External and Internal Factors Influencing the Adoption of Post-Quantum Cryptography in Companies

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Abstract

Quantum computers are on the rise. Their code-breaking capabilities can pose threats to companies' data security. To counteract this, they should implement quantum computer-secure cryptography measures as soon as possible. In this regard, post-quantum cryptography measures are likely to be more accessible to many. While deciding on establishing such a new technology in a company, external and internal factors can have an influence. These were sought by means of a literature analysis to help companies with the transition in the future. Three key external influencing factors are customers, government and other companies. While customers mainly trigger pressure through their demand, the government can exert influence through legal regulations or even incentives. Other companies can act as supporters in the joint exploitation of an unknown technology through the exchange of expertise or as motivators to develop a relative advantage over the competition, although competition can also hinder adoption. Three key internal influencing factors are employees, general internal knowledge and management. The expertise of employees in the company or in the market in general can influence successful technology adoption. Internal knowledge and development structures and knowledge built up within the company also have an influence. Another key factor is management, whose attitude can both drive and hinder successful technology adoption. Based on these findings, further investigations, such as the construction of a simulation program, can be carried out in order to support companies in the adoption of quantum computer secure cryptography methods in the future.

Keywords: quantum computing, customers, government, competition, technology adoption

1. Introduction

Quantum computers (and quantum cryptography) are a radical innovation (Warnke *et al.*, 2019). A radical innovation is characterized by the fact that the development takes place over a long period of time and is marked by great potential success, but also great risk. Large

investments are often necessary (O'Connor and McDermott, 2004). The success of a radical innovation opens up a completely new area of activity or business for the companies involved.

Quantum computing and converging technologies and methods currently have a good image due to various hopes in society (Ernst, Warnke and Schröter, 2020), but have not yet been conclusively researched (BSI, 2021) and thus initially act as a black box for adopting companies. Using new cryptography techniques adapted to quantum computing may however be necessary to continue to protect companies from attack. Both quantum cryptography and post-quantum cryptography are currently seen as suitable quantum computer secure encryption methods. Due to the conditions of the market and the market participants, the use of post-quantum cryptography is considered the more probable means initially (BSI, 2021). Therefore, this paper is created with post-quantum cryptography in mind. This way, restrictions like the unavailability of quantum computers are not considered.

Technology adoption describes the introduction and use of new technological means in a company. While technology spreads throughout society, adoption follows a bell curve (Rogers, 2003). In this curve, the first innovators are increasingly joined by other users. Since quantum computers and associated cryptography measures are a completely new development (Warnke *et al.*, 2019), this dissemination is currently only starting. At the beginning of an adoption stands the decision to do it. The factors influencing this decision in a company will be considered in this paper. Influencing factors that could accelerate and slow down the diffusion of post-quantum cryptography among companies are identified. These findings can subsequently be used, for example, to drive the spread of post-quantum cryptography measures in companies and thus protect them in the long term.

In a study, company size and industry sector were found not influencing the readiness to adopt (Wamba and Carter, 2013). However, based on their size, companies face different challenges (Zhu, Kraemer and Xu, 2006). Small companies can have greater problems in terms of financial and human resources (Acs and Preston, 1997). Especially when the focus is on a company's financial capabilities, larger companies with more financial resources are more likely to implement a technological innovation (Akhavein, Frame and White, 2005). In principle, all company sizes and all industries are considered here, as these do not necessarily have an influence on the adoption behaviour towards new technologies (Del Aguila-Obra and Padilla-Meléndez, 2006; Hitchens *et al.*, 2005; Jeon, Han and Lee, 2006; Romero and Martínez-Román, 2012; Wamba and Carter, 2013).

As part of this paper, a literature search was conducted via Google Scholar. The keywords "technology adoption", "technology diffusion" and "enterprise adoption" were used. A total of 100 papers were considered. Since related surveys are usually conducted on a qualitative basis, concrete figures are not available (Abed, Dwivedi and Williams, 2015).

Due to the nature of a radical innovation, businesses may face difficulties while implementing them. These barriers can be both external and internal (Sandberg and Aarikka-Stenroos, 2014). Internal and external factors can affect diffusion and adoption of new technologies in a

company (Chong and Bauer, 2000). In the context of external barriers, customers, government and other companies emerge as relevant factors. Internally relevant factors are management and employees (Sandberg and Aarikka-Stenroos, 2014) and the general internal culture and knowledge of a company.

2. Influencing factors

Based on past adoption behaviour of companies concerning new technologies, influencing factors can be derived that affect a company's decision and ability to (successfully) implement a new technology for itself.

The image of the technology being adopted can influence the diffusion of it. Public perception of the technology, as well as perceived benefits, existing knowledge, ease of use and associated fears, can inhibit or promote adoption (Chong and Bauer, 2000; Sparling, Toleman and Cater-Steel, 2007; Teo, Chan and Parker, 2004; Thong and Yap C.S., 1996; van Akkeren and Cavaye, 1999; Xiong, Qureshi and Najjar, 2013). Since this knowledge can both be driven internally and externally, it is not classified in any of the categories.

External factors are those that, at their core, affect a company from outside and therefore cannot necessarily be controlled by the company. In turn, factors are internal if they are related to the internal structure of a company. As a result, companies generally have greater influence on these than on external factors.

2.1 External factors

To adopt a technology like post-quantum cryptography, first awareness of it is needed. External influences can create awareness (Quaddus and Hofmeyer, 2007). Pressure can be exerted this way (Premkumar and Roberts, 1999). The more companies adopt post-quantum cryptography, the larger the critical mass becomes - a wider acceptance may convince others to join (Chong and Bauer, 2000). An overview of the external factors and how they influence companies can be found in Table 1.

Table 1: Main external factors influencing a company's decision to adopt

External factor	Details on influence
Customers	Customers can exert pressure on companies to adopt a new technology like post-quantum cryptography (Beckinsale, Levy and Powell, 2006; Maduku, Mpinganjira and Duh, 2016; Scupola, 2003), possibly being the main driving force behind adoption of information technology (Nguyen, Newby and Macaulay, 2015). Satisfying customer needs better than the competition and thereby gaining a relative advantage can also be a motivator for adoption (Senarathna *et al.*, 2018). If informed customers that have realized the benefits of post-quantum cryptography demand the utilisation of it from companies (whether in the final product offered to customers or just in the way internal customer data is protected), companies are pressured to adapt to retain these customers.

Government	Legal and regulatory barriers (Zaied, 2012) or institutional unpreparedness (Riyadh, Akter and Islam, 2009) can cause companies to be prevented from adopting new technologies. If a new technology like post-quantum cryptography is inadequately addressed by the legislator, the resulting uncertainty may dissuade companies from adopting it. The same is true if legal barriers make adoption outright impossible, whether intentionally or not. On the other hand, regulatory support could also help with adoption (Jeon, Han and Lee, 2006; Riyadh, Akter and Islam, 2009) by reducing uncertainty in the market (Solaymani, Sohaili and Yazdinejad, 2012), e.g. by providing legal guidelines on the implementation of data security using post-quantum cryptography for companies. While government programs do not necessarily make technology adoption happen more effectively, government incentives (such as financial support and training for companies on post-quantum cryptography) can lower the threshold for adoption (Scupola, 2003; Yap, Thong and Raman, 1994). Smaller companies in particular could benefit from financial incentives (Solaymani, Sohaili and Yazdinejad, 2012) because they may lack the resources to successfully adopt on their own (Haddara and Elragal, 2013). Being provided the financial resources to pay for standardized post-quantum cryptography solutions by security software providers or to employ experts that help with adoption in the company could increase adoption especially in companies that are financially constrained.
Other companies	Pressure from competitors, suppliers or trading partners can affect adoption of a new technology like post-quantum cryptography (Chong and Pervan, 2007; Forman, Goldfarb and Greenstein, 2005; Kwon *et al.*, 2020; Premkumar and Roberts, 1999; Scupola, 2003; Teo, Chan and Parker, 2004). Gaining a relative advantage over competing companies by adopting post-quantum cryptography (and becoming more interesting for customers or business partners this way) can act as a powerful motivator (Chong and Pervan, 2007; Senarathna *et al.*, 2018). While competition may initially be conductive to increasing adoption (Chong and Bauer, 2000; Damaskopoulos and Evgeniou, 2003), too much competition may also cause companies to have difficulty subsequently establishing a routine with the adopted technology (Zhu, Kraemer and Xu, 2006). Expanding connections with other companies can help build technologies and know-how that are not accessible or affordable for a single company (Beckinsale, Levy and Powell, 2006; Gibbs, Sequeira and White, 2007; Giotopoulos *et al.*, 2017; Gomes-Casseres, 1999; Reich, 1994). Researching the merits and adoption of post-quantum cryptography can be done easier if multiple companies work together and share their resources to gain insights and facilitate adoption. The expertise of external companies can be called upon during implementation if, for example, internal knowledge is insufficient (Thong, Yap and Raman, 1997). An example of this is the consulting of providers of standardized security solutions that could offer help implementing post-quantum cryptography in a company. Trade associations and local intermediaries between companies may have the task of informing companies about the existence, benefits and dangers of post-quantum cryptography if there is a lack of internal knowledge (Lockett and Brown, 2006).

2.2 Internal factors

A company's internal culture can influence its behaviour toward innovation (Chong and Bauer, 2000; Kwon *et al.*, 2020), just as the organizational structure can (Del Aguila-Obra and Padilla-Meléndez, 2006). The company location may also influence the ability to adopt, possibly with advantages in urban areas (Baptista and Swann, 1998; Forman, Goldfarb and

Greenstein, 2005; Wamba and Carter, 2013). An overview of the main internal influencing factors and how they work can be found in Table 2.

Table 2: Main internal factors influencing a company's decision to adopt

Internal factor	Details on influence
Employees	Lack of employees with knowledge in the IT field or knowledge related to post-quantum cryptography can inhibit adoption (Giotopoulos *et al.*, 2017; Thomas *et al.*, 2013). This includes not only the availability of trained employees in the company, but also in the market (Damaskopoulos and Evgeniou, 2003). If no experts with knowledge of the implementation of post-quantum cryptography are available, adoption is hindered.
General internal knowledge	Internal development of the company (such as the awareness of post-quantum cryptography) can serve as an adoption motivator (Senarathna *et al.*, 2018). In order to be able to establish a completely new technology like post-quantum cryptography in the company, internal training and further development within the company is necessary (Rush and Bessant, 1992), as changes will have to be made to the internal data security landscape. The level of internal knowledge on this subject may also affect the expanse of adoption after the decision to adopt is made (Beckinsale, Levy and Powell, 2006; Maduku, Mpinganjira and Duh, 2016; Thong and Yap C.S., 1996). To make an adoption successful, bringing in external consultants can be useful if internal capabilities are lacking (Del Aguila-Obra and Padilla-Meléndez, 2006).
Management	Management attitudes can influence the adoption of post-quantum cryptography (Ajimoko, 2018; Chong and Bauer, 2000; Del Aguila-Obra and Padilla-Meléndez, 2006; Maduku, Mpinganjira and Duh, 2016; Nguyen, Newby and Macaulay, 2015; Premkumar and Roberts, 1999; Teo, Chan and Parker, 2004). A CEO more willing to innovate might help adoption (Al-Qirim, 2005; Giotopoulos *et al.*, 2017; Thong and Yap C.S., 1996). Knowledge about post-quantum cryptography is important for this (Jeon, Han and Lee, 2006). Management's general experience with technology could be adoption-promoting also (Chong and Bauer, 2000; Sparling, Toleman and Cater-Steel, 2007). The manager's age may influence how readily a company adopts a new technology with younger managers being more likely to adopt (Meyer, 2011; Wamba and Carter, 2013). Good cooperation between management and employees can support the implementation of new technologies (Thong, Yap and Raman, 1997) like post-quantum cryptography in the company.

An interplay and mutual interaction of external and internal factors can create individual conditions for each company to adopt a new technology. In order to support a company in the adoption of a desired technology, such as post-quantum cryptography, it is possible to assist by means of the influencing factors. Depending on the position of the supporter (outside or inside the company), external or internal factors may be more relevant and easier to influence.

3. Conclusion

Within the scope of this paper, two categories of influencing factors (external and internal) and three strong influencing factors each could be identified.

This overview of external and internal influencing factors is subject to certain limitations. Because quantum computing is a new development that has not yet been able to spread

throughout society, there are no studies that have looked at the specific factors influencing the adoption of post-quantum cryptography yet. Therefore, the influencing factors must be inferred based on the adoption of technology novelties in the past. Because these factors have often been documented differently, if at all, some abstraction of these findings must be done. Due to the lack of studies it is also not possible to make a precise statement about the strength of an influencing factor. The internal and external factors listed here are not exhaustive. Numerous other factors that may arise in the individual situation of a company are conceivable. Since the focus of this paper is on companies, other entity-specific factors (such as those of a private individual or a government institution) have thus been left out.

This overview of possible influencing factors is suitable for forming a greater awareness of the levers that can act on a company's adoption decision. Knowledge of these can be used to work more effectively on exerting a positive influence on the information security situation of companies in a post-quantum era. This paper provides a basis for future, more specific research projects or simulations of the diffusion of new technologies, especially post-quantum cryptography in companies.

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