The Openness between Platforms. What Changes in an IoT Context?

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Preface

Delft, 29 August 2019

Dear reader,

In front of you lies the master thesis that marks the end of my study period at the TU Delft. After all the stories I had heard from fellow students, I was afraid that writing a thesis would be a horrible process. However, fortunately this was not the case! For sure, there were moments were I had difficulties motivating myself or were I had to work until a bit later than envisioned but in general, I enjoyed working on my thesis. While this had partly to the with the topic, which I find very interesting, it also certainly has to with the people I was surrounded with during this time. I would like to make use of this opportunity to thank them.

Firstly, I would like to thank Mark de Reuver, who chaired my committee but acted as first supervisor. I really enjoyed our discussions, which were quite conceptual at times and I highly appreciate his involvement and the effort he took to supervise me. I hope that after my graduation, we will come across again! Secondly, I would like to thank Aaron Ding, who provided valuable feedback on my thesis and helped me in arranging some interviews. If something was not clear he did not mind it when I 'chased him to his office' to continue our discussion. Thirdly, Geerten van de Kaa also gave me useful insights and provided critical feedback on numerous occasions, which helped me to improve my thesis to what it is now. Fourthly, I like to thank Hans van der Marel, who was my external supervisor at KPMG. He helped me in arranging interviews, he was always available when I needed help and he gave me the freedom to write this thesis without any restrictions. Finally, I would like to thank my friends, who helped me to keep motivated when the deadline was near and the workload was high. Without them, the library sessions would have been a lot less fun.

I hope you enjoy this reading this thesis!

Warm regards,

Lars Mosterd

Executive Summary

The main problem hampering innovation in the Internet of Things (IoT) is the fragmentation and lack of interoperability between IoT platforms. A possible solution for IoT platforms to overcome this problem, would be to open up towards each other. To better understand how the IoT platform market is evolving and to inform future decisions regarding the desired degree of openness between IoT platforms, insight in the business and context factors driving these strategic considerations is required. The amount of scientific literature addressing this is limited, which is why this thesis aimed to develop a theory on the openness between IoT platforms by identifying, prioritizing and theorizing the interrelations between factors driving the decisions from IoT platform owners related to the openness of their platform towards other IoT platforms. The following research question stood central in this thesis: *Which business and context factors influence the decisions from IoT platform sponsors regarding the desired degree of openness towards other IoT platforms?*

Because there is little research related to the factors and trade-offs influencing the desired degree of openness between IoT platforms, an exploratory research methodology has been used to answer the main research question. However, it was also not necessary to completely start from scratch because there is some related theory on the openness of other platforms. Nevertheless, these theories are not sufficient to answer the main research question due to the some noticeable differences between IoT- and other platforms. Therefore, this research is grounded in semi-structured exploratory interviews held with decision makers and field experts. The interviews were structured based on a *preliminary* theoretical model, based on the related research. To this end, the existing literature on technological innovation platforms, multi-sided platforms and digital platforms was compared with IoT platforms to develop a preliminary theoretical framework conceptualising and explaining the desired degree of openness between IoT platforms.

As a result of this research, an IoT platform is defined as *the software-based system that allows applications to interact with the smart objects connected to it*. An important observation is that IoT platforms mediate between smart objects and applications. This entails that, in contrast with other platforms, network effects are less important because they do not necessarily have to mediate between two users groups. The openness between IoT platforms has been conceptualised as *the degree to which data and services can be shared among different IoT platforms*. The main characteristic that sets IoT platforms apart from other technological or multi-sided platforms is their cyber-physical nature. This nature entails that the IoT domain is characterised by a high need for specialisation and that platforms are often developed from a product-centric, bottom-up approach. This results in a fragmented market in which there are strong complementarities between IoT platforms that lead to a high need for openness between them. Because the network effects are also less strong for IoT platforms compared to other multi-sided platforms, winner takes all dynamics are to a lesser extent present, which gives more room for collaboration between platforms in the form of platform level openness.

In total, 13 interviews have been conducted within the healthcare and automotive domain. These domains where selected due to variability on the context variables in the preliminary theoretical model, to generate as many possible insights as possible within the time constraints of this study. The type of respondents that were interviewed are: IoT device providers, platform owners and field experts. The candidates were selected based on their affinity with the topic, (sub)domain and experience. An interview protocol was developed based on the preliminary theoretical framework. Due to the semi-structured nature of the interviews, in a few cases additional topics were added during the interviews when novel insights came forward. In the subsequent interviews with people related to the topic, these topics where discussed as well. All interviews were recorded and transcribed to text such that they could be analysed with coding software. Respondents had the opportunity to provide feedback on the transcripts and the quotes used in the report.

The semi-structured interviews held with decision makers and field experts learned that decisions on platform level openness are influenced by (1) the perceived effect of the decision on the business outcome and (2) the legal requirements. With respect to the perceived effect on the business outcome, a few import factors play a role. Probably the most important factor relates to the attractiveness of the business case surrounding the openness decision; if opening up doesn't mean that extra profits can be gained, opening up won't make sense for a lot of companies. It is found that openness decisions are mainly driven by the presence of complementarities. Complementarities arise when the value of the combined service is higher than the combined value of the two separate services.

However, it is not always necessary that the business case is profitable. Organisations can also open due to strategic considerations. For example to influence market developments, to strengthen the market position of the platform or to generate knowledge about the way in which the market is developing or about other players in the ecosystem. Furthermore, privacy and security considerations also play an important role due to the cyber-physical nature of IoT platforms. In general, privacy and security considerations causes IoT platforms to be more closed. The effect that legal requirements have is quite straightforward; if something is not allowed, companies won't do it.

Furthermore, decisions about platform level openness are always made in a specific context, with respect to a specific use case. Important contextual factors are the characteristics of the market and the organisation itself. The most notable way in which market characteristics impact openness decisions, is through end-user demand; organisations that provide a service to end-users will have to fulfil some expectations. The end user demand is closely related to the need for specialisation; if companies cannot provide a whole service by themselves, they could open up towards other platforms that provide this service such that they can still offer a complete service to their end users. Compared with other platforms, there is more need for specialisation in the IoT because products require dedicated manufacturing facilities to benefit from economies of scale. The maturity of the market also plays a role. For example, through the availability of mature compatibility standards. Especially in the complex settings found in the automotive domain, organisations usually do not want to open up towards each other without a widely accepted compatibility standard.

Important organisational characteristics relate to the strategic focus of an organisation and the closely related vertical integration; a company producing both the hardware and the platform might have different considerations than an organisation only providing the platform – the focus could be on profiting from hardware instead of software. Furthermore, the maturity of a company also affects openness decisions; a smaller company, that needs to set foot in a market has different considerations than a big company trying to protect its market share.

Finally, decisions regarding the desired degree of openness are always made in the context of a certain use case. Organisations don't just open up their whole platform, instead, they open up their platform for a specific application and a specific partner, in a specific way. An example of a use case could be, sharing aggregated location data (=application) to inform authorities (=partner) where there is traffic by making use of a meta platform (=mode of openness). With respect to the application, organisations usually only want to open up for use cases characterised by complementarities or synergies. In line with this organisations do not want to open up towards a direct competitor (i.e. a platform with a similar service offering). Furthermore, it was found that most organisations prefer interoperability via a meta-platform over direct interoperability.

Thus, IoT platform owners have to make a trade-off between (1) the profitability of the business case, (2) their strategic position and (3) privacy and security considerations, while fulfilling legal requirements. How the factors in this trade-off are prioritized is determined by the context in which the openness decisions are taking place. Next to the characteristics of the use case, the context consist of the market- and organisational characteristics. The main market characteristics that influence how trade-offs are being made are the intensity of competition and the maturity of a market. In immature markets and in markets with intense competition, strategic considerations are often relatively more important. The main way in which the organisational characteristics influence how the trade-offs are being made relate to the strategic focus of the platform. For example, there is a trade-off between benefiting from the product (through increased sales) and benefiting from the platform (through a high amount of users affiliated with it). In addition, the overall business objective of a company also influences the trade-offs. A non-profit or governmental organisation will most likely have different considerations than a for-profit organisation.

This master thesis has some important implications for theory and practice. Firstly, based on empirical research, an early theory identifying, prioritizing and interrelating factors driving the decisions of IoT platform sponsors regarding the desired degree of openness towards other IoT platforms is developed. This advances the scientific body of knowledge on the governance of IoT platforms, specifically on the openness of IoT platforms. As part of this theory, a definition of IoT platforms, suitable for studying their governance, has been developed. Furthermore, existing conceptualisations of openness have been enriched by introducing two new concepts: platform level openness and device level openness. Practically, the theory that has been developed in this research can be used by IoT platform sponsors to guide decisions on the desired degree of platform level openness. It gives an indication of the factors and trade-offs that should be taken into consideration in the decision making process. It was found that meta-platforms are the most promising mode of platform level openness. Therefore, IoT platform sponsors are recommended to make use of these platforms when designing new platform level openness solutions.

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1 Introduction

1.1 Problem Identification

An increasing trend in our society is the switch from product and service competition towards platform based competition (Tiwana, 2013). An example of a popular platform ecosystem is the Android operating system for mobile phones, together with its collection of apps. Characterizing a platform is the fact that it has a stable core and a variable periphery (Baldwin & Woodard, 2009). In terms of this definition, the Android operating system is the core, while the 2.6 million apps in the Google Play Store form the periphery.

An important trade-off in the governance of such platforms concerns the degree of openness. The openness of a platform is related to the easing of restrictions on the use, development, and commercialisation of the platform (Boudreau, 2010). Because a lot of functionalities of the Android operating system are open for app-developers, the value for end users can increase without the involvement of the platform owner as new and innovative apps are constantly being added by third-party developers. In the literature, this is described with the concept of generativity (Wareham, Fox, & Cano Giner, 2014). On the other hand, opening up also results in a loss of control and increased coordination costs (Wareham et al., 2014).

Whereas the governance of software platforms is increasingly being studied, research on the governance of Internet of Things (IoT) platforms is currently lacking. IoT refers to the trend that increasingly more devices are being connected to the internet. This results in new concepts, such as a smart home, in which for example your lightbulbs, fridge, thermostat and doorbell are connected to the internet. In order to unleash the true value of IoT, all these devices should be able to 'talk' to each other (Ganzha, Paprzycki, Pawłowski, Szmeja, & Wasielewska, 2018; Wortmann & Flüchter, 2015). An example of this, related to smart homes, could be that the lights in the hallway switch on when someone rings the doorbell. IoT platforms, such as Apple HomeKit, aim to facilitate this. IoT platforms should facilitate applications in the monitoring, management and control of the connected devices (Lamarre & May, 2017).

Unfortunately, the reach of these platforms is often limited to the sensors and devices from a single manufacturer (Ganzha et al., 2018; Mineraud, Mazhelis, Su, & Tarkoma, 2016). Therefore, different devices are not able to 'talk' to each other, which limits the added value of IoT and often entails that users have to install a different application for every IoT appliance they use. The lack of interoperability between different IoT platforms is one of the key issues to be solved before the true potential of IoT can be unleased (Ganzha et al., 2018; Mineraud et al., 2016).

From a technical perspective, it is becoming easier to make different platforms interoperable and the availability of open standards continues to grow. However, the decision to open up is also a strategic one, grounded in the business interests of the parties involved. To better understand how the IoT platform market is evolving and to inform future decisions regarding the desired degree of openness between IoT platforms, insight in the business and context factors driving these strategic considerations is required. The amount of scientific literature addressing this is limited, which is why the lack of insight in these factors will be the central problem in this study.

1.2 Scientific Problem

The goal of this section is to unravel the state of the art on the openness between IoT platforms. This is done by discussing the concept of openness in the context of IoT platforms in section 1.2.1. After that, different perspectives on how IoT platforms can open up towards each other are discussed in section 1.2.2. Finally, the factors driving these decisions are discussed in section 1.2.3.

1.2.1 Openness in the Context of IoT platforms

There is a lot of variation in the functionalities that IoT platforms offer because platform providers focus on different aspects of the technology stack (Wortmann & Flüchter, 2015). One factor that could explain the diversity in focus of platform providers is the degree of vertical integration. For example, hardware manufacturers often follow a bottom-up approach and position their platform on top of their device offerings, which entails that the available functionalities are dictated by the product portfolio of the manufacturer. On the other hand, software-based companies often follow a top-down approach and start from the functionalities that the platform should have (Hodapp, Remane, Hanelt, & Kolbe, 2019).

Due to the variety in IoT platforms and because there are multiple, competing definitions, it is hard to understand what an IoT platform exactly entails. However, shared among most conceptualisations is the belief that an IoT platform should be the connection between end-users and IoT devices. This is illustrated by the following definition: *the middleware and the infrastructure that enables the end-users to interact with smart objects"* (Mineraud et al., 2016, p. 5). Other definitions are more implicit and define IoT platforms based on the capabilities it should have (e.g., Schreieck, Hakes, Wiesche, & Krcmar, 2017).

It is also not clear what openness entails in the context of IoT platforms due to the lack of theory on the subject. Some scholars characterise IoT platforms based on a definition of openness that relates to the degree to which a platform makes use of open source components (Hodapp et al., 2019; Mineraud et al., 2016). However, in the theory related to the openness of software platforms, the concept is used differently. There it relates to the easing of restrictions on the use, development, and commercialisation of a platform (Boudreau, 2010). A conceptualisation more in line with the software platform perspective is used by Schreieck et al. (2017). They distinguish between openness towards end-users and openness towards third party developers and they relate these dimensions to respectively the degree to which access to the platform is granted and the degree to which control over the platform is given up.

Unfortunately, these conceptualisations don't fit well in the context of this study, where the high degree of fragmentation and lack of interoperability between IoT platforms is the central problem. Intuitively, this could be seen as the openness *between* platforms. However, there is no theory or conceptualisation of openness in the context of IoT platforms – or in the context of software platforms – addressing this issue. For example, Schreieck et al. (2017) only distinguish between openness towards end-users and third-party developers but they do not consider the openness between IoT platforms. In a conceptualisation of openness in the context of Industrial Internet of Things (IIoT) platforms, Menon, Kärkkäinen, & Wuest (2017) did acknowledge the horizontal dimension of openness but they focussed primarily on the ownership structure. Therefore, a clear conceptualisation of openness in the context of IoT platforms, which also accounts for the openness between platforms, is required.

1.2.2 Different Perspectives on the Openness between IoT Platforms

Essentially, greater openness between IoT platforms can be achieved in two ways (see Figure 1). Firstly, platforms could open up towards each other by creating a meta-platform on which different platforms can share their services and data. A technological solution in line with this argument is sketched by Mineraud et al. (2016), who introduce the concept of IoT-marketplaces as the solution to the interoperability problem. These marketplaces should accomodate the flow of data across different IoT platforms, thereby making them interoperable via the sharing of (real-time) data. Keijzer-Broers, Florez-Atehortua, & De Reuver (2016) present a prototype for such a platform in the healthcare domain. Secondly, platforms could open up in a more direct way to each other by making them interoperable via gateways and API's. Savaglio, Fortino, Gravina, & Russo (2018) share this perspective and they consequently propose a software development methodology for integrating multiple IoT platforms to aid in this envisoned transition. Of course, a merely technical solution will not be sufficient and a proper governance structure is required in both cases (cf. Gawer & Henderson, 2007).

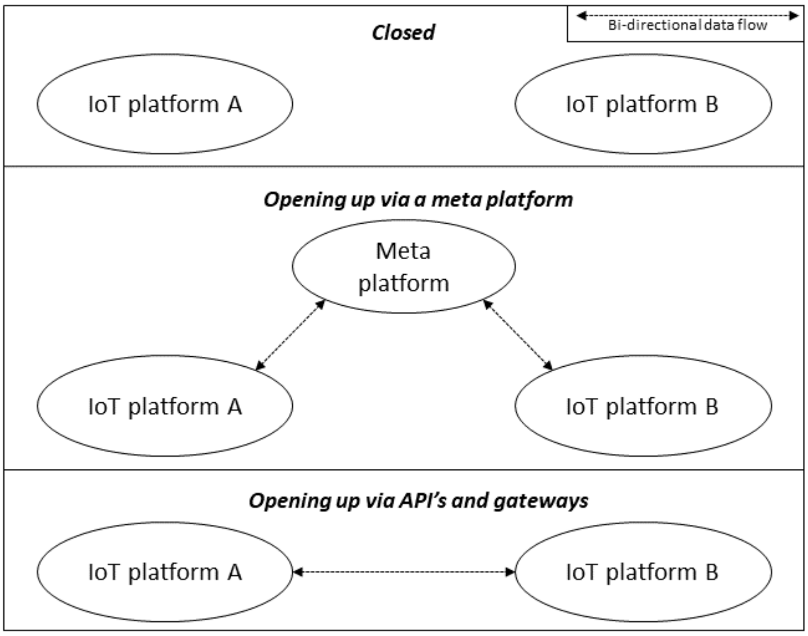

Figure 1: Modes of opening up between platforms

A different perspective is taken by Degrande, Vannieuwenborg, Verbrugge & Colle (2018), who argue that it is likely that one or two platforms will emerge as a leading IoT platform providers, driven by winner-take-all dynamics. Their argument is based on an analogy with the success of the Google Play Store and the Apple Store. Due to the high potential gains for the owner of such a platform, market parties will most likely try to achieve such a situation. Ochs & Riemann (2017) have pointed out the benefits of a situation in which winner-takes-all dynamics occur by arguing that a single, integrated IoT platform can be the enabler for an IoT ecosystem in which previously disparate business areas are linked. This could lead to greater operational efficiency, responsive manufacturing and improved product design.

However, it is questionable if this analogy is valid because the IoT platform market differs from the market for software platforms in some important aspects. According to economic theories on platforms, winner-take-all dynamics occur if the following conditions are satisfied (Eisenmann, Parker, & Van Alstyne, 2006, p. 7):

1. Multi-homing costs (i.e. the costs a user incurs to affiliate himself with multiple platforms) are high for at least one user-side;
2. Network effects are positive and strong;
3. The need for niche specialisation is low;

For IoT platforms, the first condition can be satisfied by creating high switching costs – for example by making use of proprietary standards to lock-in end-users. However, the positive network effects are less strong compared to other multi-sided platforms due to the high degree of fragmentation in the IoT market (Schreieck et al., 2017). The high fragmentation entails that there are a lot of market players, all providing different services. Degrande et al. (2018) argue that the high fragmentation is caused by the immaturity of the market. However, IoT applications are found in virtually all domains in everyday life (Nicolescu, Huth, Radanliev, & De Roure, 2018; Wortmann & Flüchter, 2015). Therefore, it is more likely that the fragmentation results from the high need for niche specialisation caused by the diversity of the application domains and use cases in which IoT can be utilised. Furthermore, in contrast to other multi-sided platforms, the main objective of an IoT platform is enabling users to interact with smart objects, instead of enabling interaction with other user groups – which gives rise to the positive cross-side network effects.

Thus, it is unlikely that winner-take-all dynamics will occur due to the high need for niche specialization and the associated fragmentation that leads to low network effects. Without winner-take-all dynamics and the associated intense competition, there is more room for platforms to open up towards each other in one of the two ways sketched in Figure 1. Opposing the benefits of a single integrated IoT platform, sketched by Ochs & Riemann (2017), there are also some downsides. For example, all user data from different application domains, stored in a central place will constitute a honeypot of personal data. This will disturb the power balance in the market as a lot of power will reside with one party. Furthermore, it elevates the risk of being hacked and it could be an easy target for governments as the data can be used to strengthen their scope of control. Such an elaborate data collection will also raise privacy concerns because a lot of insights can be gained by combining the data.

1.2.3 Business and Context Factors Influencing the Openness between IoT Platforms

The business and context factors influencing the openness between IoT platforms can either be distilled from research done in the context of IoT platforms or from the theory concerning the openness of software platforms. With respect to the first option, there is very limited research on the business factors driving openness decisions in the context of IoT platforms. Schreieck et al. (2017) argue that deciding about the degree of openness is one of the main trade-offs IoT platform owners have to make but they only acknowledge the importance of this trade-off and they do not discuss the underlying factors. This claim is supported by Nikayin, De Reuver, & Itälä (2013), who show that the openness towards third party developers is one of the main factors driving collaboration decisions related to an IoT platform for independent living services.

Menon et al. (2017) studied the effect of openness on the strategy of platforms in the Industrial Internet of Things (IIoT). However, this research is done in a different context and does not target the openness between platforms. Besides this, they studied the consequenses of a certain decision about the degree of openness and not the antecedents of that decision (i.e. the factors that drive decisions on openness). Nevertheless, by reasoning backwards, the study from Menon et al. (2017) could provide some insights that can be used for identifying those antecedents.

The business and context factors influencing decisions regarding the openness between IoT platforms can partly be distilled from the theory on the openness of software platforms. For example, Boudreau (2010, 2012) studied the influence of openness on the innovative capabilities of a platform and Ghazawneh & Henfridsson (2013) developed the boundary resource model to describe the tensions that might arise when managing the third party developers affiliated with a platform. Unfortunately, most research in this field is related to the openness towards the users of a platform (e.g. third party app developers). Some studies address the openness towards other platforms, but mostly in an indirect manner. For example, Eisenmann, Parker & Van Alstyne (2009) discuss horizontal strategies of opening up but they do not address the openness between platforms explicitly as they mix the discussion on interoperability between platforms with licencing and broadening sponsorship. Karhu, Gustafsson & Lyytinen (2018) address the issue of forking – which could be a risk from a high degree of openness between platforms – but they do not position their research in this context.

Furthermore, the theory on the openness of software platforms is not directly applicable to the context of IoT platforms because there are some notable differences between IoT and software platforms. Firstly, in contrast to software platforms, there is an interaction between IoT platforms and the physical world through the sensors and actuators connected to the platform. Consequently, there might be different considerations (e.g. regarding privacy or security) influencing the decision of a platform owner regarding the desired degree of openness. For example, imagine what would happen if someone would get unauthorised access to the smart lock on your front door through a badly configured smart lamp. Secondly, as argued in 1.2.2, network effects play a less important role in the IoT platform market compared to the software platform market. Finally, there could also be different business interests driving the decisions on the openness of IoT platforms as IoT platforms can also be delivered by product manufacturers – as a complement to their products – instead of by software developers (Hodapp et al., 2019).

1.3 Research Objective

As discussed in section 1.1, the main problem hampering IoT platform innovation is the high level of fragmentation and the lack of interoperability between IoT platforms (Ganzha et al., 2018; Mineraud et al., 2016). Because there are contradicting views on how the IoT platform market will evolve to tackle the issues related to this, it is important to gain insight in the business and context factors driving the decisions from platform owners related to the openness of their platforms towards other IoT platforms. These insights could be used to steer future research efforts and to aid platform owners in their decision making process.

From section 1.2, it can be concluded that there is little scientific research related to openness in the context of IoT platforms. Firstly, the governance of IoT platforms in general is ill studied. Because of this, fitting conceptualisations of IoT platforms and openness in the context of IoT platforms are lacking. Secondly, although openness is studied in the context of other platforms, research on the openness *between* platforms is fairly limited and only implicitly studied. Therefore, it is not clear what the concept of openness between platforms exactly entails. Furthermore, this entails that related work is of limited value. Thirdly, the related work in the context of software platforms is hard to translate to the context of IoT platforms due to the aforementioned differences between the two settings.

Thus, the openness between IoT platforms is not studied before and insight in this phenomenon is required to advance IoT platform innovation. Therefore, studying the business and context factors influencing decisions related to the openness between IoT platforms is required to build a theory on the openness between IoT platforms. As a first step, these factors will be identified. This is complicated by the fact the IoT platform market is highly fragmented, both within and across the huge diversity of domains (Nicolescu et al., 2018; Wortmann & Flüchter, 2015). This requires an exploratory research approach as the phenomenon will likely manifest itself differently across domains. Therefore, context factors will also be taken into consideration. Furthermore, usable conceptualisations of the key concepts are lacking, which makes developing them imperative. Besides merely identifying the factors, trade-offs between them are elicited and the relative importance of the factors and trade-offs is assessed.

The main focus will be on the decisions made by the platform sponsor because the platform sponsor exercises the property rights over the platform and has the formal control over its strategic development (Eisenmann et al., 2009). However, in the context of software platforms, it is shown that other actors in the ecosystem also influence how the platform evolves (Eaton, Elaluf-Calderwood, Sorensen, & Yoo, 2015). Among other things, the research from Eaton et al. (2015) relates to the openness towards app developers. However, it seems logical that similar mechanisms also apply to the openness between platforms. The perspectives of the other actors in the ecosystem will therefore also be taken into account. Nevertheless, the focus will be on the decisions made by the platform sponsor because in the end, the platform sponsor makes the final decisions regarding the governance of a platform – motivated by other ecosystem players or not. To summarize, this research has the following objective:

> Research objective: *this research aims to develop a theory on the openness between IoT platforms by identifying, prioritizing and theorizing the interrelations between the business and context factors affecting the decisions from IoT platform owners related to the openness of their platform towards other IoT platforms.*

1.4 Research Questions

In line with the research objective presented in section 1.3, this study answers the following research questions:

> Main research question: *Which business and context factors influence the decisions from IoT platform sponsors regarding the desired degree of openness towards other IoT platforms?*
>
> Sub questions:
>
> 1. *What does the concept of openness entail in the context of IoT platforms?*
> 2. *Which business factors influence the decisions of an IoT platform sponsor regarding the desired degree of openness towards other IoT platforms?*
> 3. *Which context factors influence the decisions of an IoT platform sponsor regarding the desired degree of openness towards other IoT platforms?*
> 4. *Which trade-offs exist between the identified factors?*

1.5 Research Approach

Currently there is little research related to the factors and trade-offs influencing the desired degree of openness between IoT platforms. Therefore, an exploratory research methodology is best suited to answer the main research question because it concerns a problem on which little or no previous research has been done and it aims at forming a basis for theory and hypothesis building (Sekaran & Bougie, 2016). By conducting this research, future research efforts can be steered to directions worth pursuing at an early point in time, thereby saving time and other scarce resources (Dudovskiy, 2018).

Usually in the social sciences, either a case study, experiment or survey is used as research approach. However, given the underdeveloped stage of this field, none of these methodologies have a proper fit with the research objective of this thesis. As argued in section 1.3, different business factors might manifest themselves in different contexts. Therefore, a large sample of use cases across different domains should be investigated in order to find as much factors as possible. Because of this, a detailed case study, focussing at only one or a few cases, is of limited value. Similarly, an experiment is of limited value in this exploratory stage because this method is often focussed on testing hypotheses that require a theoretical basis. Finally, although a survey can be exploratory in nature, it is not suited as a starting point for developing a theory because it is hard to investigate relations and trade-offs between factors without reciprocity between the researcher and the respondent.

However, it is also not necessary to completely start from scratch. As discussed in section 1.2.3, there is some related theory (e.g. the boundary resource model or theories on network effects) that can be used to get an idea of the business and context factors that could play a role in decisions regarding the openness between IoT platforms. However, these theories are not sufficient to answer the research question due to the aforementioned differences between IoT- and software platforms. Therefore, this research is grounded in semi-structured exploratory interviews held with decision makers and field experts. The interviews will be structured based on a *preliminary* theoretical model, based on the related research.

Semi-structured interviews are an appropriate methodology because they strike a balance between the explorative open interviews and the more conclusive closed interviews as they allow for reciprocity between the researcher and the respondent (Galletta, 2013). They are specifically suitable for settings where open ended questions require follow-up queries as they enable the researcher to meander around the topics on the agenda and dive into potentially unforeseen issues (Adams, 2015). In this case, that means that the related theory can be used to structure the interviews while there is still enough room to investigate in what way the different context influence the existing theories. Furthermore, it allows the researcher to deviate from the interview protocol if new factors surface.

A possible downside of this approach is related to the qualitative data it generates. Due to the nature of this data, interpretation is subject to bias (Sekaran & Bougie, 2016). To compensate, an extensive interview protocol is created which aims to guide the researcher in asking unbiased questions and clarifying concepts when necessary. This interview protocol is discussed in chapter 3. The analysis is also approached in a structured manner, by making use of coding software in order to limit the room for bias by the researcher. Another potential pitfall relates to the generalizability of this type of research as, due to the time intensive process of gathering the data, it usually makes use of a modest number of samples (Adams, 2015; Dudovskiy, 2018). Therefore, due to the fragmentation of IoT across and within domains, a trade-off has to be made between the number of industries to sample from and the number of perspectives within an industry to include (see section 1.6 and chapter 3). To make sure that as many factors as possible are found and that valid conclusions can be drawn about the relative importance of the factors, the saturation principle will be used when selecting respondents. This entails that the sampling of new respondents will only stop when there is no new information surfacing anymore.

1.6 Research Process

This section outlines the different steps which are followed to answer the main research question and corresponding sub questions. The process is visualised in the research flow diagram in Figure 2. As discussed in section 1.2.1, there is not a fitting theoretical framework that defines openness in the context of IoT platforms. Therefore, the first step to answering the main research question is to define IoT platforms and clarify what the concept of openness entails in the context of IoT platforms. This is done by utilizing the theory on the openness of other platforms (e.g. software platforms and matchmaking platforms) and taking into account the characteristics of the IoT trend. Based on the characterizing differences between IoT platforms and other multi-sided platforms, a *preliminary* theoretical framework defining and explaining openness in the context of IoT platforms is developed. This theoretical framework constitutes the answer to the first research question. The required information will be gathered by making use of scientific article databases, desk research and informal talks with field experts.

Based on the theoretical framework, an interview protocol will be developed that will be used to structure the subsequent interviews with field experts and decision makers. The semi-structured exploratory interviews will be used to identify the business and context factors driving the decisions of IoT platform sponsors related to the openness of their platform towards other platforms. Furthermore, the relative importance of the factors is assessed and trade-offs between the factors are elicited. The data gathered from the interviews is used to update the preliminary theoretical framework that resulted from answering the first research question. This updated theoretical framework constitutes the answers to the second, third and fourth sub question. The interviews will recorded and transcribed to text such that they can be coded and analysed with help of the ATLAS.ti software.

The type of respondents that will be interviewed are: IoT device providers, platform sponsors/providers and field experts with knowledge about IoT platforms (e.g. researchers or people working in the sector). Respondents will be sampled from two industries such that there are sufficient respondents within each industry. To ensure that as much factors as possible will be found, two relatively different industries will be picked. The domains will be selected based on the relative context factors that come forward in the preliminary theoretical framework. Finally, conclusions will be drawn to answer the main research question.

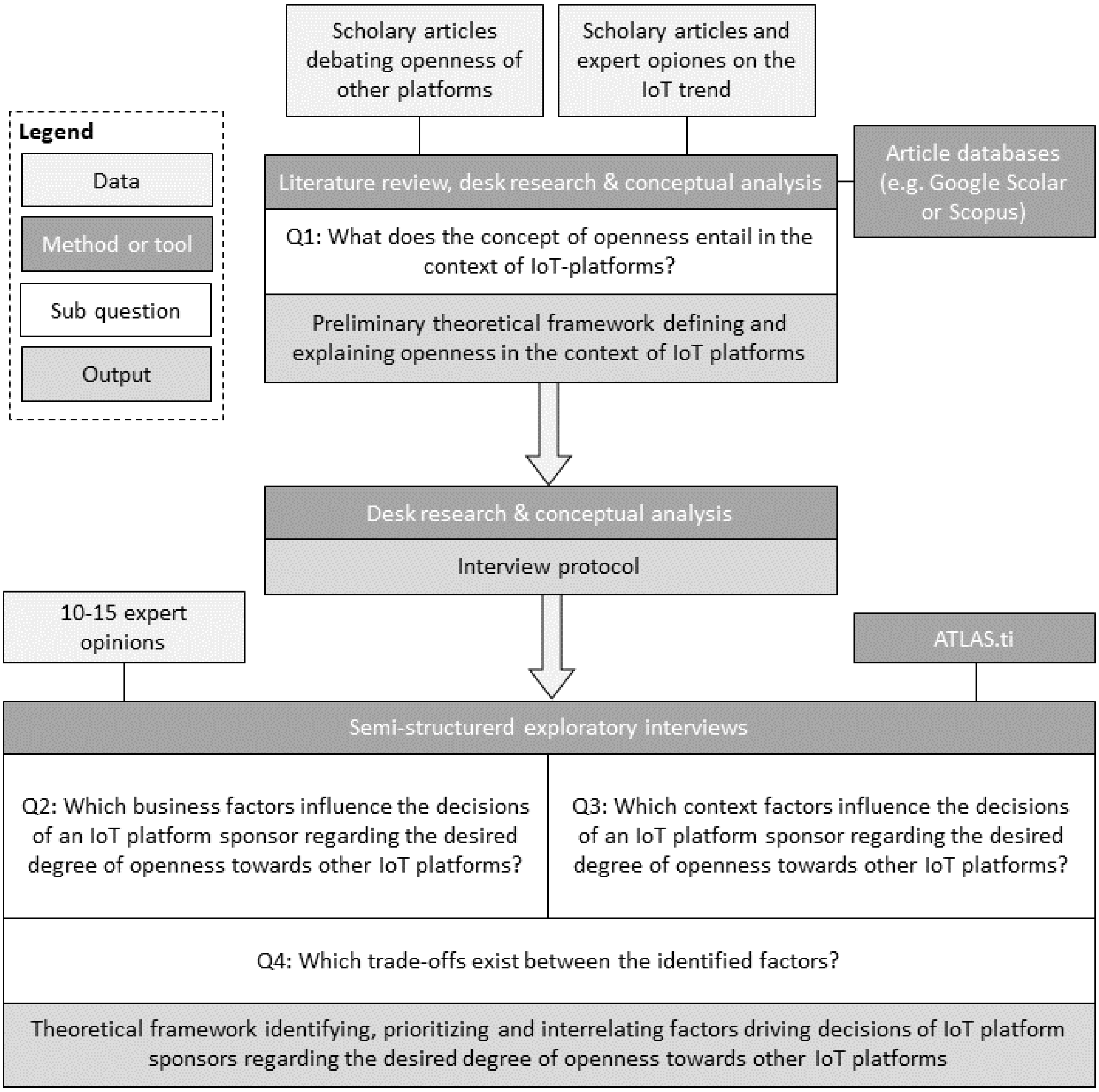

Figure 2: Research flow diagram

1.7 Scientific Contributions

This master thesis contributes to the existing scientific literature in a few ways. Firstly, based on empirical research, an early theory identifying, prioritizing and interrelating factors driving the decisions of IoT platform sponsors regarding the desired degree of openness towards other IoT platforms is developed. This advances the scientific body of knowledge on the governance of IoT platforms, specifically on the openness of IoT platforms. Secondly, because research on the openness *between* platforms is also lacking in the related literature, this study contributes to the theory of platform openness in general as well.

Thirdly, the governance of IoT platforms in general is ill studied. Because of this, definitions and conceptualisations of IoT platforms and openness in the context of IoT platforms are lacking. These definitions and conceptualisations are developed as part of this study. Fourthly, in the process of defining and conceptualising IoT platforms and the openness of IoT platforms, the digital and innovation management perspectives on platforms are discussed and compared with IoT platforms.

This bridges the gap between the different perspectives and contributes to the integration of the different perspectives on platforms.

1.8 Relevance for Master Programme

This master thesis is in line with the learning objectives of the CoSEM master program because it is related to designing an intervention within a complex socio-technical system. In this system, the technical complexity arises from the IoT platforms while the social complexity is rooted in the coordination problems between platform sponsors, device manufacturers and end-users. The insights that will be gained during this study can be used to inform decisions of IoT platform sponsors regarding the desired degree of openness towards other IoT platforms.

1.9 Reading Guide

The remainder of this thesis is structured as follows. In chapter 2, a preliminary theoretical framework conceptualising and explaining openness in the context of IoT platforms is developed. Based on this conceptualisation, an interview protocol is created in chapter 3. In chapter 4, the results of the interviews are presented and discussed. This results in an early theory identifying, prioritizing and interrelating factors driving the decisions of IoT platform sponsors regarding the desired degree of openness towards other IoT platforms. The results of this thesis are discussed in chapter 5 while conclusions are drawn in chapter 6. Finally, limitations and recommendations for further research are presented in chapter 7.

2 Theoretical Framework

The goal of this chapter is twofold. Firstly, IoT platforms and openness in the context of IoT platforms are defined and conceptualised. Secondly, a *preliminary* theoretical framework is developed that gives an indication of the business and context factors that might influence decisions regarding the desired degree of openness between IoT platforms. Together, this constitutes the answer to the first sub question. As explained in chapter 3, the preliminary model is used to structure the interviews with field experts and decision makers. This chapter is structured as follows. Relevant background information is provided in section 2.1. In section 2.2, conceptualisations of IoT platforms and openness in the context of IoT platforms are developed. Finally, in section 2.3, the preliminary conceptual model explaining the desired degree of openness between IoT platforms is developed.

2.1 Background

In this section, relevant background information is provided that serves as a basis for the conceptualisations that are developed in this chapter. Section 2.1.1 gives an overview of the Internet of Things. Section 2.1.2 discusses the different perspectives on platforms and section 2.1.3 discusses existing literature on the openness of platforms.

2.1.1 The Internet of Things

The goal of this subsection is to provide a brief overview of the Internet of Things. To this end, different visions on IoT, the enabling technologies and the technological architecture are discussed. Following that, the different application domains are touched upon briefly. Finally, current open issues are reviewed.

2.1.1.1 Vision

Basically, the Internet of Things (IoT) refers to the trend that an increasingly number of devices are being connected to the internet. The IoT enables physical objects to sense the environment and act accordingly. By connecting these objects to each other, information can be shared and decisions coordinated; both within and across domains. According to the United Nations' International Telecommunication Union (ITU), the IoT represents a transition from anytime, anywhere connectivity for anyone to connectivity for anything (ITU, 2005). The ultimate goal is to provide ubiquitous services (Al-Fuqaha, Guizani, Mohammadi, Aledhari, & Ayyash, 2015). Stankovic (2014) sketches a future in which there is a big sensing and actuating platform that makes IoT a utility, like water and electricity, affecting every aspect of our lives. Key in his vision is that the IoT should be seen as "a critical, integrated infrastructure upon which many applications and services can run" (Stankovic, 2014, p. 3). In contrast, Al-Fuqaha et al. (2015) envisions domain specific sensing and actuating networks interacting with domain independent services (e.g. analytics). A widely adopted definition of IoT does not exist yet.

2.1.1.2 Enabling Technologies

Identification, sensing and communication technologies are important enablers for the IoT concept (Atzori, Iera, & Morabito, 2010). By making use of these technologies, IoT applications can provide different types of services. Identity-related services are the most basic and relate to the identification of objects. Once objects can be identified, their sensory data can be collected and aggregated via information aggregation services. On top of this, collaborative-aware services use the obtained data to make decisions and react accordingly (Al-Fuqaha et al., 2015). For this to happen, the data needs to be stored and analysed. A centralised cloud based infrastructure that can be shared across applications is believed to be the best choice for this (Al-Fuqaha et al., 2015; Gubbi, Buyya, Marusic, & Palaniswami, 2013). However, due to the enormous amounts of data that will potentially be generated by the IoT, edge computing could also be utilized to transfer some of the computing power closer to the smart devices to increase the overall performance (Al-Fuqaha et al., 2015).

2.1.1.3 Architecture

There are multiple architectures proposed for the IoT and currently, it has not yet converged to a single reference model (Al-Fuqaha et al., 2015; Gubbi et al., 2013; Stankovic, 2014). At first, a three layer architecture was composed – consisting of a perception, network and application layer. However, this reference model has insufficient explanatory power to completely understand the structure and connotation of the IoT (Miao Wu, Ting-Jie Lu, Fei-Yang Ling, Jing Sun, & Hui-Ying Du, 2010). In a response to this observation, multiple architectures where developed but according to Al-Fuqaha et al. (2015), the five-layer model in Figure 3 is the most applicable. This model has been used in various papers with slightly different naming (e.g., Khan, Khan, Zaheer, & Khan, 2012; Miao Wu et al., 2010).

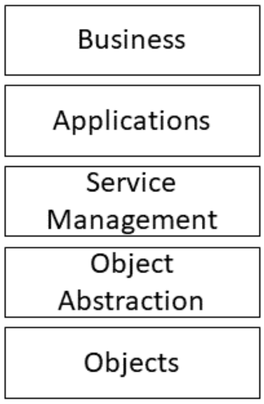

Figure 3: IoT architecture

- The object or perception layer represents the physical sensors and actuators that collect and process information (Al-Fuqaha et al., 2015). In this layer, the perceived information is converted to digital signals (Miao Wu et al., 2010).
- The object abstraction layer acts as a bridge between the physical objects and the service management layer by transferring the produced data through secure channels. Technologies that can be used at this layer are, for example, 3G, WiFi or ZigBee (Al-Fuqaha et al., 2015). In similar models, this layer is called the transport or network layer (Khan et al., 2012; Miao Wu et al., 2010).
- The service management or middleware layer processes the data received from the object abstraction layer, makes decisions and delivers the required services over the network wire protocols to the application layer. It enables IoT application programmers to work hardware agnostic (Al-Fuqaha et al., 2015). Technologies like databases and cloud computing are used in this layer (Miao Wu et al., 2010).
- The applications make use of the services from the service management layer and here, the information interpretation occurs. Applications vary based on vertical markets, the nature of the device data, and business needs (Internet of Things World Forum, 2014). Thus, application complexity can vary widely. This layer provides the services requested by the end-users (Al-Fuqaha et al., 2015). It's function is to provide all kinds of applications for each industry (Miao Wu et al., 2010). An application can also be another service management layer, which can be the case if two systems are integrated (Guth, Breitenbücher, Falkenthal, Leymann, & Reinfurt, 2016).
- The final layer represents the integration of the IoT system into existing business processes. It is like a manager of the IoT system, dealing with business model questions, managing the

applications and thinking about strategy (Miao Wu et al., 2010). The objective of this layer is to empower people to do their work better; applications should give business people the right data at the right time so they can do the right thing (Internet of Things World Forum, 2014).

2.1.1.4 Application Domains

As noted before, the IoT is ought to impact in every aspect of our lives. Therefore, the number of possible application domains is very large (Hodapp et al., 2019; Nicolescu et al., 2018). Healthcare and manufacturing applications are projected to have the biggest economic impact (Manyika et al., 2013). An example of an application in the healthcare domain is the use of sensing services to monitor patients from a distance. This could for example be employed in the elderly care (Gubbi et al., 2013). Manufacturing applications could range from improving the traceability of production parts to the monitoring of machines. The transportation and logistics domain is also an area in which IoT could have a big impact. For example through the monitoring of the supply chain or via assisted driving (Atzori et al., 2010).

2.1.1.5 Open Issues

While research in the IoT has definitely made progress over the past years, there is still a lot to be done in order for the IoT to scale and to realize its potential. Open issues are for example related to: the type of architecture that should be used (Gubbi et al., 2013; Stankovic, 2014), resolving dependencies between different applications (Stankovic, 2014), energy efficiency of sensor networks (Gubbi et al., 2013), privacy and security (Al-Fuqaha et al., 2015; Atzori et al., 2010; Gubbi et al., 2013; Stankovic, 2014), interoperability and the standardisation of protocols (Al-Fuqaha et al., 2015; Atzori et al., 2010; Gubbi et al., 2013), robustness and maintaining Quality of Service (Al-Fuqaha et al., 2015; Gubbi et al., 2013; Stankovic, 2014) and the optimization of scenarios in which humans are involved and interacting with the IoT (Stankovic, 2014).

2.1.2 Different Perspectives on Platforms

Platforms are currently being studied from multiple perspectives: industrial innovation management, economics and information systems (De Reuver, Sørensen, & Basole, 2018). Key in all perspectives is that the platform is part of a system in which it is the relatively stable core, consisting of components with low variety and a high reusability and that it supports variability and evolvability in the system (Baldwin & Woodard, 2009). Knowledge of these perspectives is required to thoroughly analyse and conceptualise IoT platforms, which is why they are elaborated upon in this section.

The theory developed from the economic perspective mainly helps to understand competition between platforms. It explains why a “winner-take-all” competitive outcome occurs and why some platforms become dominant (Gawer, 2014). However, the economic perspective makes it hard to address platform innovation because users on both sides of the platform are seen as equal and treated as simple consumers who only make consumption decisions (Gawer, 2014). There is no distinction between users who only consume and users who also develop complementary products and services for the platform. The industrial innovation management perspective does provide this insight because it is aimed at understanding how technological platforms stimulate innovation. As discussed in section 2.1.2.3, digital platforms can be seen as a subset of technological platforms.

However, there are some differentiating, theoretically relevant characteristics that should be taken into account when analysing digital platforms. Therefore, they are discussed separately.

2.1.2.1 Economic Perspective: Multi-Sided Platforms

The economic literature on platforms focusses on the analysis of multi-sided markets, in which multiple distinct user groups interact with each other (De Reuver et al., 2018). Multi-sided platforms (MSPs) mediate between these user groups and can be defined as *"technologies, products or services that create value primarily by enabling direct interactions between two or more customer- or participant groups"* (Hagiu, 2014, p. 71). Two key features differentiating platforms from retailers and other intermediaries are (Hagiu & Wright, 2015):

1. They enable direct interaction between the sides: this entails that the sides have control over the key terms of the interaction, such as the price or quality in case of a transaction.
2. Each side is affiliated with the platform: this entails that user groups on all sides have made platform-specific investments that enables them to directly interact with each other.

In contrast to a lot of competing definitions that focus on the presence of cross-side network effects, this definition makes it easy to distinguish between retailers or other intermediaries and MSPs (Hagiu & Wright, 2015). Thus, according to this definition Airbnb can be considered a MSP because the landlord and the tenant interact with each other and they are both connected to the platform. In contrast, Netflix cannot be considered a MSP because there is no direct interaction between its end users and the producers of the series and films on the platform (i.e. Netflix controls the key terms of the interaction, like price). This has been visualised in Figure 4.

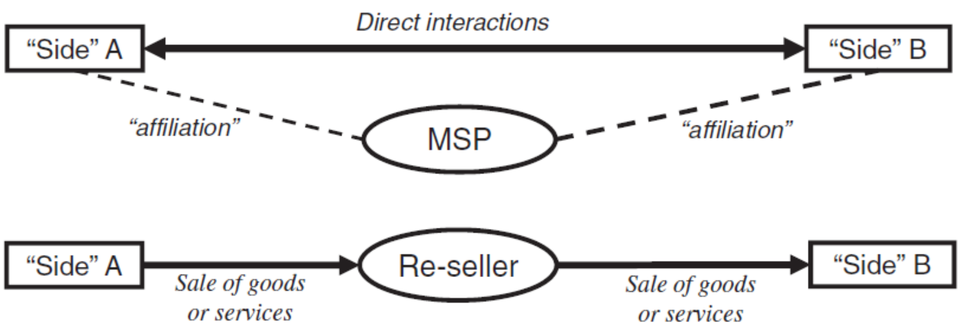

Figure 4: Multi-sided platforms, adapted from Hagiu & Wright (2015)

An important feature of most MSPs is the presence of network effects. The presence of network effects implies that a technology's usefulness depends on the number of users in the network (Katz & Shapiro, 1985). The network effects that affect MSPs can either be positive or negative, direct or indirect and cross-side or same-side. Cross-side network effects imply that the value for users on one side increases if the number of users on another side grows. Indirect network effects arise if there are cross-side network effects in two directions. Then, the benefits for users on side A depend on the number of participants in side B, which depend on the number of participants in side A. Thus, the benefit for the users on side A depends indirectly on the number of users in side A (Hagiu & Wright, 2015). MSPs are often characterised by positive indirect network effects (Hagiu, 2014). Next to creating positive network effects, MSPs can also add value because they are often characterised by economies of scale. This is especially the case for software-based MSPs as they usually have high up-front development costs and close to zero marginal costs (Hagiu, 2014).

One of the most difficult challenges for MSPs is to attract users in the early stage of the platform's lifecycle (Hagiu, 2014). Due to the cross-side network effects, the technology becomes valuable to one of the sides if there are enough users on the other side. This means that, in the beginning, it is hard to get a side on board without already having the other side. This challenge is known as the chicken and egg problem. However, once a critical mass of users on each side is achieved, the positive cross-side network effects can drive further growth (Evans, 2009). Achieving a critical mass is thus a necessary condition for platform ignition (Ondrus, Gannamaneni, & Lyytinen, 2015). Furthermore, it is important that this critical mass on all sides is achieved within a certain timeframe because early adopters can leave if they have to wait too long (Evans, 2009). In order to reach a critical mass in time, a certain market potential is required (Ondrus et al., 2015). Proper governance mechanisms should be in place to achieve this. One of these governance mechanisms is related to the openness of a platform. Other important strategic considerations relate to (Hagiu, 2014): the number of user groups (i.e. sides) to bring on board, the design of the platform, pricing structures and governance mechanisms.

2.1.2.2 Industrial Innovation Management Perspective: Technological Architectures

In the industrial innovation management perspective, platforms are seen as purposefully designed technological architectures (Gawer, 2014). It are products that meet the need of a core group of customers that can be modified through the addition, substitution, or removal of features (Wheelwright & Clark, 1992, p. 73). Gawer (2014, p. 1242) summarises the core of this perspective as follows: *"platform definitions all share the commonality of systematic re-use of components across different products within a product family, which allows economies of scope in production to occur. Hence, the systematic creation and harnessing of economies of scope in innovation can be seen as one fundamental principle of platform-based new product development"*. Thus, according to this perspective, an important function of a platform is to stimulate and facilitate innovation.

Gawer (2014) classifies technological platforms based on the organisational setting in which they occur – within firms, across supply chains or across an industry. An example of the first type of platform is Black & Decker's scalable motor design. Black & Decker designed a motor that can easily be adapted to be used in all of their power tools as all motors can be produced by the same machine (Simpson, 2004). Examples of supply chain platforms can be found in automotive or aerospace manufacturing (Gawer, 2014). For example, the chassis of a car is used across several modules and brands and the manufacturer assembles the car with parts that are specifically designed for a certain chassis (i.e. platform), provided by supply chain partners (Simpson, 2004). Finally, an example of an industry platform is the Android operating system for mobile phones for which app developers, not bound by a supply chain contract, provide complements (i.e. apps). Android is a special type of industry platform due to its digital nature. Section 2.1.2.3 further elaborates on digital platforms.

Technological platforms facilitate innovation through their modular architecture (Baldwin & Clark, 2000). Modularity deals with the complexity of complex systems by partitioning the system into discrete subsystems that interact with each other through standardised interfaces (Gawer, 2014). Interdependencies between modules are reduced, which allows complementors (i.e. designers of new modules) to threat the other modules as black boxes. The interfaces between the modules indicate how the module interacts with the larger system and this abstraction hides the complexity of the other modules (Baldwin & Clark, 2000). Interfaces are therefore fundamental to how modularity facilitates innovation; they connect the different modules and acts as a divider of labour (Gawer, 2014).

In this respect, compatibility standards play an important role. A compatibility standard can be defined as "a set of technical specifications that define the interface between two or more elements that are interoperable" (Den Uijl, 2015, p. 2). The interfaces of a platform are often codified into compatibility standards (Den Uijl, 2015). Thus, compatibility standards are part of a platform ecosystem and they ensure compatibility among the different components (Eisenmann et al., 2009). The degree of openness of the interface (i.e. compatibility standard) influences the extent to which a platform can facilitate innovation and can be understood as the degree to which the interface contains information that is accessible and usable by external agents to facilitate them in building complementary products (Gawer, 2014). Therefore, open compatibility standards are essential for a platform to stimulate innovation.

2.1.2.3 Information Systems Perspective: Digital Platforms

A digital platform can be defined as *"The extensible codebase of a software-based system that provides core functionality shared by the modules that interoperate with it, and the interfaces through which they interoperate"* (Tiwana, Konsynski, & Bush, 2010, p. 675). In this definition, modules are defined as the add-on software components that add functionality to the platform. The modules specific to a platform, together with the platform itself, are called the platform's ecosystem (Tiwana et al., 2010). This has been visualised in Figure 5. An example of a platform ecosystem is the Android mobile operating system (i.e. the platform) together with its collection of apps (i.e. the modules). Digital platforms can be seen as a subset of industry platforms, a concept related to the industrial innovation management perspective (Gawer, 2014). However, Gawer (2014) does not take the specific characteristics of digitality into account while this is theoretically relevant (De Reuver et al., 2018).

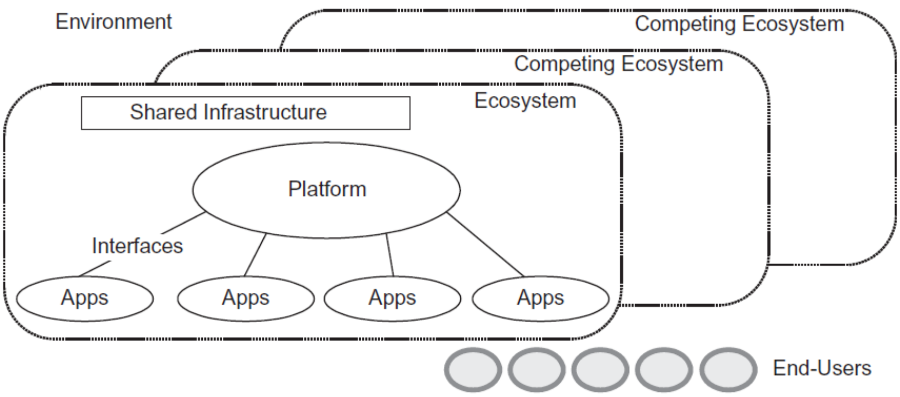

Figure 5: Digital platforms, adapted from Tiwana (2013)

Two important characteristics that set digital platforms apart from other technological platforms relate to flexibility and scalability in the design of the platform, which entails that digital platforms can be redesigned much faster than tangible platforms (Henfridsson, Mathiassen, & Svahn, 2014). Firstly, the modularisation of digital platforms is not governed by an overarching design hierarchy and new functionalities can be added at any point in time after manufacturing due to the reprogrammable nature of digital platforms (De Reuver et al., 2018; Henfridsson et al., 2014).

Furthermore, due to the loose coupling between the software and the physical product executing the software, the physical products are open for new meanings after manufacturing which leads to greater generativity (Yoo, Henfridsson, & Lyytinen, 2010). Secondly, the design of a digital platform is also very scalable because a software product can be reproduced and distributed at virtually zero marginal costs. In contrast to tangible products, there is no distinction between design and production which entails that economies of scale in production are less relevant (Henfridsson et al., 2014).

These characteristics enable the platform owner to distribute innovation among third-party developers, who can add value enhancing complements to the platform after it has been deployed (Tiwana, 2013). Think for example of the Android operating system, which value is largely determined by the apps available for it. These applications can also change the functionalities of the phone on which it installed. By installing a selection of desired applications, the user essentially determines the phone's primary functions (Yoo et al., 2010). This makes the platform owner and the complementors dependent on each other, which is causing product competition to be replaced by platform competition (Tiwana, 2013).

An important design criterion is related to the platform's architecture that describes *"how the platform is partitioned into a relatively stable platform and a complementary set of modules that are encouraged to vary, and the design rules binding on both"* (Tiwana et al., 2010, p. 677). The architecture of a platform should serve two overarching functions (Tiwana, 2013): partitioning and systems integration. Partitioning refers to the way in which the platform ecosystem is broken down into relatively independent subsystems while systems integration deals with the management of the dependencies between the different subsystems. Similar to other technological platforms, digital platforms are ideally fully modular. This entails that changes in a subsystem do not create ripple effects in the behaviour of other parts of the system (Tiwana et al., 2010). Platform architectures should have the following desirable properties (Tiwana, 2013): simple, resilient, maintainable and evolvable.

Since the faith of the platform owner and the complementors is tied to each other, managing the relation with the complementors is an important task of the platform owner. Ghazawneh & Henfridsson (2013) explain this with the boundary resource model, in which boundary resources are the *"software tools and regulations that serve as the interface for the arm's-length relationship between the platform owner and the application developer"* (Ghazawneh & Henfridsson, 2013, p. 176). Through these boundary resources, the platform owner can manage the contributions of third party developers. An important governance consideration for digital platforms is the degree of openness towards app developers, which will be further discussed in section 2.1.3.

2.1.3 The Openness of Platforms

The openness of a platform is related to the easing of restrictions on the use, development, and commercialisation of the platform (Boudreau, 2010). West (2003) argues that platform openness is not a binary concept and one should thus talk about the degree of openness. In addition to this, Eisenmann, Parker & Van Alstyne (2009) argue that you should also distinguish between the different roles a platform ecosystem encompasses when discussing its openness. These roles include 1) *demand-side users*, often referred to as the end-users of a platform; 2) *supply-side users*, who offer the services used by the demand-side users; 3) *platform providers*, who operate the platform; and 4) *platform sponsors*, who formally own the platform.

Ondrus, Gannamaneni & Lyytinen (2015) built onto this conceptualisation by identifying four levels of openness and hence four distinct ways to open up a platform. The first level they identify is the sponsor level, relating to the ownership structure of the platform. Secondly, they identify the provider level, which refers to the degree to which multiple platform providers cooperate with each other to provide a service together. Thirdly, they state that openness on the technology level refers to the degree to which a platform is interoperable with other platforms (i.e. through the use of API's or gateways). Finally, with openness on the user level they refer to the degree to which users from other platforms and/or users not yet part of a platform can join the platform. Within user level openness one can further distinct between the openness towards demand- and supply-side users. These different levels of openness are visualised in Figure 6.

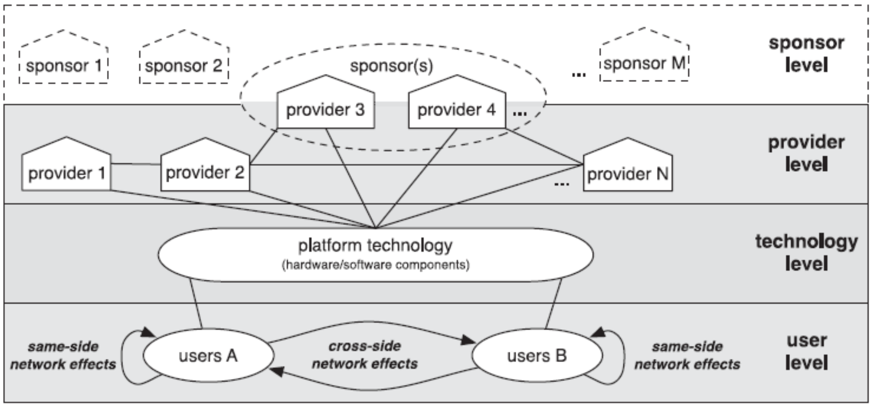

Figure 6: Levels of openness, adapted from Ondrus et al. (2015)

The levels of openness described by Ondrus et al. (2015) are only applicable to platforms operating in an ecosystem; marketplace or industry platforms (including digital platforms). For technological platforms used in an internal or supply chain context, openness usually refers to degree to which the interfaces (i.e. compatibility standards) contain information that is accessible and usable by external agents to facilitate them in building complementary products (Gawer, 2014). The openness of a compatibility standard can be limited if it contains so called essential intellectual property rights (essential IPRs), which are required for the standard to be implemented. This is for example the case with the GSM standard, which contains a lot of essential IPRs. The owners of these essential IPRs often find themselves in dominant market positions (Bekkers, Duysters, & Verspagen, 2002).

In the context of software platforms, Benlian, Hilkert & Hess (2015) further operationalised openness from the perspective of supply-side users by differentiating between the transparency and the accessibility of both the technical platform and the distribution channels through which their complements are distributed. The platform provider manages the relation with the supply side users through boundary resources: *"the software tools and regulations that serve as the interface for the arm's length relationship between the platform owner and the application developer"* (Ghazawneh & Henfridsson, 2013, p. 176). Boundary resources also include the Software Development Kits or API's offered by the platform (De Reuver et al., 2018). By designing and redesigning boundary resources, the platform provider tries to make sure that the third party developers act in line with the goals of the platform. However, Eaton et al. (2015) showed that other actors in the ecosystem also influence the development of the boundary resources through what they call distributed tuning.

Benlian et al. (2015) argue that studying openness from the perspective of the platform provider is of limited value because the platform provider is dependent on the complementors (i.e. supply-side users) and is therefore limited in its ability to exercise hierarchical control. They further strengthen their argument by pointing out that since the group of supply-side users is heterogeneous, complementors will react different to openness-related stimuli. Although studying openness from the perspective of the supply-side users is useful to better understand their contribution behaviour to the platform, it is insufficient to capture all the considerations platform providers have when deciding about the desired level of openness. For example, the extent to which a platform owner can appropriate rents from its platform not only depends on the relation it has with the supply-side users but also on the ownership structure (i.e. sponsor level openness) and the relation with other platform providers (i.e. provider level openness).

The four levels of openness from Ondrus et al. (2015) can be mapped to the more general approaches to opening up a platform identified by Boudreau (2010). He argues that opening a platform can be done it two distinct ways; by giving up control over the platform or by granting access to the platform. In terms of these strategies, opening up on the sponsor, provider or technology level corresponds to giving up control over the platform while opening up on the user level relates to giving access. Karhu, Gustafsson & Lyytinen (2018) refer to these strategies with respectively the concepts of resource and access openness.

The openness of a platform is fundamental to its success. For technological platforms, the openness of a platform determines the degree to which the platform has access to innovative capabilities – ranging from interfirm to across the whole ecosystem (Gawer, 2014). Also for platforms mediating between user groups (i.e. marketplace platforms), deciding about the degree of openness is a critical governance decision (Eisenmann et al., 2009). For example, a sufficient level of openness is required to overcome the chicken and egg problem and reach a critical mass of users in time (Ondrus et al., 2015). The factors influencing openness decisions are further discussed in section 2.3.

2.2 Internet of Things Platforms

The goal of this section is to develop a theoretical framework conceptualising openness in the context of IoT platforms. To this end, existing conceptualisations are discussed in section 2.2.1. After that, the differences and similarities between IoT platforms and other types of platforms are discussed in section 2.2.2. In section 2.2.3, a definition of IoT platforms is developed. Finally, section 2.2.4 deals with the conceptualisation of openness in the context of IoT platforms.

2.2.1 Existing Conceptualisations of IoT Platforms

In the scientific literature, two competing views on IoT platforms are found; one resulting from a technical (i.e. Information Systems) perspective and one resulting from an economic perspective. Depending on the issue that is studied, one of these or a combined perspective is adopted (Hein, Böhm, & Krcmar, 2018). For example, a technical perspective is often used when studying issues related to standardisation while an economic perspective is better suited to study issues related to network effects. When adopting a technical view, IoT platforms can be defined as *“the middleware and the infrastructure that enables the end-users to interact with smart objects”* (Mineraud et al., 2016, p. 5). Schreieck et al. (2017) define IoT platforms based on seven required capabilities, such as the availability of external interfaces or analytics functionality (Gawer & Cusumano, 2014). Since these building blocks are all technical in nature, this definition can be seen as an extension of the definition from Mineraud et al. (2016). Ray (2016), who did a survey on cloud platforms, follows a similar approach tailored to cloud platforms.

Secondly, some scholars define IoT platforms based on the principles of multi-sided platforms (MSPs) discussed in the economic literature (Degrande et al., 2018; Schreieck et al., 2017). Schreieck et al. (2017) identify two types of IoT platforms: a standard platform that connects devices with end users and an advanced platform that also includes a marketplace which allows complementors (i.e. app developers) to interact with the end users (Figure 7). Following the definition from Hagiu & Wright (2015), they state that only advanced IoT platforms can be seen as MSPs due to the direct interaction between complementors and end users. Even though there is also direct interaction between IoT devices and end-users, this relation is of a whole different nature, because devices are not humans or organisations, and therefore require a completely different analysis (Schreieck et al., 2017). This line of reasoning has been adopted by Degrande et al. (2018). In contrast, from a technical perspective such a marketplace is just seen as an additional capability instead of a requirement (Mineraud et al., 2016). Therefore, a 'standard' (i.e. basic) IoT platform would be considered an IoT platform according to the technical definition but not according to the economic definition.

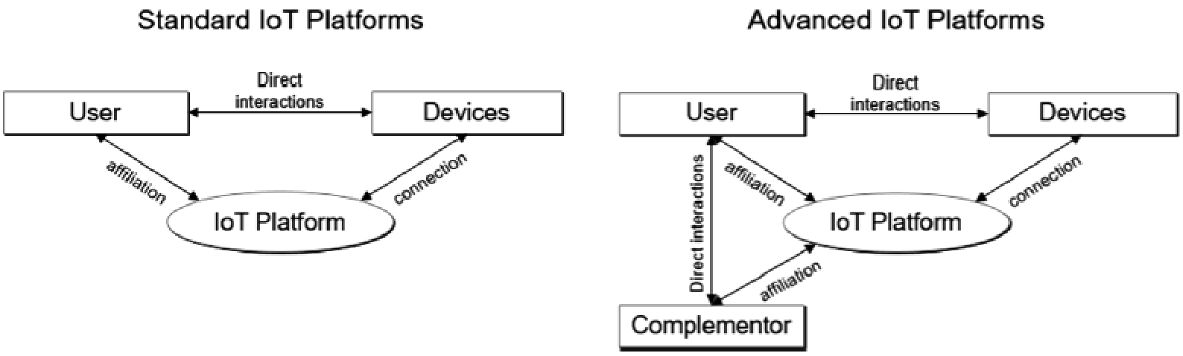

Figure 7: An economic perspective on IoT platforms, adapted from Schreieck et al. (2017)

2.2.2 IoT Platforms Compared With Other Platforms

The economical, innovation management and digital perspectives on platforms are all useful for the analysis of IoT platforms because IoT platforms share some characteristics with all three perspectives. However, they also differ from these three types of platforms. In this section, these similarities and differences are discussed. They are summarized in Table 1 at the end of this section.

2.2.2.1 IoT platforms Compared With Multi-Sided Platforms

As noted by Schreieck et al. (2017), when looking at the interaction between app developers and end users via a marketplace for apps, IoT platforms can be seen as multi-sided platforms (MSPs). However, in contrast to a typical MSP, enabling interaction between two user groups is not the core function of the platform and most IoT platforms do not even have a marketplace for applications. In terms of the classification from Schreieck et al. (2017), only 'advanced' IoT platforms have this capability. In the first place, IoT platforms should facilitate interaction between end users and the devices connected to the platform. Nevertheless, a part of the latter interaction can be analysed with a MSP perspective when considering the interactions between end users and the IoT device *providers* instead of the devices itself. A standard (i.e. basic) IoT platform exhibits some characteristics of a MSP when mature and open compatibility standards for connecting IoT devices with the platform are not being used. For example, Schreieck et al. (2017) found that many platform providers work together with device providers to ensure a smooth integration of their products. Furthermore, some of the IoT platforms require a proprietary gateway to connect devices to their platform (Mineraud et al., 2016).

If there is close collaboration between the device providers and the platform and there is not a mature and open compatibility standard, the 'standard' IoT platform (Figure 7) can also be seen as a MSP according to the definition from Hagiu & Wright (2015).

- The platform enables direct interaction between the device providers and the end users because the devices cannot be used without the platform. To fit the definition of a multi-sided platform, the key terms of the interaction, such as the price of the devices or the service provided by them, should be controlled by the device providers and the end-users, not by the platform (Hagiu & Wright, 2015).
- Both the end-users and device providers are affiliated to the platform through their platform specific investment. Device providers have to support a proprietary standard which can only be used with the specific platform and end users invest time and/or money for connecting to the platform.

If the conditions above are met, indirect network effects between the device provider and end-users arise. These network effects can be used to explain competition dynamics between platforms. For example, take Strava, a platform connecting different brands of wearable activity trackers. If there are more end-users, it becomes more attractive for device providers to make a connection to the platform. If there are more device providers, it becomes more attractive for users to affiliate themselves with the platform. Thus, in accordance with economic theories on network effects, competition between the platforms will increase (Katz & Shapiro, 1985; Rochet & Tirole, 2003).

However, if the platform supports a widely accepted and mature open compatibility standard, device providers are not affiliated to a specific platform and the indirect network effects disappear. For example, imagine an activity tracker that supports open compatibility standards for connecting to a fitness platform like Strava. In that case, the manufacturer of the activity tracker might not even be aware of all the platforms on which his product is used. This entails that he does not have to make a decision on which platform to join. In other words, the cross-side network effects are only one way and therefore, there cannot be indirect network effects (Hagiu & Wright, 2015)[1]. The more devices a platform supports, the more the value increases for end-users but if there are more end-users on a *specific* platform, it will not increase the value for device providers. For them, it does not matter on which platform their device is being used. In essence, when there is a mature and widely spread open compatibility standard, devices are becoming a commodity and for device providers, the platform dynamics are not important anymore (given that there are enough platforms to choose from).

2.2.2.2 IoT Platforms Compared With Technical Innovation Platforms

IoT platforms can be seen as technical innovation platforms when following the definition from Wheelwright & Clark (1992) because it is the common core for a group of customers (i.e. device

[1] See also section 2.1.2.1 for a discussion on the definition of indirect network effects

providers) that can be modified through the addition, substitution or removal of features (i.e. devices). This allows for economies of scope and innovation (Gawer, 2014). However, an important differentiating characteristic with innovation platforms is that the platform itself is of a digital nature, while the complements are physical. As discussed in section 2.1.2.3, the digitality of a platform allows for greater flexibility and scalability in the design of the platform, even after it has been deployed. Furthermore, due to the loose coupling between the IoT platform and the devices, the products are open for new meanings after manufacturing (cf., Yoo et al., 2010). However, in contrast to fully digital platforms, the complements are tangible. Based on current theories on platform openness, it is not clear what effect this cyber/physical nature has. Presumably, this puts IoT platforms somewhere in between digital and tangible innovation platforms.

Just as with innovation platforms, compatibility standards plan an equally important role in facilitating innovation. Depending on how open the compatibility standards are, IoT platforms can either be considered as internal, supply chain or industry platforms. Gawer (2014) notes that over time, technological platforms can transition between these three organisational forms. For IoT platforms, these transition are likely to happen faster because the interfaces (i.e. compatibility standards) are of a digital nature. Following the same line of reasoning as in the preceding paragraph, it can be assumed that digital interfaces exhibit a greater flexibility and scalability in its design compared to tangible standards.

Another differentiating characteristic with innovation platforms is that the affiliation between a device provider and the platform is less strong compared to the relation between a complementor and a technical platform. Platform providers often support open standards for the connection of devices to their platform (Mineraud et al., 2016). Due to the digital nature of the interfaces, it could also be that one product supports multiple compatibility standards. If this is the case, platform specific investments for the device provider are smaller compared to complementors who only innovate on a certain platform because their products can be used with multiple platforms. This entails that multi-homing costs for the device providers are lower. To illustrate this, think of the chassis of a car as platform, on which multiple complementors build their cars; those cannot be simply transferred to another chassis. In contrast, a smart watch can be connected to multiple platforms. This is also true for digital platforms; a software application is built for a specific platform.

2.2.2.3 IoT Platforms Compared With Digital Platforms

IoT platforms also show a lot of resemblance with software platforms if they have the possibility for third party developers to add functionalities to the platform. For example, issues related to boundary resources (e.g. API’s), partitioning or control mechanisms are important concepts when studying IoT platforms. However, in contrast with digital platforms, IoT platforms cannot always be extended with software complements, some platforms just have the core functionalities provided by the platform provider. Besides that, application development is different because the applications make use of the data produced by hardware that is not standard a part of the platform (i.e. devices can be added at any time). For software platforms, applications are developed for relatively stable hardware (e.g. the functionalities of phones do not differ that much). On the other hand, developers have less freedom when writing software for IoT devices because software platforms are often deployed at general purpose machines (e.g. a phone or pc).

A lot of literature related to the governance of software platforms is concerned with the dynamics of innovation in the ecosystem, which is characterised by enabling third party complementors to innovate on behalf of the platform. The generative capabilities of digital platforms are often named as key reason for their success (Tiwana, 2013). Probably, if an IoT platform does not have an application store, the generative abilities of the platform are limited as it only has access to internal innovation capabilities just as with the internal innovation platforms described by Gawer (2014). However, due to the digitality of the platform, It can be redesigned much faster. Together with the loose coupling between the IoT devices and the IoT platform, generative capabilities are probably higher than those for an internal platform (cf., Yoo et al., 2010).

This focus on innovation makes that most literature on openness is related to the openness towards app developers, as they are the ones innovating on the platforms. The literature addressing openness between platforms is very limited. As argued in section 1.2.2, winner-take-all dynamics are to a lesser extent present for IoT platforms if compared to software platforms. This allows for more collaboration between platform companies and could possibly a reason why the openness between platforms are ill studied in the context of software platforms while they are important for IoT platforms.

Furthermore, the need for specialisation within a domain is higher for IoT platforms. This is related to the physical products on which the IoT is based. Due to the economies of scale that arise when producing products, dedicated manufacturing facilities are required to do this efficiently on a large scale. In contrast, software products can be reproduced at zero costs after they are developed, which makes it easier for a single firm to provide multiple software products. Due to the high need for specialisation within a domain, the IoT platform landscape is quite fragmented as the IoT platforms are often provided as complementary service by the hardware manufacturers. Therefore, there is a higher need for openness between platforms if an organisation wants to provide a complete service to the end-users.

Thus, next to managing the relation with app developers, the relation with device providers should also be managed (if a widely spread and open compatibility standards are not used). Furthermore, the relation with other platforms, resulting from the higher openness between platforms, should also be managed. This causes IoT platforms to be even more complex objects than digital platforms (cf., De Reuver et al., 2018).

Table 1: IoT platforms compared with other platforms

	IoT platforms	
	Similarities	**Differences**
Multi-sided platforms	• IoT platforms can add value by enabling direct interactions between end users and app developers via a marketplace for apps. • 'Standard' IoT platforms can be seen as MSPs governing the relation between end users and device providers when there is not a mature and open compatibility standard for connecting devices to the platform.	• The marketplace transactions are only complementary to the other functionalities of the platform; it will never be the core functionality of the platform. Besides, not all IoT platforms have a marketplace. • 'Standard' IoT platforms that support mature and open compatibility standards for connecting devices to the platform cannot be seen as MSPs.
Innovation platforms	• IoT platforms can be seen as innovation platforms if you look at the relation between the platform and device providers.	• In contrast with tangible innovation platforms, the platform itself is of a digital nature while the complements are of a physical nature. • The affiliation between device providers and a platform is less strong compared to the affiliation between complementors and an innovation platform because devices can be used on multiple platforms. This is a result from the digital nature of the compatibility standards.
Digital platforms	• When seeing IoT platforms as expandable software platforms, they can be seen as digital platforms.	• IoT platforms can be extended with devices and/or with software modules. While the former is always the case, the latter is not always possible. This make IoT platforms an ever more complex object to analyse. • Application development is different because the applications make use of the data produced by non-generic hardware that is not standard a part of the platform (i.e. devices can be added at any time). For software platforms, applications are developed for generic and relatively stable hardware. • Openness between platforms is more important for IoT platforms due to the higher need for specialisation in the IoT domain.

2.2.3 Defining IoT Platforms

For the purpose of this research, a definition for IoT platforms will be composed based on the existing conceptualisations discussed in section 2.2.1 and the comparison with other platforms discussed in section 2.2.2.

From a technical perspective, an IoT platform can be defined as *"the middleware and the infrastructure that enables the end-users to interact with smart objects"* (Mineraud et al., 2016, p. 5). The good thing about this definition is that it emphasises the core functionality that an IoT platform should provide: enabling interaction between end users and smart objects. Some define IoT platforms based on the availability of certain functionalities (Gawer & Cusumano, 2014; Schreieck et al., 2017) or on the choice of a certain infrastructure (Ray, 2016). However, different applications require different characteristics. Therefore, by not specifying a type of infrastructure or the required functionalities, a definition will be more easily general applicable.

A platform can either be built around specific hardware, software or communication standards (Degrande et al., 2018). A downside of the definition from Mineraud et al. (2016) is that it encompasses multiple layers from the software stack presented in section 2.1.1.3 and that it encompasses both hardware (i.e. the infrastructure) and software (i.e. the middleware). The focus in this research will be on software based IoT platforms. Hardware based platforms are not seen as a viable basis for a platform due to the multitude of IoT devices and manufacturers. Software platforms have the capability to integrate hardware devices from different manufacturers and can thereby reduce fragmentation. Depending on the use case, different communication standards might be feasible which is why picking one as a basis for a platform won't solve the issue of fragmentation.

From section 2.2.1 and 2.2.2 it becomes clear that there is a huge diversity of IoT platforms. In some cases IoT platforms mediate between end-users, add-on software modules bought via an on-demand marketplace and hardware modules (i.e. devices connected to the platform). In other cases, they just mediate between an end-user and a single type of device. Therefore, a generalizable definition of IoT platforms should be agnostic to:

- whether or not the software base is extendible with add-on applications (i.e. apps) that can potentially be bought in a marketplace.
- whether or not (add-on) applications are developed by the platform provider or by third party application developers.
- whether or not the platform supports open and mature compatibility standards for connecting devices to the platform.
- whether or not heterogeneous devices are supported.

Furthermore, IoT platforms do not necessarily interact with end-users. They can also be deployed in automated business processes that are not controlled by end-users. Therefore, by taking the above into account, IoT platforms can be defined as the service management layer in the software stack presented in section 2.1.1.3 (see Figure 8). In addition, Tilson, Sorensen, & Lyytinen (2012) argue to adopt a socio-technical perspective when analysing digital infrastructures. This entails that a digital platform also encompasses the organisational structures (e.g. compatibility standards) necessary for the platform to function. This leads to the following definition:

> <u>Definition of an IoT platform:</u> *the software-based system and related organisational structures that allow applications to interact with the smart objects connected to it*.

Depending on the level of analysis, the smart objects can either be independent sensors or actuators or more complex objects. For example, when analysing the autonomous driving capabilities of a car, the IoT platform under analysis resides inside the car and is connected to the enormous amount of sensors and actuators in the car. When analysing the interaction between a connected car and the information facilities of a city, the IoT platform resides probably somewhere in the cloud and is connected to multiple cars (i.e. the more complex objects) and the different information services of a city.

Figure 8: The definition of an IoT platform mapped on the software architecture stack

2.2.4 Defining Openness in the Context of IoT Platforms

Based on the definition presented in section 2.2.3 and the discussion on the differences with other types of platforms in section 2.2.2, the concept of openness can be defined for IoT platforms. As a starting point, the conceptualisation of openness from Ondrus et al. (2015) will be used. Recall that they define openness on four levels: the sponsor, provider, technical and user level (see section 2.1.3 for a more elaborate discussion). Note that all levels are related to each other in the sense that decisions on one level can affect decisions on another level.

2.2.4.1 Sponsor Level Openness

Since there are no characterising differences with other platforms that relate to the sponsor level, the definition of sponsor level openness from Ondrus et al. (2015) can be used, which refers to the ownership structure of the platform (i.e. *the extent to which an IoT platform is owned by more than one stakeholder*).

2.2.4.2 Platform Level Openness

In terms of Ondrus et al. (2015), provider level openness refers to the degree to which multiple platform providers cooperate with each other to provide a service (i.e. platform) together. With openness on the technology level they refer to the degree to which a platform is interoperable with other platforms – through the use of gateways or API's. As discussed in chapter 1, there are two distinct ways for a platform to open up towards other platforms:

- Directly: if two platforms are directly made interoperable via gateways or API's (e.g., Ochs & Riemann, 2017).
- Via a broker service or meta-platform: for example via an IoT marketplace that accommodates the flow of data across different IoT platforms (e.g., Mineraud et al., 2016).

When mapping these two modes of openness to the levels of openness defined by Ondrus et al. (2015), the first mode overlaps with openness on the technology level while the second mode only partly overlaps with openness on the provider level. In terms of Ondrus et al. (2015), openness on the provider level refers to multiple firms providing a single platform. However, in this situation there is only a single platform and you cannot speak of openness *between* platforms anymore. Thus, an important characteristic of platform level openness is that if two platforms open up towards each other, they both keep existing. For example, imagine that two platforms – say platform A and B – open-up towards each other via a broker service or meta-platform. In this case you end up with three platforms: platform A, B and the meta-platform. If platform A and B would integrate into a single platform, the original platforms stop existing. Thus, collaboration modes as licencing and integration are not seen as platform level openness because the original platforms are not maintained in these cases. Instead, they can be seen as a form of sponsor level openness because it affects the ownership structure. Therefore, platform level openness can be defined as *the degree to which data and services can be shared among different IoT platforms*.

In terms of the more general approaches of opening up by giving up control or by granting access to the platform (Boudreau, 2010) – or the interchangeable concepts of resource and access openness (Karhu et al., 2018) – the newly made definition of platform level openness can be seen as a form of access openness. If services are shared amongst platforms, one platform grants the other platform access to the service (e.g. through an API) but no control is given over the content over the service (i.e. what the service entails). For example, if platform A controls the actuators of platform B via an API, platform B has still control over which actuators are controlled and under what conditions they can be controlled. The same is true for when only data is shared.

2.2.4.3 User Level Openness

With user level openness, Ondrus et al. (2015) refer to the *degree to which users from other platforms and/or users not yet part of a platform can join the platform*. Within user level openness one can further distinct between the demand- and supply-side users. Both sublevels apply to IoT platforms as well if you see the third party application developers as the demand side users. However, as discussed in section 2.2.3, IoT platforms are not always open for third party developers. Within this definition of user level openness, this can be modelled as closed towards demand-side users.

2.2.4.4 Device Level Openness

Because IoT platforms can be extended by both software and hardware modules (i.e. smart objects), another new level of openness has to be introduced – openness towards devices. As discussed in section 2.2.2, the affiliation of device providers with the platform is less strong compared to relation between the platform and app developers. Furthermore, the same device can be produced by multiple manufacturers. Therefore, it makes sense to define openness towards devices instead of device providers. The openness towards devices can be defined as *the degree to which* *heterogeneous devices are supported by the platform*. Platforms that are considered open on the device level will often make use of one or more open compatibility standards.

2.3 Preliminary Conceptual Model Explaining the Desired Degree of Openness between IoT Platforms

In this section, a preliminary conceptual model explaining the desired degree of openness towards other IoT platforms is developed. The model (Figure 9) is made based on the literature discussing the openness of other types of platform and the identified similarities and differences with IoT platforms (section 2.2.2). This section is structured around the different categories found in the model in Figure 9. This preliminary model will be used as a basis for structuring the interviews. The following process was used to develop the model:

1. The researcher identified key literature on the openness of platforms, based on knowledge of the relevant research domains and the snowballing technique. The resulting literature that was used to develop the preliminary framework is presented in Table 2.
2. While reading the literature, research notes were kept to identify all factors that could potentially be related to the desired degree of openness of a platform. In this step, no preselection was made based on the relevance of the factors for the IoT domain or the specific level of openness.
3. Based on the identified similarities and differences with IoT platforms in section 2.2.2, relevant factors that could potentially explain the openness *between* IoT platforms are identified.
4. Based on informal talks with field experts and knowledge of the IoT domain, additional factors were added.
5. Factors were grouped in categories and subcategories, leading to the following main categories:
    a. Perceived effect on business outcome
    b. Market characteristics
    c. Organisational characteristics
    d. Corporate Social Responsibility
    e. Legal requirements
6. Relations between the categories were identified to come up with the following structure. The perceived effect on the business outcome is naturally the main driver for all business decisions and therefore also for business decisions regarding the desired degree of platform level openness. Next to this, the legal requirements (i.e. what is allowed at what is not) and Corporate Social Responisibility related motives (i.e. what is the right thing to do) also have a direct impact on the desired degree of platform level openness. Wheter or not the business outcome of a certain decisions is perceived as good or bad depends on the context in which the decision takes place. This context consists of the focal organisation and the market in which this organsiation operates (Boudreau, 2010; Wareham et al., 2014). The resulting model is displayed in Figure 9.

Table 2: Key literature on the openness of platforms, used to develop the preliminary theoretical model

#	Article	Context
1	(Boudreau, 2010)	Technology platforms – handheld computing systems (focus on hardware complements)
2	(Boudreau, 2012)	Technology platforms – handheld computing systems (focus on software complements)
3	(Eisenmann et al., 2009)	Multi-sided platforms
4	(Gawer, 2014)	Technology platforms
5	(Hagiu & Wright, 2015)	Multi-sided platforms
6	(Karhu et al., 2018)	Digital platforms – smartphone OS (Android)
7	(Ondrus et al., 2015)	Multi-sided platforms – mobile payment
8	(Parker & Van Alstyne, 2018)	Digital platforms
9	(Tilson, Lyytinen, & Sørensen, 2010)	Digital platforms
10	(Wareham et al., 2014)	Digital platforms – ERP system
11	(West, 2003)	Technology platforms – computers

2.3.1 Perceived Effect on Business Outcome

Four categories are distinguished that together determine the perceived effect on the business outcome of a company. These are: direct profits & losses, the effect on the userbase, the effect on the strategic position of a company and finally, considerations related to data privacy and security.

2.3.1.1 Direct Profit & Losses

One of the most obvious factors influencing the perceived effect on the business outcome are the direct profits and losses flowing from the openness decision. Of course, building an interoperability solution is costly and these costs (e.g. development- or R&D costs) have to be taken into consideration (Eisenmann et al., 2009). This could also lead to opening up if your market share is lower than the minimum efficient scale necessary to support proprietary R&D (West, 2003). However, opening up on the provider level can also lead to new streams of revenue. For example, by opening up you expose your platform to a new user group that you can charge for access (Parker & Van Alstyne, 2018). Opening up could also affect margins, in a positive or negative way (Eisenmann et al., 2009).

2.3.1.2 Effect on Userbase

One of the main reasons why traditional software platforms would open up is to increase the end user adoption by harnessing the positive indirect network effects that cause the value of the platform to increase with the number of users connected to the platform (Katz & Shapiro, 1985; West, 2003). Having a sufficient level of openness is required to reach a critical mass of users in time (Ondrus et al., 2015). After reaching this critical mass of users, the positive network effects will be strong enough to permit sustainable growth (Evans, 2009). Furthermore, by allowing third parties access to a platform, its generative ability can be increased (Tilson et al., 2010; Wareham et al., 2014). This entails that the platform is ecosystem is better equipped to provide value in previously unforeseen use cases; a concept closely related to the innovativeness of a platform (Boudreau, 2010). This research is mainly written from the perspective of user level openness. Nevertheless, it can also be assumed that the above considerations also hold for platform level openness because if two platforms in the same sector become interoperable, the market potential of both platforms becomes the union of the market potentials of the separate platforms (Ondrus et al., 2015). This logic can easily be extended to the already adopted users.

Besides a direct effect on the userbase, opening up can also impact the quality of the platform, which will influence the userbase indirectly through a change in sales. For example, reputational damage can occur when bad complements are added to the platform (Boudreau, 2012). However, additional complements also increase the usefulness of the platform (West, 2003). This logic can easily be extended to 'adding' another platform to the focal platform (instead of complements. When a platform is connected to multiple other platforms, the overall architecture has to be loosely coupled to avoid added complexity due to interdependencies between the platforms (Baldwin & Clark, 2000). Risks of such a loosely coupled platform infrastructure are: fragmentation, inefficiency, inferior user and overcrowding (Wareham et al., 2014). More tightly coupled architectures are often characterised by a more holistic and cohesive user experience. On the other hand, they can also constrain innovation and platform evolution (Wareham et al., 2014).

Other considerations related to the quality of a platform relate to quality issues that occur due to technological compromises, either unavoidable or due to a deliberate choice out of strategic considerations, in order to maintain differentiation (Eisenmann et al., 2009). Finally, if platforms become interoperable and there is a reduced chance of lock-in, it could be a reason for users to adopt earlier (West, 2003).

2.3.1.3 Strategic Position

An important reason to keep the platform closed (on any level) relates to a decrease in the ability to appropriate rents from the platform (West, 2003). One way to protect the market position is by creating lock-in and switching costs via closed product-specific interfaces (Wareham et al., 2014). This provides better barriers against imitation and lowers the competition among platform providers because firms without proprietary technology cannot enter the market; you increase the entry barrier and thereby decrease competition. This also entails that you often have better margins if you remain closed (Eisenmann et al., 2009; West, 2003). Because network effects play are to a lesser extent important for IoT platforms (Schreieck et al., 2017), these considerations could be more favourable for IoT platforms in comparison with other platforms. Other possible downsides to opening up are the loss of control (e.g. over product development) and the associated increase in coordination costs (Boudreau, 2010; Tilson et al., 2010; Wareham et al., 2014). Furthermore, by opening up you increase your exposure to exploitation strategies, such as forking (Karhu et al., 2018).

On the other hand, a reason to open up could be that the organisation's market does not have not enough market power to resist buyer demands for open standards or the standards contest could 'tip' in favour of an open standard, making it not profitable to establish or maintain a proprietary standard (West, 2003). Finally, you could open up due to a change in your business model. For example, if you accept commoditisation of a certain layer in the value chain and decide to shift your competitive advantage to another layer (West, 2003).

2.3.1.4 Data Privacy & Security

In contrast to the previously discussed categories, this category results from informal talks with field experts related to the specific characteristics of IoT. One of the most heard drawbacks of the IoT in the public discourse, is the big impact on privacy. Because, due to IoT, more and more data is collected that can be related to individuals (e.g. through activity trackers). Besides that, due to the sensors and actuators connected to the platform, IoT has a direct impact in the real world. These issues increase the need increases the need for security measures and the importance to think about what kind of data is collected. This has also been stressed in the scientific literature (Al-Fuqaha et al., 2015; Atzori et al., 2010; Gubbi et al., 2013; Stankovic, 2014). Data privacy and security considerations have been categorised as a business outcome because bad security and privacy measures can for example have an impact through damage claims or loss of customers. Of course, it could also be the other way around.

2.3.2 Legal Requirements & Corporate Social Responsibility

Of course, all businesses deal with legal requirements which also means that they play a role in decisions about the platform level openness of IoT platforms. Besides the need to comply with regulations, there can also be uncertainty about (upcoming) regulations that can affect openness decisions (Setzke, Böhm, & Krcmar, 2019). A prominent example of legislation that impacts business decisions on collaboration is the GDPR privacy regulation in Europe. Furthermore, next to legal requirements, companies could also choose to pick a less then optimal business outcome as a result of their Corporate Social Responsibility guidelines. This could for example relate to the possibility to increase public health or safeguard the environment.

2.3.3 Market Characteristics

The characteristics of the market are an important type of context variable that determine (1) if a certain openness decision is perceived as good or bad and (2) which decisions can be considered. A defining characteristic of a market is the competitive landscape; how are market shares divided (Eisenmann et al., 2009), are there dominant players and who are your competitors. Secondly, the maturity of the market is important (Boudreau, 2010; Wareham et al., 2014). This could relate to the availability of mature (and open) compatibility standards (Den Uijl, 2015) and whether the market is ‘tipping’ towards a certain standard (Boudreau, 2010; West, 2003). Or it could relate to technological or cultural constraints (Setzke et al., 2019)

Another important characteristic of the market relates to the need for specialisation; the degree to which a single organisation is capable of providing a complete service offering on its own. If the need for specialisation is high, the service offerings might be fragmented over the market, which results in a greater need of platform level openness.

2.3.4 Organisational Characteristics

Next to the market characteristics, the characteristics of a certain organisation are also an important context variable. Most obviously, this relates to the overall objective of a company; profit vs. non-profit (Wareham et al., 2014). Besides that, and closely related to the need for specialization described above, is the degree of vertical integration (i.e. how much of the services in the value chain are offered by the organization). For example, if a device manufacturer also makes a platform, it might have other considerations than a company that only provides a platform. A higher degree of vertical integration is often associated with higher quality products whereas a low degree of vertical integration could lead to more product variety and broader indirect network effects (Hagiu & Wright, 2015).

Furthermore, the market position of a company could also play a role (Eisenmann et al., 2009); smaller companies might make different decisions regarding openness than bigger companies for example. Closely related to this is the maturity of the organization (Boudreau, 2010; Wareham et al., 2014). For example, technological capabilities determine how an interoperability solution would look like (Setzke et al., 2019). Finally, it can also be assumed that openness on the other levels plays a role, most notably on the user & device level. For example, an organization could argue that because it is not open on the user level, it does not connect with another platform to keep their platform shielded from the other platform's users.

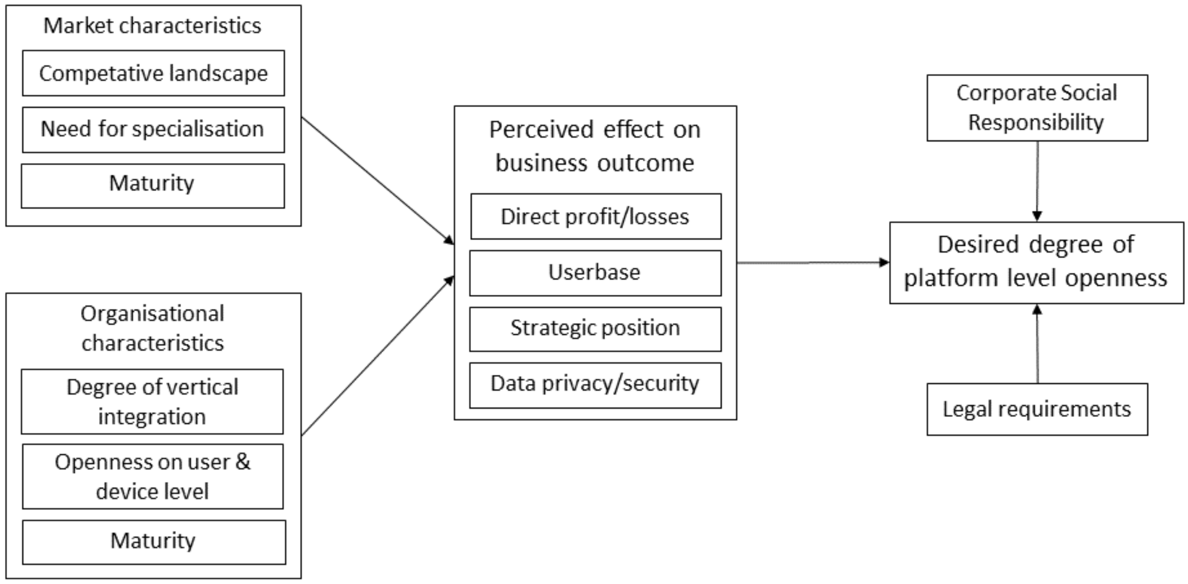

Figure 9: Preliminary conceptual model explaining the desired degree of openness between IoT platforms

3 Methodology

This chapter outlines the methodology that was used to answer the research questions. In section 3.1, the selected application domains are discussed. Section 3.2 discusses criteria for selecting the interview candidates. An overview of the selected candidates is also presented in this section. Then, the interview protocol is discussed in section 3.3. Finally, the approach to analysing the interviews is discussed in section 3.4.

3.1 Selection of Application Domains

As argued in section 1.4, respondents are sampled from two relatively different industries, that have enough available data and which are exemplary of the trade-offs that are expected to be present based on the desk research. Therefore, the domains are selected based on the variables related to the market characteristics. As discussed in section 2.3, these are:

- Competitive landscape
- Need for specialisation
- Maturity

The two selected domains are the healthcare and automotive domain as these differ on all three aspects. The healthcare domains has a very complex competitive landscape, which is influenced by heavy regulation. There are a multiple sub domains, which are very different from each other. The need for specialisation is high due to the intense competition and fragmentation of service offerings. In contrast, the automotive domain is characterised by the dominance of the OEMs producing cars and trucks. Although the competition between them is high, the ecosystem is less complex since all IoT offerings are connected to the vehicles. The market is very immature as there are no mature standards yet that govern the information exchange with the vehicles. Section 3.1.1 and 3.1.2 discuss the service offerings in the healthcare and automotive domain in more detail.

3.1.1 Healthcare

The healthcare domain consist of two main sub domains that can be characterised based on the level of regulation and the application. On the one hand, you have highly regulated applications related to hospital care. The most obvious use case relates to medical equipment that can be controlled and read out from a distance. Use cases are endless, from connected MRI scanners and ECGs to continuous glucose monitoring and closed loop (automated) insulin delivery for diabetes patients[2]. Other promising applications related to Internet of Medical Things (IoMT) are[3]:

- Patient identification to identify patients and track there cure process in order to reduce the margin of error (e.g. related to blood transfusions or ingestible sensors).
- Monitoring from a distance: with the help of mobile applications and IoT devices a doctor could monitor his patients from a distance. This would allow patients to leave the hospital sooner or let elderly people live at home longer. Examples of IoT devices that would allow for such applications are fall detection sensors, portable alarms or connected (wearable) sensors.
- Inventory management of medical supplies and tracking of (expensive) medical devices.

[2] https://econsultancy.com/internet-of-things-healthcare/
[3] https://www.zorg-en-ict.nl/newsitem/24079

- Improving visitor experience. For example a mobile application assisting visitors in the navigation through a hospital or by providing real time information on waiting times.
- Predictive use cases. By making use of data generated through the IoMT, trends and striking events can be identified.

Next to the regulated subdomain, you also have a less regulated consumer subdomain. These applications are often related to a fitness or sports setting. For example, smart wearables and activity trackers are gaining in popularity. The market for wearables is expected to grow from $1.5B to $2.9B in the period from 2018 until 2023 (Markets and Markets, 2019). Besides wearables, health data is also collected and analysed through applications such as Apple Care or Google Fit or via connected fitness equipment in gyms and workplaces. These use cases allow consumers to gain a better understanding of their health and sports performance.

3.1.2 Automotive

In the automotive domain, IoT applications are structured around the connected car. One class of applications relate to assisted or automated driving. Through Vehicle to Vehicle (V2V) or Vehicle to Infrastructure (V2I) communication, automated driving capabilities of cars and trucks could be enhanced. Current autonomous driving applications are based on sensing the environment, if cars could directly connect to the infrastructure (e.g. traffic lights) or other cars, more information can be gathered on which autonomous driving decisions can be based. Other types of services, not aiming at assisted or automated driving, are[4]:

- Fleet management can be used by owners of large fleets to track fuel consumption, track asset utilisation, real time vehicle tracking, predictive maintenance or automated trip logging.
- Insurance policies can be tailored to the individual by collecting data about the driving behaviour. Based on this data, it can be easier to determine liability or drivers can be given discounts on their insurance fees if they drive in a safe way.
- V2X connectivity. Vehicle to Anything connectivity allows a car to connect to every IoT device that can affect it. Examples could relate to autonomous driving capabilities as discussed above (e.g. other cars or traffic lights) but they can also relate to city information (e.g. availability of parking facilities), commercial enterprise offerings (e.g. location based discounts) or traffic alerts.
- Through mobile apps consumers can interact with their vehicles, examples include reminders of where you are parked, pre-heating the car or collision notifications from cars of family members.
- In-car content and services such as Apple Car or Android Auto.

3.2 Selection of Interview Candidates

The interview candidates are sampled over the selected domains and subdomains. An overview of the conducted interviews is presented in Table 3. The interviews are held between May and June 2019. The type of respondents that are interviewed are: IoT device providers, platform sponsors/providers and field experts. The candidates are selected based on their affinity with the topic, (sub)domain and experience. The ideal respondent is someone who has a lot of experience

[4] https://igniteoutsourcing.com/automotive/telematics-and-connected-car/

with IoT in general or with a specific IoT platform in particular. Furthermore, respondents ideally hold senior positions and have decision making power regarding the openness of an IoT platform towards other IoT platforms. The most important characteristic on which interview candidates are varied, relate to the (sub)domain in which they work.

The sample represented in Table 3 fulfils these requirements quite well:

- The sample is quite balanced with respect to the (sub)domains. Out of the 13 respondents, 7 work in the automotive domain, 5 in the healthcare domain and 1 respondent has a cross industry focus. It is a deliberate choice to have the majority of the respondents related to a specific domain to ensure sufficient generalisability. One respondent with a cross industry focus was selected due to his extensive experience in the field (IoT industry leader at a multinational software services and consulting firm and 28 years of experience within that firm).
- Within the healthcare domain, 2 respondents work in the more regulated medical subdomain while 3 work within the consumer oriented fitness domain. Within the automotive domain, 3 OEMs are interviewed (as services are all related to vehicles), 1 governmental organisation and 3 connected car related service providers.
- The experience of all respondents is adequate as they hold senior positions, have a lot of experience within the company (> 5 years) and/or gathered experience fast due to the nature of the work (PhD candidate).

Table 3: Overview of interview candidates

#[5]	(Sub)domain	Organisation	Position	Years at company
	Healthcare			
1	Medical	Manufacturer of medical equipment	Director	<1 year
2	Medical	Platform integrating medical data	CEO	14 years
3	Fitness	University	PhD candidate focussed at fitness wearables	4 years
4	Fitness	Platform integrating fitness services	CTO	2 years
5	Fitness	Manufacturer of fitness equipment	Integration specialist	11 years
	Automotive			
6	All	Governmental	Stakeholder manager for connected car experiments	22 years
7	All	Car OEM	General manager connected car	16 years
8	All	Car OEM	Technology & trend scout	7 years
9	All	Truck OEM	Principal engineer vehicle connectivity	?
10	Service provider	Payment provider	Head of connected car & IoT	19 years

[5] In chapter 4, this number is being used to refer to the interviews

11	Service provider	Automotive driver association	Head of connected car	9 years
12	Service provider	Provider of fleet management software	Product manager connected car	4 years
	General			
13	All	Software services and consulting	IoT industry leader	28 years

3.3 Interview Protocol

3.3.1 Interview Procedures

In contrast to methodologies like Grounded Theory, in which the interview process often starts with little information about the theoretical relations (Corbin & Strauss, 1990), a preliminary theoretical framework was available to guide the interviews. Nevertheless, some principles were borrowed from the Grounded Theory approach as, to some degree, the interview protocol was iteratively altered based on the results of the interviews. Due to the semi-structured nature of the interviews, in a few cases additional topics were added during the interviews when novel insights came forward. In the subsequent interviews with people related to the topic, these topics where discussed as well. Also, as the interviews progressed and the domain knowledge of the researcher deepened, some topics were structured around different examples if it was found that respondents were better able to familiarise with them.

Furthermore, definitions and conceptualisations were sharpened in dialogue with the interview respondents. Especially in the first four interviews, it took relatively more time to establish a shared vision on the definitions of openness and IoT platforms. Insights from the discussions used to reach a common understanding were used to improve the explanation of the definitions and conceptualisations in the interviews that followed. However, although the phrasing might have changed during the first four interviews, the idea behind the definition remained the same. In the end, the same shared vision was used across all interviews. Compared to a typical grounded theory process, the interview topics were altered to a far lesser degree. By keeping the interview topics relatively constant, the comparability between the interviews increases and more robust conclusions can be drawn about the topics in the preliminary framework (Sekaran & Bougie, 2016).

The interviews lasted between 29 and 75 minutes, with a mean duration of 50 minutes and a standard deviation of 13 minutes. All interviews were recorded and transcribed to text such that they could be analysed with coding software (see section 3.4). In most interviews, it often occurred that respondents were thinking out loud. Part of these thought processes were omitted in the transcripts (e.g. stop words like 'uhh..' or 'well…'). After transcribing, the interview recordings were deleted. To comply with the GDPR and research ethics guidelines of the TU Delft, all respondents gave their explicit and written consent for the way in which their personal information is processed. The form that was used for this is presented in Appendix B, together with the accompanying information sheet. The interview respondents were asked to provide feedback on the transcripts but none the respondents did this. However, all quotes used in this report were send back to the respective interview respondents and only used after approval. All quotes were altered as suggested.

3.3.2 Interview Topics

The list of topics with possible introductory questions and examples is presented in Table 4. The questions are only meant as a *possible* introduction to the topic. The first question in the section "Core Topics" in Table 4 was asked during all interviews. Based on the response, follow-up questions were asked and the natural conversation that followed often covered a large part of the topics. Thus, the other questions in Table 4 weren't always asked if they were already covered in the discussion that followed from one of the preceding questions. For topics that were partially covered, additional follow-up questions were asked. Trade-offs between factors were also covered in follow-up questions. If respondents did not understand a question, one or more of the examples presented in the third column of Table 4 were used. Sometimes, as discussed in section 3.3.1, a discussion between the researcher and respondent found place until the respondent and researcher had a shared understanding about the idea behind the question or definition.

Table 4: Interview protocol

Topic	**Possible introduction question to start the discussion on the topic**	**Optional examples**	**Comments**
Introduction			
Personal introductions	Could you explain what you are doing at [company name]?	-	Both the researcher and respondent introduce themselves
Informed consent & start of recording	-	-	
Research introduction	-	-	The goal of the research is explained
Concepts			
IoT platform	-	Google Home/Amazon Alexa, tailored example (e.g. the IoT platform in a car for interviews in the automotive industry)	Discuss the definition of IoT platforms developed in this research
IoT platform openness	-	Examples tailored to the example used for introducing the concept IoT platform	Discuss the definitions of IoT platform openness developed in this research
	Do you have any comments based on this conceptualisation?	-	
Core Topics - General			
	Which factors determine your/the platform owner's desired degree of openness towards other IoT platforms?	Direct profit/losses	Open question without further introduction
Legal Requirements & CSR			

Legal requirements	In what way do legal requirements play a role?	GDPR, competition law	
Corporate Social Responsibility	In what way does Corporate Social Responsibility plays a role?	-	Highlight difference with legal requirements by explaining the legitimacy motive of CSR
Perceived Effect on Business Outcome			
Strategic position	In what way does the perceived effect on your/the platform owner's strategic position plays a role?	Lock-in, risk of forking, market position	Phrasing differs based on function and company of respondent
Userbase	In what way does the perceived effect on the growth of your/the platform owner's userbase plays a role?	Network effects	Phrasing differs based on function and company of respondent
Direct profit/losses	In what way does the perceived effect on the direct business case plays a role?	Development costs for the interoperability solution, the possibility to charge access fees	Explain that this relates to the costs and revenues directly following from the interoperability with other platforms
Data privacy/security	In what way do data privacy and security considerations play a role?	GDPR, start-up not capable of adequate data protection	
Market Characteristics			
Competitive landscape	In what way does the competitive landscape in this market plays a role?	Dominant market players, intensity of competition	
Need for specialisation	In what way does the need for specialisation in this market plays a role?	-	Explain what need for specialisation entails
Maturity	In what way does the maturity of this market plays a role?	Availability of technologies/standards, end-user adoption over whole market, partly working products	
	Can you think of any other market characteristics that impact your/the platform owner's desired degree of platform level openness?	-	Phrasing differs based on function and company of respondent
Organisational characteristics			
Degree of vertical integration	In what way does the degree of vertical integration plays a role?	Whether or not a company also produces hardware	

Openness on the user level	In what way does the degree of openness on the user level plays a role?	Openness towards app developers in Google Play store	Repeat conceptualisation
Openness on the device level	In what way does the degree of openness on the device level plays a role?	-	Repeat conceptualisation
Maturity	In what way does the maturity of your/the platform owner's organisation plays a role?	-	Phrasing differs based on function and company of respondent
	Can you think of any other organisational characteristics that impact your/the platform owner's desired degree of platform level openness?	-	Phrasing differs based on function and company of respondent
Closure			
Missed factors	Given this interview, can you think of any other factors that impact your/the platform owner's desired degree of platform level openness?	-	Phrasing differs based on function and company of respondent
Prioritisation of factors	Given the factors we discussed in this interview, which ones do you consider the most important?	-	
Further comments	Do you have any further comments?	-	
Transcribed interview	Do you want to review the transcribed interview?		
Thanks and goodbye			

3.4 Interview Analysis

Usually, when analysing transcribed interviews, the coding process consist of three stages: open, axial and selective coding (Corbin & Strauss, 1990). The result of the open coding phase is a list of codes that segments the raw data into fragments that have similar meanings. Each fragment is represent by a code – a conceptual label that expresses the meaning of the fragment (Boeije, 2009). In the axial coding stage, the level of abstraction increases; similar codes are combined and the codes are grouped into categories and sub categories. Relationships between (sub)categories are defined (Boeije, 2009). Finally, the selective coding phase marks the end of the analysis and aims at building a theory to answer the research question. Important categories and possibly a core category (i.e. central phenomenon around which all the other categories are integrated) are determined (Boeije, 2009).

The general strategy described above is also followed for this research. However, because a preliminary theory was available, the coding process didn't start with the raw data. Instead, an initial list of codes and categories was developed based on the preliminary theory (theoretical framework in section 2.3). Then, during the open coding phase, new codes were added to this list. This is a more goal oriented approach with the advantage that you are able to build on existing theory (Miles & Huberman, 1984; Sekaran & Bougie, 2016). Table 5 describes the coding process. Throughout the whole coding process, notes were kept during the analysis of each interview, describing the most important factors and interrelations. These notes were used as a basis for drawing conclusions and writing chapter 4. The transcribed interviews were analysed with help of the ATLAS.ti coding software.

Table 5: Coding process

Phase	#Codes	#Categories/ #Sub categories	Approach and examples

Initial	85	6 / 10	Categories and sub categories are copied from the preliminary theoretical framework presented in section 2.3. Codes are assigned based on the literature that lead to developing this preliminary conceptual model.
			• A reduced chance of lock-in could be a reason for end-users to adopt a platform earlier (West, 2003).
			    o Code: low chance of lock-in
			    o Category: perceived effect on business outcome
			    o Sub category: userbase
			• Reputational damage will occur if bad complements are added to a platform (Boudreau, 2012)
			    o Code: reputation of company
			    o Category: organisational characteristics
			    o Sub category: maturity

Open	181	6 / 10	The initial list of codes is used to label fragments in the interviews, if a fragment did not fit with one of the codes, a new code was assigned.
			• *"I guess that sometimes platform providers may have incentives to keep the platform closed and to create some kind of lock in and high switching costs so that their customers don't escape to another platform."* (Interview 3)
			    o Assigned codes: create lock-in, create switching costs, platform level openness
			• *"We cannot share everything, also due to privacy reasons and stuff and also al lot of discussion is ongoing; who is owning which set of data? So what is car generated, what is customer generated, what is in between. Therefore we are very careful. But the kind of data that we could share – especially for safety reasons – we are more than willing to share."* (Interview 7)
			    o Assigned codes: ability to safeguard end-user privacy, GDPR/privacy law, importance of data privacy and security, possibility to

			improve public safety, platform level openness
Axial	104	6 / 12	The categories developed in the initial stage are reconsidered and similar codes are merged. • The category 'Corporate Social Responsibility' is merged with the sub category 'Values', under the main category 'Organisational Characteristics' • A new main category – 'Characteristics of potential partner' – is created. • The code 'Impact on margins' is merged with the code 'Ability to capture rents'.
Selective	104	6 / 12	A theory is developed by relating important categories around the core category (platform level openness), see chapter 4.

4 Results

This chapter aims to answer the second, third and fourth research question by identifying, prioritizing and theorizing the interrelations between factors influencing the desired degree of openness between IoT platforms[6]. Section 4.1 and section 4.2 respectively discuss the business and context factors influencing the decisions from platform providers regarding the desired degree of platform level openness. The trade-offs between those factors are discussed in section 4.3. As a result from analysing the interview transcripts, the preliminary conceptual model developed in section 2.3 has been updated. The updated theoretical framework is presented in Figure 14. Compared with the preliminary framework, the following has been changed with respect to the general structure (i.e. the main categories):

- The main category 'Corporate Social Responsibility' is removed because it turned out that this is very company specific. In the new model, it falls under the sub category 'Values', under 'Organisational characteristics'. In the new theoretical framework CSR is mediated by the 'Perceived effect on business outcome' instead of having a direct impact on the desired degree of platform level openness. This entails that the evaluation of a certain use case (i.e. desired degree of platform level openness) is affected by the organisation's attitude towards CSR via the impact of the category 'organisational characteristics' on 'perceived effect on business outcome'.
- An arrow is added from 'Market characteristics' to 'Legal requirements' because it has been found that some categories of 'legal requirements' are dependent on the market.
- Sub categories have been altered and a second level of sub categories has been added in some cases. These changes are discussed in the respective sub sections.

4.1 Business Factors Influencing the Desired Degree of Openness between IoT Platforms

This section discusses the business factors influencing the decisions from platform providers regarding the desired degree of platform level openness. In doing so, it provides an answer to the second research question. The identified categories of business factors are the perceived effect on business outcome and the legal requirements. These are discussed in respectively section 4.1.1. and section 4.1.2. Because it has been found that decisions on platform level openness are always made in the context of a certain use case, several dimensions have been added to the dependent variable 'desired degree of platform level openness'. These dimensions are discussed in section 4.1.3.

4.1.1 Perceived Effect on Business Outcome

The interviews proved that the perceived effect on the business outcome is the main driver for all decisions regarding the desired degree of platform level openness. Esentially, the factors that are grouped in this category explain the ideal level of platform level openness withouth taking into account the legal restrictions. With respect to the preliminary model developed in section 2.3, only a minor change in structure has occurred; the categories 'Effect on userbase' and 'Direct profit & losses' are grouped under 'Business case' due to their interrelated nature. Section 4.1.1.1 discusses this in more detail. Strategic considerations and data privacy & security considerations are discussed respectively in section 4.1.1.2 and 4.1.1.3.

[6] Interviews are referred to by the numbers in the first column of table 3 (e.g. [I12] for Interview #12).

4.1.1.1 Attractiveness of Business Case: Economic Considerations

Nearly all respondents said that the most important factor in deciding about the desired degree of platform level openness is related to the business case; whether you can profit from the openness or not. To determine if a business case is profitable, several factors have to be taken into consideration. Firstly, you have the direct costs and benefits resulting from the openness decision. Secondly, the impact on the attractiveness of service offering and thirdly, the uncertainty about value. An overview of these factors and the relations between them is presented in Figure 10. The remainder off this section describes these factors in more detail.

Costs of Platform Level Openness

First and foremost, there are the costs directly following a decision about platform level openness. Examples of such costs are: maintenance costs, development costs and R&D costs of the interoperability solution. In general it means that if these costs are high, a platform will be less willing to open up because the benefits of opening up must be greater to outweigh the higher costs. Obviously, these costs are highly depended on the context in which the openness decision is made. For example, in immature markets, R&D and development costs are generally higher (e.g., I11). The impact of the market maturity and other context factors on the direct costs following a platform level openness decision are further discussed in section 4.2.

While the high costs associated with an interoperability decision usually limit platform level openness, they could indirectly lead to higher platform level openness through shared development and strategic partnerships. For example, one of the reasons why an automotive driver association chose to develop the IoT platform for their service offerings together with other automotive driver associations is related to the high development costs (I11). While this is strictly not defined as platform level openness because there is no exchange between two independent platforms (see section 2.2.4), it leads to more interoperability because otherwise, independent platforms would have been developed in which the services would not have been interoperable.

Another example can be found in government sponsored partnerships, aimed at facilitating innovation and finding new possibilities for collaboration. A senior engineer at a truck OEM indicated that without governmental subsidies, his company would not have worked together with a competing truck OEM to jointly develop V2X technologies (I9). Furthermore, governmental sponsored projects, aimed at facilitating knowledge sharing, often lead to new partnerships and ultimately higher platform level openness (I6). Thus, the impact of partnerships shared development on the degree of platform level openness is twofold. Firstly, because the direct costs associated with an interoperability solution can be spread over multiple partners, the business case for opening up will become attractive faster because the benefits will outweigh the costs earlier. Secondly, there is also a direct impact on the degree of platform level openness since working together often entails that the platforms will open up towards each other (e.g. as a result from using the same standards).

Another interesting finding is that a lot of organisations are either not sure about how valuable the data is they have or how they should profit from it. An IoT expert with a cross domain focus, servicing large companies across all industries, labelled this as the hidden value of data (I13):

> *"Today, a lot of companies have a lot of data, and they do not want to share it simply because they are afraid somebody else sees a value that they don't see. They are afraid that they are giving away something for free. We are actually observing this in the marketplace with our customers: companies do not want to share data even if they don't know the actual*

reason. They are afraid to give something away and find out later that there was value in it." – IoT Industry Leader (I13)

This is also reflected in some of the interviews held within the automotive industry. Multiple respondents said that OEMs are not sure how they should profit from all the data they have or that they are looking for an 'outlet' for their data (I10; I12; I7). Another source of uncertainty relates to the immaturity of the market, which makes investing in certain technologies riskier if you don't know if the technology is going to prevail. The impact of market maturity is discussed in more detail in section 4.2.1.3.

Benefits of Platform level openness

An IoT platform can also benefit, either direct or indirect, from increased platform level openness. Direct benefits could result from the ability to charge fees for access to the platform (e.g. every time an API is invoked) or increased revenues from a new pricing model, made possible by the interoperability decision. An example of the latter option can be found in the healthcare industry, where service oriented business models are replacing the traditional product oriented business models. Within hospitals, there is increasingly more collaboration between formerly separated departments. This trend is also reflected in the service offerings of equipment manufacturers because nowadays, there is often one company responsible for the design of a whole care path[7] (I1). This entails that instead of selling just the medical equipment, the manufacturer also advises and in some cases helps to finance the reorganisation.

The increased inter-organisational collaboration in hospitals also requires that data can flow more easily between the medical devices. Because not all equipment is manufactured by the same company, there is need for higher openness between the IoT platforms used to manage the equipment from the different brands. So instead of paying a one-time and periodic maintenance fee for each piece of equipment, hospitals pay a service fee for everything related to a care path to a single manufacturer (who could make use of the equipment from other manufacturers in order to provide a full service package). This has numerous advantages:

- Care becomes more flexible and efficient because the equipment is designed for interoperability.
- There are more long term contracts between hospitals and equipment manufacturers, which leads to less risk for both parties.
- The purchasing process becomes more efficient because equipment from other manufacturers can be bought in bulk by the company providing the service to the hospital
- Manufacturing costs can be reduced because there is less need to release new versions of a product to keep up with the competition. Thus, fewer versions of a machine can be maintained (e.g. 2 types of CT-scanners instead of 20). The focus shifts to the whole service package instead of a single piece of equipment.

A similar trend can be seen in the fitness industry, where there is an increased need for platforms integrating different services (I4). This benefits both the platform provider and the company making use of the platform, such as a gym. The gym has to maintain fewer relations with parties providing parts of a service because the platform acts as a broker between the connected services and the

[7] The subsequent steps, decision moments and criteria in the care taking process for a group of patients with a specific care need - http://hetkleinezorgpadenhandboek.nl/wat-is-een-zorgpad-2/

gym. This leads to savings in coordination costs and an improved service delivery. For the platform provider, having such a position is beneficial due to strategic reasons (e.g. it controls all cash flows).

Apart from the direct costs and benefits related to the opening up, there is also an indirect effect on the attractiveness of a business case, which can cause platforms to open up on the platform level. A lot of respondents mentioned that they opened up to other platforms because it would enhance the quality and attractiveness of their services for end users. In this way, then can either sell more products and services to new users or additional features and products to existing users. These decisions are often motivated by end-user demand. An example would be to connect your platform to more data sources in order to increase the quality of the algorithms. In general, opening up to another platform is beneficial if the potential partner does not threaten the business model of the focal platform and if there are complementarities between the service offerings. This is discussed in more detail in section 4.1.3.

Next to increasing the attractiveness of the service offering, the size of the userbase (and therewith the attractiveness of the business case) can also be effected by network effects. For example, a platform integrating fitness equipment is more interesting for end users if the number of compatible fitness devices increases. The other way around: it is more interesting for manufacturers of fitness equipment (or other connected services) if more people make use of the platform (I4). Another way to directly affect the sales is via the removal or creation of switching costs. By lowering switching costs, a platform becomes more attractive to end-users but on the other hand, it could also result in existing customers migrating to other platforms (i.e. churn). Especially within the fitness domain, there is a tendency to create high switching costs to maintain existing userbases (I3; I4).

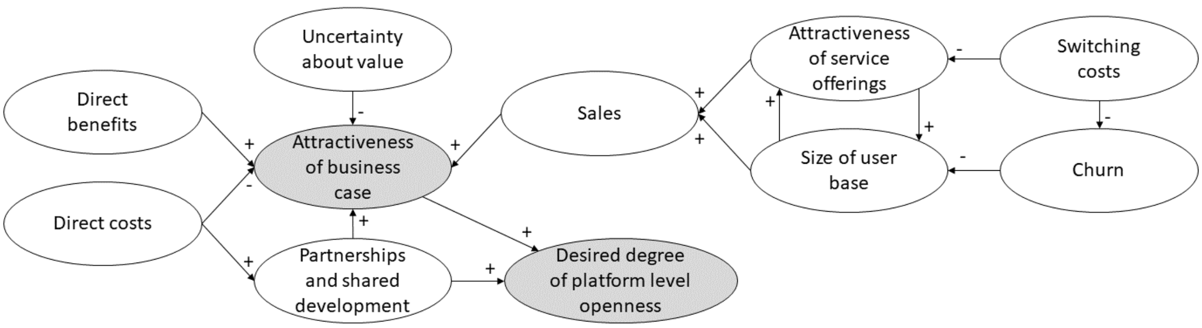

Figure 10: Factors influencing the attractiveness of an IoT platform level openness business case

4.1.1.2 Strategic Considerations

Besides economic reasons, there are also strategic reasons influencing the desired degree of platform level openness. These strategic considerations can be grouped in the following categories: knowledge development, market position and control over product development. These categories are discussed in this section.

Knowledge Development

Especially in the automotive industry, there are currently a lot of EU- or government funded projects. For example, within the EU-funded SOCRATES$^{2.0}$ project, governmental parties, car manufacturers and other technology companies work together to explore different use cases related to smart traffic management. Examples of such use cases are smart routing advice based on current traffic or real time updates concerning dangerous road situations. To make such services possible, the IoT platforms of the different ecosystem players have to become interoperable, which entails that the platforms have to open up towards each other.

The main reason for ecosystem players to collaborate in such projects and to open up their platforms is to generate knowledge (I6; I7). By working together, the ecosystem players can find out which use case have potential. In this way, they generate knowledge about the way in which the market is developing. They could also generate knowledge about other ecosystem players (I6; I9). For example, which data they have, which role they want to play or what the rationale is behind their decisions is (e.g. gain insight in the governmental view on autonomous driving). These insights are then used to steer their own product development and R&D efforts.

Obviously, these projects are most often found in immature markets. Because the main objective is to generate knowledge, other factors are less important in the decision to participate in such a project or not. For example, participants will most likely not earn anything and will be less reluctant to work with a direct competitor in a pilot setting. The main goal is to gain insights in how the playing field is changing and how the focal company should position itself within this playing field. It could be that a pilot project leads to a permanent collaboration afterwards but this will often not be the case and new partnerships will be formed based on the required insights (I6).

Market Position

When making decisions on whether or not to make an IoT platform interoperable with other IoT platforms, organisations also think of their strategic position in the market. For example, a company integrating fitness equipment makes different platform level openness decisions in various countries, affected by the respective market shares (I4). In countries where they have a small market share, they try to integrate their platform with as many other platforms as possible, to introduce their product to other ecosystem players and to expand their userbase as fast as possible. However, in countries where they have a leading position in the market, they follow a more closed strategy to avoid that their existing customers run away to their competitors. Other considerations related to the maturity of a company are discussed in section 4.2.2.2. Exploitation strategies like forking[8] could also play a role but none of the respondents indicated that the risk of forking was a reason for them to remain closed.

Closely related to the impact on market power is the ability to influence market developments. An example of this is related to the formation of standards (either de jure or de facto[9]). For example, car and truck OEMs have multiple projects running related to autonomous driving. In these projects different technologies are used and the OEMs want to influence future market developments in such a way that ‘their’ standard is used (I7; I9). By opening up to other platforms, companies can prove that their standards work. This gives them more credibility in negotiations at round tables and standardisation bodies that try to establish de jure standards. Furthermore, by actively pushing a standard in the market (which entails higher openness), companies try to turn their standard into the de facto standard. Standards are discussed in more detail in section 4.2.1.3.

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[8] A specific type of exploitation strategies where companies try to create a spin-off based on an existing platform to attract users to their own platform.
[9] De jure standards are established by law while de facto standards have obtained widespread acceptance (>50% market share) through market competition (Den Uijl, 2015).

Control Over Product Development

In the healthcare domain, companies also work together in immature markets to *"define the string of pearls" – Director at company manufacturing medical equipment* (I1). In an early stage of the market, there are no established ways of working or vested interests resulting from large investments in other interoperability solutions. Therefore, companies can adopt a more greenfield approach which entails that they have more control over their own product development. If you wait until other market players develop solutions, there will be more resistance if your own solution is conflicting with the interests of the other market players. Also the type of interoperability solution can affect the control a company has over its product development. For example a company manufacturing medical equipment only wants to be interoperable via a meta-platform that is loosely coupled with their own products because otherwise dependencies with other manufacturers become too large, affecting the room to develop their own product portfolio (I1).

Another example of how autonomy over product development relates to openness can be found in the automotive industry. Wanting to have greater control over their own product development was a reason for a company offering a service in the automotive industry to develop a platform with sister companies who had the same goal instead of with a producer of aftermarket car parts (I11). They started off with the latter company but quickly found out that their goals differed too much. Working together with likeminded companies was beneficial in multiple ways:

- It lead to savings on R&D and development costs (see also section 4.1.1.1)
- More power in negotiations with other market players, resulting from the greater size of the combined platform (see also section 4.1.1.2).
- More control over own product development compared to working together with another type of company (but less control compared to doing it all by yourself).

4.1.1.3 Data Privacy and Security Considerations

As expected based on the preliminary conceptual model, data privacy and security considerations play a major role in decisions about the openness of IoT platforms. However, how important data privacy and security considerations are in decisions related to platform level openness is determined by the attitude of the market towards data privacy and security in general and the attitude from a specific organization in particular. Besides this, legal requirements also play a role.

Generic Privacy and Security Considerations

The introduction of the GDPR privacy regulation in Europe has forced organizations to take better care of the personal data from the end-users of their products and services. Respondents in both domains mentioned that data privacy and security is, partly due to the new GDPR regulation, now one of the primary concerns when making decisions about platform level openness. A PhD candidate researching wearables in the fitness domain also indicated that besides the legal implications, the GDPR also caused a change in attitude towards the importance of data privacy and security for most of the companies he researched. In general, data privacy and security considerations causes platforms to be less open towards other platforms. This has several causes:

- Partners are selected more strictly. Organisations that care about privacy and security will only do business with those partners that have the technological and organisational capabilities to follow the same standards as the focal company. This judgement can be based on certifications (I2) or the reputation of a potential partner (e.g. I13). If two organisations decide to work together, privacy and security demands are often anchored in the contract or service level agreement (SLA) (e.g. I5). An example of this can be found in the fitness domain, where current partners of a platform integrating fitness devices have a veto over whether or not another party can join the platform (I4).

- Less applications are considered. If an application involves the sharing of personal data from end-users, their explicit consent is required. This makes it harder to introduce new features to a product or service because every time, the consent of the users is required (the consent has to be for a specific application). This constraints development (I11) but also limits the type of applications that are considered because organisations don't want to ask for consent over and over again and because they are aware that users will only give their consent if they get something out of it (I7; I8). In the automotive domain for example, OEMs are reluctant to share data due to this (I6; I7; I8).
- Less ways to open up are considered. A civil servant – coordinating IoT projects in the automotive domain – mentioned that the organisations participating in the project where only willing to share data via a Trusted Third Party (TTP), due to security concerns and the related fear that their data might end up with their competitors.
- There is more economic friction[10]. Because there are more formal requirements, for example in the form of a data processing agreement or the requirement of a Privacy Impact Assessment, it will cost organisations more to be compliant. Therefore, the economic threshold of when a certain use case becomes profitable will be higher. Besides this, it could be that certain use cases cannot be organised optimally because it is prohibited to share or link certain data. An example of this can be found in the medical sector (I1). Scheduling services in the hospital care could be better organised if the scheduler would have access to more data. For example: the agenda of patients and doctors, where a patient lives and whether he or she has to use public transportation or if a patient has been to a certain hospital or doctor before.

However, data privacy and security considerations can also cause platforms to be more open. This is a result of the data portability regulations that are part of the GDPR (I11; I3). Due to these regulations, customers should be enabled to take their data with them to another organization. It thereby lowers the switching costs and increases the possibility to multi-home. However, in practice it is often not possible to fully transfer all of your data (I3).

Domain- and Organisation Specific Privacy and Security Considerations

Where the above conclusions hold for all domains and organisations (probably because the GDPR and other general regulations concerning privacy and security are domain independent), there are also differences between organisations and markets. Especially in the medical sector data privacy and security is of utmost importance due to the extreme sensitivity of data. Something that is also reflected in the sector specific regulation. A director of a company producing medical equipment indicated that it usually takes them two to three years to introduce a new feature where it would take a company in the fitness domain only a few months (I1). This is partly because in the medical sector, a company is fully liable for errors caused by its equipment. Because you are dealing with human lives, such claims can reach enormous amounts.

However, according to a PhD candidate researching wearables in the fitness domain, respondents in his research also mentioned that data privacy and security is one of their top concerns when making

[10] Extra costs not directly related to the primary product or service delivery. See also section 4.1.3.

decisions about openness (I3). This was also reflected in an interview with the CTO of a platform integrating fitness equipment (I4). In contrast, an integration specialist of a company manufacturing fitness equipment indicated that they do take privacy and security considerations into account but that it is more a boundary condition, not something that plays at the forefront of the decision making process around platform level openness (I5). This indicates that the importance of privacy and security in decisions regarding platform level openness can differ between companies, even within the same domain.

Another factor that influences how privacy and security considerations play a role, is the country of the focal company. For example, multiple respondents indicated that German companies have a stronger focus on privacy and security. This was reflected in interviews with German respondents, but also in interviews with Dutch respondents who talked about their German partners. Besides this, one respondent representing a car OEM mentioned that after Dieselgate[11] (ethical) values, such as valuing end-user privacy, are considered more in decisions that OEMs make (I8). Finally, the overall company objective (i.e. profit vs. non-profit) also determines how important end-user privacy and security is for an organization (I11).

4.1.2 Legal Requirements

Legal requirements influence platform level openness in multiple ways. They have to be adhered to and in that way, they could either limit or fuel platform level openness. Legal requirements are a cause of lower platform level openness when they impose restrictions or additional demands on collaboration or interoperability with other IoT platforms. In such cases, legal requirements are a cause of economic friction (i.e. extra costs not directly related to the primary product or service delivery). These costs could for example be associated with requirements for documentation or other obligations, like the requirement to do a privacy impact assessment. Due to economic friction, a higher profitability threshold has to be passed before a business case becomes profitable and therefore they can limit platform level openness (see Figure 11).

However, the presence of economic friction can also be a reason to design legislation aimed at reducing this friction. This is often the case with standardisation, where the presence of a compatibility standard makes it more easy to collaborate and thus makes opening up on the platform level more attractive. Besides general laws & regulations (e.g. dealing with contract law or liability), respondents mentioned the influence of the following categories of laws & regulations specifically. These categories are elaborated upon below.

- Privacy and security regulations
- Sector specific regulations
- Competition law

4.1.2.1 Privacy and Security Regulations

Nearly all respondents indicated that privacy and security are among the most important factors to consider when making decisions about platform level openness. The recent introduction of the GDPR in Europe plays a big role in this. Due to the importance of this factor and the interrelatedness with other factors, privacy and security considerations are discussed separately in section 4.1.1.3.

[11] A scandal related to the manipulation of environmental performance data of diesel cars that got a lot of media attention.

4.1.2.2 Sector Specific Regulation

Sector specific regulation is often focused at data privacy & security (discussed in section 4.1.1.3) or compatibility standards (discussed in section 4.2.1.3). In heavily regulated domains, like healthcare, sector specific regulation makes up for a large part of the legal requirements that a company has to follow. Because sector specific regulation is often slightly different across various countries, it can impose an extra burden for companies that do business across borders. Furthermore, differences in regulations between (sub)domains make it difficult to organize interoperability between those (sub)domains (I13; I3). This is for example the case in the healthcare domain, where you have the highly regulated medical subdomain and the less regulated fitness subdomain. The data gathered by fitness wearables could be useful for medical applications but due to the high legal requirements in the medical subdomain it is hard to make use of this data.

An example of sector specific regulation in the automotive industry is the requirement for trucks to have a tachograph: some kind of black box that logs certain details about the ride, like if a driver has rested enough. Recently, new regulations were implemented in the EU that forces truck OEMs to integrate specific communication capabilities into the tachograph, such that they can be read out from a distance. There was a lot of resistance from the automotive industry because there was no specific benefit for them and there were superior technologies available that could more easily be integrated with V2X applications that were being developed at the time (I9). Thus, in this case, sector regulation is a cause of higher platform level openness. The mode of openness is also determined by the legislation in this case.

What often came forward in the interviews held with respondents from the automotive industry is that uncertainty about sector specific regulation can hamper product development. One example is related to the mandatory OBD-port in the car. The regulation enforcing this port was originally designed to enable independent car repair shops to do maintenance. However, a lot of aftermarket solutions where designed that made use of this port to make a car ‘connected’. This can for example be used for fleet management purposes or predictive maintenance by third parties (I11; I12). Thus, legislation concerning the OBD port unintentionally caused a higher degree of platform level openness.

Without this OBD port, access to the required data is controlled by the OEMs. Therefore, OEMs heavily oppose the use of this OBD port (because they lose a possibility to make profit out of this data). Furthermore, they argue that misuse of the port for these kind of continuous appliances can cause safety issues. Because of this, new regulations are being discussed at the EU level on how this should be dealt with. A company working on fleet management software is holding back on development of products that make use of this port due to the uncertainty about the regulations related to the OBD port (I12).

Another example related to uncertainty about legal requirements concerns the development of autonomous driving. Because current regulations are aimed at cars driven by a person, a lot of questions (e.g. relating to liability) remain unanswered for autonomous vehicles. Governments are still struggling with these issues because they do not want to hamper innovation on the one side, but also don’t want to open the road to experimental vehicles that can cause safety issues and where questions related to liability remain unanswered (I6).

4.1.2.3 Competition Law

Especially in the automotive sector, competition law has an important influence. Due to some scandals in the past, related to cartel forming, OEMs are afraid to collaborate with each other (I10). Therefore, they do a lot to make sure that a specific collaboration is allowed and in grey areas, they rather stay on the safe side. At least one OEM has a whole department called “cartel law” (I8). Such attention to possible cartel forming is something that has only been found in the automotive industry. Respondents from the other domains indicated that they pay little attention to cartel laws, probably because those domains are quite small and fragmented opposed to the automotive industry. Due to competition law, OEMs are also forced to work together (if they want to) in a standardized way, via a neutral data platform – a meta-platform hosted by a Thrusted Third Party (TTP). Interoperability via a direct converter between two OEMs is likely to be seen as cartel forming (I10).

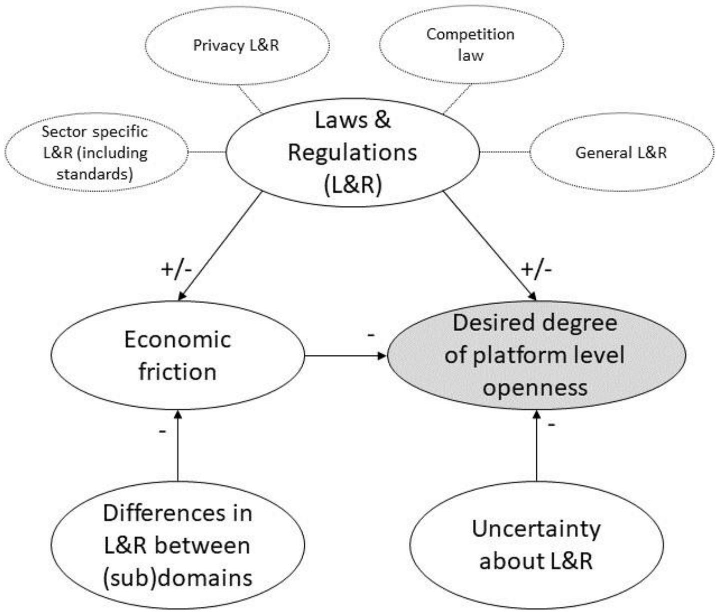

Figure 11: Legal requirements and economic friction

4.1.3 Characteristics of potential use case: Dimensions of Platform Level Openness

During the interviews, it became clear that decisions regarding the desired degree of openness are always made in the context of a certain use case. Organisations don’t just open up their whole platform, instead, they open up their platform for a specific application and a specific partner. For example, sharing aggregated location data (=application) to inform authorities (=partner) where there is traffic. Besides the application and the partner, it also matters in what way a platform opens up (mode of openness). These variables are discussed in this section. In the conceptual model in Figure 14, these variables are added as dimensions to the dependent variable ‘desired degree of platform level openness’.

4.1.3.1 Application

What came forward in almost all of the interviews is that organisations only want to open up for use cases where there are complementarities or synergies between the product portfolio of others and their own (i.e. when the value of the combined service is higher than the combined value of the two separate services). The main rationale for this is that without complementarities, you are not creating any extra value and it only increases the chance that end-users might walk away to the competitor (i.e. you are reducing lock-in). You have to ask yourself the question: when it is interesting to have data from both platforms available? Which extra services does this enable? For example, an integration specialist at a manufacturer of fitness equipment said that they will only make their platform interoperable with membership management software (something not part of their own service offerings) or other functionalities that add value to their product. They would never integrate with other gym equipment because they offer all types of gym equipment themselves and integrating with other brands of gym equipment only lowers the lock-in into their own ecosystem (I5).

Another example can be found in the automotive industry. Owners of an electric car are dependent on electronic charging stations, which are currently not very widespread. Therefore, it is in the interest of a car OEM to connect their car (i.e. IoT platform) with the IoT platform of charging station providers. This is beneficial for the car OEM, the provider of the charging stations and the consumers. The car OEM can increase the attractiveness of their product (i.e. connected car), which leads to higher sales (see also section 4.1.1.1). The charging station provider can increase the utilisation of their charging stations and for the consumers, it becomes easier to find a charging station if they need one (I13; I8). A second reason to open up, next to the presence of complementarities, could be because it is a requirement to enable a certain service. This is for example the case in the medical domain, where it is important that data can be shared across multiple pieces of equipment, made by different manufacturers (I1). Without platform level openness this is not possible. This application is extensively discussed in section 4.1.1.1.

Next to the application, also the type of data that will be shared is important. Partly due to the GDPR because you cannot share personal data of end-users without their explicit consent (I13; I7; I8). This is further discussed in section 4.1.1.3 and 4.1.2. Also, some companies are more inclined to share safety relevant data because it enables them to improve public safety and fulfil their corporate social responsibility. This is further discussed in section 4.2.2.3. Of course, the type of data is also closely related to the type of application and whether or not there are complementarities. The following quote illustrates that for a company, opening up is only beneficial if there are complementarities. In in this case because energy networks could be managed better.

> *"Data that is very car specific and is going to be used in a car specific use case; I think that is a domain that [company name] knows very well and we will try to make a business case on that. But for car data that can be used in other domains, like energy generation, we will provide a platform to give access to anonymized data to support these use cases. You could for example use information from the light sensors in a car to predict where it is going to be sunny, so you can manage your energy network better." – Technology & Trend Scout at a car OEM* (I8)

4.1.3.2 Partner

Related to the type of application is the type of partners that organisations want to become interoperable with. Because there have to be complementarities, partners will usually not have the same position in the value chain. If you become interoperable with companies that have a similar product portfolio (i.e. competitors), you have the risk that end-users might run away to the other platform. The more intense the competition is, the lesser companies are inclined to work with competitors (see also the discussion in section 4.1.1.2). However, what is interesting to see is that a lot of companies choose to be open via open API's in order to stimulate innovation around their products. This also means that they have less control over the other platforms that become interoperable with them because the API's are not restricted. For example, Garmin (i.e. brand of wearables) has open API's that can be used by other organisations. Thus, this indicates that there is a trade-off between protecting your market position on the one hand and stimulating innovation around your platform on the other hand. Other strategic considerations are discussed in section 4.1.1.2.

Besides this, the maturity of the potential partner also plays a role. Generally, the more mature a company is, the less risk there is in the collaboration. For example, smaller companies with less developed technological and organisational capabilities have more issues with providing a stable and secure interoperability solution (I4; I5). This is especially important in heavily regulated domains, like the medical domain. Especially for vertically integrated providers of IoT platforms (i.e. those who also manufacture the IoT devices) maturity is often important due to scalability in production of the devices. Other considerations with respect to the technological capabilities or reputation of the potential partner are discussed in section 4.1.3.2.

Like in all collaboration decisions, factors like the location of the headquarter (i.e. jurisdiction) or ethical values also play a role. Obviously, if a company published open API's, it is also a lot easier to become interoperable with. Furthermore, other ecosystem players can work more easily with governmental organizations because they do not have to be afraid that the government will try to steal customers or something. For example, there are multiple projects running where car OEMs share safety relevant data with governmental parties .

4.1.3.3 Mode of Openness

Just as that the type of application and the potential partner matter, it also matters in what way you open up. For example, in complex ecosystem where not just two, but multiple parties should be interoperable with each other, organisations usually want to make use of standards (see section 4.2.1.3). This can easily be combined with a meta-platform to which multiple platforms connect. An advantage of such an approach is that all data can be kept by a neutral party; one that is trusted by all players in the ecosystem. It could even be a requirement in order to avoid cartel forming (see section 4.1.2). The recent example of BMW, Audi, Daimler, Ford, Mercedes and TomTom, who are sharing safety relevant data via a neutral platform is an example of this. Other considerations that play a role here relate to the development costs of a specific interoperability solution and the time-to-market (I1). For example, a truck OEM also mentioned that they will only open up one-way, such that they receive data from other parties but not the other way around (I9).

4.2 Context Factors Influencing the Desired Degree of Openness between IoT Platforms

This section discusses the context factors influencing the decisions from platform providers regarding the desired degree of platform level openness. In doing so, it provides an answer to the third research question. The identified categories of context factors are the market and organisational characteristics. These are discussed in respectively section 4.2.1. and section 4.2.2.

4.2.1 Market Characteristics

The characteristics of the market in which the decisions regarding platform level openness are made, are an important context variable influencing how decisions are evaluated. With respect to the preliminary theoretical framework, the following structural changes occurred:

- The subcategory 'need for specialisation' was replaced with the broader subcategory 'characteristics of supply side offerings' because there are more characteristics that turned out to play a role. This is reflected in a new level of subcategories.
- The subcategory 'competitive landscape' was replaced with the broader subcategory 'characteristics of ecosystem' because besides competitors, there are more stakeholders in the ecosystem that influence decisions on platform level openness.

4.2.1.1 Characteristics of Supply Side Offerings

One of the main factors influencing platform level openness decisions is the demand of end-users; they have a large influence on the type of products offered in a market place and also on the features that these products have. In this case platform level openness. For example, Apple Health and Google Fit are compatible with a lot of fitness wearables. A lot of end-users will only buy a certain wearable if it is compatible with their preferred ecosystem. Therefore, companies are 'forced' by end-users to make their device interoperable with the two large platforms (I3). Otherwise, they will have a competitive disadvantage. Furthermore, the CTO of a platform integrating fitness services indicated that potential customers often request that certain services (often the ones which they are currently using) should added to the platform before they want to make use it (I4).

Another characteristic of the supply side offerings that is a good predictor of the amount of platform level openness, is the need for specialisation; the degree to which companies can produce a complete service on their own. Especially in the healthcare sector, you see that there is a high need for specialisation. Both in the regulated and less regulated domains. For example, a company producing medical equipment indicated that they want to be responsible for a whole clinical care path[12]. They cannot produce all required equipment themselves and therefore they have to make their products (connected to an IoT platform) interoperable with equipment from other manufacturers. Otherwise they cannot deliver a complete service package to the end users (i.e. the hospital) (I1). See also Figure 12 and section 4.1.1.1 for a more elaborate discussion of this particular example. Another example related to the need for specialisation can be found in the existence of a platform integrating fitness equipment (I4) or a platform integrating medical devices with other services and fitness wearables (I2). Such platforms can only exist because there is not a single company that is able to produce all the required components.

Closely related to the need for specialisation is the need for product differentiation: if switching costs between platforms are low or users have the possibility to multi-home, the churn rate[13] will be higher. This will be further intensified if there is a lot of competition. To counter this effect you could either create switching costs or you need to have sufficient product differentiation in order to be able to distinguish yourself and keep users affiliated with your platform (I2; I3). See Figure 12. Companies producing fitness wearables usually stick with the former strategy by creating switching

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[12] The subsequent steps, decision moments and criteria in the care taking process for a group of patients with a specific care need - http://hetkleinezorgpadenhandboek.nl/wat-is-een-zorgpad-2/

[13] Percentage of users that leaves your platform in a certain time period

costs (e.g. by making it hard to transfer your data to another platform) (I3). In contrast, the CEO of a personal healthcare environment[14] indicated that they try to be as much open as possible and keep users affiliated with their platform by making sure they have a unique value proposition (I2). See also section 4.1.1.1 for a discussion on switching costs.

Other characteristics of the supply side offerings are the importance of data privacy and security and the amount of economic friction. Since these factors are closely related to data privacy & security and legal requirements, they are discussed respectively in section 4.1.1.3 and section 4.1.2.

4.2.1.2 Characteristics of Ecosystem

Factors defining the characteristics of the ecosystem are mostly related to the amount and intensity of competition in the marketplace: how intense is the competition, how is the market divided, are there dominant market players, etc. In complex ecosystems with a high need for specialisation, there is a higher need for platforms integrating the different service offerings (see also the discussion on need for specialisation in the preceding section). Instead of making connections with other platforms, an alternative strategy could be to absorb the functionality of those platform in the focal platform, this is called envelopment (see Figure 12).

The automotive industry is an example of an ecosystem that has dominant market players. For example, if a car OEM wants to work together with owners of EV-chargers (e.g. to have them displayed on the navigation system), they can dictate the terms and conditions due to their huge market share in comparison with these smaller parties (I13). Something similar can be seen in traditional supply chains, where Wallmart dictates how other parties should work together with them. In general, markets with intense competition are associated with lower platform level openness, to avoid losing customers (see also Figure 12).

[14] Persoonlijke Gezondheids Omgeving (PGO)

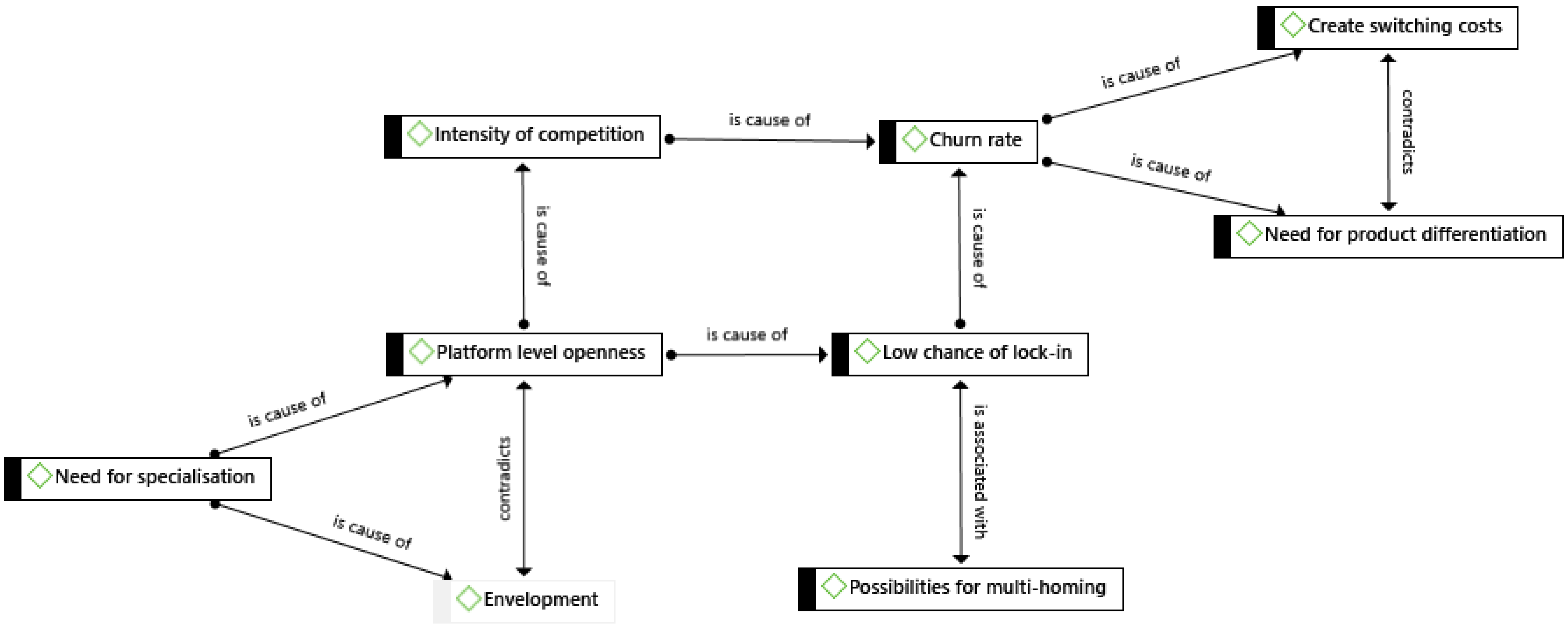

Figure 12: Need for specialisation and lock-in

4.2.1.3 Market Maturity

The maturity of a market determines to a large extent if there are economic frictions. In immature markets, it is harder to collaborate with others because the product offerings are either inefficient or subject to (possible change). This inefficiency and uncertainty comes with extra costs (i.e. economic frictions) and increase the threshold for a business case to become positive. The (im)maturity of market offerings is related to whether or not the business case is clear (section 4.1.1.1), the maturity of available technologies and the availability of mature standards (see Figure 13). As discussed in section 4.1.2, uncertainty about legal requirements also plays a role. This is for example one of the factors hampering the development of autonomous driving (I6).

Availability of Mature Compatibility Standards

In many contexts – where ecosystems are composed of many players – compatibility standards are often the only economically reasonable way to interact with each other. Think of a use case where car manufacturers share safety relevant data with each other. With only 10 car OEMs, you would already have $\binom{10}{2} = 45$ unique groups of two OEMs. If you don't agree on a common standard, high development- and maintenance costs will make interoperability economically unfeasible. Therefore, OEMs only want to be interoperable via standards (I10; I13; I9). Besides, without (open) standards, collaboration could be seen as cartel forming (see section 4.1.2).

Therefore, in some cases, the availability of mature compatibility standards is a requirement for platform level openness. Without standards, collaboration isn't possible. In markets like the automobile industry, where standards are a requirement, you often have standardization bodies: places where negotiations between market players take place to establish shared standards. In these round tables, OEMs take a seat to make sure that their unique requirements are considered in the shared standard (I7). Because often, OEMs have projects running that make use of certain technology. They prefer the standard to incorporate this technology (I9). Due to competing interests, the process can often take a long time. See also the discussion on the ability to influence market developments in section 4.1.1.2.

Examples of issues related to standards that came forward in this research can be found in both domains. In the fitness wearable domain companies have usually developed proprietary standards to work together with app developers. Reasons mentioned for doing this are: the lack of standardization bodies, the slow development of standards and the technological limitations of open standards (e.g. open standards don't support the data exchange required for a feature that the manufacturer wants to incorporate) (I3). An example in the automotive industry is related to truck platooning. There are two competing standards for V2X technologies: the WiFi-standard IEEE 802.11p and the celluar standard 5G. Different truck OEMs had projects running with one of these standards but because it was unclear which standard will be enforced by regulators, nearly all truck OEMs stopped their projects (I9).

Availability of Mature Technologies

The maturity of available technologies can also play a role in platform level openness decisions. If something is technically not possible, you cannot do it of course. However, most respondents mentioned that technology is often not the limiting factor (but standards or strategic considerations are for example) (I4; I6). For example, in the automotive industry R&D centres of OEMs typically only work with technologies that are already proven in the market, they only make the translation from another domain to the automotive industry (I9). An example of this is the 5G technology that will be introduced by mobile operators and can later be adapted for V2X appliances. However, also proven technologies can have technical limitations. For example, a car generate gigabytes of data. It is technically not possible to upload all this data to the cloud. This is why not all openness applications can be realized (I7).

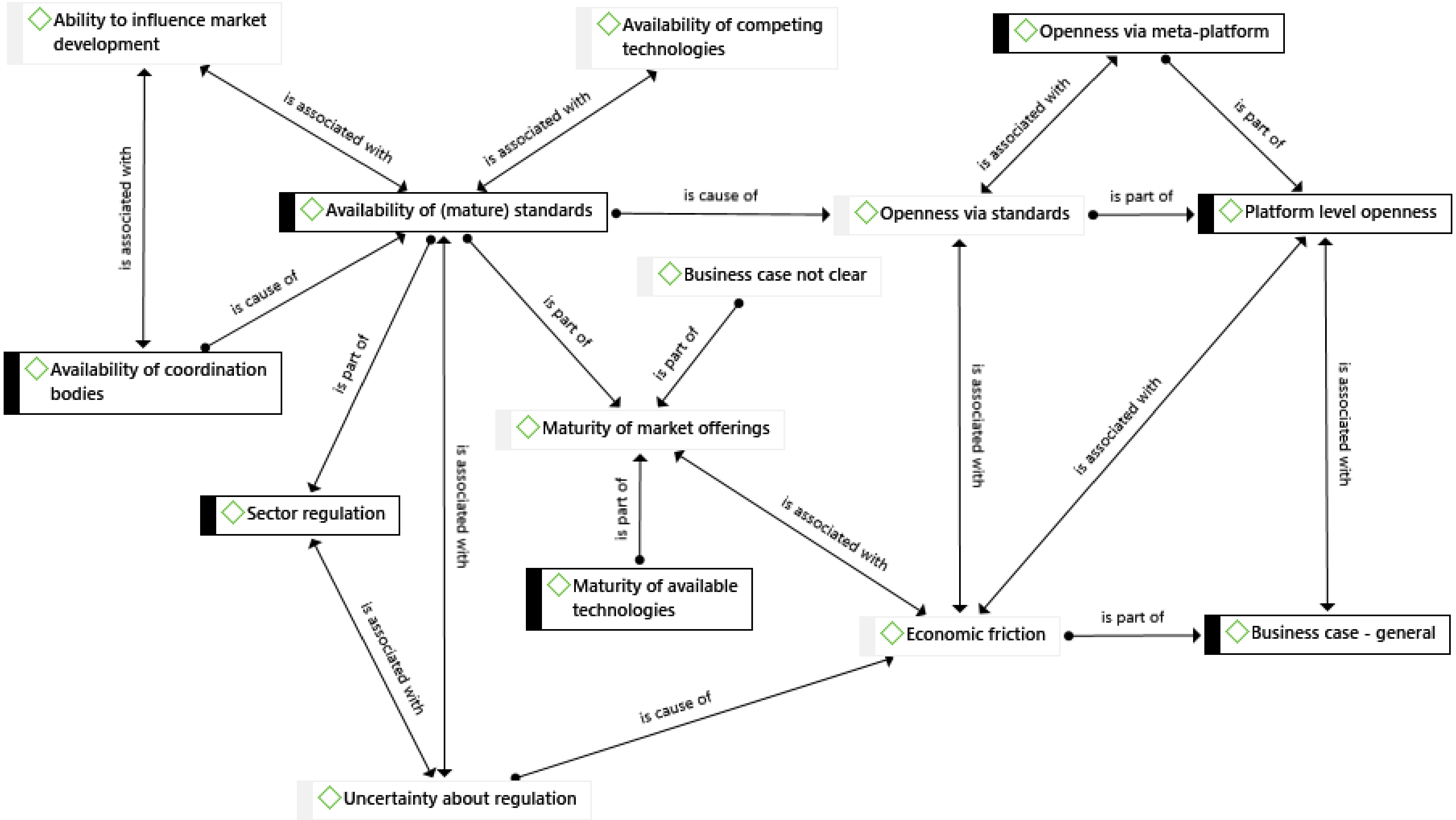

Figure 13: Availability of standards and economic friction

4.2.2 Organisational Characteristics

Next to the market characteristics, the characteristics of the focal organisation also determine whether or not the business outcome of a certain decisions is perceived as good or bad. With repsect to the preliminary theoretical framework, the following has changed:

- As discussed in the beginning of this chapter, the main category 'Corporate Social Responsibility' is removed and now falls under the sub category 'Values'. This is discussed in section 4.2.2.3.
- The categories 'Degree of vertical integration' and 'Openness on user and device level' have been grouped in the category 'Strategy' because they are a result of the strategy that a company wants to pursue. Next to these considerations, other considerations related to the strategy of a company also play a role. These discussed in section 4.2.2.1.

4.2.2.1 Strategy

Two key determining factors for platform level openness are the strategic focus of an organization and the overall business objective. The latter relates to whether you are dealing with a for-profit, non-profit or governmental organization. Because a non-profit organization does not have to make profit, they can pay more attention to altruistic motives, like improving public safety or acting sustainable (I11). The same organisation also indicated that due to their overall business objective, they value user privacy more. The overall business objective does not necessarily lead to different factors determining the desired degree of platform level openness but it will often entail that trade-offs are made differently. This is further discussed in section 4.3.

The strategic focus of a company basically determines how a company wants to earn money. For example, a company manufacturing medical equipment also has an IoT platform. However, they see this platform only as a complementary service to their hardware products and are therefore less interested in its development. Because they don't have a focus on earning money from the platform, they also make different decisions regarding its openness. They will make their platform interoperable with others if this is required to offer a complete service to their customers (i.e. if they are dependent on other market players). They see the platform, and its openness as a means to an end (I1). Namely, to serve their hardware products. For a business case to be evaluated positively, it should be in line with the strategic focus of an organization. This is also why manufacturers of fitness wearables want to connect to as much platforms as possible; they are not interested in profiting from a platform but instead, they want their devices to be sold as often as possible (I3). Which helps if it can connect to multiple platforms because that enhances the attractiveness of their product, leading to bigger sales (see also section 4.1.1.1).

Closely related to the strategic focus of a company is the degree of vertical integration. Often, the strategic focus will be reflected in the degree of vertical integration (i.e. whether or not the platform providers also manufactures the IoT devices). For example, the CEO of a platform integrating medical data indicated that they are not interested in producing IoT devices themselves because that would make it harder for them to profit from the platform. Because now, there are complementarities between the focal platform and the IoT devices connected to it. If they would start to produce the devices themselves, they would threaten the business of their connected services which would make them more reluctant to work with the platform (I2). A similar rationale surfaced in the interview with the CTO of a platform integrating fitness services; because they don't produce the fitness equipment themselves, they can remain independent from their connected services (I4).

Another factor mostly driven by the strategic focus of an organization is the openness on other levels. An interesting observation confirmed by multiple respondents is that there is a correlation between platform level openness and openness on the other levels: opening up is related to a shift in the leadership and company culture, it has to do with your attitude towards openness (I12; I4). Thus, if successes are created by opening up in general (on any of the levels), companies will be more willing to open up in the future. The following quote illustrates this:

> *"So, if I say to a developer that we want lead management and CRM in our fitness platform, he says: 'alright, I will build it'. He doesn't have a vision like: 'alright, which ones are already out there and good, so I can make a connection with one of them'. So, it is a mind shift and cultural thing that has to change within IT companies." – CTO of a platform integrating fitness services* (Interview 4 [translated], 2019).

4.2.2.2 Organisational Maturity

The most prominent way in which the organizational maturity impacts decisions on platform level openness is related to the market position of a company. Examples of this can be found in section 4.1.1.2: strategic considerations. Besides this, more mature companies often have legacy technologies in their own organization or deployed in the market, at customers which they still have to support. This can hamper innovation (I11) or it creates some kind of path dependency (I9). For example, a truck OEM indicated that if they develop a new telematics unit, they will first do a roll-out on new trucks but will always consider previous trucks already in the market (due to the long life span of a truck) to provide them with updates (I9). Obviously, the maturity of a company also influences the quality of the interoperability solution.

4.2.2.3 Values

The values of a company represent considerations with respect to Corporate Social Responsibility (CSR) on the one hand and the importance of data privacy and security on the other hand (see section 4.1.1.3 for a discussion on the latter). For most companies, CSR is something that is always there in the background but if decisions about interoperability have to be made, they will primarily look at business drivers. However, some companies pay more attention to this. An example can be found in a recent consortium of BMW, Volvo, Mercedes, Daimler, Ford and TomTom. Safety related data from car sensors (like obstacles on the road or if its slippery) will be send to a neutral cloud platform by making use of cellular technologies. At this cloud platform, the data has been made available under a create commons license. A non-profit company also indicated that they are actively pursuing environmental and safety related goals (I11).

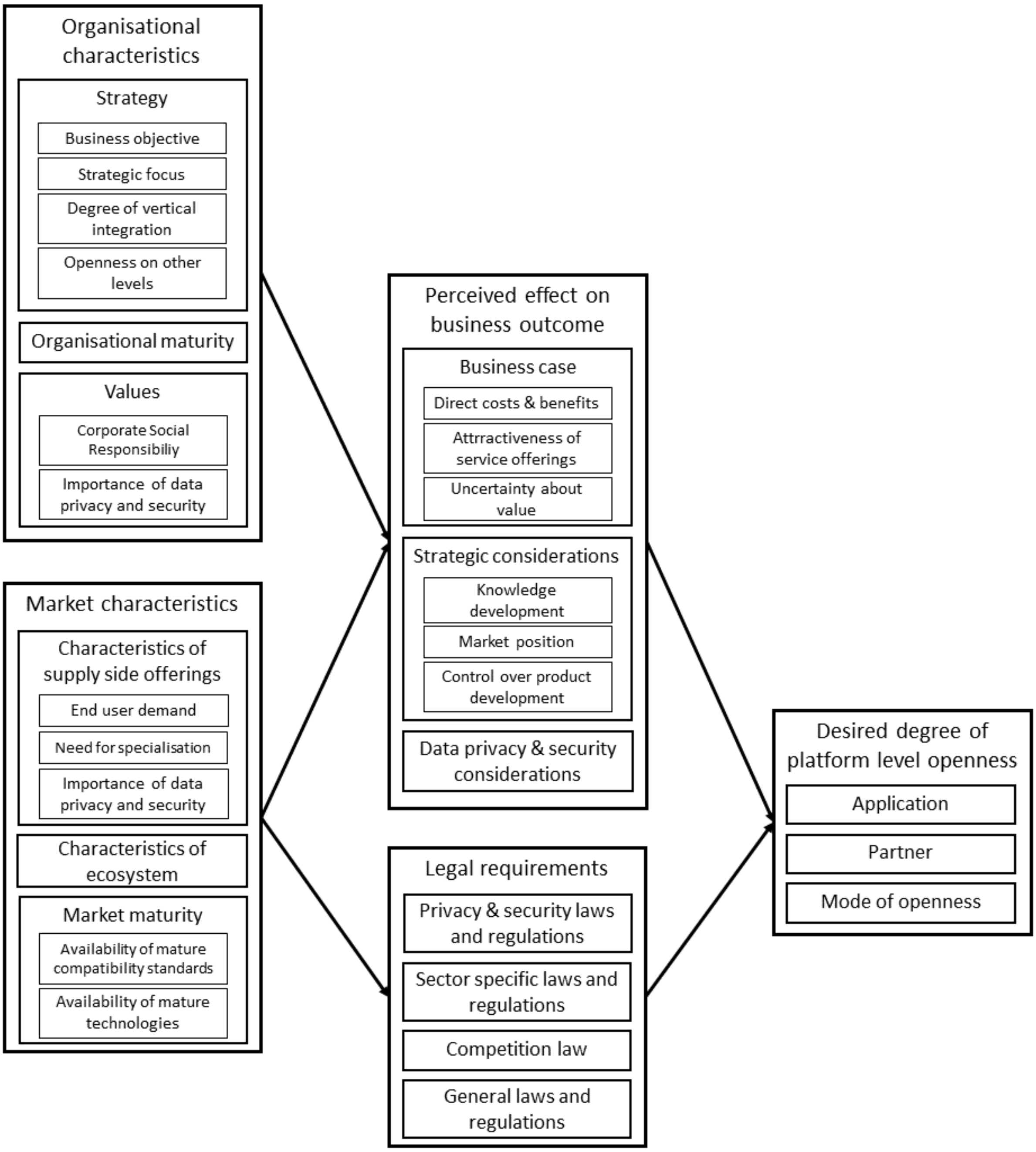

Figure 14: Theoretical model explaining the desired degree of openness between IoT platforms

4.3 Trade-offs between Factors Influencing the Desired Degree of Openness between IoT Platforms

In section 4.1 and 4.2, the business and context factors that influence the desired degree of platform level openness were discussed. The trade-offs that are being made between those factors are discussed in this section. In section 4.3.1, the general trade-offs that are made will be outlined. As shown in this section, trade-offs are very context dependent. Therefore, the impact of the context factors on how the trade-offs are being made are discussed in section 4.3.2. The context dependence of the trade-offs is illustrated by a discussion of the trade-offs that are being made in the two domains researched as part of this study: the healthcare and automotive domain.

4.3.1 General Discussion on Trade-Offs

This study researched the business-, context- and legal factors that influence the desired degree of platform level openness. As expected based on the preliminary conceptual model, it is found that only the business and legal factors have a direct impact on the desired degree of platform level openness while the context factors have an effect through the business and legal factors. This entails that the context factors determine how the trade-offs are being made between the different legal and business factors (i.e. which sub factors are the most important). This section describes the trade-offs that exist between the business (section 4.3.1.1) and legal (section 4.3.1.2) factors while section 4.3.2 discusses how this is influenced by the context factors.

4.3.1.1 Trade-offs between Business Factors

The business factors that are studied are all grouped under the category 'perceived effect on business outcome'. As discussed in section 4.1.1, this category consists of the following factors: attractiveness of business case, strategic considerations, and data privacy & security considerations. Essentially, it is found that on a high level, these factors are very interrelated and are always weighted against each other. Thus, trade-offs exist between all three categories of factors described above.

For most organisations, the attractiveness of the business case and the strategic considerations are the main factors driving decisions on platform level openness while the data privacy and security considerations can be seen as restrictive factor that usually limits the type of openness use cases that are considered (e.g., I1; I10; I3). This entails that opening up on the platform level (w.r.t. a certain use case) should either have a good business case or strategic benefits. If both of them are not present, there is no benefit to open up. Furthermore, data privacy and security must be of an adequate level. Without adequate protection a business case will not be considered. In this respect, data privacy and security requirements impose a threshold on the type of use cases that are considered. For a more elaborate discussion on how this threshold is composed, see section 4.1.1.3. What 'adequate protection' means depends on the context. Therefore, this is discussed in section 4.3.2.

For most organisations, the business case is the first thing to look at (e.g., I10; I13; I3). Organisations ask themselves the question whether they can profit from opening up or not. This is logical because in the end, most companies have objectives related to making money and even non-profit or governmental organisations need to have sufficient profits to outweigh the costs of becoming open. An elaborate discussion on when a business case is attractive can be found in section 4.1.1.1. However, there can be a good reason to let a business case be temporarily unprofitable (or less profitable) out of strategic concerns, which entails that there exists a trade-off between the attractiveness of a business case and the strategic benefits. Obviously, if something does extreme strategic harm, a business case will never be considered because in the end, business continuity is nearly always the most important organisational objective and it will always be more important than short time profits (e.g., I4). The existence of trade-offs between the attractiveness of a business case and the strategic benefits is illustrated by the following examples.

- *Attractiveness of product offering vs. market power.* As discussed in section 4.1.1.1, you could increase the attractiveness of your product offering by opening up on the platform level. However, this could also entail that you make it easier for end-users to walk away to a competing platform (i.e. you reduce the chance of lock-in) (I4). For example, the CTO of a platform integrating fitness services indicated that the membership administration module of their platform has limited functionalities. By working together with another membership management system (i.e. opening up on the platform level), they could increase the usefulness of their product which could lead to bigger sales. However, the company decided not to open up in order to protect their market position (as the other company was a competitor). Instead, they rather developed the required functionalities themselves. Even though this costs more money and the time to market is longer. Thus, in this case the company favoured long term strategic considerations above short term profits.
- *Attractiveness of business case vs. market share.* Especially in markets characterised by high network effects, there is an incentive to gain a big market share quickly at the expense of profitability (I1). This can for example be observed by looking at the strategy Uber followed; they offered their service below cost price to gain market share rapidly, hoping that in the long run it will turn out profitable.
- *Attractiveness of product offerings vs. possibility to create lock-in (i.e. growth vs. risk).* By opening up, you could attract more users but it also reduces the possibilities for lock in (I3; I4). Key in making this trade-off is to determine in which case you end up with more users. The example described to illustrate the first trade-off (i.e. not becoming interoperable with a membership management system) shows that a company chose for creating lock in. The same company also indicated that in other scenario's, they chose for attractiveness of product offerings because there are similar membership management software packages with which they became interoperable (I4). The rationale behind this was that end users wanted to keep using their existing membership management system but they did want to make use of other modules provided by the focal platform. It was an opportunity to attract new users. Thus essentially, this is a trade-off between growth and the risk.
- *Attractiveness of product offerings vs. possibility to create lock-in (i.e. growth vs. risk).* Another example of this trade-off can be found in the market for fitness wearables, were most manufacturers offer open API's to connect their devices to a platform. This means that they have no control over the other platforms that become interoperable with them because the API's are not restricted. However, the product becomes more attractive which leads to increased sales of the physical product.
- *Learning vs. profitability*. Companies participate in projects to learn but they probably won't earn anything from it.
- *Risk vs. control over product development.* Essentially, all strategic partnerships and shared development is a way to spread risk. You will have lower R&D and development costs but also less control over strategic development (I1; I11).

The final category of business factors relate to privacy and security considerations. As discussed above, privacy and security considerations can be seen as a threshold factor; an adequate level of privacy and security is required before a certain use case is considered. However, once this threshold has been passed, no much thought is given to it anymore (e.g., I1; I3; I7). It can be seen as a boundary condition. Therefore, there aren't much trade-offs related to privacy and security. The main trade-off organisations have to make relates to the amount of risk they are willing to take. This is also highly context depended and therefore more extensively discussed in section 4.3.2.

Making this trade-off involves deciding about the degree of privacy/security safeguards within your own organization (i.e. how much are you willing to spend to mitigate privacy and security risks). Secondly, it relates to the potential partners and types of applications that you are willing to consider. In the first case, there is a trade-off between costs and risks. In the second case, there is a trade-off between business opportunities and risk. The main risks relate to reputation damage or costs resulting from potential damage claims.

4.3.1.2 Trade-offs Related to Legal Factors

Just as with privacy and security considerations, legal requirements impose a boundary conditions on the use cases to consider. Therefore, trade-offs related to legal factors are also limited (i.e. you just have to fulfil the legal requirements). There is some room to make trade-offs resulting from the uncertainties surrounding legal requirements. For example, due to bad enforcement, organisations can choose to not fulfil certain legal requirements. The only example of this found in the interviews relate to the data portability regulation that is part of the GDPR. This regulation entails that customers should be able to easily transfer data to competing platforms. However, this is highly conflicting with the business interests of platform providers because it reduces the lock-in on their platforms. Therefore, in practice, easy data portability is often not possible (I3). Note that also here, organisations have to decide how much risk they are willing to take. Another example relates to the uncertainty related to competition law. Due to this uncertainty, organisations might be afraid to work together because it could be seen as cartel forming. This is especially the case in the automotive domain due to some scandals from the past. This is more extensively discussed in section 4.1.2.

4.3.2 The Influence of Context Factors on the Trade-offs between Business and Legal Factors

As discussed in section 4.3.1, the context factors have an influence on the desired degree of platform level openness through the business- and legal factors. In that way, they determine how important a factor is when deciding about the desired degree of platform level openness. Thus, essentially they determine how the trade-offs described in section 4.3.1 are being made. The context factors are composed of the market and organizational characteristics. The impact of the former is discussed in section 4.3.2.1 while the impact of the latter is discussed in section 4.3.2.2. Note that these factors are also extensively described in section 4.2. Therefore, this section will mainly focus on how these context factors influence how the high level trade-offs between the main sub categories are being made. For an elaborate discussion on how the different context factors influence the importance of specific factors, section 4.2 can be consulted.

4.3.2.1 Impact of Market Characteristics on the Trade-offs between Business and Legal Factors

The main market characteristics that influence how trade-offs between the high level business and legal factors are being made are the intensity of competition and the maturity of a market. In markets where the competition is high, consumers have relatively more power because they have more alternatives to choose from. Therefore, it is more important to protect your userbase in such markets. Thus, there is a higher need to create switching costs and establish a lock in to your platform. Markets with a lower need for specialisation are often characterised by higher levels of competition because there are less possibilities for product differentiation (which is an alternative strategy to keep customers affiliated with your platform, next to creating lock-in). This results in more similar product offerings with a higher need to create lock-in.

This is something that can be observed in the fitness domain, where a PhD researcher studying fitness wearables, the CTO of a platform integrating fitness services and an integration specialist at a manufacturer of fitness equipment all indicated that they are trying to establish high lock-in to avoid customers running away to competitors (I3; I4; I5). Thus, in markets with a high degree of competition, strategic considerations are relatively more important in determining the desired degree of openness compared to markets where this is not the case. In such markets, increasing the attractiveness of your product offering might be more important. If taking the examples discussed in section 4.3.1, this observation entails that in markets with a high degree of competition relatively more importance is given to the possibility to create lock in, the market power or the market share of an organisation. Compared with the attractiveness of your product offering. In contrast, the CEO of a company integrating medical data indicated that they rather differentiate themselves from competitors instead of creating lock in (I2).

Secondly, the maturity of the market also influences how trade-offs between factors are made. In immature markets, strategic considerations are usually more important. For example, as explained in section 4.3.1.1, in markets characterised by high network effects, there is an incentive to gain a big market share quickly at the expense of profitability. Once sufficient users have affiliated themselves with the platform (i.e. when the critical mass has been reached), network effects can take over and drive further growth (Evans, 2009). This is especially important in immature markets because not all end users have affiliated themselves with a platform, which makes attracting them easier. This can be illustrated with an example from a manufacturer of fitness equipment. As part of their old product portfolio, they also offered an activity tracker. However, when they realised that other activity trackers were better and users bought those instead, they stopped the production because it became too hard to compete with the other activity trackers (I5). The competitors' platforms were fuelled by network effects, which increased the value too fast to keep up with. Furthermore, strategic considerations related to learning and influencing market developments are also more relevant in immature markets.

4.3.2.2 Impact of Organisational Characteristics on the Trade-offs between Business and Legal Factors

The main organisational characteristics that impact how the trade-offs between business and legal factors are being made are the overall business objective and the values of a company. Firstly, the overall business objective of an organisation (i.e. profit, non-profit or governmental) determines how important profitability is. For example, a non-profit company indicated that because they don't have a profit objective, they can pay more attention to data privacy and security (I11). Secondly the values of a company are an important determinant for the type of strategy that a company pursues. For example, whether a company focusses more on profitability or growth is very company specific. Another example relates to the risk adversity of an organisation. This determines how the trade-offs related to privacy & security considerations and other legal factors are made (see section 4.3.1). Thirdly, the maturity of an organisation also plays a role. For example, a start-up usually has a higher focus on gaining market share than on profitability. This is for example the case with Tesla and Uber. Finally, data privacy and security considerations are more important for companies dealing with sensitive personal data. This is usually the case in the medical domain.

5 Discussion

This chapter positions the results of this study in the existing scientific literature. Section 5.1 discusses why the concept of platform level openness is more important for IoT platforms compared to other platforms. Then, in section 5.2, it is argued that in contrast to other platforms, decisions regarding the openness of IoT platforms are often made from a product- instead of a platform-centric perspective. Following that, IoT platforms are analysed from an innovation management perspective in section 5.3. Finally, before theoretical and practical implications are presented in section 5.5 and 5.6, the future of IoT platforms is discussed in section 5.4.

5.1 Higher Importance of Platform Level Openness for IoT platforms Compared to Other Platforms

In this section, it is argued that the concept of platform level openness is more relevant for IoT platforms than for digital or other multi-sided platforms. This has two reasons. Firstly, IoT platforms are characterised by a higher need for platform level openness because there are stronger complementarities between the services of different IoT platforms. This is discussed in more detail in section 5.1.1. Secondly, there are also more opportunities for platform level openness because winner-take-all dynamics are to a lesser extent present. This is further discussed in section 5.1.2.

5.1.1 Higher Need for Platform Level Openness Due to Stronger Complementarities

IoT platforms are characterised by a higher need for platform level openness, compared to other multi-sided and technology platforms. The IoT platform market is characterised by a high degree of fragmentation (Ganzha et al., 2018; Mineraud et al., 2016). Because of this fragmentation, there is a higher need for openness between platforms as services from multiple IoT platforms should be combined in order to provide a complete service to end users. In other words, there are stronger complementarities between the services of different IoT platforms.

Degrande, Vannieuwenborg, Verbrugge, & Colle (2018) argue that the fragmentation is a result of the immaturity of the market. However, IoT applications are found in virtually all domains in everyday life (Nicolescu et al., 2018; Wortmann & Flüchter, 2015). Therefore, it is more likely that the fragmentation results from the high need for niche specialisation caused by the diversity of the application domains and use cases in which IoT can be utilised. The need for specialisation is related to the physical products on which the IoT is based. To produce these products efficiently on a large scale, dedicated manufacturing facilities are required due to the economies of scale that characterise the production. In contrast, an application for a software platform (e.g. Android) can be built by a single developer. For software platforms, there is no distinction between design and production which entails that economies of scale in production are less relevant (Henfridsson et al., 2014).

The high need for platform level openness due to complementarities can be observed in the automotive domain, where a lot of different IoT devices are required to make the 'connected car' as useful as possible. A first example can be found in a recent consortium of BMW, Volvo, Mercedes, Daimler, Ford and TomTom. These companies share safety related data from their sensors (e.g. warnings if there are obstacles on the road or when it is slippery) with each other such that this data can be made available in all cars. A second example in the automotive domain relates to electric charging stations. By providing access to the location and availability data of these charging stations, users can better plan their 'fuel' stops (I13). A third example in the automotive domain relates to the

EU-funded SOCRATES$^{2.0}$ project, in which governmental parties, car manufacturers and other technology companies work together to explore different use cases related to smart traffic management (e.g. smart routing advice based on current traffic or real time updates concerning dangerous road situations). To make such services possible, the IoT platforms of the different ecosystem players have to become interoperable, which entails that the platforms have to open up towards each other (I6).

Also in the healthcare domain, there is a high need for platform level openness resulting from complementarities between IoT platforms. As discussed in section 4.1.1.1, the inter-organisational collaboration within hospitals is increasing. This requires that the IoT platforms of different manufacturers, used to control medical equipment, should become interoperable to allow the data to flow more easily between the medical devices (I1). A second example in the medical domain relates to a platform integrating medical data. In this platform, data from different IoT devices (e.g. smart scales, EEG recordings or glucose level meters) is combined to better interpret the data (I2). Finally, complementarities in the fitness domain can be illustrated by the need for an IoT platform integrating IoT devices such as activity trackers, fitness equipment or physical control ports for managing access to a gym (I4).

5.1.2 More Opportunities for Platform Level Openness Due to Weaker Winner-Take-All Dynamics

Next to a higher need for platform level openness, there are also more opportunities for platform level openness due to winner-take-all dynamics that are to a lesser extent present. Because of this, there is less competition between platforms and thus more room for platforms to open up towards each other. Winner-take-all dynamics are a characteristic of the typical competition between multi-sided platforms and they occur if (Eisenmann et al., 2006): (1) multi-homing costs are high for at least one user side, (2) positive network effects are strong for that same side and (3) there is no need for niche specialisation. Based on the discussion in section 5.1.1, it can already be observed that the third condition does not hold. If there is need for niche specialisation, platforms can avoid competition by differentiating themselves from other platforms. This is illustrated by the CEO of a company integrating medical data, who indicated that they rather differentiate themselves from competitors instead of creating lock in (I2). For a more elaborate discussion on this, see section 4.3.2.1.

Note that the discussion in section 5.1.1 is based on IoT platforms without an application store for add-on software complements. Schreieck et al. (2017) argue that IoT platforms with such an application store can be seen as multi-sided platforms. These platforms are similar to software platforms and are expected to exhibit winner-take-all dynamics. Nevertheless, the positive network effects – and the magnitude of the winner-take-all dynamics – will probably be smaller. Due to high need for specialisation, there is a smaller group of potential users to which the network effects apply. Unfortunately, no proof for this conceptual claim has been found in the interviews because only one of the platforms considered as part of this study had an application store and due to the early stage of the platform's maturity, it was too early to observe MSP dynamics.

However, the main factors explaining competition between platforms are the indirect positive network effects between user groups (e.g., Katz & Shapiro, 1985; Rochet & Tirole, 2003). The relation that remains, in which network effects could occur – if there is no app store – is the one between device providers and end-users. In section 2.2.2.1, it was argued that if there are no mature and open compatibility standards governing the relation with device providers, IoT platforms are expected to exhibit MSP dynamics. The argument in chapter two was based on the definition from Hagiu & Wright (2015), who state that MSPs are characterised by a direct affiliation with the platform of at least two user groups who control the key terms of the interaction that is facilitated between them.

This claim can be validated by the dynamics in the fitness domain, where the competition between platforms is high. Two platforms in the fitness industry indicated that they only open up on the platform level if there are complementarities to be gained. They do not open up to platforms with a similar value proposition because they want to attract as much users as possible (I4; I5). In both cases, the connections between the different devices and the platforms are platform specific (i.e. not a mature open standard). This finding is in line with Nikayin et al. (2013), who found that an IoT platform for independent living services was only open for device providers who are not competitors of the device providers already affiliated to the platform. Platforms in the medical (I1) and automotive domain (I10; I7; I8) also indicated that they only want to collaborate if there complementarities. However, they only want to do so via open standards to maximize the benefit from the complementarities. This entails that there is higher risk that a competitor might benefit from the increased level of platform level openness. This difference in attitude could partly be explained by the product oriented focus characterising most IoT platforms. This will be further discussed in section 5.2.

5.2 A Product Centric Versus a Platform Centric Approach to Openness

The complementarities described in section 5.1.1 reside between IoT devices and not necessarily between IoT platforms. However, this often entails the same due to the high degree of vertical integration characterising the IoT platform market. The high degree of vertical integration entails that IoT platforms are often provided by the same organisations that are also manufacturing the devices connected to it. This is for example the case with fitness wearables, where brands like Fitbit, Garmin and Polar all have their own IoT platform (I3). But this is also the case in the medical (I1) and automotive domains (I7; I8). The high degree of vertical integration could result from the immaturity of the market. This would be an extension of the argumentation from Degrande et al. (2018), who argue that the fragmentation in the IoT platform market results from the immaturity of the market.

However, other alternative explanations are more plausible. Firstly, it is also possible to extent the line of argumentation related to the high need for specialisation from IoT devices to IoT platforms. Because IoT platforms are the bridge between the physical and the digital realm, there are high dependencies between the IoT device and the IoT platform. This could be supported by the claim of a director at a company manufacturing medical equipment, who said that the process of getting the raw data from the device and transforming it to usable data on a platform is the most difficult aspect of the IoT (I1). Therefore, it makes sense if the IoT platform connecting the device is also developed by the manufacturer of the device. This would also avoid dependencies on other platform providers.

Secondly, compared to other software platforms, the stand-alone value of a single complement for an IoT platform (i.e. IoT device) is higher. This entails that IoT devices in itself are very useful and connecting them to the internet and other IoT devices via a platform only increases the functionality (Wortmann & Flüchter, 2015). For example, a lightbulb is useful because it provides light. When connecting the lightbulb to the internet you increase the usefulness because you can remotely control it. If you connect it to other products (such as a doorbell) you can further increase the value by letting the products interact with each other. Again, it makes sense for a manufacturer of an IoT device to provide the platform as well to avoid being dependent on other platform providers for the functionality of their products. In contrast, software platforms have digital components that are specifically designed as *addition* to a certain platform. An application cannot be used without the platform it is designed for.

Due to the high need for specialisation and the high stand-alone value of IoT devices, IoT ecosystems are often characterised by a product-centric design approach while software platforms are characterised by a platform-centric design approach. Due to this difference in focus, other decisions regarding the openness of platforms are being made. Hodapp et al. (2019) argue that hardware manufacturers often follow a bottom-up approach and let their product portfolio dictate the functionalities of the IoT platform while software-based companies often follow a top-down approach and start from the functionalities that the platform should have.

That this argument also applies to platform level openness can be illustrated with the strategy followed by manufacturers of fitness wearables. These manufacturers choose to be open via open API's in order to make their product interoperable with as many platforms as possible, to increase the sales of their products. This also means that they have less control over the other platforms that become interoperable with them because the API's are not restricted. This lowers the lock-in to the platform. For example, Garmin (i.e. brand of wearables) has open API's that can be used by other organisations, including competing platforms like Strava. This indicates that there is a trade-off between benefiting from the product (through increased sales) and benefiting from the platform (through a high amount of users affiliated with it).

The manufacturers of fitness wearables don't care about making money from an IoT platform, for them the platform is just a means to an end in order to increase the sales of their physical product (I3). The same holds for a company producing medical equipment. Also for them, IoT platforms are just seen as a complement to the hardware products they sell and the openness decisions they make are based on the service they want to provide. If opening up is required to deliver a complete service to the end user, they will do so to increase the sales of their physical products (I1).

5.3 How IoT Platforms Stimulate Innovation

In the innovation management perspective, stimulating innovation in the ecosystem is seen as the core functionality of a platform (Gawer, 2014). While IoT platforms do exhibit the characteristics of an innovation management platform (see section 2.2.2.2), the product centric approach to designing IoT platforms often entails that they are currently not being used as such. However, this is different for platforms that are developed in collaboration (i.e. from a platform oriented perspective). This is for example the case with the platform used by an automotive driver association, that has been developed together with sister companies. All affiliated companies make use of the same platform to reduce R&D costs. This hints to economies of scope in innovation, which is seen as a defining characteristic of innovation management platforms (Gawer, 2014). This could also be the case for other platforms that are jointly developed by different ecosystem players. However, there were no other jointly developed platforms that were a part of this study. Although there are some projects in which ecosystem players collaborate, this is mostly in a learning setting (I6).

IoT platforms could also benefit from increased innovation if they have an app store through which they can draw upon the innovative capacities of a large group of third party developers (cf., Gawer, 2014). Based on an analogy with the success of application stores in the mobile phone domain, IoT platform providers have indicated that they also want an application store as part of their platform. By doing this, they can draw upon the capabilities of third party developers. There is one platform in the medical domain that already has an app store, although in an immature stage (I2). Other platforms in the fitness (I4; I5) and aftermarket automotive domain (I11; I12) have indicated that they are planning to introduce the feature.

However, it is questionable if application stores for IoT platforms will experience the same success as application stores for mobile phones. One of the main characteristics setting software platforms apart from other innovation platforms, is the layered modular architecture that characterises them (Yoo et al., 2010). Due to the loose coupling between the software and the physical product (i.e. mobile phone) executing the software, the physical products are open for new meanings after manufacturing which leads to greater generativity. This is to a lesser extent the case for IoT platforms. In contrast to software platforms and the generic physical devices on which they are executed (e.g. a mobile phone or a pc), there are more dependencies between the IoT devices and the platforms used to control them. IoT platforms are often designed with a specific product in mind (see section 5.2) and therefore, the generative capabilities are probably lower (cf., Yoo et al., 2010). Furthermore, because positive network effects are less strong for IoT platforms (Schreieck et al., 2017), it will be harder to attract app developers. The question is if the pool of potential developers is large enough and if the demand is big enough for the network effects to kick in.

5.4 The Value of The Meta Platform as Mode for Platform Level Openness

As argued in section 2.2.4.2, there are multiple modes of opening up on the platform level: either direct (e.g., Ochs & Riemann, 2017) or via a meta-platform (e.g., Mineraud et al., 2016). From the interviews it became clear that a meta-platform is probably the best way to open up on the platform level. This has several reasons.

- An IoT platform sponsor limits its dependency on other market players because the interoperability solution is not designed with a specific partner in mind. If this would be the case, and the interoperability partner chooses not to collaborate anymore, the platform sponsor would have to redesign and renegotiate interoperability with others. In contrast, a meta-platform allows for plug-and-play functionality (I1). As expected based on the comparison with innovation platforms in section 2.2.2.2, compatibility standards play an important role in this respect because this only works if all relevant market players are willing to adopt the compatibility standard required for a connection to the platform.
- For collaboration in complex ecosystems, coordination costs will be lower; the platform provider only has to manage one connection instead of multiple (e.g., I10).
- Due to the modular technological architecture of a meta platform, it is easier to organise for innovation because interdependencies between modules (i.e. the platforms connected to the meta-platform) are reduced (I1). This is in line with the innovation management perspective on platforms (cf., Baldwin & Clark, 2000).
- Because interdependencies are lower, you have more control over your own product development (I1; I7)
- To avoid incompliance with competition laws. This especially plays a role in the automotive industry because the OEMs have a very dominant market position. Direct collaboration can easily be seen as cartel forming and due to large fines in the past, OEMs are afraid to work together without making use of a neutral data platform (I10; I6). This is also illustrated by the recent cellular v2v project initiated by BMW[15]. There, organisations also work together

[15] https://www.nrc.nl/nieuws/2019/06/04/bmw-openbaart-autodata-die-gevaar-voorspellen-a3962458

via a neutral data platform instead of via direct interoperability between cars even though the technology for direct interoperability is also available. For example, the IEEE 802.11p standard (i.e. WiFi-P) is used in experiments by Truck OEMs. However, uncertainty about the future support for this standards has caused most truck OEMs to put their projects on hold (I9).

- Out of data security considerations. Companies like Google prefer to disclose their data through trusted third parties to make sure that their data is secure (I6).

Meta platforms capitalise on the fact that there is a high need for complementarities within and across IoT domains. They are characterised by winner-take-all dynamics when they make use of proprietary standards for governing the relation with the other platforms (see section 5.1.2). Furthermore, at a higher level of abstraction, the need for specialisation is lower because a meta platform integrates the services of other IoT platforms. Essentially, the other platforms are can be seen as the components of a meta platform. Because the need for specialisation is lower, there is also less need for platform level openness because the complementarities are weaker (see section 5.1.1). Note that this only relates to the abstraction level of the meta platform. There are a lot of complementarities with platforms at the lower level (i.e. the 'complement' of a meta platform). Thus, this entails that multiple perspectives should be used when analysing meta platforms. If looking at the relation between meta platforms, a multi-sided platform perspective can be adopted. However, when looking at the relation between the meta platform and the platform of which it integrates the services, the lens of complementary economics is more useful.

However, because multi homing costs for device providers on a meta platform are lower, the winner-take-all dynamics will probably still be lower compared to software platforms (cf., Eisenmann et al., 2006). An example of this is Fitbit who multi-homes on multiple platforms. One product can support multiple standards, in contrast with tangible platforms. This is a result from the cyber/physical nature that sets IoT platforms apart from other types of innovation platforms (see section 2.2.2). However, this is also context dependent. For example, a connected car cannot simple be connected to another platform because there are a lot of interdependencies between the platform and the car (i.e. the need for vertical integration, resulting from higher need for specialisation is higher).

Meta platforms can be found in in the medical (I1) and fitness (I4) domain, but they have not been observed in the automotive domain. There could be several reasons for this. Firstly, due to the cyber/physical nature of IoT platforms, privacy and security considerations are very important. This has been stressed by all interview respondents in the automotive domain (e.g., I10; I7). A second explanation could be that the automotive domain is characterised by a few dominant market players – the OEMs. Due to the high costs of a car, it is also difficult to multi-home or switch to another brand of car. The OEMs control the data from their cars and there are no incentives for them to provide this data to a competing meta-platform that could potentially be used for all connected cars. One of the interview respondents indicated that this could also be one of the reasons why Google is currently interested in developing a car (I6).

5.5 Theoretical Implications

A few theoretical implications can be derived from this master thesis. Firstly, based on empirical research, an early theory identifying, prioritizing and interrelating factors driving the decisions of IoT platform sponsors regarding the desired degree of openness towards other IoT platforms is developed. This advances the scientific body of knowledge on the governance of IoT platforms, specifically on the openness of IoT platforms. As part of this theory, a definition of IoT platforms, suitable for studying their governance, has been developed. Furthermore, existing conceptualisations of openness have been enriched by introducing two new concepts: platform level openness and device level openness. These concepts relate to respectively the relation of an IoT platform with other platforms and with devices.

The theory developed in this research is especially relevant for studying openness in the context of the IoT. As argued in section 5.1, the concept of platform level openness is less relevant for other technological or multi-sided platforms. However, further research could investigate this. Because platform level openness is mostly driven by complementarities, it could potentially be a useful lens for studying inter-domain interoperability for other types of platforms. This research was conducted in the healthcare and automotive domain and it turned out that the desired degree of platform level openness is highly dependent on the use case and the context in which the IoT platform operates. Thus, when applying this theory to other domains within the IoT, specific attention to the context variables is required. Nevertheless, the identified factors are probably to a large extent the same because the same factors were observed in both domains and the context mainly changed how trade-offs between those factors are made.

In the process of developing this theory, the digital and innovation management perspectives on platforms were discussed and compared with IoT platforms. This bridges the gap between the different perspectives and contributes to the integration of the different perspectives on platforms. The theory developed in this research could be enriched by further drawing on the literature from these other perspectives. For example, the boundary resource model (Ghazawneh & Henfridsson, 2013) could be adapted such that it can be used for studying IoT platforms and other levels of openness (e.g. platform and device level openness). Furthermore, researchers could further elaborate on the importance of the context by drawing upon other management theories (e.g. contingency theory). Finally, further research could investigate the interactions between the different levels of openness in more detail.

5.6 Practical Implications

This master thesis has also a few practical implications. Firstly, the theory that has been developed in this research can be used by IoT platform sponsors to guide decisions on the desired degree of platform level openness. It gives an indication of the factors and trade-offs that should be taken into consideration in the decision making process. In section 5.4, it was argued that the meta-platforms are the most promising mode of platform level openness. Therefore, IoT platform sponsors are recommended to make use of these platforms when designing new platform level openness solutions. Furthermore, section 5.1.2 discusses the conditions under which positive network effects can occur that can drive winner-take-all dynamics. These insights can also be used by platform sponsors to gain a competitive advantage.

6 Conclusion

The main problem hampering innovation in the Internet of Things (IoT) is the fragmentation and lack of interoperability between IoT platforms. A possible solution for IoT platform sponsors to overcome this problem is to open up towards other platforms. To better understand how the IoT platform market is evolving and to inform future decisions regarding the desired degree of openness between IoT platforms, insight in the business and context factors driving these strategic considerations is required. The amount of scientific literature addressing this is limited, which is why this thesis aims to develop a theory on the openness between IoT platforms by identifying, prioritizing and theorizing the interrelations between factors driving the decisions from IoT platform owners related to the openness of their platform towards other IoT platforms.

As a result of this research, an IoT platform is defined as *the software-based system that allows applications to interact with the smart objects connected to it*. An important observation is that IoT platforms mediate between smart objects and applications. This entails that, in contrast with other platforms, network effects are less important because they do not necessarily have to mediate between two users groups. The openness between IoT platforms has been conceptualised as *the degree to which data and services can be shared among different IoT platforms*. The main characteristic that sets IoT platforms apart from other technological or multi-sided platforms is their cyber-physical nature. This nature entails that the IoT domain is characterised by a high need for specialisation and that platforms are often developed from a product-centric, bottom-up approach. This results in a fragmented market in which there are strong complementarities between IoT platforms, which lead to a high need for openness between them. Because the network effects are also less strong for IoT platforms compared to other multi-sided platforms, winner-take-all dynamics are to a lesser extent present, which gives more room for collaboration between platforms in the form of platform level openness.

The semi-structured interviews held with decision makers and field experts learned that decisions on platform level openness are influenced by (1) the perceived effect of the decision on the business outcome and (2) the legal requirements. With respect to the perceived effect on the business outcome, a few import factors play a role. Probably the most important factor relates to the attractiveness of the business case surrounding the openness decision; if opening up doesn't mean that extra profits can be gained, opening up won't make sense for a lot of companies. Besides this, the effect on the strategic position of an organisation and the privacy and security considerations also play an important role. The effect that legal requirements have is quite straightforward; if something is not allowed, companies won't do it.

Zooming in on the perceived effect on the business outcome, it is found that openness decisions are mainly driven by the presence of complementarities. Organisations often don't want to open up to platforms with a similar product portfolio, who are directly competing with them. This reduces switching costs and increases the risk of end-users leaving the platform. Although the end-users of the platforms might benefit from a reduced lock-in, there is no benefit to be gained by the platform companies if there is no extra value created through the presence of complementarities; dividing the total profits will be a zero-sum game. However, companies do want to open up towards other platforms that fulfil a different role in the ecosystem if there are complementarities between the product offerings. Then, extra value is created and both companies can profit from the openness; dividing the pie becomes a positive sum game. This extra value can either be the result from extra services for which money can be charged or more indirect, via an improved product that results in more sales.

However, the value that is created through the complementarities should not be off-set by the cost of becoming open. These costs can either be direct (e.g. development costs) or more subtle. An interesting finding is that a lot of organisations are either not sure about how valuable the data is they have or how they should profit from it. Due to this uncertainty, organisations are reluctant to open up because they are afraid that somebody else might see a value that they don't see; they are afraid that they are giving away something for free. This entails that currently, the immaturity of the market is one of the factors withholding platforms providers to open up towards other platforms. This uncertainty also plays a role with respect to the legal requirements. For example, the lack of regulation governing autonomous driving applications can cause companies to put projects on hold. Furthermore, especially in the automotive industry, competition law also has an impact because OEMs are reluctant to work together out of the fear that it might be seen as cartel forming.

Next to a profitable business case, strategic considerations also play a role. It is not always necessary that the business case is profitable, organisations can also open up out of strategic considerations. For example to influence market developments (e.g. via participation in standardisation committees) or to generate knowledge about the way in which the market is developing or about other players in the ecosystem. Reasons why organisations would remain closed out of strategic considerations relate to the loss of control over their product development or to protect their market position. In general, privacy and security considerations also causes companies to be more closed on the platform level. Compared to other types of platforms, privacy and security considerations are more important for IoT platforms due to connection with the physical world.

The decisions about platform level openness are always made in a specific context, with respect to a specific use case. Important contextual factors are the characteristics of the market and the organisation itself. The most notable way in which market characteristics impact openness decisions, is through end-user demand; organisations that provide a service to end-users will have to fulfil some expectations. For example, if users want an integration with a different service, companies will consider this. If the other service has a dominant market position, it is likely that the platform will open up towards this service to avoid a competitive disadvantage. Think for example of a platform like apple health, nearly all activity trackers are interoperable with this service. The end user demand is closely related to the need for specialisation; if companies cannot provide a whole service by themselves, they could open up towards other platforms that provide this service such that they can still offer a complete service to their end users. Compared with other platforms, there is more need for specialisation in the IoT because products require dedicated manufacturing facilities to benefit from economies of scale. The maturity of the market also plays a role. For example, through the availability of mature compatibility standards. Especially in the complex settings found in the automotive domain, organisations usually do not want to open up towards each other without a widely accepted compatibility standard.

Important organisational characteristics relate to the strategic focus of an organisation and the closely related vertical integration; a company producing both the hardware and the platform might have different considerations than an organisation only providing the platform – the focus could be on profiting from hardware instead of software. Vertically integrated platform providers also adopt a product-centric bottom-up approach when deciding which functionalities to develop for the platform. Due to this, different considerations will be driving decisions regarding openness. Furthermore, the maturity of a company also affects openness decisions; a smaller company, that needs to set foot in the market has different considerations than a big company trying to protect its market share.

Finally, decisions regarding the desired degree of openness are always made in the context of a certain use case. Organisations don’t just open up their whole platform, instead, they open up their platform for a specific application and a specific partner, in a specific way. An example of a use case could be, sharing aggregated location data (=application) to inform authorities (=partner) where there is traffic by making use of a meta platform (=mode of openness). With respect to the application, organisations only want to open up for use cases characterised by complementarities or synergies. The type of data that is being shared is also important. Organisations might not want to share detailed data (e.g. because it contains personal or sensitive information) but they do want to share aggregated data. The type of applications IoT platforms want to open up to are also closely related to the potential partners they want to open up to. Organisations do not want to open up towards a direct competitor (i.e. a platform with a similar service offering). They rather open up to a platform in another domain or a governmental party. Furthermore, it was found that most organisations prefer interoperability via a trusted third party or meta-platform over direct interoperability.

Thus, IoT platform owners have to make a trade-off between (1) the profitability of the business case, (2) their strategic position and (3) privacy and security considerations, while fulfilling legal requirements. How the factors in this trade-off are prioritized is determined by the context in which the openness decisions are taking place. Next to the characteristics of the use case, the context consist of the market- and organisational characteristics. The main market characteristics that influence how trade-offs are being made are the intensity of competition and the maturity of a market. In markets where the competition is high, consumers have relatively more power because they have more alternatives to choose from. Therefore, it is more important to protect your userbase in such markets and strategic considerations will be relatively more important. In immature markets, strategic considerations are usually more important. For example, in markets characterised by high network effects, there is an incentive to gain a big market share quickly at the expense of profitability. Once sufficient users have affiliated themselves with the platform, network effects can take over and drive further growth. This is especially important in immature markets, where not all end users have affiliated themselves with a platform. This makes attracting them easier.

The main way in which the organisational characteristics influence how the trade-offs are being made relate to the strategic focus of the platform. For example, it has been argued that there is a trade-off between benefiting from the product (through increased sales) and benefiting from the platform (through a high amount of users affiliated with it). Vertically integrated platform providers will usually choose for the former strategy while platform centric organisations will choose for the latter. In addition, the overall business objective of a company also influences the trade-offs. A non-profit or governmental organisation will most likely have different considerations than a for-profit organisation.

7 Limitations

There are some limitations to this research that could be addressed in further research. To start, only two application domains where considered in this research: the automotive and healthcare domain. These domains where selected due to variability on the context variables, to generate as many possible insights as possible in this early stage of theory development. However, the research also made clear that the desired degree of platform level openness is highly dependent on the use case and the context in which the IoT platform operates. Thus, when applying this theory to other domains within the IoT, specific attention to the context variables is required. Nevertheless, the identified factors are probably to a large extent the same because the same factors were observed in both domains and the context mainly changed how trade-offs between those factors are being made.

Secondly, there were some conceptual issues of which it is unsure how it impacts the results. Sometimes, it was hard to make a distinction between device and platform level openness because there are some vertically integrated platforms where there is a 1:1 relation between the platform and the device connected to it. This is also the case for the distinction between user level openness and device level openness because users often interact with the platform through the device. Further research could look at the relation between platform-, user- and device level openness to see if this impacts the results. Furthermore, it was often hard to distinguish between the openness of an IoT platform towards another IoT platform versus the openness of an IoT platform towards other types platforms (e.g. data platforms) because respondents talked about the different types of platforms interchangeably.

Finally, the literature on the governance of the Internet of Things as a whole is also evolving. This entails that there are no shared definitions and conceptualisations. In this research, IoT platforms and their openness have been conceptualised based on a comparison with other types of platforms. Further research could enrich this conceptualisation by further elaborating on the relations with other domains. For example, the relation between standards and platform level openness is a very complex one. On the one hand, standards facilitate platform level openness and thereby create value. On the other hand, they limit the possibilities to create network effects and thereby reduce the capabilities of a platform owner to appropriate rents. How this influences decisions on platform level openness is not clear yet and is something that could be addressed in further research.

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Appendix A: Scientific Paper

The Openness Between Platforms

What Changes in an IoT Context?

Information Systems Journal

Running Headline

The Openness Between IoT platforms

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Words

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Abstract

The main problem hampering innovation in the Internet of Things (IoT) is the fragmentation and lack of interoperability between IoT platforms. A possible solution for IoT platform sponsors to overcome this problem is to open up towards other platforms. To better understand how the IoT platform market is evolving and to inform future decisions regarding the desired degree of openness between IoT platforms, this thesis aimed to develop a theory on the openness between IoT platforms by identifying, prioritizing and theorizing the interrelations between factors driving the decisions from IoT platform owners related to the openness of their platform towards other IoT platforms. To this end, a preliminary theoretical framework was developed which was used as input for 13 semi-structured interviews with decision makers and field experts. It was found that openness between platforms is mostly driven by complementarities. Due to the cyber-physical nature of the IoT, the domain is characterised by a high need for specialisation and platforms are often developed from a product-centric, bottom-up approach. This results in a fragmented market in which there are strong complementarities between IoT platforms. It is found that these complementarities are the main factor driving the openness between IoT platforms.

Keywords: Internet of Things, Platforms, Openness, Interoperability, Decision Making, Governance

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- First Supervisor: dr. A.Y. Ding
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1 Introduction

An increasing trend in our society is the switch from product and service competition towards platform based competition (Tiwana, 2013). An example of a popular platform ecosystem is the Android operating system for mobile phones, together with its collection of apps. Characterizing a platform is the fact that it has a stable core and a variable periphery (Baldwin & Woodard, 2009). In terms of this definition, the Android operating system is the core, while the 2.6 million apps in the Google Play Store form the periphery.

An important trade-off in the governance of such platforms concerns the degree of openness. The openness of a platform is related to the easing of restrictions on the use, development, and commercialisation of the platform (Boudreau, 2010). Because a lot of functionalities of the Android operating system are open for app-developers, the value for end users can increase without the involvement of the platform owner as new and innovative apps are constantly being added by third-party developers. In the literature, this is described with the concept of generativity (Wareham, Fox, & Cano Giner, 2014). On the other hand, opening up also results in a loss of control and increased coordination costs (Wareham et al., 2014).

Whereas the governance of software platforms is increasingly being studied, research on the governance of Internet of Things (IoT) platforms is currently lacking. IoT refers to the trend that increasingly more devices are being connected to the internet. This results in new concepts, such as a smart home, in which for example your lightbulbs, fridge, thermostat and doorbell are connected to the internet. In order to unleash the true value of IoT, all these devices should be able to 'talk' to each other (Ganzha, Paprzycki, Pawłowski, Szmeja, & Wasielewska, 2018; Wortmann & Flüchter, 2015). An example of this, related to smart homes, could be that the lights in the hallway switch on when someone rings the doorbell. IoT platforms, such as Apple HomeKit, aim to facilitate this. IoT platforms should facilitate applications in the monitoring, management and control of the connected devices (Lamarre & May, 2017).

Unfortunately, the reach of these platforms is often limited to the sensors and devices from a single manufacturer (Ganzha et al., 2018; Mineraud, Mazhelis, Su, & Tarkoma, 2016). Therefore, different devices are not able to 'talk' to each other, which limits the added value of IoT and often entails that users have to install a different application for every IoT appliance they use. The lack of interoperability between different IoT platforms is one of the key issues to be solved before the true potential of IoT can be unleased (Ganzha et al., 2018; Mineraud et al., 2016).

From a technical perspective, it is becoming easier to make different platforms interoperable and the availability of open standards continues to grow. However, the decision to open up is also a strategic one, grounded in the business interests of the parties involved. To better understand how the IoT platform market is evolving and to inform future decisions regarding the desired degree of openness between IoT platforms, insight in the business and context factors driving these strategic considerations is required. The amount of scientific literature addressing this is limited, which is why the lack of insight in these factors will be the central problem in this study. To this end, this study aims to answer the following research question: *Which business and context factors influence the decisions from IoT platform sponsors regarding the desired degree of openness towards other IoT platforms?*

Currently there is little research related to the factors and trade-offs influencing the desired degree of openness between IoT platforms. Therefore, this research makes use of an exploratory approach, grounded in semi-structured interviews with field experts and decision makers. At this point, too little theory on the subject has been developed to make use of more conclusive methodologies like case studies, experiments or surveys. However, there is a lot of literature on the openness of technological and multi-sided platforms that can be used to get an idea of the factors that could play a role. Based on the related literature, a preliminary theoretical framework was developed that is used to structure the interviews.

The remainder of this paper continues as follows. In chapter 2, a theoretical framework conceptualising openness in the context of IoT platforms is developed. Chapter 3 outlines the approach to the interviews, while in chapter 4, the results of the interviews are presented and discussed. This results in an early theory identifying, prioritizing and interrelating factors driving the decisions of IoT platform sponsors regarding the desired degree of openness towards other IoT platforms. The results of this study are then discussed in chapter 5. Finally, conclusions are drawn in chapter 6.

2 Theoretical Framework

The goal chapter is to define and conceptualise IoT platforms and openness in the context of IoT platforms. In section 2.1, a definition of IoT platforms is developed. Then, section 2.2 discusses the concept of openness between platforms for the IoT and finally, section 2.3 deals with the conceptualisation of openness in the context of IoT platforms.

2.1 Defining IoT Platforms

In the scientific literature, two competing definitions of IoT platforms are found: one resulting from a technical perspective and one resulting from an economic perspective. When adopting a technical view, IoT platforms can be defined as *"the middleware and the infrastructure that enables the end-users to interact with smart objects"* (Mineraud et al., 2016, p. 5). Secondly, some scholars define IoT platforms based on the principles of multi-sided platforms (MSPs) discussed in the economic literature (Degrande, Vannieuwenborg, Verbrugge, & Colle, 2018; Schreieck, Hakes, Wiesche, & Krcmar, 2017). Schreieck et al. (2017) identify two types of IoT platforms: a standard platform that connects devices with end users and an advanced platform that also includes a marketplace which allows complementors (e.g. app developers) to interact with the end users (Figure 7). Following the definition from Hagiu & Wright (2015), they state that only advanced IoT platforms can be seen as MSPs due to the direct interaction between complementors and end users. In contrast, from a technical perspective such a marketplace is just seen as an additional capability instead of a requirement (Mineraud et al., 2016). Therefore, a 'standard' IoT platform would be considered an IoT platform according to the technical definition but not according to the economic definition.

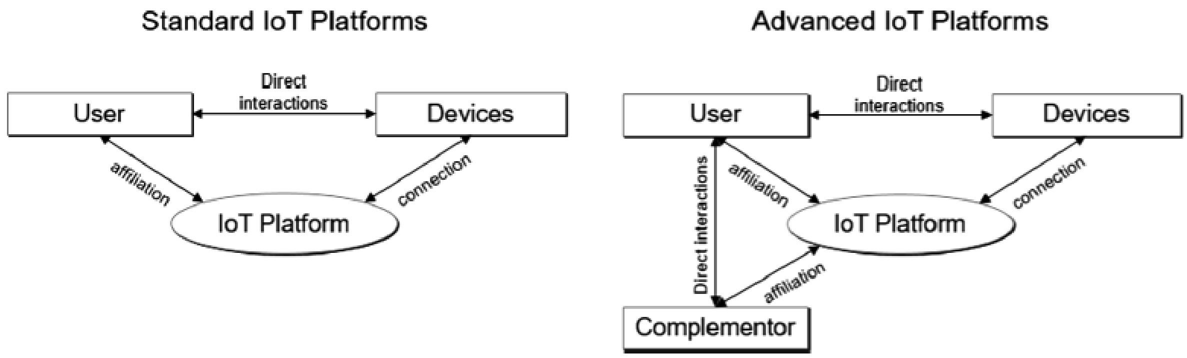

Figure 15: An economic perspective on IoT platforms, adapted from (Schreieck et al., 2017)

The good thing about the definition from Mineraud et al. (2016) is that it emphasises the core functionality that an IoT platform should provide: enabling interaction between end users and smart objects. However, a downside of this definition is that it encompasses multiple layers from the IoT architecture; both the hardware (i.e. the infrastructure) and the software (i.e. the middleware). A platform can be built around specific hardware, software or communication standards (Degrande et al., 2018). The focus in this research will be on software based IoT platforms. Hardware based platforms are not seen as a viable basis for a platform due to the multitude of IoT devices and manufacturers. Software platforms have the capability to integrate hardware devices from different manufacturers and can thereby reduce fragmentation. Depending on the use case, different communication standards might be feasible which is why picking one as a basis for a platform won't solve the issue of fragmentation.

IoT applications are found in virtually all domains in everyday life and there is a lot of variation in the functionalities that IoT platforms offer because platform providers focus on different aspects of the technology stack (Wortmann & Flüchter, 2015). One factor that could explain the diversity in focus of platform providers is the degree of vertical integration. For example, hardware manufacturers often follow a bottom-up approach and position their platform on top of their device offerings, which entails that the available functionalities are dictated by the product portfolio of the manufacturer. On the other hand, software-based companies often follow a top-down approach and start from the functionalities that the platform should have (Hodapp, Remane, Hanelt, & Kolbe, 2019). In some cases IoT platforms mediate between end-users, add-on software modules bought via an on-demand marketplace and hardware modules (i.e. IoT devices connected to the platform). In other cases, they just mediate between an end-user and a single type of device. Therefore, a generalizable definition of IoT platforms should be agnostic to:

- whether or not the software base is extendible with add-on applications (i.e. apps) that can potentially be bought in a marketplace.
- whether or not (add-on) applications are developed by the platform provider or by third party application developers.
- whether or not heterogeneous IoT devices are supported.

Furthermore, IoT platforms do not necessarily interact with end-users. They can also be deployed in automated business processes that are not controlled by end-users. In addition, Tilson, Sorensen, & Lyytinen (2012) argue to adopt a socio-technical perspective when analysing digital infrastructures. This entails that a digital platform also encompasses the organisational structures (e.g. compatibility standards) necessary for the platform to function. This leads to the following definition:

> <u>Definition of an IoT platform:</u> *the software-based system and related organisational structures that allow applications to interact with the smart objects connected to it*.

Depending on the level of analysis, the smart objects can either be independent sensors or actuators or more complex objects. For example, when analysing the autonomous driving capabilities of a car, the IoT platform under analysis resides inside the car and is connected to the enormous amount of sensors and actuators in the car. When analysing the interaction between a connected car and the information facilities of a city, the IoT platform resides probably somewhere in the cloud and is connected to multiple cars (i.e. the more complex objects) and the different information services of a city.

2.2 Openness between IoT Platforms

It is also not clear what openness entails in the context of IoT platforms due to the lack of theory on the subject. Some scholars characterise IoT platforms based on a definition of openness that relates to the degree to which a platform makes use of open source components (Hodapp et al., 2019; Mineraud et al., 2016). However, in the theory related to the openness of software platforms, the concept is used differently. There it relates to the easing of restrictions on the use, development, and commercialisation of a platform (Boudreau, 2010). A conceptualisation more in line with the software platform perspective is used by Schreieck et al. (2017). They distinguish between openness towards end-users and openness towards third party developers and they relate these dimensions to respectively the degree to which access to the platform is granted and the degree to which control over the platform is given up.

Unfortunately, these conceptualisations don't fit well in the context of this study, where the high degree of fragmentation and lack of interoperability between IoT platforms is the central problem. Intuitively, this could be seen as the openness *between* platforms. However, there is no theory or conceptualisation of openness in the context of IoT platforms – or in the context of software platforms – addressing this issue. For example, Schreieck et al. (2017) only distinguish between openness towards end-users and third-party developers but they do not consider the openness between IoT platforms. In a conceptualisation of openness in the context of Industrial Internet of Things (IIoT) platforms, Menon, Kärkkäinen, & Wuest (2017) did acknowledge the horizontal dimension of openness but they focussed primarily on the ownership structure. Therefore, a clear conceptualisation of openness in the context of IoT platforms, which also accounts for the openness between platforms, is required.

Essentially, greater openness between IoT platforms can be achieved in two ways (see Figure 16). Firstly, platforms could open up towards each other by creating a meta-platform on which different platforms can share their services and data. A technological solution in line with this argument is sketched by Mineraud et al. (2016), who introduce the concept of IoT-marketplaces as the solution to the interoperability problem. These marketplaces should accomodate the flow of data across different IoT platforms, thereby making them interoperable via the sharing of (real-time) data. Keijzer-Broers, Florez-Atehortua, & De Reuver (2016) present a prototype for such a platform in the healthcare domain. Secondly, platforms could open up in a more direct way to each other by making them interoperable via gateways and API's. Savaglio, Fortino, Gravina, & Russo (2018) share this perspective and they consequently propose a software development methodology for integrating multiple IoT platforms to aid in this envisoned transition. Of course, a merely technical solution will not be sufficient and a proper governance structure is required in both cases (cf. Gawer & Henderson, 2007).

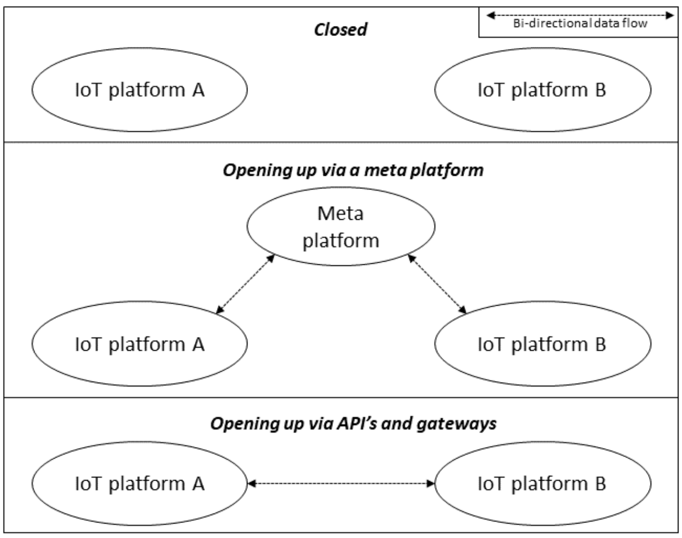

Figure 16: Modes of opening up between platforms

2.3 Defining Openness in the Context of IoT Platforms

As a starting point for defining openness in the context of IoT platforms, the conceptualisation of openness from Ondrus et al. (2015) will be used, who identify four levels of openness and hence four distinct ways to open up a platform. The first level they identify is the sponsor level, relating to the ownership structure of the platform. Secondly, they identify the provider level, which refers to the degree to which multiple platform providers cooperate with each other to provide a service together. Thirdly, they state that openness on the technology level refers to the degree to which a platform is interoperable with other platforms (i.e. through the use of API's or gateways). Finally, with openness on the user level they refer to the degree to which users from other platforms and/or users not yet part of a platform can join the platform. Within user level openness one can further distinct between the openness towards demand- and supply-side users. These different levels of openness are visualised in Figure 6. To adapt this conceptualisation of openness to the IoT context, several adaptations have to be made, these will be discussed when discussing the level to which they apply.

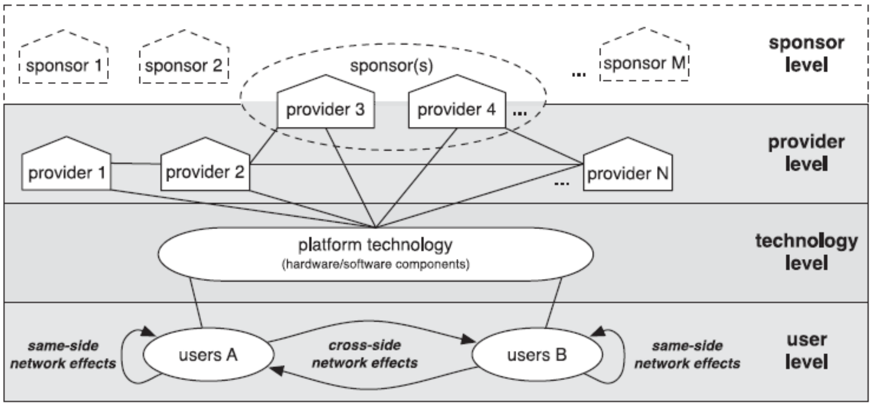

Figure 17: Levels of openness, adapted from Ondrus et al. (2015)

2.3.1 Sponsor Level Openness

Since there are no characterising differences with other platforms that relate to the sponsor level, the definition of sponsor level openness from Ondrus et al. (2015) can be used, which refers to the ownership structure of the platform. Because Ondrus et al. (2015) leaves the sponsor level outside the scope of their analysis, they have not explicitly defined it. Therefore, the following definition will be used: *the extent to which an IoT platform is owned by more than one stakeholder*.

2.3.2 Platform Level Openness

In terms of Ondrus et al. (2015), provider level openness refers to the degree to which multiple platform providers cooperate with each other to provide a service (i.e. platform) together. With openness on the technology level they refer to the degree to which a platform is interoperable with other platforms – through the use of gateways or API's. As discussed in section 2.2, there are two distinct ways for a platform to open up towards other platforms:

- Directly: if two platforms are directly made interoperable via gateways or API's (e.g., Ochs & Riemann, 2017).

- Via a broker service or meta-platform: for example via an IoT marketplace that accommodates the flow of data across different IoT platforms (e.g., Mineraud et al., 2016).

When mapping these two modes of openness to the levels of openness defined by Ondrus et al. (2015), the first mode overlaps with openness on the technology level while the second mode only partly overlaps with openness on the provider level. In terms of Ondrus et al. (2015), openness on the provider level refers to multiple firms providing a single platform. However, in this situation there is only a single platform and you cannot speak of openness *between* platforms anymore. Thus, an important characteristic of platform level openness is that if two platforms open up towards each other, they both keep existing. For example, imagine that two platforms – say platform A and B – open-up towards each other via a broker service or meta-platform. In this case you end up with three platforms: platform A, B and the meta-platform. If platform A and B would integrate into a single platform, the original platforms stop existing. Thus, collaboration modes as licencing and integration are not seen as platform level openness because the original platforms are not maintained in these cases. Instead, they can be seen as a form of sponsor level openness because it affects the ownership structure. Therefore, platform level openness can be defined as: *the degree to which data and services can be shared among different IoT platforms*.

2.3.3 User Level Openness

With user level openness, Ondrus et al. (2015) refer to the *degree to which users from other platforms and/or users not yet part of a platform can join the platform*. Within user level openness one can further distinct between the demand- and supply-side users. Both sublevels apply to IoT platforms as well if you see the third party application developers as the demand side users. However, IoT platforms are not always open for third party developers (Schreieck et al., 2017). Within this definition of user level openness, this can be modelled as closed towards demand-side users.

2.3.4 Device Level Openness

Because IoT platforms can be extended by both software and hardware modules (i.e. smart objects), another new level of openness has to be introduced – openness towards devices. IoT devices could be generic (e.g. temperature sensor) and therefore, they can be produced by multiple manufacturers. Thus, it makes sense to define openness towards devices instead of device providers. The openness towards devices can be defined as *the degree to which heterogeneous devices are supported by the platform*. Platforms that are considered open on the device level will often make use of one or more open compatibility standards.

3 Methodology

This chapter outlines the methodology that was used to approach this research. Section 3.1 discusses criteria for selecting the interview candidates. An overview of the selected candidates is also presented in this section. Then, the interview protocol is discussed in section 3.2. Finally, the approach to analysing the interviews is discussed in section 3.3.

3.1 Respondent Selection

This research is grounded in 13 interviews with field experts and decision makers. Because the IoT is characterised by a high degree of fragmentation, respondents are sampled from two relatively different industries to ensure that as much factors as possible are found. The two selected domains are the healthcare and automotive domain as these differ on all three aspects. The healthcare domains has a very complex competitive landscape, which is influenced by heavy regulation. There are a multiple sub domains, which are very different from each other. The need for specialisation is high due to the intense competition and fragmentation of service offerings. In contrast, the automotive domain is characterised by the dominance of the OEMs producing cars and trucks. Although the competition between them is high, the ecosystem is less complex since all IoT offerings are connected to the vehicles. The market is very immature as there are no mature standards yet that govern the information exchange with the vehicles.

The interview candidates are selected based on their affinity with the topic, (sub)domain and experience. The ideal respondent is someone who has a lot of experience with IoT in general or with a specific IoT platform in particular. Furthermore, respondents ideally hold senior positions and have decision making power regarding the openness of an IoT platform towards other IoT platforms. The most important characteristic on which interview candidates are varied, relate to the (sub)domain in which they work. The final sample (see appendix A) fulfils these requirements quite well:

- The sample is quite balanced with respect to the (sub)domains. Out of the 13 respondents, 7 work in the automotive domain, 5 in the healthcare domain and 1 respondent has a cross industry focus. It is a deliberate choice to have the majority of the respondents related to a specific domain to ensure sufficient generalisability. One respondent with a cross industry focus was selected due to his extensive experience in the field (IoT industry leader at a multinational software services and consulting firm and 28 years of experience within that firm).
- Within the healthcare domain, 2 respondents work in the more regulated medical subdomain while 3 work within the consumer oriented fitness domain. Within the automotive domain, 3 OEMs are interviewed (as services are all related to vehicles), 1 governmental organisation and 3 connected car related service providers.
- The experience of all respondents is adequate as they hold senior positions, have a lot of experience within the company (> 5 years) and/or gathered experience fast due to the nature of the work (PhD candidate).

3.2 Interview Protocol

3.2.1 Interview Procedures

In contrast to methodologies like Grounded Theory, in which the interview process often starts with little information about the theoretical relations (Corbin & Strauss, 1990), a preliminary theoretical framework was available to guide the interviews (see appendix B). Nevertheless, some principles were borrowed from the Grounded Theory approach as, to some degree, the interview protocol was iteratively altered based on the results of the interviews. Due to the semi-structured nature of the interviews, in a few cases additional topics were added during the interviews when novel insights came forward. In the subsequent interviews with people related to the topic, these topics where discussed as well. Also, as the interviews progressed and the domain knowledge of the researcher deepened, some topics were structured around different examples if it was found that respondents were better able to familiarise with them.

Furthermore, definitions and conceptualisations were sharpened in dialogue with the interview respondents. Especially in the first four interviews, it took relatively more time to establish a shared vision on the definitions of openness and IoT platforms. Insights from the discussions used to reach a common understanding were used to improve the explanation of the definitions and conceptualisations in the interviews that followed. However, although the phrasing might have changed during the first four interviews, the idea behind the definition remained the same. In the end, the same shared vision was used across all interviews. Compared to a typical grounded theory process, the interview topics were altered to a far lesser degree. By keeping the interview topics relatively constant, the comparability between the interviews increases and more robust conclusions can be drawn about the topics in the preliminary framework (Sekaran & Bougie, 2016).

The interviews lasted between 29 and 75 minutes, with a mean duration of 50 minutes and a standard deviation of 13 minutes. All interviews were recorded and transcribed to text such that they could be analysed with coding software (see section 3.4). In most interviews, it often occurred that respondents were thinking out loud. Part of these thought processes were omitted in the transcripts (e.g. stop words like 'uhh..' or 'well…'). After transcribing, the interview recordings were deleted. To comply with the GDPR and research ethics guidelines of the TU Delft, all respondents gave their explicit and written consent for the way in which their personal information is processed. The interview respondents were asked to provide feedback on the transcripts but none the respondents did this. However, all quotes used in this report were send back to the respective interview respondents and only used after approval. All quotes were altered as suggested.

3.2.2 Interview Topics

The list of topics with possible introductory questions and examples is presented in appendix C. The questions are only meant as a *possible* introduction to the topic. The first question in the section "Core Topics" in the table in appendix C was asked during all interviews. Based on the response, follow-up questions were asked and the natural conversation that followed often covered a large part of the topics. Thus, the other questions in appendix C weren't always asked if they were already covered in the discussion that followed from one of the preceding questions. For topics that were partially covered, additional follow-up questions were asked. Trade-offs between factors were also covered in follow-up questions. If respondents did not understand a question, one or more of the examples presented in the third column of appendix C were used. Sometimes, as discussed in section 3.3.1 – interview procedures, a discussion between the researcher and respondent found place until the respondent and researcher had a shared understanding about the idea behind the question or definition.

3.3 Interview Analysis

Usually, when analysing transcribed interviews, the coding process consist of three stages: open, axial and selective coding (Corbin & Strauss, 1990). The result of the open coding phase is a list of codes that segments the raw data into fragments that have similar meanings. Each fragment is represent by a code – a conceptual label that expresses the meaning of the fragment (Boeije, 2009). In the axial coding stage, the level of abstraction increases; similar codes are combined and the codes are grouped into categories and sub categories. Relationships between (sub)categories are defined (Boeije, 2009).

Finally, the selective coding phase marks the end of the analysis and aims at building a theory to answer the research question. Important categories and possibly a core category (i.e. central phenomenon around which all the other categories are integrated) are determined (Boeije, 2009).

The general strategy described above is also followed for this research. However, because a preliminary theory was available, the coding process didn't start with the raw data. Instead, an initial list of codes and categories was developed based on the preliminary theory (theoretical framework in appendix B). Then, during the open coding phase, new codes were added to this list. This is a more goal oriented approach with the advantage that you are able to build on existing theory (Miles & Huberman, 1984; Sekaran & Bougie, 2016). Appendix D describes the coding process. Throughout the whole coding process, notes were kept during the analysis of each interview, describing the most important factors and interrelations. These notes were used as a basis for drawing conclusions and writing chapter 4. The transcribed interviews were analysed with help of the ATLAS.ti coding software.

4 Results

The semi-structured interviews held with decision makers and field experts learned that decisions on platform level openness are influenced by (1) the perceived effect of the decision on the business outcomes and (2) the legal requirements. These factors are discussed in section 4.1. Furthermore, it is found that decisions about platform level openness are always made in a specific context, with respect to a specific use case. The impact of the characteristics of a potential use case are discussed in section 4.2 while the impact of the context factors is discussed in section 4.3. Finally, trade-offs between the factors are discussed in section 4.4. The updated theoretical model has been presented in appendix E.

4.1 Perceived Effect on Business Outcome & Legal Considerations

With respect to the perceived effect on the business outcome, a few important factors play a role. Probably the most important factor relates to the attractiveness of the business case surrounding the openness decision; if opening up doesn't mean that extra profits can be gained, opening up won't make sense for a lot of companies. It is found that openness decisions are mainly driven by the presence of complementarities. Organisations often don't want to open up to platforms with a similar product portfolio; who are directly competing with them. This reduces switching costs and increases the risk of end-users leaving the platform. Although the end-users of the platforms might benefit from a reduced lock-in, there is no benefit to be gained by the platform companies if there is no extra value created through the presence of complementarities; dividing the total profits will be a zero-sum game. However, companies do want to open up towards other platforms that fulfil a different role in the ecosystem if there are complementarities between the product offerings. Then, extra value is created and both companies can profit from the openness; dividing the pie becomes a positive sum game. This extra value can either be the result from extra services for which money can be charged or more indirect, via an improved product that results in more sales.

However, the value that is created through the complementarities should not be off-set by the cost of becoming open. These costs can either be direct (e.g. development costs) or more subtle. An interesting finding is that a lot of organisations are either not sure about how valuable the data is they have or how they should profit from it. Due to this uncertainty, organisations are reluctant to open up because they are afraid that somebody else might see a value that they don't see; they are afraid that they are giving away something for free. This entails that currently, the immaturity of the market is one of the factors withholding platforms providers to open up towards other platforms. This uncertainty also plays a role with respect to the legal requirements. For example, the lack of regulation governing autonomous driving applications can cause companies to put R&D projects on hold. Furthermore, especially in the automotive industry, competition law also has an impact because OEMs are reluctant to work together out of the fear that it might be seen as cartel forming.

Next to a profitable business case, strategic considerations also play a role. It is not always necessary that the business case is profitable, organisations can also open up out of strategic considerations. For example because they want to influence market developments via participation in standardisation committees. This is the case in the automotive domain, where car and truck OEMs actively try to push their standards in the market in the hope that their standard becomes the de facto standard. Another strategic reason is related to the participation in EU- or government sponsored projects. In such projects, multiple ecosystem players work together to generate knowledge about the way in which the market is developing or about other players in the ecosystem. Reasons why organisations would remain closed out of strategic considerations relate to the loss of control over their own product development (e.g. through shared development) or to protect their market position. In general, privacy and security considerations also causes companies to be more closed on the platform level. Compared to other types of platforms, privacy and security considerations are more important for IoT platforms due to their cyber-physical nature. High privacy and security standards mean that less potential use cases can fulfil them, which lead to lower platform level openness.

4.2 Characteristics of Potential Use Case

It was also found that decisions regarding the desired degree of openness are always made in the context of a certain use case. Organisations don’t just open up their whole platform, instead, they open up their platform for a specific application and a specific partner, in a specific way. An example of a use case could be, sharing aggregated location data (=application) to inform authorities (=partner) where there is traffic by making use of a meta platform (=mode of openness). With respect to the application, organisations usually only want to open up for use cases characterised by complementarities or synergies. The type of data that is being shared is also important. Organisations might not want to share detailed data (e.g. because it contains personal or sensitive information) but they do want to share aggregated data. The type of applications IoT platforms want to open up to are also closely related to the potential partners they want to open up to. Organisations do not want to open up towards a direct competitor (i.e. a platform with a similar service offering). They rather open up to a platform in another domain or a governmental party. Furthermore, it was found that most organisations prefer interoperability via a trusted third party or meta-platform over direct interoperability.

4.3 Context Factors Influencing the Desired Degree of Platform Level Openness

The decisions about platform level openness are always made in a specific context, with respect to a specific use case. Important contextual factors are the characteristics of the market and the organisation itself. The most notable way in which market characteristics impact openness decisions, is through end-user demand; organisations that provide a service to end-users will have to fulfil some expectations. For example, if users want an integration with a different service, companies will consider this. If the other service has a dominant market position, it is likely that the platform will open up towards this service to avoid a competitive disadvantage. Think for example of a platform like apple health, nearly all activity trackers are interoperable with this service. The end user demand is closely related to the need for specialisation; if companies cannot provide a whole service by themselves, they could open up towards other platforms that provide this service such that they can still offer a complete service to their end users. Compared with other platforms, there is more need for specialisation in the IoT because products require dedicated manufacturing facilities to benefit from economies of scale. The maturity of the market also plays a role. For example, through the availability of mature compatibility standards. Especially in the complex settings found in the automotive domain, organisations usually do not want to open up towards each other without a widely accepted compatibility standard.

Important organisational characteristics relate to the strategic focus of an organisation and the closely related vertical integration; a company producing both the hardware and the platform might have different considerations than an organisation only providing the platform – the focus could be on profiting from hardware instead of software. Vertically integrated platform providers also adopt a product-centric bottom-up approach when deciding which functionalities to develop for the platform. Due to this, different considerations will be driving decisions regarding openness. Furthermore, the maturity of a company also affects openness decisions; a smaller company, that needs to set foot in the market has different considerations than a big company trying to protect its market share.

4.4 Trade-offs

As argued above, IoT platform owners have to make a trade-off between (1) the profitability of the business case, (2) their strategic position and (3) privacy and security considerations, while fulfilling legal requirements. How the factors in this trade-off are prioritized is determined by the context in which the openness decisions are taking place. Next to the characteristics of the use case, the context consist of the market- and organisational characteristics. The main market characteristics that influence how trade-offs are being made are the intensity of competition and the maturity of a market. In markets where the competition is high, consumers have relatively more power because they have more alternatives to choose from. Therefore, it is more important to protect your userbase in such markets and strategic considerations will be relatively more important. In immature markets, strategic considerations are usually more important. For example, in markets characterised by high network effects, there is an incentive to gain a big market share quickly at the expense of profitability. Once sufficient users have affiliated themselves with the platform, network effects can take over and drive further growth. This is especially important in immature markets, where not all end users have affiliated themselves with a platform. This makes attracting them easier.

The main way in which the organisational characteristics influence how the trade-offs are being made relate to the strategic focus of the platform. For example, it has been argued that there is a trade-off between benefiting from the product (through increased sales) and benefiting from the platform (through a high amount of users affiliated with it). Vertically integrated platform providers will usually choose for the former strategy while platform centric organisations will choose for the latter. In addition, the overall business objective of a company also influences the trade-offs. A non-profit or governmental organisation will most likely have different considerations than a for-profit organisation.

5 Discussion

This chapter positions the results of this study in the existing scientific literature. Section 5.1 discusses why the concept of platform level openness is more important for IoT platforms compared to other platforms. Then, in section 5.2, it is argued that in contrast to other platforms, decisions regarding the openness of IoT platforms are often made from a product- instead of a platform-centric perspective.

5.1 Higher Importance of Platform Level Openness for IoT platforms Compared to Other Platforms

In this section, it is argued that the concept of platform level openness is more relevant for IoT platforms than for digital or other multi-sided platforms. This has two reasons. Firstly, IoT platforms are characterised by a higher need for platform level openness because there are stronger complementarities between the services of different IoT platforms. This is discussed in more detail in section 5.1.1. Secondly, there are also more opportunities for platform level openness because winner-take-all dynamics are to a lesser extent present. This is further discussed in section 5.1.2.

5.1.1 Higher Need for Platform Level Openness Due to Stronger Complementarities

IoT platforms are characterised by a higher need for platform level openness, compared to other multi-sided and technology platforms. The IoT platform market is characterised by a high degree of fragmentation (Ganzha et al., 2018; Mineraud et al., 2016). Because of this fragmentation, there is a higher need for openness between platforms as services from multiple IoT platforms should be combined in order to provide a complete service to end users. In other words, there are stronger complementarities between the services of different IoT platforms.

Degrande, Vannieuwenborg, Verbrugge, & Colle (2018) argue that the fragmentation is a result of the immaturity of the market. However, IoT applications are found in virtually all domains in everyday life (Nicolescu, Huth, Radanliev, & De Roure, 2018; Wortmann & Flüchter, 2015). Therefore, it is more likely that the fragmentation results from the high need for niche specialisation caused by the diversity of the application domains and use cases in which IoT can be utilised. The need for specialisation is related to the physical products on which the IoT is based. To produce these products efficiently on a large scale, dedicated manufacturing facilities are required due to the economies of scale that characterise the production. In contrast, an application for a software platform (e.g. Android) can be built by a single developer. For software platforms, there is no distinction between design and production which entails that economies of scale in production are less relevant (Henfridsson, Mathiassen, & Svahn, 2014).

The high need for platform level openness due to complementarities can be observed in the automotive domain, where a lot of different IoT devices are required to make the ‘connected car’ as useful as possible. An example of this relates to electric charging stations. By providing access to the location and availability data of these charging stations, users can better plan their ‘fuel’ stops. Also in the healthcare domain, there is a high need for platform level openness resulting from complementarities between IoT platforms. The inter-organisational collaboration within hospitals is increasing. This requires that the IoT platforms of different manufacturers, used to control medical equipment, should become interoperable to allow the data to flow more easily between the medical devices. A second example in the medical domain relates to a platform integrating medical data. In this platform, data from different IoT devices (e.g. smart scales, EEG recordings or glucose level meters) is combined to better interpret the data.

5.1.2 More Opportunities for Platform Level Openness Due to Weaker Winner-Take-All Dynamics

Next to a higher need for platform level openness, there are also more opportunities for platform level openness due to winner-take-all dynamics that are to a lesser extent present. Because of this, there is less competition between platforms and thus more room for platforms to open up towards each other. Winner-take-all dynamics are a characteristic of the typical competition between multi-sided platforms and they occur if (Eisenmann, Parker, & Van Alstyne, 2006): (1) multi-homing costs are high for at least one user side, (2) positive network effects are strong for that same side and (3) there is no need for niche specialisation. Based on the discussion in section 5.1.1, it can already be observed that the third condition does not hold. If there is need for niche specialisation, platforms can avoid competition by differentiating themselves from other platforms. This is illustrated by the CEO of a company integrating medical data, who indicated that they rather differentiate themselves from competitors instead of creating lock in.

However, the main factors explaining competition between platforms are the indirect positive network effects between user groups (e.g., Katz & Shapiro, 1985; Rochet & Tirole, 2003). The relation that remains, in which these network effects could occur – if there is no app store – is the one between device providers and end-users. It can be argued that if there is a close collaboration between the device providers and the platform and if this relation is not being governed by open and mature compatibility standards, IoT platforms are expected to exhibit MSP dynamics. This argument is based on the definition of multi sided platforms from Hagiu & Wright (2015), who state that MSPs are characterised by a direct affiliation with the platform of at least two user groups who control the key terms of the interaction that is facilitated between them. This is the case in the situation sketched above because:

- The platform enables direct interaction between the device providers and the end users because the devices cannot be used without the platform. To fit the definition of a multi-sided platform, the key terms of the interaction, such as the price of the devices or the service provided by them, should be controlled by the device providers and the end-users, not by the platform (Hagiu & Wright, 2015).
- Both the end-users and device providers are affiliated to the platform through their platform specific investment. Device providers have to support a proprietary standard which can only be used with the specific platform and end users invest time and/or money for connecting to the platform.

This claim can be validated by the dynamics in the fitness domain, where the competition between platforms is high. Two platforms in the fitness industry indicated that they only open up on the platform level if there are complementarities to be gained. They do not open up to platforms with a similar value proposition because they want to attract as much users as possible. In both cases, the connections between the different devices and the platforms are platform specific (i.e. not a mature open standard). This finding is in line with Nikayin et al. (2013), who found that an IoT platform for independent living services was only open for device providers who are not competitors of the device providers already affiliated to the platform.

5.2 A Product Centric Versus a Platform Centric Approach to Openness

The complementarities described in section 5.1.1 reside between IoT devices and not necessarily between IoT platforms. However, this often entails the same due to the high degree of vertical integration characterising the IoT platform market. The high degree of vertical integration entails that

IoT platforms are often provided by the same organisations that are also manufacturing the devices connected to it. This is for example the case with fitness wearables, where brands like Fitbit, Garmin and Polar all have their own IoT platform. But this is also the case in the medical and automotive domains. The high degree of vertical integration could result from the immaturity of the market. This would be an extension of the argumentation from Degrande et al. (2018), who argue that the fragmentation in the IoT platform market results from the immaturity of the market.

However, other alternative explanations are more plausible. Firstly, it is also possible to extent the line of argumentation related to the high need for specialisation from IoT devices to IoT platforms. Because IoT platforms are the bridge between the physical and the digital realm, there are high dependencies between the IoT device and the IoT platform. This could be supported by the claim of a director at a company manufacturing medical equipment, who said that the process of getting the raw data from the device and transforming it to usable data on a platform is the most difficult aspect of the IoT. Therefore, it makes sense if the IoT platform connecting the device is also developed by the manufacturer of the device. This would also avoid dependencies on other platform providers.

Secondly, compared to other software platforms, the stand-alone value of a single complement for an IoT platform (i.e. IoT device) is higher. This entails that IoT devices in itself are very useful and connecting them to the internet and other IoT devices via a platform only increases the functionality (Wortmann & Flüchter, 2015). For example, a lightbulb is useful because it provides light. When connecting the lightbulb to the internet you increase the usefulness because you can remotely control it. If you connect it to other products (such as a doorbell) you can further increase the value by letting the products interact with each other. Again, it makes sense for a manufacturer of an IoT device to provide the platform as well to avoid being dependent on other platform providers for the functionality of their products. In contrast, software platforms have digital components that are specifically designed as *addition* to a certain platform. An application cannot be used without the platform it is designed for.

Due to the high need for specialisation and the high stand-alone value of IoT devices, IoT ecosystems are often characterised by a product-centric design approach while software platforms are characterised by a platform-centric design approach. Due to this difference in focus, other decisions regarding the openness of platforms are being made. Hodapp et al. (2019) argue that hardware manufacturers often follow a bottom-up approach and let their product portfolio dictate the functionalities of the IoT platform while software-based companies often follow a top-down approach and start from the functionalities that the platform should have.

That this argument also applies to platform level openness can be illustrated with the strategy followed by manufacturers of fitness wearables. These manufacturers choose to be open via open API's in order to make their product interoperable with as many platforms as possible, to increase the sales of their products. This also means that they have less control over the other platforms that become interoperable with them because the API's are not restricted. This lowers the lock-in to the platform. For example, Garmin (i.e. brand of wearables) has open API's that can be used by other organisations, including competing platforms like Strava. This indicates that there is a trade-off between benefiting from the product (through increased sales) and benefiting from the platform (through a high amount of users affiliated with it). The manufacturers of fitness wearables don't care about making money from an IoT platform, for them the platform is just a means to an end in order to increase the sales of their physical product.

6 Conclusion

The main problem hampering innovation in the Internet of Things (IoT) is the fragmentation and lack of interoperability between IoT platforms. A possible solution for IoT platform sponsors to overcome this problem is to open up towards other platforms. To better understand how the IoT platform market is evolving and to inform future decisions regarding the desired degree of openness between IoT platforms, insight in the business and context factors driving these strategic considerations is required. The amount of scientific literature addressing this is limited, which is why this thesis aims to develop a theory on the openness between IoT platforms by by identifying, prioritizing and theorizing the interrelations between factors driving the decisions from IoT platform owners related to the openness of their platform towards other IoT platforms. As a result of this research, an IoT platform is defined as *the software-based system that allows applications to interact with the smart objects connected to it*. The openness between IoT platforms has been conceptualised as *the degree to which data and services can be shared among different IoT platforms*.

When deciding about the desired degree of platform level openness, it was found that IoT platform owners have to make a trade-off between (1) the profitability of the business case, (2) strategic considerations and (3) privacy and security considerations, while fulfilling legal requirements. How the factors in this trade-off are prioritized is determined by the context in which the openness decisions are taken. This context consists of three pillars: the market characteristics, the organisational characteristics and the characteristics of the potential use case. The main characteristic that sets IoT platforms apart from other technological or multi-sided platforms is their cyber-physical nature. This nature entails that the IoT domain is characterised by a high need for specialisation and that platforms are often developed from a product-centric, bottom-up approach. This results in a fragmented market in which there are strong complementarities between IoT platforms, which lead to a high need for openness between them. Because the network effects are also less strong for IoT platforms compared to other multi-sided platforms, winner-take-all dynamics are to a lesser extent present, which gives more room for collaboration between platforms in the form of platform level openness.

A limitation of this research is that only two application domains where considered in this research: the automotive and healthcare domain. These domains where selected due to variability on the context variables, to generate as many possible insights as possible in this early stage of theory development. However, the research also made clear that the desired degree of platform level openness is highly dependent on the use case and the context in which the IoT platform operates. Thus, when applying this theory to other domains within the IoT, specific attention to the context variables is required. Nevertheless, the identified factors are probably to a large extent the same because the same factors were observed in both domains and the context mainly changed how trade-offs between those factors are being made.

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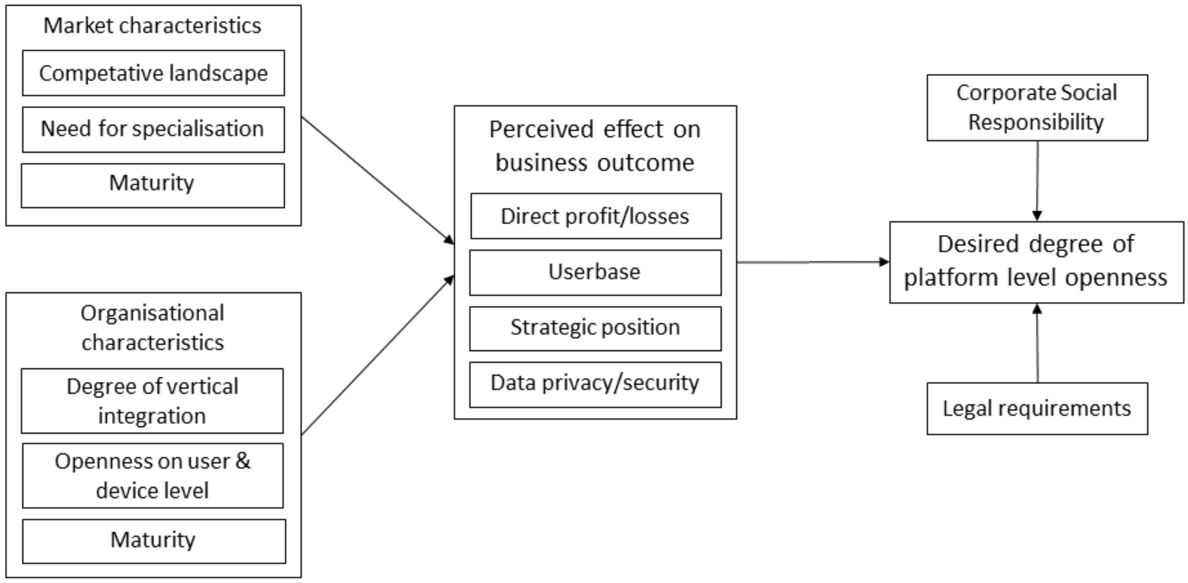
Appendix A: Interview Respondents

#[16]	(Sub)domain	Organisation	Position	Years at company
	Healthcare			
1	Medical	Manufacturer of medical equipment	Director	<1 year
2	Medical	Platform integrating medical data	CEO	14 years
3	Fitness	University	PhD candidate focussed at fitness wearables	4 years
4	Fitness	Platform integrating fitness services	CTO	2 years
5	Fitness	Manufacturer of fitness equipment	Integration specialist	11 years
	Automotive			
6	All	Governmental	Stakeholder manager for connected car experiments	22 years
7	All	Car OEM	General manager connected car	16 years
8	All	Car OEM	Technology & trend scout	7 years
9	All	Truck OEM	Principal engineer vehicle connectivity	?
10	Service provider	Payment provider	Head of connected car & IoT	19 years
11	Service provider	Automotive driver association	Head of connected car	9 years
12	Service provider	Provider of fleet management software	Product manager connected car	4 years
	General			
13	All	Software services and consulting	IoT industry leader	28 years

[16] In chapter 4, this number is being used to refer to the interviews

Appendix B: Preliminary Theoretical Model



Appendix C: Interview Topics

Topic	**Possible introduction question to start the discussion on the topic**	**Optional examples**	**Comments**
Introduction			
Personal introductions	Could you explain what you are doing at [company name]?	-	Both the researcher and respondent introduce themselves
Informed consent & start of recording	-	-	
Research introduction	-	-	The goal of the research is explained
Concepts			
IoT platform	-	Google Home/Amazon Alexa, tailored example (e.g. the IoT platform in a car for interviews in the automotive industry)	Discuss the definition of IoT platforms developed in this research
IoT platform openness	-	Examples tailored to the example used for introducing the concept IoT platform	Discuss the definitions of IoT platform openness developed in this research
	Do you have any comments based on this conceptualisation?	-	
Core Topics - General			
	Which factors determine your/the platform owner's desired degree of openness towards other IoT platforms?	Direct profit/losses	Open question without further introduction
Legal Requirements & CSR			
Legal requirements	In what way do legal requirements play a role?	GDPR, competition law	
Corporate Social Responsibility	In what way does Corporate Social Responsibility plays a role?	-	Highlight difference with legal requirements by explaining the legitimacy motive of CSR
Perceived Effect on Business Outcome			
Strategic position	In what way does the perceived effect on your/the platform owner's	Lock-in, risk of forking, market position	Phrasing differs based on function and company of respondent

	strategic position plays a role?		
Userbase	In what way does the perceived effect on the growth of your/the platform owner's userbase plays a role?	Network effects	Phrasing differs based on function and company of respondent
Direct profit/losses	In what way does the perceived effect on the direct business case plays a role?	Development costs for the interoperability solution, the possibility to charge access fees	Explain that this relates to the costs and revenues directly following from the interoperability with other platforms
Data privacy/security	In what way do data privacy and security considerations play a role?	GDPR, start-up not capable of adequate data protection	
Market Characteristics			
Competitive landscape	In what way does the competitive landscape in this market plays a role?	Dominant market players, intensity of competition	
Need for specialisation	In what way does the need for specialisation in this market plays a role?	-	Explain what need for specialisation entails
Maturity	In what way does the maturity of this market plays a role?	Availability of technologies/standards, end-user adoption over whole market, partly working products	
	Can you think of any other market characteristics that impact your/the platform owner's desired degree of platform level openness?	-	Phrasing differs based on function and company of respondent
Organisational characteristics			
Degree of vertical integration	In what way does the degree of vertical integration plays a role?	Whether or not a company also produces hardware	
Openness on the user level	In what way does the degree of openness on the user level plays a role?	Openness towards app developers in Google Play store	Repeat conceptualisation
Openness on the device level	In what way does the degree of openness on the device level plays a role?	-	Repeat conceptualisation
Maturity	In what way does the maturity of your/the platform owner's organisation plays a role?	-	Phrasing differs based on function and company of respondent
	Can you think of any other organisational characteristics that impact	-	Phrasing differs based on function

	your/the platform owner's desired degree of platform level openness?		and company of respondent
Closure			
Missed factors	Given this interview, can you think of any other factors that impact your/the platform owner's desired degree of platform level openness?	-	Phrasing differs based on function and company of respondent
Prioritisation of factors	Given the factors we discussed in this interview, which ones do you consider the most important?	-	
Further comments	Do you have any further comments?	-	
Transcribed interview	Do you want to review the transcribed interview?		
Thanks and goodbye			

Appendix D: Coding Process

Phase	#Codes	#Categories/ #Sub categories	Approach and examples

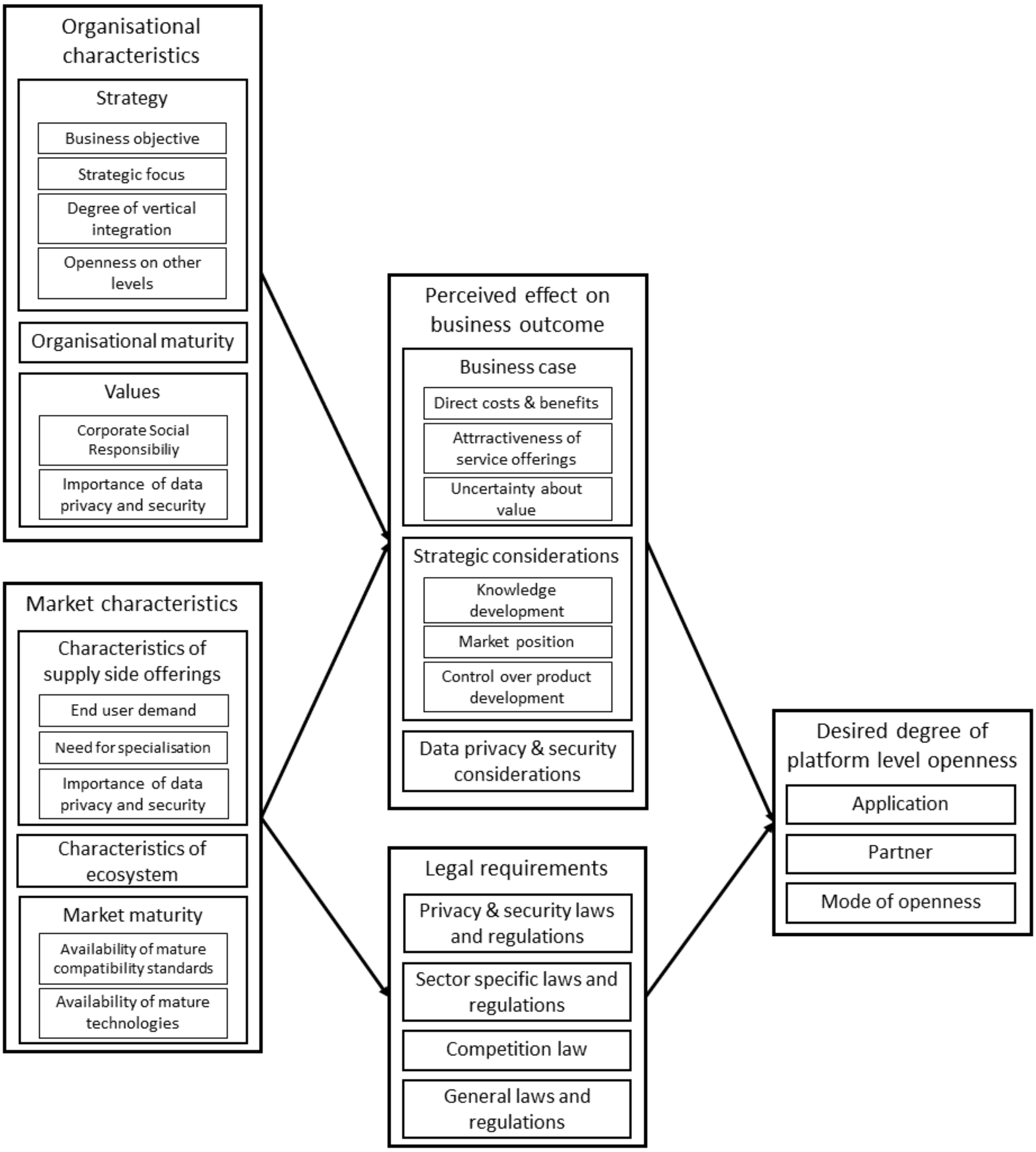
Initial	85	6 / 10	Categories and sub categories are copied from the preliminary theoretical framework presented in section 2.3. Codes are assigned based on the literature that lead to developing this preliminary conceptual model.
			• A reduced chance of lock-in could be a reason for end-users to adopt a platform earlier (West, 2003).
			    o Code: low chance of lock-in
			    o Category: perceived effect on business outcome
			    o Sub category: userbase
			• Reputational damage will occur if bad complements are added to a platform (Boudreau, 2012)
			    o Code: reputation of company
			    o Category: organisational characteristics
			    o Sub category: maturity

Open	181	6 / 10	The initial list of codes is used to label fragments in the interviews, if a fragment did not fit with one of the codes, a new code was assigned.
			• *"I guess that sometimes platform providers may have incentives to keep the platform closed and to create some kind of lock in and high switching costs so that their customers don't escape to another platform."* (Interview 3)
			    o Assigned codes: create lock-in, create switching costs, platform level openness
			• *"We cannot share everything, also due to privacy reasons and stuff and also al lot of discussion is ongoing; who is owning which set of data? So what is car generated, what is customer generated, what is in between. Therefore we are very careful. But the kind of data that we could share – especially for safety reasons – we are more than willing to share."* (Interview 7)
			    o Assigned codes: ability to safeguard end-user privacy, GDPR/privacy law, importance of data privacy and security, possibility to improve public safety, platform level openness

Axial	104	6 / 12	The categories developed in the initial stage are reconsidered and similar codes are merged. • The category 'Corporate Social Responsibility' is merged with the sub category 'Values', under the main category 'Organisational Characteristics' • A new main category – 'Characteristics of potential partner' – is created.

			• The code ‘Impact on margins’ is merged with the code ‘Ability to capture rents’.
Selective	104	6 / 12	A theory is developed by relating important categories around the core category (platform level openness), see chapter 4.

Appendix E: Theoretical Model Explaining the Desired Degree of Openness Between IoT Platforms



Appendix B: Informed Consent

Consent Form for study: The openness of IoT platforms

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information dated 29-04-2019, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that taking part in the study involves participation in an audio-recorded interview that will be transcribed as text. The audio recording will be destroyed after transcribing.	○	○
Use of the information in the study		
I understand that information I provide will be used for the researcher's master thesis, (scientific) publications or other educational purposes.	○	○
I understand that personal information collected about me that can identify me, such as my name or where I work, will not be shared beyond the study team.	○	○
I agree that my information can be quoted in research outputs, after I gave my explicit consent for using the specific quotes.	○	○

Signatures

______________________	______________________	__________
Name of participant	Signature	Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Lars Mosterd	______________________	__________
Researcher name	Signature	Date

Study contact details for further information

Lars Mosterd

[Phone number]

[E-mail]

The Openness of IoT Platforms

Exploring the influencing factors

Purpose of the Research

The goal of this research is to provide insight in the factors influencing the decisions from IoT platform providers regarding the desired degree of openness towards other IoT platforms. Specifically, the focus will be on IoT platforms in the healthcare and automotive sector. As part of this research, semi-structured exploratory interviews will be held with relevant experts and decision makers. This study is the researcher's master thesis.

Processing of Personal Information

To comply with scientific standards, the interviews will be recorded and transcribed as text. The audio recordings will be destroyed after transcribing. The transcripts will not be made publically available. They will only be archived for traceability purposes. Information that can identify a participant (such as his/her name or company) will only be accessible to the researcher and his graduation committee.

Anonymised insights gathered during the interviews can be used for the researcher's master thesis, (scientific) publications or other educational purposes. In these publications, anonymised quotes may be used.

Rights of the Participants

Participants have the right to request access to and rectification or erasure of any personal data collected for the purpose of this research. Participants can withdraw at any moment from the study by notifying the researcher. Complaints can be filed with the TU Delft's data protection officer.

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Affiliated research institute: TU Delft (data protection officer: privacy-tud@tudelft.nl)

Other affiliated institutions: this master thesis is written as part of an internship at KPMG NL