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The case of the Internet of Things

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DOI
10.1016/j.technovation.2021.102331

Publication date
2022

Document Version
Final published version

Published in
Technovation

Technovation 108 (2021) 102331

Contents lists available at ScienceDirect

Technovation

journal homepage: www.elsevier.com/locate/technovation

Context dependent trade-offs around platform-to-platform openness: The case of the Internet of Things

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ARTICLE INFO

Keywords:
Internet-of-Things
Digital platforms
Platform openness

ABSTRACT

As digital platforms are dominating the digital economy, complex ecologies of platforms are emerging. While the openness of digital platforms is an important theme in platform studies, the openness between platforms has hardly been studied. This paper explores factors that affect decisions by platform owners to open their platforms to other platforms. The focus is on Internet-of-Things platforms for automotive and healthcare applications. According to the findings, platform owners make trade-offs on whether to open up on a case-by-case basis. We identify a complex array of factors relating to direct benefits and costs (e.g., revenues from selling platform data), indirect benefits (e.g., attractiveness of the focal platform to users) as well as strategic consideration (e.g., improving bargaining power towards other actors). How businesses make trade-offs on these factors depends on market-level context (e.g., maturity of the market and standards) and organizational context (e.g., strategic focus and business objectives). Our findings provide a basis for future studies on the openness between platforms, which will become increasingly important as platforms proliferate in every layer of the digital industry.

1. Introduction

Digital platforms are emerging in every part of the digital economy (Nambisan et al., 2017). For instance, platforms from Google and Apple enabled developers to create millions of apps (de Reuver et al., 2018). As digital platforms proliferate, increasingly complex interrelations between platforms and complementary offerings are emerging (Cenamor et al., 2013; Henfridsson et al., 2018; Yoo et al., 2010). Digital platforms can build on top of others (Gawer and Cusumano, 2014; Karhu et al., 2018), for instance, a social media platform that runs on top of a mobile operating system platform. Alternatively, platforms are nested within other platforms (Tiwana, 2013) or third parties build bridges that interconnect platforms, for instance, connecting two smart home platforms (Hilbolling et al., 2020). As such, platforms are embedded in increasingly complex constellations of platforms and complementary offerings, on different levels of the technological architecture (de Reuver et al., 2018), leading to an 'ecology of platforms' (Hilbolling et al., 2020). Facing such complex constellations in which their platforms are embedded, platform providers face questions on what interrelations they would like to promote (cf., Henfridsson et al., 2018), for instance by creating open interfaces to other platforms (cf., Ondrus et al., 2015).

The openness of platforms has long been recognized as a crucial issue in the design and management of digital platforms (Cusumano and Gawer, 2002; West, 2003). Generally, platform openness refers to the easing of restrictions on the use, development, and commercialization of a platform (Boudreau, 2010). By opening up, owners of platforms (i.e. platform sponsors) make their technologies available to third parties (Eisenmann et al., 2009). In this way, open platforms enable third parties to innovate with complements that go beyond what platform owners could develop or even foresee themselves (Boudreau, 2012; Parker and Van Alstyne, 2018). Most existing platform studies exclusively focus on openness towards complementors, for instance in a context of openness of operating systems or app stores towards app developers (Benlian et al., 2015; Ghazawneh and Henfridsson, 2015), game consoles towards game developers (Cennamo and Santaló, 2013), and payment platforms towards payment service providers (De Reuver and Ondrus, 2017). Conceptually, scholars recognize that platforms can also open up towards other platforms (Eisenmann et al., 2009; Ondrus et al., 2015), for instance through technological interoperability standards (Gallagher, 2012). Yet, empirical studies on platform-to-platform openness, which we conceptualise as *the extent to which a platform is interoperable with other platforms*, are mostly lacking. Greater platform-to-platform openness and platform-to-app openness both result in added functionality. However, the two forms of openness are

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https://doi.org/10.1016/j.technovation.2021.102331
Received 26 May 2020; Received in revised form 8 June 2021; Accepted 21 June 2021
Available online 1 July 2021

distinctly different from each other due to the type of functionality that is unlocked by opening up (see Fig. 1 for a schematic representation of the differences, the dashed line indicates where functionality is added). An app is a complementary product, which entails that it makes use of the functionalities of the platform core. In contrast, a platform is a stand-alone structure with its apps and add-on functionality. Hence, platform-to-app openness concerns the unlocking of add-on functionality (left part of the figure), whereas platform-to-platform openness concerns the unlocking of stand-alone functionality (right part of the figure).

The premise of this paper is that, as platforms become embedded in increasingly complex constellations of platforms, applications and infrastructures, platform sponsors face the issue of how to open towards other platforms. To explain this argument, consider, on the one end, the stylized case of a mobile smartphone platform. Such a platform provides access to one specific brand of smartphone operating systems (either iOS or Android), whereas consumers typically own one smartphone. As such, there is little need to provide interlinkages *between* the smartphone platforms. For application developers that want to target all consumers, they can simply develop apps for both Android and iOS, a phenomenon termed *multi-homing* (Hagiu, 2006). On the other end, consider an Internet-of-Things (IoT) environment such as the smart home, consisting of many sensors, devices, and objects, all from different vendors. To access these systems, IoT platforms are emerging with sometimes (partly) overlapping functionality (Nicolescu et al., 2018; Wortmann and Flüchter, 2015). Most platforms only give access to the sensors and devices of one specific manufacturer (e.g. a smart lighting system which is only compatible with a specific brand of smart light bulbs and not with other types of home automation devices or smart lights from other manufacturers) (Mineraud et al., 2016). App developers and end-users will likely want to build on platforms that give access to the heterogeneous set of smart home systems (e.g., meta platforms like Google Home that are compatible with a broad range of home automation devices, allowing for interaction between the different device types). While multi-homing is still principally possible, the complexity of doing so is high, and likely leads to low complement quality (Kang et al., 2019). For these reasons, it becomes relevant to consider platform-to-platform openness, for instance, through standardization or meta-platforms (cf. Ondrus et al., 2015).

Given that studies on platform-to-platform openness lack in the literature, and that the openness between platforms has only recently become of practical significance, the goal of the present paper is to explore factors why firms choose to open up their platforms to other platforms. While we can draw from existing literature on why businesses open their platforms to complementors, this paper shows that the specific nature of platform-to-platform openness requires considering novel factors. We focus on the domain of IoT platforms, in which the heterogeneity of platforms is currently high (Wortmann and Flüchter, 2015), and specifically on the area of IoT platforms for automotive and healthcare. We define IoT platforms as the software-based system that allows end-users and applications to interact with the smart objects connected to it (Hodapp et al., 2019; Mineraud et al., 2016). So far hardly any literature discusses comprehensively what platform openness entails in the context of IoT. Some scholars focus on the general usage of open source components in IoT platforms (Hodapp et al., 2019; Mineraud et al., 2016). Others exclusively consider the openness of IoT platforms towards end-users and third-party developers (Schreieck et al., 2017). To achieve openness, engineering literature on IoT does suggest two main ways. First, comparing with 'Closed' setting, a meta-platform or broker service can be defined on top of two platforms, for instance, an IoT data marketplace to share data (e.g. Mineraud et al., 2016). Second, APIs or gateways can allow one platform to directly request data from another (e.g. Ochs and Riemann, 2017).

The related research question is: *What factors influence decisions from IoT platform* sponsors *regarding the desired degree of openness towards other IoT platforms (i.e., platform-to-platform openness)?* Considering the lack of prior work on platform-to-platform openness in general, as well as on IoT platform openness, we take an exploratory approach. Specifically, we derive categories of factors from the literature and develop a framework of factors through semi-structured interviews with experts and decision-makers.

The paper's primary contribution is to platform literature, being a first to explore factors affecting the desired openness between platforms. Recent reviews also highlight that platform studies mainly focus on relationships with complementors (or app developers) rather than with other stakeholders (McIntyre and Srinivasan, 2017). A secondary contribution is to IoT platform studies by being a first to focus on the openness between IoT platforms. Earlier studies focus primarily on value propositions, customer relationships and internal architectures that change due to IoT (Kiel et al., 2017). In the context of IoT, a few studies focus on platform openness, yet only on the relationship with end-users and developers of complementary goods (e.g. Schreieck et al., 2017).

2. Background and gap analysis

2.1. Digital platforms and openness

Platforms are foundations upon which unrelated actors can offer complementary services and products (Gawer, 2009, p. 54). Platforms have a stable core and variable periphery (Baldwin and Woodard, 2009). The platform core provides reusable and generic functionality (Tiwana et al., 2010). The platform periphery comprises additional functionality, typically applications that utilize the platform core. In between, boundary resources mediate access to the core (Ghazawneh and Henfridsson, 2013).

Platforms are subject of various streams of literature (see for

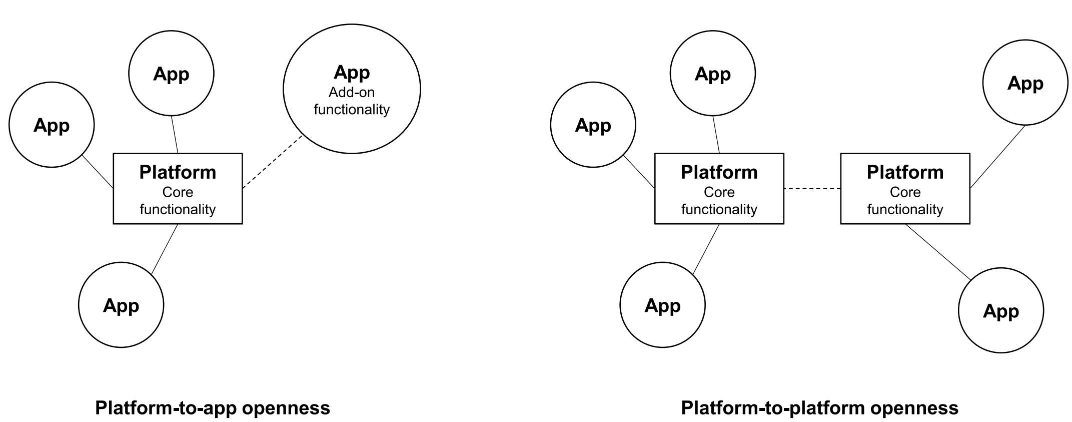

Fig. 1. Platform-to-app openness versus platform-to-platform openness.

extensive reviews, Constantinides et al., 2018; de Reuver et al., 2018; Gawer, 2014). In economics, platforms are seen as intermediaries that bring together two or more user groups (Rochet and Tirole, 2003). Such platforms exhibit network effects: they become more valuable as more users join (Katz and Shapiro, 1985). Platforms-based markets are often characterised by winner-takes-all dynamics resulting in single de-facto interface standards (Schilling, 2002). In engineering design and innovation management, platforms are not only seen as connecting user groups but also as a stable set of technical modules, upon which complementary add-on modules run that provide additional functionality (Baldwin and Woodard, 2009; Gawer, 2009). Actors recombine platform and add-on modules to create innovations (Baldwin and Clark, 2000; Henderson and Clark, 1990). Information systems literature specifies the notion of recombinant innovation, focusing on the digital nature of platforms (de Reuver et al., 2018). 'Digitality' implies that platforms consist of *extensible* software modules (e.g. operating systems) on which third parties can develop complementary offerings (e.g. mobile apps) (Tiwana et al., 2010). In this stream of literature, the primary rationale of opening up (digital) platforms is to enable third-party innovation (Cennamo and Santaló, 2013; Gawer and Cusumano, 2008).

In this paper, we focus both on the mediating role of platforms (i.e., bringing together two or more user groups) and the extensible nature of platforms (i.e., enabling third-party complementary offerings). The openness of platforms has attracted scholarly attention from the very early platform work (Cusumano and Gawer, 2002; Eisenmann et al., 2009; West, 2003). More recently, empirical studies on openness have been done on a broad range of platforms, such as operating systems (Benlian et al., 2015), app stores (Ghazawneh and Henfridsson, 2015), game consoles (Cennamo and Santaló, 2013) and payment (De Reuver and Ondrus, 2017).

Defining platform openness is challenging (Nikayin et al., 2013). Open platforms reduce 'restrictions on use, development and commercialization of a technology' (Boudreau, 2010, p. 1851). Any restrictions posed should be reasonable and non-discriminatory (Eisenmann et al., 2009). The openness of a platform is not an either-or choice, but a continuous scale (West, 2003).

Two main approaches to open platforms are distinguished in literature. First, providers can relinquish control over their resources (Boudreau, 2010; Karhu et al., 2018). The most notable instance of this approach is open source (Casadesus-Masanell and Llanes, 2011; Niculescu et al., 2018; Shaikh & Henfridsson, Ola, 2017). Second, and most relevant within our study context, is selectively opening up technologies through interfaces (Boudreau, 2010; Karhu et al., 2018). In this approach, boundary resources have become an influential construct, referring to, for instance, application programming interfaces (APIs) through which providers can access a platform (Ghazawneh and Henfridsson, 2013). By making boundary resources available, and securing them at the same time, platform providers can set the degree of openness of their platform core (Ghazawneh and Henfridsson, 2013).

Our premise that platforms not only open towards complementors but also towards other platforms, is not new. At least three conceptual papers discuss openness on different levels. Eisenmann et al. (2009) distinguish openness towards different user groups of a platform: demand-side users (e.g. end-users), supply-side users (e.g. complementors), platform providers (i.e. actors that operate platforms) and platform sponsors (i.e. actors that own the property rights of platforms). Building on this, Ondrus et al. (2015) suggest four levels of openness: (1) sponsor level (i.e. towards platform owners); (2) provider level (i.e. towards other platform providers); (3) technology level (i.e. interoperability between platforms); and (4) user-level (i.e. towards users from other platforms). Jacobides et al. (2018) distinguish relations of platforms with (1) providers of components that are integrated into the platform, (2) providers of competing platforms, and (3) complementors that provide add-on functionality to the platform. Yet, despite these conceptualizations, most existing empirical studies on platform openness exclusively focus on user-level openness (e.g. Benlian et al., 2015), realized through APIs and SDKs (Ghazawneh and Henfridsson, 2013).

In our conceptualization of platform-to-platform openness, we expand on the definition of technology level openness from Ondrus et al. (2015) by acknowledging that platform-to-platform openness is not a mere technological issue as organizational arrangements should also be made for two platforms to become interoperable. This view incorporates the idea that a platform is a socio-technical construct (Tilson et al., 2012). We adopt the following definition of platform-platform openness: *the extent to which a platform is interoperable with other platforms*. Platform-to-platform openness is a form of access openness. Whereas licensing and integration of two platforms into one are solutions to achieve interoperability, we do not consider these modes here as ways of platform-to-platform openness, since, in those modes, the original platforms no longer exist. Hence, the integration of two platforms into one is a form of resource openness since it affects the property rights of the platform(s).

Platform openness as the selective opening up of platforms could have similarities with partner selection research which argues that partners are chosen based on complementarities (Franko, 1971), and prior research has focused on guidelines for selecting suitable partners (e.g., Geringer and Hebert, 1991; Hitt et al., 2000), or criteria for partner selection (e.g., Dacin et al., 1997; Geringer, 1991) While recent definitions of platform-based ecosystems also make reference to partner selection (e.g., Adner, 2017; Jacobides et al., 2018), a key difference is that platform-based ecosystems render customized contractual agreements unnecessary. In a more recent take on partner selection, Wei et al. (2020) frame partner selection as a response to a task or demand uttered by customers. Platform-to-platform openness may also serve that purpose, but not exclusively as it adds the functionality of a different platform and its ecosystem of complementors. In addition, platforms are emergent (Smorodinskaya et al., 2017) and platform openness includes *generativity* (Cennamo and Santaló, 2019), as explained in section 2.2. In this way, platform-to-platform openness is fundamentally different from partner selection because it is about selection an ecosystem of partners rather than an individual partner.

2.2. Factors explaining the openness of platforms

Opening up a platform creates *direct benefits and costs*. Generally, higher degrees of platform openness can directly increase revenues, for instance, from license fees of using the platform (Parker and Van Alstyne, 2018). Opening up platforms also incurs costs for platform sponsors, for instance, for setting up open interfaces (cf. Ghazawneh and Henfridsson, 2013). Control mechanisms, such as monitoring users of the open platform, may also incur costs (Gulati et al., 2012; Wareham et al., 2014), especially as the number of platform users grows (Almirall and Casadesus-Masanell, 2010). Open platforms can also reduce revenues and profits when third parties offer complements that directly compete with the platform provider (Eisenmann et al., 2009; Parker et al., 2017).

Openness increases the motivation of third parties to contribute to a platform, due to indirect network effects: by being open towards third parties, consumer adoption grows, which makes it more attractive for third parties to join the platform (Srinivasan and Venkatraman, 2010; Venkatraman and Lee, 2004). Studies on open source platforms show that increased levels of openness stimulate intentions of app developers to join the platform (Anvaari and Jansen, 2010; Koch and Kerschbaum, 2014). Other studies do not focus directly on platform openness but control mechanisms, finding that the degree to which control is exerted affects intrinsic and extrinsic motivations of app developers (Goldbach et al., 2014; Schaarschmidt et al., 2019). However, high levels of openness may also reduce motivations of third parties, because high openness also increases competition (Boudreau, 2010) and induce a fear of competition (Nikayin et al., 2013). Openness may also reduce incentives for third parties because coordination costs increase, as shown in a study on platform component providers (Choia et al., 2017).

Opening a platform also *indirectly* affects a platform sponsor through the mechanism of generativity. Generativity entails that platforms enable unanticipated complementary offerings (Boudreau, 2012) without active involvement of the platform provider (Bygstad, 2017; Hilbolling et al., 2020; Tilson et al., 2010). Consequently, how others can use the platform becomes more varied (Boudreau, 2010) and potentially more innovative (Parker and Van Alstyne, 2018). On the other hand, generative platforms also enable low-quality complements, which harm the reputation and integrity of the platform (De Reuver and Bouwman, 2012; Wareham et al., 2014). Low-quality complements can even threaten the integrity and stability of the platform (Wessel et al., 2017). For IoT specifically, opening up a platform may create security and privacy risks (Al-Fuqaha et al., 2015; Atzori et al., 2010; Gubbi et al., 2013; Stankovic, 2014). If not appropriately addressed, security and privacy incidents can harm the reputation of platforms and lead to damage claims.

On a *strategic level*, platform openness can affect the positioning of the platform sponsor in the market. Open platforms can help providers to win a new market more quickly by attracting more users (Ondrus et al., 2015), and can build the legitimacy of aspiring platform providers in existing markets (Khanagha et al., 2020). On the other hand, closed product-specific interfaces can help to lock-in customers and prevent imitation by new entrants, which creates barriers to market entry (Wareham et al., 2014). Keeping a platform closed also enables providers to set higher margins (Eisenmann et al., 2009; West, 2003). Furthermore, open platforms have higher exposure to exploitation strategies, such as forking by other platforms (Karhu et al., 2018), which implies that the open platform becomes incorporated in 'meta-platforms' from competitors (Ghazawneh and Henfridsson, 2013; Pon et al., 2014). By strategically opening up platforms in certain ways, what Henfridsson et al. (2018) term 'path channelling', platform sponsors could promote specific platforms or complements to be defined on top of their platforms.

Market-level context affects how openness decisions affect performance and strategic position. The competitive landscape is relevant, as market shares influence how openness decisions affect outcomes (Eisenmann et al., 2009). Maturity of the market is relevant as well: whether openness strategies are feasible depends on the availability of compatibility standards (Den Uijl, 2015) and their degree of dominance in the market (Boudreau, 2010; West, 2003). Timing of opening up also affects whether the benefits of doing so can be attained (Tsai, 2018).

On the level of the *organizational context*, openness decisions differ between for-profit and non-profit organizations (Wareham et al., 2014). Besides, openness decisions depend on the maturity of the organization (Boudreau, 2010; Wareham et al., 2014), including the market position of a firm (Eisenmann et al., 2009). In specific cases where companies have low market power while facing dominant competitors and mature industry standards, openness may even have to be stretched towards fully giving up control over the platform (Khanagha et al., 2020). Specifically, regarding openness, providers tend to open up their technologies gradually over time, as documented in studies of Alibaba (Tan et al., 2015) and an anonymized case (Saarikko, 2016). The degree of vertical integration is relevant as well: low vertical integration implies that more diverse complements can be added to a platform, which amplifies the network effects gained from openness (Hagiu and Wright, 2015).

While not the primary focus of the present paper, we are aware that *legal and legitimacy concerns* may also drive openness decisions. Regulations may require platforms to open, for instance, related to antitrust law. Privacy laws may make firms reluctant to open their platforms or require openness due to demands of data portability (as in the General Data Protection Regulation). Besides the need to comply with regulations, uncertainty about (upcoming) regulations can affect openness decisions (Setzke et al., 2019). The preliminary framework in Table 1 summarizes the categories of factors found in this section.

Table 1
Preliminary framework of factors affecting platform openness decisions.

Factor	Examples
Direct benefits and costs	License fees paid by complementors Costs of maintaining interfaces
Indirect benefits and costs	Low-quality complements harm the reputation of the platform
Strategic-level factors	Barriers to entering markets
Market-level context factors	Competitiveness of the market
Organizational context	Maturity of the organization
Legal and legitimacy concerns	Antitrust law requiring platforms to open up

3. Methodology

This article opts for a qualitative empirical research approach, in line with the open research question of this study (Yin, 2003). While some theory has been developed on platform openness in general, a platform-to-platform openness has not yet been studied empirically, and the understanding of the phenomenon is limited. This study aims to identify factors influencing openness decisions which requires the operational tracing of links between factors and openness decisions overtime (Langley and Abdallah, 2011), justifying the inductive nature of this study (Edmondson and Mcmanus, 2007; Eisenhardt and Graebner, 2007).

This study draws on the Grounded Theory approach, which differs from other qualitative approaches by seeing data collection and analysis as an interrelated process (Corbin and Strauss, 1990). Grounded Theory involves iterations of the interview protocol as data is analysed, and the understanding of the topic increases. Semi-structured interviews offer enough flexibility to explore new meanings of a topic while being sufficiently structured to study specific aspects of a topic (Galletta, 2013).

Semi-structured interviews were conducted with field experts and decision-makers in the IoT domain within Europe. Interviewees were selected from two industry sectors in which IoT plays a role. The selected sectors, healthcare and automotive differ from each other in terms of business context and technical aptness. The two domains were selected due to the variability in the context variables, to generate as many possible insights as possible in this early stage of theory development. The healthcare industry comprises many actors and sub-sectors, with heavy regulation. Therefore, we expect that healthcare IoT platforms have a high degree of fragmentation across platforms, which makes platform-to-platform openness more suitable. The automotive industry is dominated by original equipment manufacturers (OEMs) and has a less complicated market structure since all IoT offerings are ultimately connected to vehicles. Hence, the possible points for interconnecting platforms are lower.

3.1. Data collection

Selected interviewees have experience with IoT in general or with a specific IoT platform. Experience wise, interviewees hold senior positions with at least five years of industrial experience and decide or advise on the openness of IoT platforms. We strive for a varied set of interviewees, see Table 2 for an overview. Of the thirteen interviewees, seven work in the automotive industry, five in healthcare and one in multiple industries. Within healthcare, two respondents are in the medical domain, whereas three others work in consumer fitness. Within automotive, we interviewed three OEMs, one government organization and three connected car service providers.

All interviewees work at companies that operate IoT platforms at the time of the interview, except for the government representative and the three experts. Seven out of nine interviewees had IoT platforms that had been offered for a considerable amount of time, while two others were only introduced recently on the market. For almost all interviewees, we

Table 2
Interviewees.

Interviewee	Organization	Profile
Manufacturer-Medical	Manufacturer of medical equipment	Director
Platform-Medical	Platform integrating medical data	CEO
Manufacturer-Fitness	Manufacturer of fitness equipment	Integration specialist
Platform-Fitness	Platform integrating fitness services	CTO
Expert-Fitness	University	Researcher (fitness wearables)
Government-Automotive	Governmental	Project manager connected car
OEM1-Automotive	Car OEM	General manager connected car
OEM2-Automotive	Car OEM	Technology & trend scout
OEM3-Automotive	Truck OEM	Principal engineer vehicle connectivity
Non-profit-Automotive	Automotive driver association	Head of connected car
Software-Automotive	Fleet management software provider	Product manager connected car
Expert-Automotive	Payment provider	Head of connected car & IoT
Expert-General	Software services and consulting	IoT industry leader

inferred that they were advanced regarding their decision making about platform openness, which is the main criterion for our judgment sampling. We infer this from the comments they made (e.g., 'as soon as a mature compatibility standard is available, we will open up our platform').

Interviews were semi-structured. First, the topic of platform-to-platform openness was explained, in line with the explanation in Section 2. For some of the concepts, a discussion was needed to obtain a shared understanding between interviewee and interviewer. In line with the literature reviewed in Section 2, questions were asked on how openness decisions depend on (1) direct benefits and costs; (2) indirect performance implications; (3) strategic considerations; (4) contextual conditions on the market level; and (5) contextual conditions on the organizational level. To control for other factors, questions were also asked about regulatory pressures (e.g., regarding privacy) and legitimacy concerns (e.g., corporate responsibility). Following each question, a natural conversation followed. If concepts were too abstract for interviewees, examples were presented. If a certain aspect of a topic was not discussed, follow-up questions were asked. Follow-up questions also probed about trade-offs between factors. During the interview series, the interview protocol was refined based on the insights obtained, especially in terms of the examples and working definitions provided.

Platform-to-platform openness has received scant attention, but platform competition and platform openness, in general, are well understood. This means that compared to a typical grounded theory process, the interview topics were altered to a far lesser degree. Especially in the first four interviews, it took relatively more time to establish a shared vision of 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. 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 and Bougie, 2016).

Interviews lasted between 29 and 75 min, with an average of 50 min. All interviews were recorded and transcribed after obtaining informed consent in writing. Transcripts were fed back to interviewees for validation, which did not prompt any corrections.

3.2. Data analysis

We started the research from the observation that much is known on platform-to-app-openness (PTAO), but little about platform-to-platform-openness (PTPO). From this observation, we wondered whether existing understandings about PTAO could (simply) be applied to PTPO, whether they would need to be specified in new ways due to the unique characteristics of PTPO, and whether new factors would emerge that are unique to PTPO. Our main criterion of 'success' of our paper was the 'richness' of the factors, sub-factors and examples that would emerge from this exercise. Given that we do not intend to generalize to populations of interest, our criteria did not include statistical generalizability or the level of agreement about factors between our interviewees. Rather, when factors or examples were mentioned by interviewees in ways that are convincing (e.g., supported by their argumentations, resonating the existing factor list and/or supported by examples mentioned by interviewees), we would include them in our results.

Three rounds of coding were done, supported with Atlas. ti software. Memos were recorded on the main points of each interview. The analysis started with an initial code list, containing categories that were based on the preliminary framework. The use of an initial coding list gives direction and purpose to a qualitative analysis (Yin, 2003). To prevent missing out on completely new and unexpected factors, we kept an open mind open to new factors as our analysis proceeded (Miles and Huberman, 1994). Through open coding, new codes were added to the list, to cover topics that were not in the preliminary framework. For instance, one interviewee mentioned that platform providers may sometimes create lock-in and high switching costs to retain their customers, upon which codes 'lock-in' and 'switching costs' were added. Another example is that an interviewee explained a trade-off between end-user

Table 3
Coding scheme example.

Quote	Assigned codes
"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." [Expert-Fitness]	- Lock-in - Switching costs - Platform-to-platform openness
"We cannot share everything, also due to privacy reasons and stuff. And also, a lot of discussions are ongoing; who is owning which set of data? Wo 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." [OEM1-Automotive]	- Ability to safeguard end-user privacy - GDPR/privacy law - Importance of data privacy and security - Possibility to improve public safety - Platform-to-platform openness

Table 4
Examples of code merging in axial coding phase.

Original codes	Merged into code
Market pressure	End-user demand
Changing end-user expectations	
End-user demand	
Impact on margins	Ability to capture rents
Ability to capture rents	
Age of market (groundedness: 0)	Deleted; overlapped with other maturity characteristics
Adoption rate	Attract new users
Attract new users	

privacy and public safety in cars, upon which we added a code 'public safety'. See Table 3 for two specific examples.

Through axial coding, similar codes were merged. For instance, a code 'impact on margins' was merged with 'ability to capture rents'. Table 4 provides examples of the codes merged in the axial coding phase.

In the axial coding phase, categories were reconsidered, and sub-categories were added, see Table 6 in the Appendix for the groundedness of the categories and sub-categories. In a final round of selective coding, coding was revisited to develop an understanding on how the codes relate to the core topic of platform openness decisions. This final round of coding was done by the first and last author of the paper. The first author created so-called network views of the main categories and sub-categories. These network views make clear how codes are related conceptually, for instance, whether there are causal or associational relations between codes. From these network views, the first author developed an extensive descriptive text on each of the code categories and sub-categories. As a next step, the last author of the paper went through the selected categories and sub-categories to check for consistency. While doing so, the last author revised the naming of the sub-categories to attain consistency with the underlying quotes. The last author then created a summary table with the factors and examples of factors, which is provided at the end of Section 4. Both axial and selective coding were supported with Atlas TI, to ensure that all quotations and codes are managed consistently.

4. Results

This section presents the results of the three rounds of coding, summarized in a refined framework. While discussing the factors, we use identifiers from Table 2 (e.g. [Manufacturer-Medical]) to refer to the interviewees.

4.1. Business factors influencing the desired degree of platform-to-platform openness

The interviews showed that the perceived effect on the business outcome is the main driver for all decisions regarding the desired degree of platform level openness. Essentially, the factors that are grouped in this category explain the ideal level of platform level openness without considering the legal restrictions.

Importantly, most interviewees argued that organizations selectively open their platform for a specific application and a specific partner. For instance, an IoT platform sponsor in the automotive industry may choose to open its platform for one specific application (e.g., location data) to one specific partner (e.g., road safety authorities) by using a meta-platform. This implies that decisions regarding the desired degree of openness should be contextualized within a specific use case setting.

Many respondents comment that the decision to open up is made on a case-by-case basis, by considering the business case and commercial opportunities. Some interviewees struggled to provide any motivations for opening up their platforms that go beyond business case calculations

Table 5
Summary table of interview findings in a refined framework.

Category	Factor	Impact on openness decisions	Examples
Direct benefits and costs	Costs	Negative yet small	Creating interoperability solutions Small costs from creating open interfaces
	Direct revenues	Positive	Fees for accessing platform interfaces Revenues from selling platform data
	Uncertainty about value of data	Negative	Fear that competitors may benefit from platform data in ways unanticipated by platform owner Unclear who would purchase platform data
	New business opportunities	Positive	Data from other platforms enable new service offerings
Indirect benefits and costs	Attractiveness of the platform	Positive	Users of other platforms can adopt platform owner's services Data and features from other platforms can be integrated, making the platform owner's offerings more comprehensive
	Data privacy and security concerns	Negative	Platform owner's reputation being harmed if other platforms do not respect user privacy
Strategic considerations	Knowledge gains	Positive	Knowledge spill-over from other platforms (e.g., use cases, strategies, data) Collaboration and experiments create new knowledge
	Market position	Positive	Increase addressable market in new markets Promote own standards Improve bargaining position towards other actors by having more data
Market-level context	End-user demand	Positive	End-users demand platforms that are interoperable with others
	Need for specialization	Positive	High levels of specialization in e.g., devices require platforms that provide access to multiple device manufacturers
	Competition between platforms	Negative	Keep platform closed to avoid losing customers to competitors
	Market maturity	Mixed	Low market maturity leads to uncertainty over business cases, lack of interoperability standards Low market maturity implies that risks of openness have low impact
	Maturity of compatibility standards	Positive	Compatibility standards needed to achieve platform-to-platform openness
Organizational context	Business objectives	Mixed	For-profit companies attribute higher

(continued on next page)

Table 5 (*continued*)

Category	Factor	Impact on openness decisions	Examples
			importance to direct benefits and costs
	Strategic focus	Mixed	Device manufacturers are more inclined to open their platforms to those platforms offering complementary services. Providers avoid opening up to platforms from direct competitors. Platform providers that focus on device sales are more inclined to open their platforms so more software can be used to use their devices
	Openness to app developers and end-users	Positive	Platforms that are open to app developers are more likely to be open towards other platforms
Legal and legitimacy factors	Privacy and security regulations	Negative	Requirement to obtain user consent (e.g., GDPR) complicates openness and increases costs
	Sector-specific regulations	Mixed	Sector-specific regulation complicates opening up platforms that span across domains (e.g., fitness and medical) Some regulation (e.g., on-board units in automotive) explicitly promotes platform openness Uncertainty over regulation inhibits decisions over openness
	Competition law	Negative	Fear that regulators may see platform-to-platform openness as antitrust case

[Platform-Medical]. "*If there is a commercial opportunity, that consideration [to open up] will always be made. It is not a priori said: this what we don't do or this is what we do*" [Software-Automotive].

4.1.1. Direct benefits and costs

Most interviewees agreed that within the category of performance implications the expected impact on the business case is a main driver for openness decision.

Openness creates direct costs. *Costs* come from developing and maintaining interoperability solutions, which are larger if markets are not yet mature [Non-profit-Automotive]. Sometimes, opening up a platform allows providers to collaborate with others, which reduces the costs of interoperability solutions. Almost all interviewees point out that opening up their platforms for other platforms, for instance by creating APIs or other linkages, incurs costs, although several interviewees comment that these costs are marginal.

Direct benefits from openness include *direct revenues*. For instance, openness may incur fees for accessing platform APIs or platform data. Several interviewees mentioned the hope or expectation that they would be able to earn revenues by selling data from their platforms, although they were often not sure to whom they would sell data, and for what price. In this regard, it is striking that while some interviewees take for granted that they will charge for access to their platforms [OEM1-Automotive], others take for granted the exact opposite view [Manufacturer-Fitness]. *"In principle, we engage into linkages with parties if we see a market in it, that our package becomes better, the customer experience improves. We will, in principle, not directly charge a* fee *for connecting to other platforms" [Manufacturer-Fitness]; "Basically, we are open to everyone asking us for getting data. But of course, it is not for free"* [OEM1-Automotive].

***Uncertainty about value* of IoT data negative affects openness**. Platform providers fear that, by opening up, they are sharing data which is valuable to competitors in ways that they cannot anticipate [Expert-Automotive]. Another source of uncertainty is that it is unclear who might purchase IoT data from opened up platforms [OEM1-Automotive, Expert-Automotive, Software-Automotive]. This links back to the decision making about platform-to-platform openness on a case-by-case basis: interviewees express the need to retain control over who gets access to what. *"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."* [Expert-Automotive].

A part of the interviewees argued that they would benefit from *new business opportunities*. For instance, a healthcare device manufacturer that is looking to offer integrated healthcare services expects that data sharing with other platforms opens up opportunities to offer complementary services [Manufacturer-Medical].

4.1.2. Indirect benefits and costs

Respondents argued that openness to other platforms can increase the *attractiveness of the platform.* For instance, products and services running on the focal platform become more attractive to users of other platforms, since they can be accessed without having to switch. In addition, features from other platforms can be integrated into the offerings to the existing user base. Especially certain integrated service offerings such as mobility-*as*-a-service are only feasible if a comprehensive set of data is available, which implies that smaller players may be incentivized to engage in data sharing [Government-Automotive]. The same reasoning was mentioned for integrated health services [Manufacturer-Medical]. Another example is that the platform provider's algorithms can be improved with data from other platforms. Alternatively, interviewees argued that their service offerings would become more attractive as they would be able to tap into additional or higher-quality functionalities that complement the existing offerings [Non-profit-Automotive]. *"If you open up your platform for third parties (i.e.,* via *other platforms, red.), they can, with those data, create products and services through which we can become more relevant for the user"* [Non-profit-Automotive]. Thus, by opening up to another platform, the focal platform can get access to the apps and app developers of the other platform, through which (so not directly) value can be created for the focal platform.

Especially in the medical domain, *data privacy and security concerns* can limit platform-to-platform openness, due to the sensitive nature of data on IoT platforms. The importance of privacy and security considerations depends on the country [OEM2-Automotive] and between profit and non-profit companies [Non-profit-Automotive]. In the fitness domain, we found more diverse opinions. Some interviewees find privacy and security only a boundary condition, assuming this is taken care of when users agree to the terms and conditions of both platforms [Manufacturer-Fitness]. Others find privacy and security a top concern in openness decisions [Expert-Fitness, Platform-Fitness]. *"You can define a lot in contracts [...] but the biggest risk is [...] what if they go bankrupt and their database is dumped somewhere in the trash. Then we have a mega problem"* [Platform-Fitness*]*. This quote implies that privacy and security of end-users can no longer be guaranteed if a database is 'dumped' and hence, privacy and security considerations are limiting openness.

4.1.3. Strategic considerations

A strategic reason for platform-to-platform-openness is the ability to tap into *knowledge* from other platform providers, for instance about potential use cases [Government-Automotive, OEM1-Automotive]. Knowledge can also be gathered about the resources, data, strategy and decision-making that other platform providers have [Government-

Automotive; OEM3-Automotive]. Relatedly, open platforms allow trying out collaborations and experimenting, to learn about market opportunities in the future. Such knowledge gains are most relevant in immature markets and in the early pilot phase of a platform [Government-Automotive].

A second strategic reason to open up is to realize the desired *market position* of the platform provider. This concept is often about increasing market power and becoming the market leader (e.g., through creating switching costs or lock-in effects). However, in principle a platform could also aim to achieve a niche position in the market. One fitness equipment maker chooses to be open in countries where they have a small market share, trying 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 [Platform-Fitness]. Another rationale to open up a platform, related to the realizing the desired market position, is that companies want to increase the use of 'their' standards such that the provider has more influence over the developments in the market, as mentioned by automotive interviewees [OEM1-Automotive, OEM3-Automotive]. By opening up to other platforms, companies can prove that their standards work. This gives them more credibility in negotiations at round tables and standardization bodies that try to establish de jure standards. For players that have fewer data points than for instance OEMs or Google, opening up their platforms to similar, smaller platforms (and combining the data collections) could be a way to achieve a more equal playing field [Government-Automotive; Non-profit-Automotive]. *"IoT is of course a game of data. The more data you have, the more valuable you are, and the more important and interesting you are to partners"* [Non-profit-Automotive].

A similar argument was made by an automotive interviewee who argued that working with similar parties allows for more control over its own product development, since they attain a better bargaining position towards other actors [Non-profit-Automotive]. By opening their platforms, platform owners can promote the usage of their own interoperability standards, thus making it more likely that they will emerge as the de-facto standards in the market [Manufacturer-Medical].

Although we brought up forking (i.e., a meta-platform that harms the market position of the platform provider), none of the interviewees considered this a relevant concern. Some even indicated that such a scenario can be desirable: *"If they would be interested to buy our hardware and incorporate data from that hardware into their platforms, then we would be open for that. Even more, we have APIs that directly facilitate that data from our hardware […] can directly be sent to another platform"* [Software-Automotive].

4.2. *Context factors influencing the desired degree of platform-to-platform openness*

As argued above, decisions regarding the desired degree of platform-to-platform openness should be contextualized within a specific use case setting. Next to the relevance of the use case, the broader context in which openness decisions take place also influence how these decisions are being made.

4.2.1. *Market-level context*

End-user demand has a large influence on platform-to-platform openness decisions. For instance, in fitness, users typically require that applications be interoperable with multiple platforms. Given the dominance of Apple Health and Google Fit, most end-users will only acquire wearables that are compatible with these platforms. This expectation from end-users puts pressure on providers to make their device interoperable with the dominant platforms [Expert-Fitness]. *"Users do know that aggregator platforms exist and that they can be quite handy […] Smaller companies have no other choice but to integrate with bigger platforms"* [Expert-Fitness]. Similarly, 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 [Platform-Fitness].

End-user demand is closely related to the *need for specialization*: if companies cannot provide an integrated service by themselves, they could open up their platforms such that the complete service can be offered to their end-users. The need for specialization is high in IoT since physical products require dedicated manufacturing facilities to benefit from economies of scale. The need for specialization is, for instance, high in the healthcare industry, where one manufacturer cannot make all required products and devices. In those cases, platform-to-platform openness is more desirable [Manufacturer-Medical].

High levels of *competition between platforms* generally leads firms to keep their platforms closed to avoid losing customers. Interviewees explain that with intense competition, users can more easily switch to other platforms, and that keeping the platform closed is a way to retain them. *Market maturity* impacts many of the business outcome factors. In less mature markets, such as in autonomous driving [Government-Automotive], the business case is often less clear, standards for interoperability are less available, and there is more uncertainty about legal requirements, which all make openness less attractive. At the same time, in such immature markets, there is also more freedom to experiment with collaboration since the stakes are not that high. *"It is in fact very safe to collaborate now because it is not quite threatening for the real world. You can now explore collaborating with a number of parties, which may be your largest competitors. […] For companies [mobility-as-a-service] is, in terms of money, of course peanuts"* [Government-Automotive].

We found that *compatibility standards* are important, although their role differs between the fitness and automotive industry. While creating custom interfaces between platforms is theoretically possible, the efforts of doing so increase exponentially if more platforms are on the market. Therefore, having mature compatibility standards makes it easier to realize platform-to-platform openness. Relatedly, the availability of standardization bodies plays an indirect role in the decision-making about platform-to-platform openness, because such bodies can create the industry-wide compatibility standards that are required [OEM1-Automotive]. Especially in the automotive sector, in which many OEMs are active, compatibility standards are required to realize platform-to-platform openness [OEM1-Automotive, OEM3-Automotive]. One interviewee mentioned the example that efforts were abandoned to create platforms for truck platooning, because standards were not available [OEM3-Automotive]. In contrast, in the fitness industry, dominant platform owners develop their own proprietary standards, given the lack of standardization bodies and the low pace of developing industry-level standards [Expert-Fitness].

4.2.2. *Organizational context*

Whether the *business objective* is for-profit affects how trade-offs are being made on platform-to-platform openness, as non-profit organizations may prioritize user privacy or societal benefits [Non-profit-Automotive]. Overall, interviews from for-profit companies emphasized financial implications of openness more than those from non-profit organizations.

The *strategic focus* of a platform provider is also relevant: if a company sees an IoT platform as complementary to its core business of hardware sales, they will be more inclined to make the platform interoperable with other platforms that offer complementary services [Manufacturer-Medical]. For instance, manufacturers of fitness wearables are open to as many platforms as possible to increase the attractiveness and sales of their devices [Expert-Fitness]. For platform providers that produce physical devices, opening up their platforms increases the value of their devices. *"They are happy to be open, to collaborate with as many other third-party developers as possible so that their hardware can be used with as many other software offerings as possible"* [Expert-Fitness].

Similarly, an automotive service provider is more likely to collaborate with for instance energy providers than with competitors [Non-profit-Automotive]. Some interviewees pointed out their company is so concerned over potential competition to their own business, that they have to consider each use case individually: *"Every time that we have for example an initiative of sharing data, then we have to check which products [our company] offers"* [OEM2-Automotive]; *"What's important for us now: are we intending to make [the complementary functionality] ourselves? And within a foreseeable period, say a year or one and a half? In that case, we should not connect with them"* [Platform-Fitness].

A final contextual issue is the *openness to app developers and end-users*: interviewees confirm that platform-to-platform openness correlates with openness to app developers and users [Software-Automotive, Platform-Fitness]. Several interviewees in fact find it difficult to differentiate between openness towards app developers versus openness towards other platforms. And even that platforms that are open to app developers can allow bypass solutions for platform-to-platform integration: *"We scrape stuff from [the competing platform's] app, which we show to the end-user through a single sign-on, so* via *the same authentication and authorization"* [Platform-Fitness].

4.3. Legal and legitimacy factors

Legal requirements can affect openness decisions, for instance if regulation increases the costs of being open. In principle, regulations on data portability (e.g. in the European GDPR framework) enable users to take their data to other platforms, which should foster platform-to-platform openness. However, in practice, *privacy and security regulations* were generally said to reduce openness. Platform providers have become more reluctant to share data with other platforms [Government-Automotive, OEM1-Automotive, OEM2-Automotive] since users would always need to provide consent [OEM1-Automotive, OEM2-Automotive]. Platform providers are more selective in choosing partners that have certifications [Platform-Medical] or reputation [Expert-Automotive]. Security and privacy constraints are formalized into agreements [Manufacturer-Fitness]. Further, costs to be compliant with privacy regulations makes it less likely that a viable business case is reached.

Relevant *sector-specific regulation* is often focused on data privacy and security or compatibility standards. In the healthcare domain, regulation differs between sub-sectors, which makes it difficult to open up platforms between application domains and countries [Expert-Fitness]. Some regulation unintentionally promotes platform-to-platform openness: in the automotive industry, regulation requires the on-board diagnostic port in the car to be accessible for independent car repair shops, which enables third parties to use the port to connect to in-car platforms [Non-profit-Automotive, Software-Automotive]. Also here, uncertainty over regulation inhibits platform sponsors to make decisions on levels of openness: *"One body says: that should stay open […] to foster competition towards existing channels. There are other bodies that say: it breaks into the safety and integrity of vehicles and thereby creates ports that open for hackers. There are so many interests that play a role"* [Software-Automotive].

Competition law makes OEMs in the automotive industry less willing to open up, being afraid of antitrust issues. Directly connecting the platforms of two OEMs is perceived to likely raise antitrust concerns with regulators so the only option to open up is via a trusted third-party meta-platform such as Otonomo or Here [Expert-Automotive]. Regarding organizational legitimacy, the degree to which *corporate social responsibility* is important plays a role in openness decisions. Some automotive companies send their car sensor data to a third-party cloud platform to enable societally relevant applications [OEM2-Automotive; Non-profit-Automotive].

5. Summary

A summary table of the interview analysis is provided in Table 5. In the table, the categories as derived in Section 2 are listed in the first column. For each category, factors and examples are listed, as derived in this section, including the direction of impact on platform-to-platform openness decisions.

6. Towards an interrelation between the factors

In this paper, we developed a refined framework of factors for platform-to-platform openness. While not the focus of this study, the results hinted at possible interrelations between the factors that are not yet visible in the summary table in Table 5. These considerations motivated the authors to delve into the interrelations between the factors, departing from but not limited to the findings of this study. This interpretation is presented in Fig. 2.

The semi-structured interviews held with decision makers and field experts learned that, within a certain context, the desired degree of platform-to-platform openness is mainly determined by the business factors explaining the perceived effect on the business outcome. Legal and legitimacy factors mostly impact openness decisions by setting the boundary conditions. This implies that - when evaluating openness decisions - platform sponsors make a trade-off between (1) direct costs and benefits, (2) indirect costs and benefits and (3) strategic 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 (Eisenmann et al., 2009). Next to the characteristics of the use case, this context consists of the market- and organizational 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 organizational 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 number of users affiliated with it). Vertically integrated platform providers will usually choose for the former strategy while platform centric organizations will choose for the latter. In addition, the overall business objective of a company also influences the trade-offs. A non-profit or governmental organization will most likely have different considerations than a for-profit organization.

The context (both organizational and market) not only influences how trade-offs are being made between business factors, but also which openness decisions are considered and how they are evaluated. In other words, whether a certain business outcome is perceived as good or bad depends on the context in which the outcome takes place. Hence, it can be argued that the context has not a direct impact on the desired degree of platform level openness but is moderated by the perceived effect on the business outcome. Legal and legitimacy have a direct impact on the desired degree of platform-to-platform openness as they set the boundary conditions to which the implementation of the decisions must

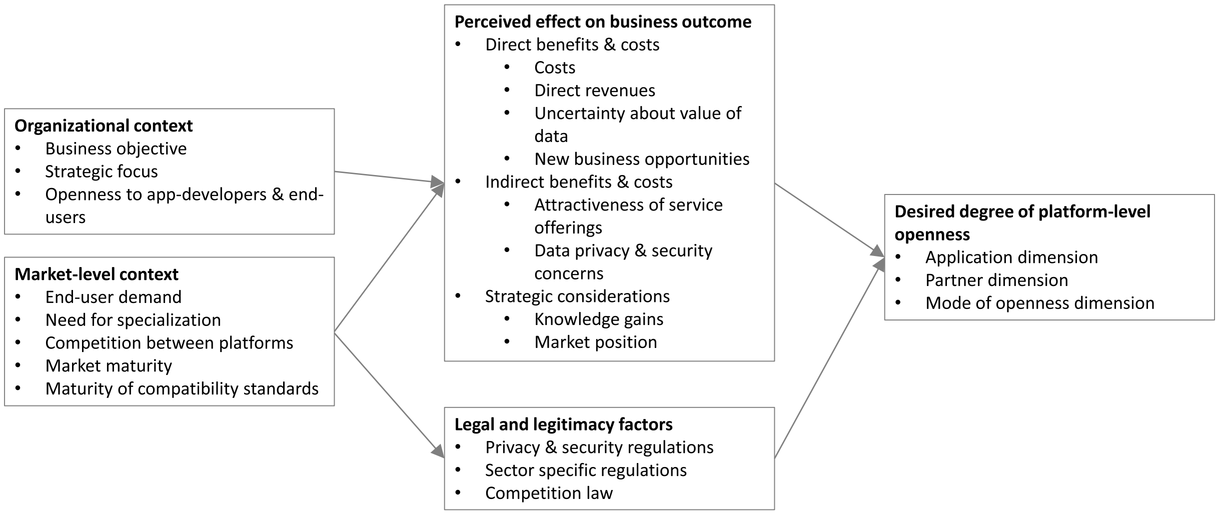

Fig. 2. Towards an interrelation between the factors.

comply. Applicable legal and legitimacy requirements are also influenced by the market context (i.e., through sector specific regulation or common practices).

7. Discussion

In this paper, we explore what factors play a role in decisions made by actors to open their IoT platforms towards the platforms owned by other players. Our findings suggest that business outcomes and legal requirements are traded off to make platform-to-platform openness decisions. How these trade-offs are made depends on market and organizational contextual factors.

An interesting observation is what constitutes platform-to-platform openness, in the reasoning of the interviewees. Some refer to creating linkages between platforms, such that services running on one platform can operate devices running on another. Others refer to the exchange or sales of data from one platform to another. These findings further underline the importance of exploring the architectures that can attain platform-to-platform openness. Whereas one architectural pattern would be to create direct linkage through compatibility standards. Another pattern would be to create meta-platforms that, for instance, aggregate data from different platforms. Some respondents also pointed to ways to create workarounds to access other platforms. For instance, by making a platform behave towards an application interface, such platform can tap into the APIs of other platforms. These workarounds to open up platforms mimic those found in literature on platformization (Gerlitz et al., 2019). This finding is also in line with the empirical study by Hilbolling et al. (2020), who found that external actors not only make dedicated complements, but also complements that bridge between a platform and other products, as well as those that embed a platform into a broader platform.

We found that platform sponsors perceive high uncertainty that prohibits making choices on platform-to-platform openness. For instance, regulatory uncertainty is perceived over whether platform-to-platform openness may raise antitrust concerns. This finding is in line with other platform studies that show that, in general, uncertainty over regulation can inhibit decisions about openness (Setzke et al., 2019). Interviewees also pointed to market-related uncertainty, regarding the value of IoT data, and who would be willing to pay for it. Uncertainty over what third parties can potentially do with platform data also plays a role, which underlines the importance of developing technologies and governance models that enhance control. This finding resembles notions in prior studies that ecosystem data governance and security are important factors for making decisions on whether to share IoT data (de Prieëlle et al., 2020).

We found that platform sponsors make case-by-case decisions on whether to open up to other platforms. This finding is in line with prior research on platform-to-platform openness (Hilbolling et al., 2020). Meanwhile, this case-by-case approach to decide about platform-to-platform openness differs from the current practice in platform-to-application openness. In the latter, decisions are often made for a whole class of application developers, as standardized terms of use, rules and conditions specify the conditions under which application developers can make use of the platform interfaces, thus implying an arm's length relationship. For IoT platforms, the decision of openness needs to be made in a more fine-grained case-driven manner.

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 specialization 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.

In section 2.1 we discuss platform openness towards different user groups and distinguish openness towards platform owners, other platform providers, complementors, between platforms (interoperability), and users (Jacobides et al., 2018; Ondrus et al., 2015). Here, platform-to-platform openness introduces another level of complexity as it unlocks standalone value of different platforms but also connects different ecosystems of add-on functionality. Platform-to-platform openness may hence reduce the need of multihoming on the user side by allowing access to functionality that earlier would have been accessible only through multihoming. Similarly, it reduces the need for multihoming on the complementor side as users can combine their devices or services with various platforms. As Armstrong (2006), and Rochet and Tirole (2003) show, users tend not to multi-home if they face a choice between functionally similar platforms, yet if they do, they tend to have a preferred platform that they use most often. A single-homing side of a platform, in turn, gives rise to monopoly power. Following the competitive bottleneck model (Armstrong, 2006), a platform can charge monopoly prices to the multihoming side for access to the single-homing side, as it is the case in non-winner takes all markets such as video games or smartphone operating systems. With potentially tens of IoT platforms, platform-to-platform openness could help make the market more transparent for both users and complementors, but also move towards a situation where several meta-platforms control single-homing users.

Platform-to-platform openness as an understudied phenomenon has a links with several other recent concepts of technology platform management. The findings suggest that platform sponsors shield their platforms against competing ones. This may have a link with the concept of platform envelopment (Eisenmann et al., 2011) which refers to the bundling of the focal platform's functionality with a that of a competing platform. Following our conceptualization of platform-to-platform openness, it exposes the standalone functionality of the focal platform, which may make it more susceptible to envelopment. Lastly, Kwak et al. (2018) introduce the concept of complementary multiplatforms which refers to parallelly developing or emerging platforms with complementary relationships that together foster an innovation ecosystem's growth. Complementary multiplatforms consist of various platforms with complementary relationships that achieve value cocreation, leverage shared user basis and contribute to the growth of an ecosystem. Complementarities may rest on technical compatibility (via standards, e.g., complementarity between design software and manufacturing), but compatibilities can also be widespread (Milgrom and Roberts, 1995), for example between skills and equipment. Notably, this concept does not draw on platform openness in whatever sense, suggesting a need to discuss the relation between the concepts.

Strategic motives on whether to open up platforms play an important role. The findings show that platform sponsors try to promote openness towards certain platforms that are complementary, whereas they shield their platforms towards competing ones. The most illustrative example found was that device manufacturers remain closed to platforms from other competing device makers but open up towards upstream platforms that focus more on software and services. This finding resembles well-known notions of coopetition and complementarities in innovation literature (Brandenburger and Nalebuff, 2011). Our finding is also in line with earlier case studies that show that device manufacturers support open IoT platforms as long as there are no competitors (Nikayin et al., 2013). Further, our finding illustrates a pattern of path channelling activities (Henfridsson et al., 2018) that promote certain ways of reusing platform features in order to benefit the strategic interests of the platform sponsor.

Regarding regulation, we find that most interviewees regarded regulation as a factor that prevents openness. This is striking given the emerging realization from policy makers that dominant platforms should be regulated and forced to open up (Cusumano et al., 2019). Our finding showing privacy regulation limits openness is in line with prior studies, which show that data portability is not sufficient to stimulate competition between platforms (Basaure et al., 2020).

Our findings can partly be explained by considering the specific nature of IoT. One specific characteristic of IoT is that connected devices and objects generate unprecedented amounts of **unstructured data**. The newness and great scope of IoT data explains why uncertainty about the value of data from platforms is especially great, which in turn makes platform providers reluctant to open up. Another implication is that **privacy** regulations require informed consent on a larger set of personal data when IoT platforms are being connected, which also negatively affects openness decisions. The fragmentation and specialization of IoT applications as well as devices increases the benefits from platform-level openness. IoT applications are emerging in virtually all domains and industries today (Nicolescu et al., 2018; Wortmann and Flüchter, 2015). As a consequence, the IoT market is fragmented, which increases the complementarity benefits between IoT applications (Ganzha et al., 2018; Mineraud et al., 2016). In addition, the IoT market is highly vertically integrated, which entails that platforms are often provided by the same organizations 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. As a result, decisions about openness are often made depending on the business model of a product or device. Consequently, complementarities between applications materialize into complementarities between platforms as well as the products connected through the platforms. For instance, by connecting a connected car platform to a charging station platform, drivers can better plan their stops. On the other hand, interviewees argued that opening up IoT platforms across industries requires following potentially highly diverse sector-specific regulation, which makes companies reluctant to open up.

The fragmented nature of the IoT landscape implies that strategic considerations are likely of lower importance than in other domains. Winner-takes-all dynamics are generally less likely to occur in markets with great need for specialization (Eisenmann et al., 2006). Because of this, concerns over strategic positions and competition rivalry are less important reasons to keep platforms closed. The relatively low competition rivalry reduces the negative strategic implications of platform level openness.

From technology perspective, platform-to-platform openness in IoT can be fostered by tackling the challenges from 1) data exchange application programming interfaces (APIs); 2) interoperability standards; 3) data sharing semantics agreements; and 4) lightweight virtualization. The data ex-change APIs will facilitate the developers from different platforms to build applications that can efficiently exchange information across platforms. The system-level interoperability standards can provide additional guarantee of service reliability especially when IoT platforms are frequently up-grading from old version to newer edition. Since IoT deployment is rapidly growing, semantics in data can become highly diverse. This requires data-level agreements across platforms to enable correct, open and transparent interpretation of data by various applications running on each platform. Furthermore, to prevent dependency on the operating system of the specific IoT platform, lightweight virtualization (Morabito et al., 2018) are needed to enhance the flexibility of service migration across IoT platforms. This can help platform providers to bring down the deployment barriers that are crucial for IoT platform-to-platform openness.

An important side-remark can be made on the nature of complementarities between IoT devices and platforms. Because IoT platforms, in particular the software stack, are the bridge between the physical and the digital realm, there are high dependencies between the IoT device and the IoT platform. However, some IoT devices also have an intrinsic value, even when not connected to open IoT platforms. For instance, a smart lightbulb still produces light, even when not interoperable with a connected doorbell. Due to high need for specialization, the physical bounding, and intrinsic stand-alone value of IoT devices, the business motivations to open up IoT platforms may differ from software platforms. Rather than benefiting from the platform business itself, many IoT device makers see platforms (and applications) merely as an add-on that make their devices more valuable to end-users. As platforms are thus a means to an end, it is far less important how opening up IoT platforms affects revenues gained from the platform, lock-in of customers and control over their own platform and its market position.

8. Conclusion

This paper explored factors that reveal why platform sponsors open up their platforms to other platforms. Platform-to-platform openness is of high relevance, given that the digital economy constitutes increasingly complex constellations of platforms, devices, and complements.

When deciding about the desired degree of platform level openness, we found that IoT platform owners consider factors relating to the direct and indirect benefits and costs, as well as strategic motives. How these trade-offs are made depends on the market-level and organizational context. We also found that platform owners make decisions on platform-to-platform openness on a case-by-case basis, which contrasts with the generic openness rules that are typically used in platform-to-app openness.

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 specialization 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. Due to the need for specialization, network effects are less strong for IoT platforms, which makes winner-take-all dynamics less prominent, which gives more room for collaboration between platforms in the form of platform level openness.

In this paper, we used interviews as a source. Next steps could include theory testing approaches, for instance through large-scale surveys. Alternatively, we suggest multi-criteria decision-making analysis as a next step, to prioritize the factors in our extensive model.

8.1. *Managerial implications*

This research could be of interest to IoT platform sponsors as it can be used to guide decisions on the desired degree of platform-to-platform openness. The theoretical framework gives an indication of the factors and trade-offs that should be taken into consideration in the decision-making process and could guide decision-making processes. Furthermore, the interviews showed that meta-platforms could play an important role in platform-to-platform openness solutions. Mostly because it limits the dependency on other market players as they are not designed with a specific partner in mind. This leads to fewer interdependencies when collaborating in complex ecosystems. As a result of this modular technological architecture, coordination costs will be lower, and it will be easier to organise for innovation. This is in line with the innovation management perspective on platforms (Baldwin and Clark, 2000). A meta-platform can also serve as a trusted-third party, which makes it easier for connected platforms to share their data; both out of data security considerations and to avoid incompliance with competition laws. Therefore, IoT platform sponsors are recommended to investigate these platforms when designing new openness solutions. Furthermore, section 4.5 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.

8.2. *Limitations & further research*

Considering the multitude of contextual conditions that we identified in this study, such future studies could especially benefit from a configurational or comparative approach (Ragin, 2014). Likely, the identified contextual conditions will not have a major effect on platform openness if they are merely considered as potential sufficient causal factors. The advantage of comparative analysis is that one can include sufficient as well as necessary conditions for platform openness outcomes, and thereby attain a more fine-grained understanding of what causes platform openness decisions (see for an example Bouwman et al. (2019)). There are some limitations to this research that could be addressed in further research. To start, in this paper, we sought to characterise platform-to-platform openness in a rich way, based on factors, sub-factors, and examples. A consequence is that we cannot make bold claims regarding the generalizability of our findings. We suggest that future studies take on this challenge and address platform-to-platform openness in more quantitative ways. Moreover, only two application domains were considered in this research: the automotive and healthcare domain. These domains were selected due to the variability in 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, confirmatory case studies in other domains are recommended to probe the theoretical relations found in this study. Nevertheless, we believe that the structure of the present theoretical model is correct because the same factors were observed in both domains and the context mainly changed how trade-offs between those factors are being made. Hence, further research could focus on the impact of the context variables on the trade-offs between the factors identified in this research.

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 complement openness and platform-to-platform openness because there are some vertically integrated platforms where there is a 1:1 relation between the platform and the devices connected to it (i.e., the complements). This is also the case for the distinction between user level openness and complement openness because users often interact with the platform through the device. Further research could look at the relation between platform-, user- and complement 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 of platforms (e.g., data platforms) because respondents talked about the different types of platforms interchangeably.

Thirdly, more research on the contrast between platform-to-platform openness and other concepts in strategic management in general a platform research in specific is suggested. While we provide a discussion of platform-to-platform openness with respect to other concepts from platform management, it seems promising to investigate these relations, also as the scholarly understanding of platform-to-platform openness increases. Furthermore, it is conceivable that platform-to-platform openness is dependent on the underlying platform type (mediating vs extensible) and hence this area is also recommended for future research.

Finally, Internet of Things platforms are an emerging technology which makes researching the governance of these platforms a challenging task. Some of the platforms that are considered in this study are still in an early stage of maturity. A confirmatory or longitudinal case study would in this case also be useful to make sure that respondents' answers are based on sufficient experience with the chosen openness strategy. While our paper addressed factors on *why* firms open up their platforms towards other platforms, we expect complementarities from studies that address *how* this is done. For instance, Sandberg et al. (2020) study ABB's transformation from a solely physical product manufacturer to the orchestrator of hybrid physical-digital systems and surrounding ecosystems. Similarly, future studies could address different phases in the transformation towards platform-to-platform openness. Furthermore, the relation between the openness of IoT platforms and other domains could also be further developed. 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. Standardization could be a feasible technical approach to enhance interoperability without requiring business agreements between platform owners. One example is the recent smart home standardization initiative "Matter", including Amazon, Apple, Google, Samsung, the Zigbee Alliance, and several industrial companies, which enables linking smart home platforms through open source standards. 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.

Acknowledgments

The work by the second and third author was supported by the EC H2020 SWAFT 12-2017 programme (grant number 788361). The work by the fourth author was partially supported by the European Union's Horizon 2020 research and innovation programme under the grant agreement 101021808, and the iSafe project funded by TU Delft Safety & Security Institute. The work by the last author was supported by funding from the European Union's Horizon 2020 Program, under grant agreement 871481 –Trusted Secure Data Sharing Space (TRUSTS). We would like to thank Hans van der Marel from KPMG for advice during the execution of the study, as well as three anonymous reviewers. The paper is partly based on thesis work as done by the first author (Mosterd, 2019).

Appendix

Table 6
Groundedness

Category	Factor	Grounded-ness	Codes	Grounded-ness
Direct benefits and costs	Costs	12	Maintenance costs	1
			Development costs interoperability solutions	6
			R&D costs	5
	Direct revenues	4	Ability to capture rents	4
	Uncertainty about value of data	14	Business case not clear	11
			Hidden value in data	3
	New business opportunities	16	Attract new users	11
			Increase of sales	2
			Churn rate	1
			Network effects	2
Indirect benefits and costs	Attractiveness of the platform	28	Ability of complementors to capture rents	1
			Availability of data	8
			Availability of services	3
			Generative ability	1
			Low chance of lock-in	1
			Possibilities for multi-homing	1
			Quality of data	1
			Quality of service delivery	11
			User experience	1
	Data privacy and security concerns	5	Importance of data privacy and security	5
Strategic considerations	Knowledge gains	15	Insight in competitors	4
			Insight in market developments	6
			Insight in other ecosystem players	5
	Market position	30	Control over platform development	4
			Impact on market power	15
			Ability to influence market development	6
			Risk of forking	2
			Control over product portfolio	3
Market-level context	End-user demand	14	End-user demand	14
	Need for specialization	14	Need for specialization	12
			Complexity of ecosystem	2
	Competition between platforms	15	Intensity of competition	12
			Dominant market players	3
	Market maturity	14	Maturity of market offerings	7
			Maturity of available technologies	7
	Maturity of compatibility standards	15	Availability of (mature) standards	12
			Availability of coordinating bodies	3
Organizational context	Business objectives	3	Business objectives	3
	Strategic focus	41	Business model focus	23
			Dependency on other market players	10
			Vertical integration	8
	Openness to app developers and end-users	17	Involvement of third-party developers	17
Legal and legitimacy factors	Privacy and security regulations	14	GDPR/privacy law	14
	Sector-specific regulations	18	Sector regulation	11
			Differences in regulation	2
			Uncertainty about regulation	5
	Competition law	7	Competition law	7

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