to opt for the in-house option. However, if there is a knowledgeable supplier, an organization contemplating whether to make or buy usually looks at the economic trade-off of doing it in-house, including the number of people that needs to be allocated to the process, versus outsourcing. Lastly, Industry Expert 2 described that the niche nature of the industry makes it challenging for suppliers to produce hardware instruments at scale. They continued to state that outsourcing in other markets is often driven by time- and costsavings, and emphasized that the highly specific needs combined with the low order volume in the quantum computing hardware market presents a barrier to outsourcing.

6 Discussion

The chapter discusses and interprets the empirical findings from the interviews, one research question at a time. Further, comparisons are made with relevant literature.

6.1 Purchasing Criteria

Eight different purchasing criteria emerged during the interviews, where the most prevalent for academic buyers were performance, price, and trust. When compared to the criteria mentioned by the commercial buyers, it can be seen that Commercial Buyer 2 mentioned all these criteria, and Commercial Buyer 1 stated all but price. This finding aligns with the industry experts' perception, who both agreed that performance, price, and trust were criteria used in the selection of suppliers of quantum computing hardware. Contrasting this with the sellers' perception, they all mentioned the ease-of-use as a factor, despite only being mentioned by two of the academic buyers, and not by any of the commercial buyers or industry experts. This indicates a discrepancy between what sellers perceive as important for buyers and what buyers actually evaluate in their selection. Regarding performance, price, and trust however, all factors were mentioned by at least one seller, with performance being mentioned twice.

Performance emerged as the most frequently cited factor among all established criteria, mentioned by all participants except Seller 1. This finding may not be entirely unexpected, considering the high-technology market that is being studied. This observation is in line with Abdolshah (2013), who found that product quality was the most important criterion when evaluating suppliers. Additionally, sales personnel from Seller 2 and 3 communicated the hardware's performance through individuals with technological expertise, thus further emphasizing performance as a criterion and aligning with Abratt (1986), who found that knowledgeable suppliers are crucial in the purchasing decision process of high-technology products.

Price was also a frequently cited theme across the groups, with a focus on the trade-off between price and performance. Moreover, Industry Expert 1 claimed that price predominantly functions as a secondary factor, supporting Abratt's (1986) findings that price is not the primary factor for selection in high-technology markets. Nonetheless, as most buyers and both industry experts brought up price as a criterion, it was still one of the most recurring purchasing criteria. Since only one of the three sellers mentioned price as a criterion, it could be that the sellers underappreciated the price-sensitivity of their customers, especially the academic ones.

Trust in the supplier emerged as a factor influencing the procurement decision across all buyers except one and was further corroborated by the industry experts. However, discrepancy between the sellers' perspectives on trust was observed, as only one seller mentioned it as a factor, suggesting that the sellers underestimate the element of trust in the supplier selection. The implied view of the sellers also contradicts with the related literature, as Abdolshah (2013) found that performance history was one of the most important criteria when choosing a supplier, and Abratt (1986) stated that the higher degree of innovation in high-technology markets increases the risk of a non-existent performance history. Performance history is one of the identified properties of trust, and the innovative hardware that is bought may pose an even greater emphasis on trust in the supplier selection. This emphasis on trust as a criterion is further supported by Janjua et al.’s (2021) recommendations that transactions carrying greater risk and complexity should incorporate the trustworthiness of the supplier.

As Kar & Pani (2014) presented, there are more than 60 different purchasing criteria used in previous research; thus, it is unsurprising that some of the identified criteria were only present in a few cases. Also, the criteria were coded such that one criterion or category contains a number of properties. The coding showed that a majority of the interview subjects discussed performance, price, and trust—as elaborated upon above—but five less frequent factors were identified as well.

As previously mentioned, every seller stressed the ease-of-use criterion, despite it not being identified by neither the commercial buyers nor the industry experts, and only being highlighted as a criterion of interest by two academic buyers. Various reasons could explain this mismatch, such as the characteristics of the sellers’ hardware, previous experience from buyers, or simply that the sellers’ perspectives are not fully aligned with the buyers’ preferences.

Geography emerged as a purchasing criterion mentioned by both industry experts, primarily due to geopolitical risks and buyers generally preferring to purchase from countries they have good political relations with. This criterion was also mentioned by one commercial buyer, who cited deliberations over the political stability. The industry experts confirmed the geopolitical sensitivity of the quantum computing market as described in section 4.3; it is thus surprising that the geography criterion was not more prevalent in the data. However, the prevalence could depend on the country in which the organization operates or that the interviewees were specialists in the technology aspects of the procurement rather than the bureaucracy.

The criteria compatibility and time were alluded to by a seller, an industry expert, and an academic buyer, and did not consistently emerge in any of the groups. The compatibility criterion might be a prerequisite for purchasing and hence not reflected upon, or it could be due to the different systems for which they purchase hardware requiring varying degrees of compatibility. Regarding the time criterion, it could be that the heavily stressed importance of performance partly covers the time aspect, as high-quality products can serve as a time-winning proxy by itself.

Abratt (1986) found in his study that service was one of the primary selection criteria for purchasing laboratory instruments. However, the service criterion was only identified during the interviews by one academic buyer and one industry expert; both stressed that access to adequate service was important as a purchasing criterion. One possible explanation for the observed deviance from Abratt's research is that the service criterion might have been covered by other criteria such as trust, since part of being a reliable supplier could be that they are stable enough to provide service in the future. On another note, it might be that servicing solutions are not as common in the early-stage market of quantum computing hardware as in other, more mature high-technology fields.

Further, the interviewees were asked if leasing was considered an option to purchasing, and if it is a criterion they evaluate when procuring hardware. As Richardson & Wang (2020) discovered, leasing can be an attractive alternative to purchasing, especially in an environment with rapid technological evolution. However, none of the respondents mentioned that they consider leasing as a factor when acquiring quantum computing hardware. Despite this disregard of the leasing option among the interview groups, it could still be an attractive venue for buyers in the future, since quantum computing hardware shares the characteristics of rapid innovation.

6.2 Order Winners

Among the identified order winners, performance, price, and trust occurred most commonly in the results. This further supports the implied importance of these factors; not only were they the most cited purchasing criteria, but also the most common denominator in winning a bid. For the academic buyers, performance and trust were the most mentioned criteria, each highlighted by three buyers respectively. Despite academia often operating under strict budgets, only one academic buyer cited price as an order winner. This might be explained by price being a common order qualifier for the academic buyers, meaning that the price is a prerequisite to qualify for the bid. Among the commercial buyers, Commercial Buyer 2 was the only one to identify a winner, mentioning performance. The industry experts held differing views on order winners. Industry Expert 1 mentioned that it varies a lot between organizations and situations which criterion is the winner, but emphasized price and performance as very important for the final purchase decision. In contrast, Industry Expert 2 highlighted trust as the winning criterion. Among sellers, price, performance, and trust were each mentioned once. Since performance, price, and trust were mentioned across the different interview groups, there seems to be an agreement on what criteria constitute a winning bid in the quantum computing hardware market. The only interviewee who deviated from any of these three order winners were Seller 3, who instead pointed out compatibility. Possibly, this could be due to the characteristics of the specific hardware that they are selling, or a lacking understanding of the differentiation between what is an order qualifier and what is an order winner, as discussed by Hill (2000).

Overall, no single criterion emerged as an order winner across the interview groups. Instead, it was observed that the criteria of performance, price, and trust were the most frequently mentioned. The broader range of winning criteria aligns with Abratt (1986), who found that price was not the primary factor for supplier selection in the purchasing of laboratory instruments in South Africa. It is important to note however that, as Hill (2000) points out, an order winner is not necessarily more or less important than a qualifier. Hence, the price criterion should not be overlooked in comparison to the two more frequently cited order winners performance and trust, as it might be the most prominent *order loser*.

6.3 Buying from Start-Ups Versus Larger Players

The four different interview groups all implied that there were unique advantages and challenges associated with the size and age characteristics of the supplier. The interviewees often described start-ups as being more collaborative and providing greater customization, while larger players were considered to offer stability and a lower perceived risk. Overall, there was an openness towards working with both start-ups and larger players, but several specific conditions under which one supplier type might be favored over the other were presented.

The academic buyers exhibited a range of views regarding buying quantum computing hardware from start-ups as well as larger players, with trust and perceived stability playing significant roles in their decision-making process. While some academic buyers presented a caution to engage with start-ups due to concerns about stability, financial backing, and the absence of prior success examples, others found start-ups to be more appealing in terms of more flexible customization options, competitive pricing, and personalized support. As has been discussed earlier, the actual performance of the hardware is a key purchasing criterion for most academic buyers. Nonetheless, factors related to the supplier's nature such as delivery times, ability to navigate bureaucratic circumstances, and the size of the supplier's sales network were also brought up when specifically discussing supplier preferences. In essence, the academic buyers tend to balance the perceived reliability and financial stability of larger players with the flexibility, customization, and collaboration opportunities provided by start-ups in their purchasing decisions. As many of the start-ups in the quantum computing field are spin-offs from universities, it might be expected that academia is open towards start-up suppliers despite their liability of newness. Further, the connections made through a partner university could counteract the perceived lower initial trust of a smaller actor.

Compared to the academic buyers, the commercial buyers generally showed a stronger preference for larger players when buying their quantum computing hardware. The inclination towards the more established suppliers was rooted in the perceived lower risk associated with them. The higher perceived risk of sourcing from a start-up was exemplified with their unstable cash flows, thus potentially yielding a scenario where a supplier that has been integrated into the system must be replaced. Although the commercial buyers mentioned that they were open to collaborate with start-ups if they could demonstrate a promising partnership and provide examples of prior success, they remained cautious due to the uncertainties that come with engaging with newer, smaller suppliers. This mindset contrasted somewhat with the academic buyers, who generally conveyed a more nuanced approach to the trade-offs in the supplier selection. In contrast to academia, commercial buyers possess an inherent risk, as they are susceptible for default if they fail to generate profit over time. As such, they could be likely to showcase risk aversion in their supplier selection, which would explain the preference towards larger, more stable players.

According to the interviewed sellers, buyers of quantum computing hardware generally prefer larger players over start-ups, mostly attributed to the sense of enhanced security. Established track records, extensive customer references, and long-term stability all form a proxy for future reliability of maintenance and support. The perception of lacking trust in start-ups align with the views presented by both the academic and the commercial buyers, who also valued signs of reliability and financial stability of the supplier. Notwithstanding that, sellers also argued that start-ups can have a competitive advantage in certain areas, including when buyers are interested in exploring more innovative solutions or desire greater flexibility. This idea resonates more with the points brought forward by the academic buyers, as they also scanned for customization, collaboration, and competitive pricing when selecting among quantum computing hardware suppliers. The general sentiment from the sellers that larger players have a competitive edge could be due to their own experience of growing in the industry and becoming increasingly established. Ultimately, across the three different interview groups, the shared notion was that larger players have an edge due to their proven performance and higher perceived long-term reliability, while start-ups still can attract attention through their collaborative nature and by offering unique solutions.

Since both start-ups and larger players bring their own unique advantages as a supplier, the industry experts suggested that buyers of quantum computing hardware are generally open-minded in their selection. They echoed the sentiments expressed by the academic buyers when arguing that start-ups tend to provide more personal support and customization, as building strong relationships with customers are essential for a start-up's growth. Further, they also mentioned larger players being more attractive due to the perceived lower risk associated with them, a point that was especially stressed by the commercial buyers and the sellers. In addition, the industry expert group stated that start-ups backed by venture capital funding are perceived as even more risky due to the uncertainty surrounding future funding rounds. However, due to the highly specialized nature of the quantum computing market, they also recognized that some hardware solutions may only be sourced through start-ups. Overall, the multi-faceted view from the industry experts regarding supplier preferences confirms the findings from the buyers and the sellers.

The findings that trust and previous performance history are critical factors in the supplier selection process are mirrored by existing literature in the high-technology field by Konya-Baumbach et al. (2019). Moreover, the notion presented by the different interview groups that larger players with established relationships are more likely to be perceived as trustworthy align with House et al.'s (1986) exploration of the liability of newness. Janjua et al. (2021) identified a gap in the literature regarding the importance of supplier trustworthiness in high-risk situations, and the interview data suggests that the perceived trust of the supplier should be considered in business-related quantum computing hardware literature. The characteristics of the quantum computing market make the hardware procurement decision a complex issue, and it could hence be expected that buyers evaluate suppliers based on dimensions such as reputation and perceived stability when determining who could be a reliable long-term partner.

6.4 Make-or-Buy Decision

The empirical findings from the interviews identified five key factors influencing the make-or-buy decision for quantum computing hardware across the four groups of interviewees. Knowledge, time, budget, and customization were interrelated elements brought up by each group, whereas the underlying consideration of the organization's mindset was mentioned by both industry experts and one of the sellers, but not by any of the buyers.

Several players discussed the make-or-buy decision in terms of an economic trade-off depending on the variables knowledge, time, and customization. If an organization lacks the knowledge to customize the hardware to the desired functionality, a vast amount of time must be allocated to the design, meaning that the opportunity cost for in-house production can outweigh the cost of outsourcing. In the contrary case, it is more attractive for an organization to opt for the make-decision, as in-house production is significantly cheaper with regard to hardware costs. Further, the sellers pointed out that the budget is often a scarce resource for academic buyers, and thus a driving factor for the in-house production. These presented sentiments align with Porter (1980), who described the make-or-buy decision as an economical one. As most buyers of quantum computing hardware—especially within academia—are constrained by their budgets, it is not surprising that the make-or-buy decision is influenced by economic trade-offs. With budget as a limiting factor, objectively assessing whether to make or buy essentially becomes an optimization problem.

Despite the economics being important for several of the interviewees, some academic buyers posited that they prefer to outsource hardware designs as it saves them time to focus on the actual quantum computing research. This tendency was also supported by the sellers, who argued that academic organizations that do choose the buy decision often are driven by dedicating more time towards what they are actually interested in. Thus, for some organizations the make-or-buy decision is not purely an economical one, but rather an interplay between the speed of innovation and the rate of research advancements, which is similar to what Bratt et al. (2010) found when studying the make-or-buy process for high-technology hardware at Ericsson. Since the quantum computing field has seen a significant increase in funding, both driven by the prospects of the technology and political incentives, the observation that some buyers assign a premium to the time aspect over the economical trade-off can be considered reasonable. Further, the notion that the buyers mentioned what they do *not* wish to make in-house—regularly determined by the interrelated factors knowledge, time, and customization—is supported by Venkatesan's (1992) research, where the author presented the principle that an organization should manufacture the hardware components that they are distinctively good at making in the context of highly engineered products. This could be seen as additional support for the rapid development context of the market, with some buyers choosing to control the innovation of only the most vital hardware.

Moscuris (2008) showed that which organizational participants are involved in the make-or-buy decision varies significantly depending on both the organization at hand as well as the solution that is being considered. The interviewees represented a broad range of participants, ranging from a PhD student to a commercial company's CEO, and although the four theoretical categories knowledge, time, budget, and customization were mentioned by all groups, each interviewee emphasized distinct factors and trade-offs in slightly different ways. Further, none of the buyers acknowledged the mindset factor as a part of the make-or-buy decision, despite both industry experts thoroughly corroborating on this aspect. This could imply that buying organizations are unable or unwilling to recognize underlying biases in their decision-making. The potential presence of factors that can lead to a subjective evaluation of the make-or-buy optimization problem aligns with Gravier et al. (2011), who found that some procurement leaders in the not-for-profit sector seek to advance other goals than the efficiency of the organization. If the mindset of key decision-makers at a potentially buying organization does play an important role in the make-or-buy decision, this could undermine an organization's unbiased analysis of the interplay between the categories knowledge, time, budget, and customization. On the other hand, the mindset could also serve as a catalyst of innovation, as some organizations are not driven by economic incentives but rather towards progressing the technology of quantum computers.

7 Conclusions and Future Research

The chapter provides the concluding remarks of the thesis by summarizing the key findings, and notes the research and managerial implications. Then, the limitations are addressed and future research directions are proposed.

7.1 Summary

The objective of this thesis was to explore decision-making factors for buyers of quantum computing hardware, with a focus on mapping the relative importance of purchasing criteria, understanding the perception of buying from start-ups versus larger companies, and investigating the factors that drive the make-or-buy decision. To fulfill the objective, the four following research questions were asked:

- What criteria are currently used in the procurement of quantum computing hardware?
- Which of these criteria are considered order winners?
- What is the perception of buying from start-ups versus established companies?
- What influences the make-or-buy decision for an organization?

The study found eight different criteria used in the procurement of quantum computing hardware: performance, price, trust, ease-of-use, compatibility, time, service, and geography. Among these criteria, the three most recurring were performance, price, and trust. Conversely, these were also the most frequently identified order winners across the interview groups. There were different perceptions between sourcing quantum computing hardware from a start-up versus a larger player; start-ups were considered more attractive in terms of innovation, customization, and their willingness to collaborate, whereas larger players had a competitive edge due to their perceived stability, lower financial risk, and established track record. The factors influencing an organization's make-or-buy decision were the economic trade-off between knowledge, time, budget, and customization, with the underlying mindset of key individuals sometimes constituting either a driver or a barrier for the decision. Based on the make-or-buy findings, a proposed model that incorporates the four intertwined factors as well as the latent mindset component is presented in figure 2.

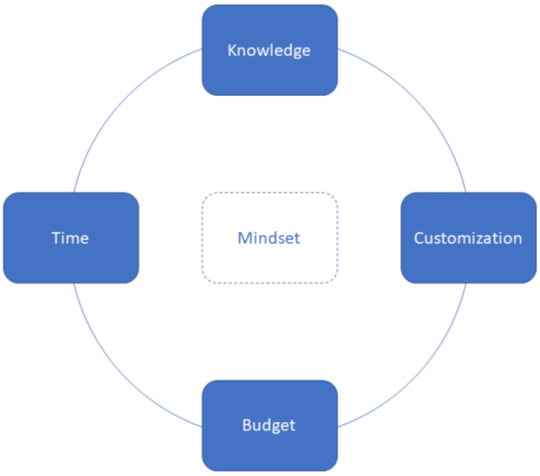

Figure 2: The proposed model for the make-or-buy decision in the quantum computing hardware market.

7.2 Research Implications

This thesis has covered decision-making factors for buyers of quantum computing hardware, thus adding to the relatively nascent body of literature in the field. In particular, it has addressed four novel research questions, including: (1) the purchasing criteria for quantum computing hardware; (2) the mapping of order winners among these criteria; (3) the influence of the buyer's perception of start-ups versus established companies on the supplier selection; and (4) the factors influencing a potential buyer's make-or-buy decision. The empirical results contribute with new findings to the high-technology field in general, and the quantum computing landscape in particular. Further, the make-or-buy decision model proposed in figure 2 introduces a framework for organizations considering whether to develop quantum computing hardware in-house or to outsource it.

7.3 Managerial Implications

The findings from this master's thesis contribute with insights into the factors influencing the supplier selection for quantum computing hardware. This information about buyer preferences can be of particular interest for sellers seeking to improve their competitive position in this rapidly evolving market. Firstly, the highlighted purchasing criteria and the subsequent categorization of them into order winners and order qualifiers can serve as a foundation for sellers to determine if their key selling points are aligned with the buyers' needs. Secondly, the presented perceptions of start-ups versus larger players could help a selling organization navigate the trade-offs between innovation and stability in their value proposition. Thirdly, the empirically derived inductive make-or-buy decision model can aid sellers in understanding what opportunities and challenges they might face when trying to persuade an indecisive buyer.

The study can also serve as guidance for buyers of quantum computing hardware, especially those with unstructured supplier selection processes. Not only can buyers draw inspiration from what other organizations consider, but the proposed make-or-buy framework can also be used for self-reflective purposes to explore if there are any underlying biases affecting the purchasing decisions.

7.4 Limitations

Given the novelty of this thesis' research as well as the limited resources with which it was conducted, there are multiple limitations associated with it. Five of these are particularly worth discussing and will be corroborated on below.

Firstly, the results of a grounded theory study can become very specific to the context that is being studied, hence lacking generalizability. The existing literature that the results were compared to were often in the context of industrial purchasing. This study however provides a snapshot of the current state of the discussed research questions in the quantum computing hardware market. Due to this dependence on context and the rapidly evolving market, it can prove difficult to replicate the study in the future.

Secondly, despite the effort to gather more insights from commercial buyers in the second step of the sampling process, no theoretical saturation was reached for this interview group. Hence, although some differences in viewpoints regarding the supplier selection preferences emerged, the sample size was not sufficient to draw confident conclusions on how academic and commercial buyers differ in their purchasing habits and needs. One reason for the low conversion rate among the commercial buyers might be due to an unwillingness to share business secrets. As the race towards fault-tolerant quantum computing is a highly sensitive field in terms of both competing hardware solutions and geopolitics, this could explain the observed reluctance to participate from the private organizations. Moreover, the limited scope of time under which the master's thesis was written did not allow for further directed sampling iterations.

Thirdly, it is worth noting that all interview participants expanded on their own personal experience. As such, the respective role of each interviewee is likely to have influenced their answer and thus the collected research data. It is for instance possible that a larger emphasis would have been placed on price and geography—both factors being stressed by the industry experts—if the interviewed academic buyers would not all have had a technical profile. Additionally, there might be more criteria involved in the supplier selection than what was found in this study, both due to elements associated with the coding process itself as well as the lack of saturation, particularly in the commercial buyer group. Further on, observed differences between buyers and sellers could also be attributed to the sellers simply describing what they believed to be the purchasing criteria. In a highly customized field such as the quantum computing market, no two buyers are the same, and efforts to generalize from the sellers can thus prove to be a difficult task.

Fourthly, the primary data was only collected through semi-structured interviews, and the coding process in grounded theory research could be under influence of research bias. Including surveys as a triangulation method to cross-check factors influencing the purchasing decision could provide more validity to the research. However, this was outside the scope of the research since the objective was to exploratively understand the purchasing decisions, not establish causation. The limited number of participants in the market could also hinder the process of establishing contact with respondents for conducting survey-based research.

Lastly, this thesis investigated quantum computing hardware purchasing in general. As there are myriad different hardware solutions within quantum computing, it is possible that the buyers' preferences might have been somewhat different if solely focusing on, e.g., platforms for superconducting qubits or trapped ions. Also, the research involved hardware procurement in all parts of the value chain. Different perspectives might have been presented by the interview groups if the scope would have been limited to one specific stage in the quantum computing supply chain.

7.5 Future Research

This thesis serves as a stepping stone towards a deeper understanding of selection criteria used by buyers in the quantum computing hardware market. As such, there are several possible future research opportunities that can further and more thoroughly investigate parts of this study; a few of these will be presented below.

With regards to the second limitation, a potential next step for a further study could be to examine the purchasing behavior exhibited by commercial buyers more closely. These results could then be compared to the findings of this thesis, and provide an increased generalizability of the results. The suggestion for further theoretical sampling could also be applied to the various hardware platforms currently developed in the market to assess if there exist variations in purchasing habits and needs among those. In line with this, broadening or changing the geographical scope that is being studied could also yield additional insights within this geopolitically sensitive field.

To broaden the understanding of the trust factor, and to compare the findings with previous results found by Elie-Dit-Cosaque et al. (2008), a future research direction could be to investigate to what extent cultural attitudes influence the emphasis on trust. A proposal would be to perform a cross-sectional study between high-trust and low-trust countries to determine whether the cultural context yields a significant difference on the element of trust or not.

Another fruitful avenue of further work is to examine the proposed multifaceted make-or-buy decision framework presented in figure 2. Aside from validating the four identified factors at interplay, it would also be worthwhile to delve deeper into the implied mindset factor. Research on the latter could focus on barriers and drivers for an objective make-or-buy evaluation process.

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Appendix A: Buyer Interview Guide

General questions

- Do you consent to being recorded for transcription purposes?
- What industry or industries is your organization in?
- In what way is your company using quantum technology?
- How would you describe your role in the organization?

Screening questions

- Does your organization purchase hardware for quantum computing applications?
    - Could you specify what hardware you are buying?
- Are you involved in the purchase of these products?

Purchasing process

- How does the process work when you choose a supplier for quantum computing hardware?
    - What is the most important part of the process, and why?
- What is your strategy for purchasing quantum computing hardware?
- What are the main challenges you face during the purchasing process?
- Who is involved in the purchasing process?
    - What role do they have?
- Are you working with public procurement? If so, could you describe this process?
- Do you negotiate the prices with suppliers?
- Do you consider leasing the hardware as an alternative to buying it?

- What is your view of buying from a start-up compared to a larger player?

Purchasing criteria

- What factors are you considering when choosing a quantum computing hardware supplier?
- Which of these factors are requirements that have to be satisfied?
- Which of these factors are most important when you decide which supplier to buy from?
- Do you consider your scaling needs when selecting a supplier?
- Do you prefer to work with a distributor or directly with a supplier?
- What is your view on buying hardware overseas?
- Do you have any purchasing demands that are currently not being met by suppliers?

In-house production

- If you are making hardware for quantum computing applications in-house that could be outsourced, why have you chosen to do so?
  - What would be needed for you to outsource this process?
  - What challenges do you face when making this in-house?

Concluding question

- What do you think I should have asked but I did not?

Appendix B: Seller Interview Guide

General questions

- Do you consent to being recorded for transcription purposes?
- What industry or industries is your organization in?
- In what way is your company using quantum technology?
- How would you describe your role in the organization?

Screening questions

- Does your organization sell hardware for quantum computing applications?
  - Could you specify what hardware you are selling?
- Are you involved in the sales of these products?

Purchasing process

- How does the quantum computing hardware sales process work?
  - What is the important part of the process, and why?
- What is your strategy for selling quantum computing hardware?
- What are the main challenges you face during the sales process?
- Which people from the customer's side are involved in the purchasing process?
  - What role do they have?
- Are you working with public procurement? If so, could you describe this process?
- Do you negotiate the prices with buyers?
- Do you offer buyers the alternative to lease the hardware instead of buying it?

- What is your perspective on how buyers view buying from a start-up compared to a larger player?

Purchasing criteria

- What factors are buyers considering when choosing a quantum computing hardware supplier?
- Which of these factors are requirements that have to be satisfied?
- Which of these factors are most important when they decide which supplier to buy from?
- Do you consider the customer’s scaling needs?
- Do you sell through a distributor or through direct sales?
- What is your view on selling the hardware overseas?
- Are there any purchasing demands that customers currently have that are not being met?

In-house production

- Are you approaching potential customers that are developing solutions in-house that you could provide?
    - What would be needed for buyers to outsource this process?
    - What challenges do you face when approaching in-house developers?

Concluding question

- What do you think I should have asked but I did not?

Appendix C: Industry Expert Interview Guide

General questions

- Do you consent to being recorded for transcription purposes?
- What industry or industries is your organization in?
- In what way are you involved with quantum technology?
- How would you describe your role in the industry?

Screening questions

- Do you have experience from purchasing hardware for quantum computing applications?
  - Could you specify what hardware you have experience in buying?
- Have you been involved in the purchase of these products?

Purchasing process

- How does the process work when buyers choose a supplier for quantum computing hardware?
  - What is the important part of the process, and why?
- What is typically the buyer's strategy for purchasing quantum computing hardware?
- What are the main challenges in the purchasing process?
- Who is involved in the purchasing process?
  - What role do they have?
- Have you been working with public procurement? If so, could you describe this process?
- Do buyers negotiate the prices with suppliers?

- Do buyers consider leasing the hardware as an alternative to buying it?
- What is the general view of buying from a start-up compared to a larger player?

Purchasing criteria

- What factors are buyers considering when choosing the quantum computing hardware supplier?
- Which of these factors are requirements that have to be satisfied?
- Which of these factors are most important when buyers decide which supplier to buy from?
- Do you consider your scaling needs when selecting a supplier?
- Do you prefer to work with a distributor or directly with a supplier?
- What is your view on buying hardware overseas?
- Do buyers have any purchasing demands that are currently not being met by suppliers?

In-house production

- If buyers are making hardware for quantum computing applications in-house that could be outsourced, why have they chosen to do so?
    - What would be needed for them to outsource this process?
    - What challenges do they face when making this in-house?

Concluding question

- What do you think I should have asked but I did not?