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Value Co-Creation in Digital Platform-based Ecosystems in the Context of the Internet of Things

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Sven Niederhöfer

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Vorsitz:	Prof. Dr. Dirk Ulrich Gilbert
Erstgutachter:	Prof. Dr. Sebastian Späth
Zweitgutachterin:	Prof. Dr. Jetta Frost
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List of Abbreviations

API	Application Programming Interface
EU	European Union
IoT	Internet of Things
IP	Internet Protocol
OECD	Organisation for Economic Co-operation and Development

Overview of Dissertation Papers

No.	Title	Authors	Journal/Outlet	Status	Conference Submissions	Acknowledgements
I	Ecosystem Perspective in Platform Research: A Bibliometric Analysis and Review of Recent Literature	Niederhöfer, S.	Journal of Management (JoM)	Preparation for submission together with a co-author	• European Academy of Management (EURAM) Annual Meeting, Lisbon, 2019	
II	Compatibility Promotion Between Platforms: The Role of Open Technology Standards and Giant Platforms	Niederhöfer, S., Spaeth, S.	Electronic Markets (ELMA)	Under Review, 3rd round	• Academy of Management (AOM) Annual Meeting, Online, 2021 • European Academy of Management (EURAM) Annual Meeting, Online, 2021	Designated for "Best Paper Award" in Technology and Innovation Management
III	Backing the Right Horse: A Study of the Effect of Membership Dynamics on Value Creation in the Smart Home Market	Niederhöfer, S., Spaeth, S.	SSRN	Published	• European Academy of Management (EURAM) Annual Meeting, Online, 2020 • Research Policy Workshop on Innovation Ecosystems and Ecosystem Innovation, Online, 2020	
IV	User Motivations in Peer Production	Spaeth, S., Niederhöfer, S.	Chapter in peer reviewed book: O'Neil, Pentzold, Toupin (Eds.): The Handbook of Peer Production, Wiley-Blackwell, pp. 123-136.	Published		

Synopsis

1. Introduction

In the early 2000s, business scholars discussed platform business models and ecosystem strategies to attain “platform leadership” within entire industries by stating (Gawer & Cusumano, 2002, pp. 268–269):

> *“It is recognizing that certain kinds of products have little value by themselves but can be extremely valuable as center of a network of complements. (...) Platform leaders and wannabes must maintain incentives for third parties to produce complementary innovations and help them do so, or the strategy will fail. We are talking about a strategy of interdependence – creating a vibrant ecosystem – that entails a fragile existence for firms that are part of the network.”*

The book reflects the observation of the transformative power of some platform companies in high-tech industries such as computing and telecommunications, which have shaped certain structures that the authors label as "ecosystems." While platforms as a phenomenon and strategic tool are not new to research and practice, the work marks a shift towards considering industry platforms that act as central control points or hubs within ecosystems as strategic impetus (Thomas et al., 2014). Before, platforms were vastly considered as strategic means to achieve efficiency gains in new product development or as network-based business models (Thomas et al., 2014). This overall movement in academics and practice focusing on platforms was accompanied by success stories describing the rise of platform companies such as Microsoft, Apple, Google, Amazon, and Facebook, scaling their business models and impressing investors in the stock market (Parker et al., 2016).

Since then, platforms across various contexts received attention, taking distinct forms such as marketplaces (e.g., Amazon, AirBnB), operating systems (e.g., iOS), social media platforms (e.g., Facebook), cloud platforms (e.g., SAP Cloud), and extensible software applications (e.g., Mozilla Firefox) (Benlian et al., 2015; Foerderer et al., 2018; OECD, 2019; Tiwana, 2015; Wareham et al., 2014). While different definitions of platforms exist, this doctoral dissertation considers platforms 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 et al., 2010, p. 675). Accordingly, platform-based ecosystems can be viewed as the assemblage of “a platform owner that implements governance mechanisms to facilitate value-creating mechanisms on a digital platform between the platform owner and an ecosystem of autonomous complementors and consumers.” (Hein et al., 2020, p. 90).

Platforms stand out due to various characteristics. Most notably, they allow leveraging economies of scope in production, innovation, and transaction (Thomas et al., 2014), with network effects allowing to quickly grow and potentially achieve a monopoly position (McIntyre & Srinivasan, 2017; Schilling, 2002). As such, they may further have impacts at the micro- and macroeconomic levels, such as reducing costs and simplifying processes, lowering transaction costs, promoting entrepreneurship, and disrupting industry structures (OECD, 2019, pp. 28–52).

Not least because of these particularities of platform business models and their impact on competition, platforms enjoy broad popularity among practitioners. A survey conducted by Accenture in 2018, covering 500 C-suite executives across 12 countries and nine industries, shows that the vast majority (88%) considers digital platforms as core to, or enabler of their organization’s business strategy (Elliott et al., 2018). However, the same survey indicates that platform strategies are not trivial to follow, showing differences in adoption progress across industries and a strong preference to develop platforms in collaboration with external vendors.

Especially in digital contexts, platforms usually exceed higher degrees of complexity. Digital platforms differ in that they not only comprise a modular architecture, but also span several layers of the technology stack (Yoo et al., 2010) positioning them within a broader infrastructure of interconnected platforms, components, and standards (Henfridsson et al., 2018; Mosterd et al., 2021) and providing access to resources through standardized interfaces that can be used by developers and rivals alike in unforeseen ways (Hilbolling et al., 2020; Mosterd et al., 2021). At the same time, they allow platform sponsors to draw on the resources and capabilities of numerous external parties (Boudreau, 2012; Ghazawneh & Henfridsson, 2013), which opens up considerable potential for value creation. The dimensions that are achievable through the contributions of external parties is evident in the examples of Apple's iOS and Google's Android, with external developers producing much of the platforms’ value. Since its launch in 2008, the number of apps and games offered in Apple's App Store has grown to more than 4.8 million in 2021.[1] In the same period, the number of apps in Google's Play Store rose to over 2.5 million.[2]

As diverse as platform business models are, so is value generation that takes place through platforms. Nonetheless, according to Scholten & Scholten (2012), value created can generally be determined threefold: (1) in the production process on the supply side, (2) in the matching between supply and demand, and (3) in the perception on the demand side. Much research on value creation in platform-based ecosystems has focused on the production of a large and diverse set of complementary products and services of high quality that meets heterogeneous needs of (prospective) end-users that were previously unmet (Boudreau, 2010; Hilbolling et al., 2021; Inoue & Tsujimoto, 2018a; Qiu et al., 2017). As such, the value perceived by end users is considerably coined by the extent to which they can combine various offers in a "mix-and-match" fashion to address their particular situations (Yoo et al., 2010, p. 730). In addition, some research focused on the impact of multihoming on complement quality (Cennamo et al., 2018) and integration of resources across platforms (Weiss & Gangadharan, 2010). Overall, value creation in digital platform-based ecosystems goes back to the combination and recombination of resources within or across platforms (Henfridsson et al., 2018; Yoo et al., 2010).

Although there has been a proliferation of research on various issues related to value co-creation in digital platform-based ecosystems, there are still a number of gaps in the literature. Particularly, many findings are limited to a few platform-based ecosystems and neglect the environment (Selander et al., 2013). As such, value creation has predominantly been studied as the outcome of combining resources within platform-based ecosystems.

This cumulative dissertation entitled *"Value Co-Creation in Digital Platform-based Ecosystems in the Context of the Internet of Things"* pursues the overarching target to study how strategic considerations and motives influence value creation in terms of product certifications, cross-vendor compatibility, and contributions by user innovators. The empirical part of this doctoral thesis considers the context of the Internet of Things, which is a fast growing technology that spans multiple industries and allows for the introduction of platform solutions for manufacturers of traditional products (Rowland et al., 2015). In this context, the complexity of digital platform-based

[1] https://www.pocketgamer.biz/metrics/app-store/
[2] https://www.appbrain.com/stats/number-of-android-apps

ecosystems becomes particularly evident, where value co-creation outside single platform-based ecosystems is a particularly crucial issue.

This introductory chapter to the four dissertation papers is structured as follows: the subsequent section provides a brief overview of the state of research in the literature streams on digital platforms, platform-based ecosystems, and technology standards. The section concludes by introducing the conceptual framework underlying the doctoral dissertation. Building on this, the third section addresses the gaps in the literature and discusses the research agenda for the four articles to then explain the methodology underlying this dissertation in the fourth section. The motivations, findings, and key implications of the four articles are then briefly summarized in the following fifth section. The sixth section then elaborates on the contribution of this dissertation to theory and practice by discussing the individual contributions of the four articles. The final section concludes the introductory chapter with an outlook on future research.

2. Theoretical Background

This section briefly reviews the three main streams of literature on which the research of this cumulative dissertation is based. To this end, I first address the conceptualizations of platforms and provide a brief overview of research groups that study platforms, where I particularly focus on value creation and characteristics of digital platforms. Then, I briefly discuss the conceptual roots of platform-based ecosystems, to give an overview of previous research interests and problems. Afterwards, I provide a brief discussion of the state of research on technology standards and standardization with respect to platforms and platform-based ecosystems. Finally, I derive a conceptual framework that guides the development of a research agenda.

2.1. Platform Research and Digital Platforms

According to the Oxford English Dictionary, the etymological roots of the term "platform" go back to the 16th century, where it is traced back to the French term "plateforme" (i.e., flat shape). Its meaning originates from the context of construction and refers to a (raised) surface on which something can be placed (Platform, n.d., 1.-2.). Later, the term was used linguistically in relation to vehicles such as buses or boats (Platform, n.d., e.g., 2. b, 2. e.).[3]

[3] Note that the term has many further meanings, including political positions, aeronautical mounts on spaceships, natural plateaus in the geographic sense, or tectonic plates (Platform, n.d.). However, all these meanings are disregarded in this dissertation.

As versatile as the term "platform" are the disciplines that research this phenomenon. Accordingly, different streams and conceptualizations of platforms have emerged (Gawer, 2009; Thomas et al., 2014). In their comprehensive, systematic literature review of research on platforms, Thomas et al. (2014) identify four distinct streams in management research: platform organizations, product families, market intermediaries, and platform-based ecosystems. Platform organizations refer to flexible structures that aggregate organizational resources and capabilities, which they recombine freely to adapt to changes in demand and emerging opportunities (Ciborra, 1996; Thomas et al., 2014). The roots of the stream on product families lie in the literature on new product development, describing the core of modular architectures that allow easy modifications for different market niches by leveraging standardized interfaces, where value arises through economics of scale and scope (Baldwin & Clark, 2000; Meyer & Utterback, 1993; Thomas et al., 2014). The stream on market intermediaries considers platforms as interaction interfaces in two-sided or multi-sided markets, where optimal matching between supply and demand as well as network effects are central to value creation (Armstrong, 2006; Katz & Shapiro, 1985; Rochet & Tirole, 2003).[4] As such, value arises through matching supply with demand (Parker et al., 2016). While both streams provide some fundamental insights as to the functioning of platform-based markets, they each focus on certain types of platforms (transaction platforms versus innovation platforms), while lacking to sufficiently explain mechanisms underlying innovation activities in networked markets (Gawer, 2014; McIntyre & Srinivasan, 2017). Literature on platform-based ecosystems builds on concepts from both of the latter streams and considers platforms as a central point of control within a technology-based business system, centrally addressing different aspects of orchestrating autonomous ecosystem participants that produce value in terms of complementary products and services (Ceccagnoli et al., 2012; Gawer & Cusumano, 2002).

In this context, Gawer & Cusumano (2002) first mentioned the concept of ecosystems in the context of platforms to shape a strategic view of a "wannabe platform leader" on platform-affiliated organizations. To date, no single definition of platform-based ecosystems has been established (de Reuver et al., 2018). Rather, there are at least two dominant definitions that link to different discourses from different research groups within the literature. Some of the literature relies on Gawer's (2014) definition, which views platforms as meta-organizations and defines them as

[4] Comprehensive reviews of contributions in this stream are provided by Rietveld & Schilling (2021) and McIntyre & Srinivasan (2017) with a particular focus on the characteristics of two-sided markets and network effects.

"evolving organizations or meta-organizations that: (1) federate and coordinate constitutive agents who can innovate and compete; (2) create value by generating and harnessing economies of scope in supply or/and in demand; and (3) entail a modular technological architecture composed of a core and a periphery" (p. 1245). Accordingly, this definition adopts the strategic view on platforms and emphasizes the need for the platform leader to govern the providers of complementary products and services. In contrast, particularly information system research relies on the more technical definition of Tiwana et al. (2010), who define platforms 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" (p. 675).

This definition forms the basis for research efforts on digital platforms and digital platform-based ecosystems (de Reuver et al., 2018; Yoo et al., 2010). Digital platforms represent digital artifacts that have special properties: reprogrammability (adjustments of the product are possible even after its delivery), homogenization of data (data are transformed into a binary representation through digitization), and self-referentiality (digital innovations require digital technologies) (Kallinikos et al., 2013). The architecture of digital technologies can be divided into layers – device, network, service, content layers – that are loosely coupled through technology standards, protocols, and homogenization of data (Yoo et al., 2010). Digital platforms thus combine a modular with a layered architecture, which provides the basis for technological generativity. Technological generativity refers to "a technology's overall capacity to produce unpromoted change driven by large, varied, and uncoordinated audiences" (Zittrain, 2006, p. 1980). Accordingly, the layered modular architecture of digital platforms provides the basis for digital innovation by allowing digital artifacts (devices, software, content) in the different layers to be combined and recombined in an endless fashion (Yoo et al., 2010). It is this process of combination and recombination that underlies generative innovation and thus value creation (Henfridsson et al., 2018; Yoo et al., 2010). In this process, resources from different platforms can be combined, usually provided through application programming interfaces[5] (Weiss & Gangadharan, 2010), which influences the strategic positioning of a platform (Henfridsson et al., 2018). Although much of recent research on platforms focuses on a digital context such as mobile operating systems (Benlian et al., 2015; Qiu et al.,

[5] Application programming interfaces are controlled access points through which resources can be retrieved and services used in a standardized fashion (Weiss & Gangadharan, 2010).

2017), Internet browsers (Tiwana, 2015), enterprise software (Wareham et al., 2014), or video games (Rietveld et al., 2019), few consider the digital nature.[6]

This dissertation builds on this stream and explores digital platforms through an ecosystem lens.

2.2. Ecosystems and Platform-based Ecosystems

Even though seminal works define the platform-based ecosystem concept from within the platform literature (Gawer, 2014; Thomas et al., 2014; Tiwana et al., 2010), the notion of ecosystem goes back to the biological metaphor introduced by Moore (1993). Moore coined the term business ecosystem to emphasize the "underlying strategic logic of change" in "complex corporate communities" (p. 75) and laid the foundation for the ecosystem strand in the information systems and management literature. Similar to its biological counterpart, the ecosystem concept in the business context emphasizes the dynamic and complex nature of assemblages of autonomously acting entities (Moore, 1993, 1996; Tansley, 1935).[7] In this context, Moore (1993, 1996) draws particularly on the concepts of co-opetition (Nalebuff & Brandenburger, 1997) and co-evolution[8] and sees the utility of the ecosystem concept in explaining the evolution of an overall community of organizations by considering dynamics that go back to simultaneous cooperation and competition.

Since then, the ecosystem concept has undergone further theoretical development (Adner, 2017; Barile et al., 2016; Jacobides et al., 2018). Most notably, Jacobides et al. (2018) identify modularity as fundamental condition for ecosystems to emerge, where they view non-generic complementarities in supply and demand as the characteristic that distinguishes ecosystems from markets and hierarchies. According to Adner (2017), conceptualizations of ecosystems can be divided into two groups: “ecosystem-as-affiliation” and “ecosystem-as-structure”. While the former reflects a hub-and-spoke structure and focuses on centralized governance and community enhancement, the latter emphasizes relative positions and activity flows as well as alignment between actors with the goal of studying value creation. The author argues that it is this degree of (mis-)alignment of interests, which creates dynamics, and thus justifies the conceptual lens of ecosystems. Some scholars emphasize the systemic nature of ecosystems, conceiving them as a

[6] See de Reuver et al. (2018) for a comprehensive review of recent studies on digital platforms.
[7] Please refer to Tansley (1935) for the original definition of the ecosystem concept in the biological context.
[8] Co-evolution denotes the process of mutual influence of that actors have on one another, leading to their adaptation in certain features (such as capabilities).

specific type of complex adaptive systems that exhibit ecological dynamics (Barile et al., 2016; Tsujimoto et al., 2018). Accordingly, ecosystems can be defined and studied at different analytical levels, where they are embedded in broader systems such as societies (Barile et al., 2016; de Reuver et al., 2018; Tsujimoto et al., 2018).

Furthermore, different ecosystem concepts have gained traction in different disciplines, most notably, innovation ecosystems and platform-based ecosystems, which can be seen as particular forms of business ecosystems (Jacobides et al., 2018; Tsujimoto et al., 2018). In this context, innovation ecosystems focus on a central value proposition or technology and include upstream and downstream actors. In contrast, platform-based ecosystems are narrower, covering only the downstream part, and typically include a central platform sponsor as well as complementors (e.g., software developers) and, in some cases, the platform provider and end users (Jacobides et al., 2018).[9] Conceptually, platform-based ecosystems are surrounded by an industrial context as well as industry consortia, user communities, and a regulatory regime (Tsujimoto et al., 2018). This more holistic view of the phenomenon of the platform and its market or technology environment is seen as a particular strength of the ecosystem perspective (Priem et al., 2013), where particularly competition between ecosystems was a key driver underlying the emergence of the concept (Moore, 1993, 1996). Still, the bulk of studies on value creation in platform-based ecosystems only considers the interactions between one central platform and a developer ecosystem conceived as a relatively homogeneous unit (Jacobides et al., 2018).

In this regard, a large proportion of studies focuses on strategic decisions, governance mechanisms, or intergenerational technology transitions and their impact on value generation in the developer ecosystem. Aspects such as a platform sponsor's entry into complementary markets (e.g., Foerderer et al., 2018), a platform sponsor's entry into new markets (e.g., Inoue & Tsujimoto, 2018b), platform openness (e.g., Wessel et al., 2017), or intergenerational technology transitions (e.g., Ozalp et al., 2018) have been explored. In the context of digital platform-based ecosystems, particular attention has been paid to boundary resources, which refers to resources that are provided

[9] Note that this study follows this conceptual differentiation and uses both lenses to adopt perspectives of different actors and consider different scopes. In this context, the platform-based ecosystem perspective is used to denote a hub-and-spoke structure characterized by manufacturers of complementary products and a central platform. This takes the perspective of a central platform sponsor making decisions. In contrast, the innovation ecosystem lens is used to examine an ecosystem around a central technology (i.e., technology standard), with both device manufacturers and chipset vendors being represented in the ecosystem. These ecosystem participants collectively contribute to building a market based on that technology.

to complementors to generate value, shaping the relationship between the platform and complementors (Ghazawneh & Henfridsson, 2013). Accordingly, the multilateral orchestration of the platform sponsor's relationships with the complementors and the impact on value generation can be studied. The influence of social boundary resources such as developer conferences (Fang et al., 2021; Foerderer, 2020), of knowledge boundary resources such as information portals (Foerderer et al., 2019), or of technical boundary resources such as APIs (Eaton et al., 2015; Ghazawneh & Henfridsson, 2013) has been studied.

Some recent studies adopted a broader view, considering interactions of platforms with their broader environment. In this context, some studies considered interactions with social and political systems. In this regard, Bazarhanova et al. (2020) examined the impact of regulatory changes on the ecosystem orchestration in the Finnish banking ecosystem. Garud et al. (2022) examined Uber's entry into a regulated market, where the company focused on rapidly building a large installed base of users to generate legitimacy within society to force policy makers to make concessions. Xu et al. (2021) adopted a sociocultural perspective and proposed an evolutionary model to service platform ecosystems that includes interactions with society. Other studies looked at market structures, and identified roles and positions within the IoT market and the smartphone market using network analysis (Basole & Karla, 2011; Toivanen et al., 2015). Furthermore, they examined how digital platforms challenge traditional incumbent producers when entering a market (Cozzolino et al., 2021), or how multiple complementary platforms can build a shared installed base of users and components in the 3D printing market (Kwak et al., 2018). Researchers in information systems research, in particular, focus on complementarities of resources across multiple digital platforms. These studies consider integration patterns of internal with external APIs (Um et al., 2013), cross-platform interoperability (Deshmukh et al., 2021), or the process of developing mashups (Stecca & Maresca, 2011).

Overall, research on the interactions between platforms and their broader environment is scarce. Moreover, the role of standards and standardization in particular is under-researched. This is a major gap in light of increasing digitization, which makes standards more relevant to study value creation and competition in the context of platforms (Henfridsson et al., 2018; Teece, 2018).

In addition to standardization bodies, user communities can also play an important role for ecosystems (Bogers et al., 2019; Tsujimoto et al., 2018). A few studies therefore considered user communities and their importance for value generation. For example, Mäkinen et al. (2014) examined the role of beta tester communities in the development of new applications, where the adoption behavior by the tester community can help to improve application developments. Rohrbeck et al. (2009) present in their qualitative study how Deutsche Telekom established an open innovation ecosystem to grasp user driven innovation. The increasing digitization and provision of boundary resources also allows end users to modify their products on their own and make them available to other users (Von Hippel, 2006). In contexts such as IoT, peer production platforms are therefore emerging alongside commercial platforms, interacting with each other and influencing the evolution of the technology as a whole (Kwak et al., 2018; Rong et al., 2018).

2.3. Technology Standards and Standardization

There is a considerable history of research on technology standards and standardization. Generally, a technology standard can be understood as "a set of specifications to which all elements of products, processes, formats, or procedures under its jurisdiction must conform" (Tassey, 2000, p. 588). Technology standards (sometimes also called interface standards or compatibility standards) are implemented in interfaces, ensuring compatibility across all products or technologies conforming to these specifications (David & Greenstein, 1990).[10] In addition, technology standards can vary in the degree of openness, with proprietary and open source representing the extremes (West, 2003). West (2003) suggests that proprietary standards are developed by a platform sponsor for its own use, with an appropriation regime. In contrast, more open technology standards are subject to fewer constraints on their integration into products, their certification, and their commercialization (West, 2007). Yet, Suarez (2004) argues that the degree of openness is mainly reflected in the licensing policies.

Standards are usually developed by standard organizations. Standard organizations emerge in response to some coordination problem, i.e., in the case of diverging interests as to which technology should be used within or across industries (Markus et al., 2006; Rysman & Simcoe, 2008). These standard organizations allow firms to find consensus, resolve issues related to overlapping intellectual property rights, and endorse and promote a particular technology (Rysman & Simcoe, 2008; Simcoe, 2012). They thus provide a focal point for orchestrating major change when leadership is distributed among firms and coordination is hence more complex (Rysman &

[10] In this dissertation, I will refer to such interface standards in the form of radio frequency communication protocols.

Simcoe, 2008). Research distinguishes between different forms of standard organizations (David & Greenstein, 1990; Leiponen, 2008). De facto standards are determined by market dynamics (Farrell & Saloner, 1986), while de jure standards are either set by governmental agencies or voluntary standard setting organizations (David & Greenstein, 1990). The former category then takes the form of standard consortia, certification bodies, and industry associations, while the latter are rather formal standard setting organizations, such as the International Standardization Organization (Leiponen, 2008). Independently of their form, standard organizations perform a range of activities, which may include the development of standards and the fostering of their diffusion, certifying the compliance of products with the technical specifications and acting as interfaces between governments and private standard organizations (Baron & Spulber, 2018; Farhi et al., 2005; Lerner & Tirole, 2006).

Some early research on standards and standardization addressed market mechanisms and technological regimes in relation to dominance battles of competing systems. In particular, switching costs (Arthur, 1989) and network effects (Katz & Shapiro, 1986) were considered as driving market mechanisms that lay the foundation for startup problems (Besen & Farrell, 1994; Katz & Shapiro, 1985), path dependencies (Arthur, 1989; Besen & Farrell, 1994), and "tipping" of the market (Arthur, 1989; Farrell & Saloner, 1986) with potential "winner-take-all" outcomes (Schilling, 2002). From a technological perspective, particular attention has been paid to the impact of compatibility and converters (Katz & Shapiro, 1985) and licensing policies (Farrell & Gallini, 1988; Suarez, 2004). In this regard, Besen & Farrell (1994) summarize the strategies as either (1) desiring to compete between standards to determine the dominant industry standard, (2) desiring to compete within one standard, with no agreement on which standard it should be, or (3) desiring to compete within a single standard agreed upon.

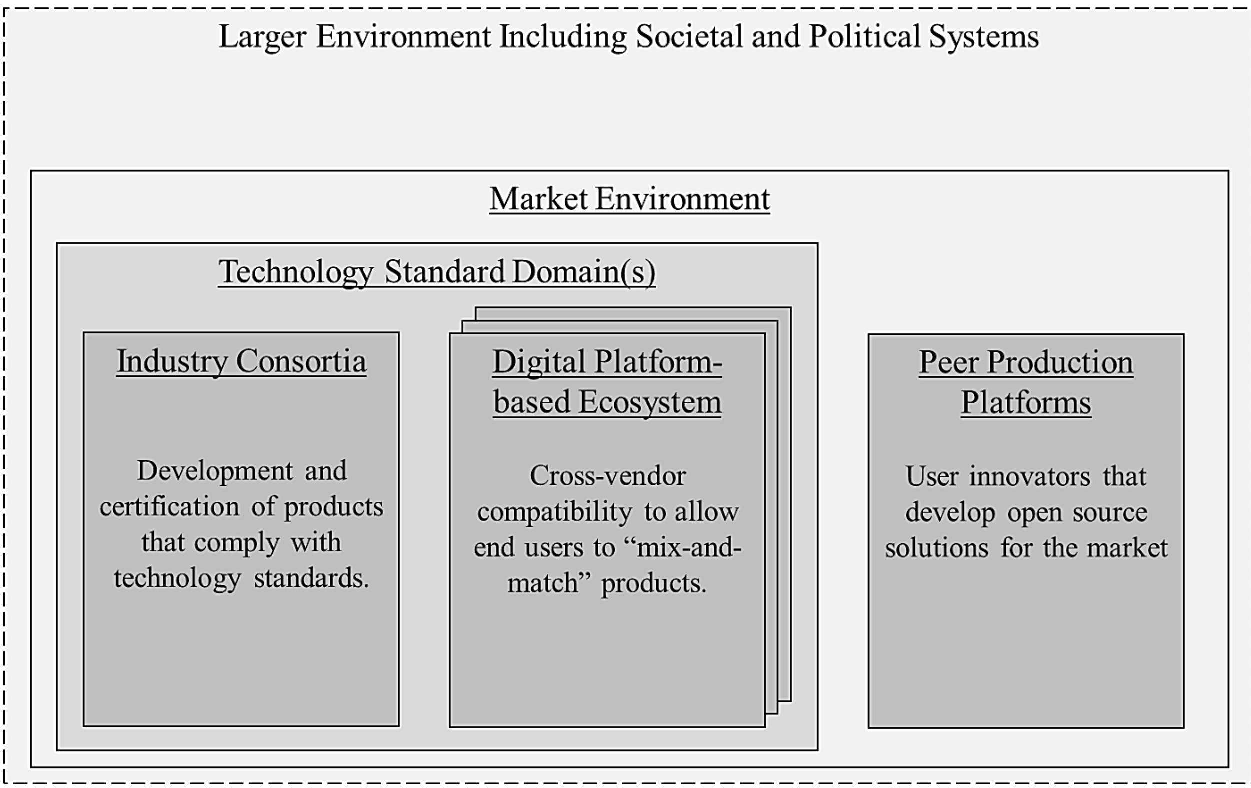
Another strand of research looks at the standardization process in standard bodies such as industry consortia. In particular, activities such as patent disclosure (Toh & Miller, 2017), consensus formation in committees (Ranganathan et al., 2018), and the formation of inter-firm relationships (Axelrod et al., 1995; Leiponen, 2008) are in focus. Some recent research adopts an ecosystem lens in this regard and examines co-opetitive dynamics in the process of standardization (Ranganathan et al., 2018; Toh & Miller, 2017). For instance, Toh & Miller (2017) examine conditions under which firms disclose patents within standardization organizations. Ranganathan et al., (2018) study how the interplay of competition and cooperation influence the voting behavior in committees.

Still, some scholars call for more research focusing on dynamics during standardization (Baron & Spulber, 2018).

2.4. Conceptual Framework

Based on the brief literature review above, this section shortly lays out the conceptual framework for the dissertation, which is illustrated in Figure 1. The conceptual framework for this dissertation builds on the contributions of Tsujimoto et al. (2018), Kwak et al. (2018), and Henfridsson et al. (2018) and considers digital platform-based ecosystems from a systemic perspective that encompasses the broader environment.

Figure 1: Conceptual framework underlying the dissertation.



Source: Own illustration based on Tsujimoto et al. (2018), Kwak et al. (2018), and Henfridsson et al. (2018).

Accordingly, digital platforms and their ecosystems do not exist in a vacuum, but are embedded in social and political systems, interact with markets and industries, and are interwoven with technical infrastructures (Tsujimoto et al., 2018; Yoo et al., 2010). The focus of this dissertation is primarily on the market and technological standards. Particularly in contexts such as IoT, several platforms constitute a shared market, where also peer production platforms can play a fundamental role (Kwak et al., 2018; Rong et al., 2018).

Digital platforms in particular leverage technology standards and protocols to enable technological generativity. Through their layered modular architectures, they are interwoven with technology standards that guide compatibility between platforms as well as their complementary products (Henfridsson et al., 2018). Accordingly, digital platform-based ecosystems are located in technology standard domains, i.e., a set of products and solutions that conform to a technical specification (Tassey, 2000). These technical specifications often derive from standard bodies, including industry consortia whose members develop and commercialize compatible products that are certified by the industry consortium (Leiponen, 2008). This is particularly salient in the Internet of Things context, where devices incorporate various open communication protocols such as Z-Wave, ZigBee or Wi-Fi (Rowland et al., 2015).

3. Research Agenda

The brief overview of the current state of the literature suggests that while research on digital platform-based ecosystems has increased massively in recent years, the focus is predominantly limited to individual platform ecosystems, and gaps remain as a result. Below, I describe in more detail four of these gaps, which will be addressed in this thesis.

First, the platform ecosystem concept exhibits similar conceptual ambiguities as the related business ecosystem and innovation ecosystem concepts do. Specifically, the platform and ecosystem concepts are considered at different analytical levels and are sometimes used as synonyms (de Reuver et al., 2018). On the one hand, this can be attributed to the fact that ecosystems are fractal in nature (Lusch et al., 2016) and can be defined at different levels, with boundaries being difficult to define (Iansiti & Levien, 2004). On the other hand, it can be attributed to the fact that platforms can denote product families (modular products) as well as market intermediaries (two-sided markets) and organizations (dynamic structures) (Thomas et al., 2014). As a result, platforms are sometimes considered the technological foundation of a surrounding ecosystem (Tiwana et al., 2010) and sometimes the ecosystem itself, that is, a meta-organization (Gawer, 2014). In addition, a variety of newly defined ecosystem terms can be observed such as “mobile platform ecosystem” (Basole & Karla, 2011), “technology ecosystem” (Wareham et al., 2014), or “mashup ecosystem” (Weiss & Gangadharan, 2010), to name a few. These terms are sometimes used synonymously with other ecosystem terms and contribute to an increasing fragmentation of the literature stream. Yet, construct clarity is essential to knowledge accumulation. Suddaby (2010, pp. 352–253) states: “[i]n the absence of common and well-articulated constructs, the boundaries between subcommunities become more sharply defined and (…) knowledge becomes increasingly fragmented.” Furthermore, some researchers have doubts about the utility of the ecosystem metaphor and criticize the missing distinction to related concepts (Oh et al., 2016). In the platform literature, the argumentation on the usefulness of the concept is predominantly led from within the platform literature and is based on its integration of two previously separate strands of literature, i.e. the strand on two-sided markets and the strand on modular product families (Gawer, 2014; Thomas et al., 2014). The properties of ecosystems initially envisioned by Moore (1993) receive only marginal attention, as the focus is on platform governance and strategy as well as on their impact on platform ecosystem evolution (Gawer, 2014; Tiwana et al., 2010). Addressing these interwoven gaps requires a bibliometric literature review that adopts the perspective of the ecosystem literature. Therefore, Paper I pursues the following three related research questions:

How is the intellectual foundation of research on platform-based ecosystems structured? What are the key concepts and how are they interrelated? How does platform research reflect key properties of ecosystems?

Second, the role of standards and standardization in the context of platform-based ecosystems has hardly been studied. A central problem that can be observed in connection with the increasing digitization of conventional products and the emergence of Internet of Things platforms is that platforms are embedded in complex infrastructures consisting of various technology standards. In this context, especially manufacturers of conventional products from certain niches are trying to gain a foothold in the platform business, where they cannot implement a full value proposition without complementary third-party products and services (Shin et al., 2018). As such, cross-vendor compatibility becomes an important source of value creation. This is even more the case in the context of the Internet of Things, as end users’ have strong preference for cross-vendor compatibility (Shin et al., 2018), allowing these users to mix and match products of different manufacturers. Furthermore, they face the decision as to which technology standards to integrate into their products and platforms. In this regard, open technology standards in particular (West,

2003) play a central role in competition between platforms, as they make a platform compatible with many complementary products, and thus more attractive to end users, while also rendering a vendor's complementary products compatible with other platforms (Rowland et al., 2015). This results in a dual role of a platform sponsor, which at the same time can also be a complementor for rival platforms. In addition, it can be observed that giant platform players have entered the market to take leading roles by addressing the fragmentation of many technology standards. In the market, it is evident that platform sponsors address this complex situation by selectively promoting specific platforms and thus making strategic decisions with respect to inter-platform compatibility. Paper II therefore addresses the interactions between adoption decisions of technology standards and promoted inter-platform compatibilities, focusing in particular on the giant platforms (Amazon, Apple, Google, IFTTT, and Samsung), and formulates the following research question:

How do platform sponsors choose the platforms to promote with respect to technology standards and platform type (i.e., giant vs non-giant)?

Third, the lack of studies on aspects related to standards and standardization in platform ecosystems also leads to a gap with respect to standardization bodies (Bogers et al., 2019). Specifically, we do not know how actors commit to or switch between bodies of standardization and what impact these dynamics in memberships have on value co-creation in the broader market. Standardization bodies have a supporting role in the coordination of actors and serve to develop a common technology standard that allows members to collectively build a market of compatible products (Rysman & Simcoe, 2008). Typically, standardization bodies also offer certification programs to ensure that products that integrate the technology standard are compatible with one another (Farhi et al., 2005). This allows forming and orchestrating an ecosystem of stakeholders around a central technology standard. Nevertheless, actors within an ecosystem pursue their own interests, with varying degrees of alignment with ecosystem interests (Adner, 2017; Bogers et al., 2019), which is reflected in fluctuations in membership. Addressing this gap, an empirical investigation of the dynamics in memberships across different standardization bodies and their impact on product certifications is needed. Furthermore, addressing this gap also contributes to further understanding of the findings of Paper II, as it provides additional insight into how compatible products come to exist in a common technology market in the first place. Hence, Paper III seeks to address the following two related research questions:

How do dynamics across competing standard bodies affect product certifications? How do orchestrators contribute to the set of certified products?

Fourth, while much of the literature on platform ecosystems takes the perspective of the central platform leader and examines predominantly commercial contexts (Selander et al., 2013), the functioning of platform-based ecosystems in non-commercial contexts remains largely unexamined. Yet, platforms that serve the production of commons, so-called commons-based peer production systems (Benkler, 2002), represent an important phenomenon that is becoming increasingly widespread. Commons-based peer production systems are a particular form of platform-based ecosystems that rely on the voluntary contributions of a number of peers and are self-organizing, in contrast to central orchestrators and commercial contributions in commercial platform-based ecosystems. In addition, peer production platforms are particularly relevant in contexts such as IoT, where individual users contribute to the market (Kwak et al., 2018; Rong et al., 2018). In this respect, the value co-creation by the peers in the peer production system becomes the focus of interest, with the question arising what is the driving force behind the voluntary contributions of the peers. Specifically, it raises the question which different motivations drive individuals to contribute to commons-based peer production systems and what impact they have on their long-term commitment. Accordingly, Paper IV pursues the following research question:

What are the factors motivating individuals to affiliate with and contribute to peer production platforms?

Overall, it is of utmost relevance to gain a better understanding of the platform-based ecosystem concept, the roles of the underlying standards and standardization bodies, and the commons-based peer production platforms, for two reasons. First, from a theoretical perspective, the concept is still in its early stage of development and needs further advancement in order to form a coherent strand of literature that can better explain the phenomenon of complex platforms which are tightly interwoven with the surrounding systems. In particular, the increasing digitization and accompanying interconnection of platforms through application programming interfaces and open technology standards requires a broader lens to understand the interactions between platform-based ecosystems as well as their impact on individual platform ecosystems. This thesis aims to advance the theoretical understanding of platform-based ecosystems by placing a market-level perspective on the phenomenon and highlighting multiple ecosystems and their interactions in terms of promoted compatibility and membership dynamics, where multiple platforms and further companies contribute to the creation of a shared market.

Second, the investigation of these research questions is also of practical use. The provision of APIs and support for open technology standards makes the governance of platform-based ecosystems more complex, as they are accompanied by issues related to unintended integrations of interfaces with rival platforms by developers or other platform sponsors (Hilbolling et al., 2021; Mosterd et al., 2021). By taking a broader view of the phenomenon that includes underlying technology standards, this thesis aims to yield concrete recommendations for action for platform sponsors. Furthermore, by considering standardization bodies and peer production systems, this thesis aims to show how alternative models allow to build vibrant ecosystems around platforms and to foster value co-creation, while at the same time showing different sources of value creation in the IoT context.

4. Methodology

The research gaps described above require both theoretical conceptualization and empirical research that can capture a broader context with many cases. Accordingly, this thesis builds on a conceptual and an empirical, quantitative approach. In the following, I will explain the research approach chosen in this thesis as well as the underlying epistemological assumptions. Then, I will elaborate on the research designs together with concrete research methods for data collection and preparation. The chapter will be concluded by a discussion on quality criteria.

Research in social sciences, particularly in management research, is characterized by different approaches to epistemology, which reflect different underlying assumptions (Gaski, 2015; Tranfield & Starkey, 1998). Strang (2015) argues that in modern management science particularly three main paradigms are applied: constructivism, pragmatism, and positivism. These paradigms can be represented as a continuum, with constructivism and positivism opposing each other and pragmatism lying in between (Creswell & Plano Clark, 2011; Gaski, 2015). In this context, constructivism and pragmatism build on an interpretivist approach, with realities being interpreted primarily by either the researcher or the participant (Gaski, 2015). From an ontological point of view, constructivism is based on the idea that realities are locally and specifically constructed and co-constructed (Lincoln et al., 2011), with insights derived predominantly through the use of qualitative methods (Creswell & Plano Clark, 2011; Gaski, 2015). Knowledge generation follows an inductive logic, leading to new theoretical insights into the phenomenon under consideration from the experiences of practitioners (Eisenhardt, 1989; Yin, 2003). Studies that follow this ideological approach are characterized by analytical depth, although they can usually examine only a few cases (Yin, 2003). Pragmatism pursues similar goals, with ontological and methodological openness among its central pillars (Emirbayer & Maynard, 2011). Therefore, mixed methods are particularly applied in this context, with theories guiding the analysis (Creswell & Plano Clark, 2011; Gaski, 2015).

In contrast, this dissertation aims to test theoretical assumptions with respect to relationships and dynamics between platform-based ecosystems, and therefore builds on a positivist stance (Popper, 2002). In general, positivism takes an evidence-based approach, where behaviors and processes are to be explained deductively through theories (Babbie, 2007; Crotty, 1998). Accordingly, falsifiable hypotheses are derived from theory and tested through stochastic inference (Popper, 2002). One advantage is that probabilistic inferences can usually be made about an entire population (Campbell & Stanley, 1963), and both statistical significance and effect sizes can be determined within predefined confidence intervals (Gaski, 2015). To date, theoretical insights into platform-based ecosystems predominantly have been brought to light through qualitative approaches (de Reuver et al., 2018; Rietveld & Schilling, 2021). This has led to limited insights to only one or few platforms (Eaton et al., 2015; Qiu et al., 2017). Moreover, most existing quantitative studies focus predominantly on the context of video game consoles (Cennamo & Santaló, 2019; Rietveld et al., 2019) or mobile operating systems (Benlian et al., 2015; Foerderer et al., 2018), where datasets are publicly available or surveys can be conducted relatively efficiently.

The positivist approach in this dissertation complements previous research by building a comprehensive dataset that covers the context of the Internet of Things to stochastically investigate the relationships and dynamics between platform-based ecosystems. In addition, this thesis adopts a conceptual research approach and aims at synthesizing empirical evidence as well as analyzing and visualizing the structure through science mapping (Cobo et al., 2011; Zupic & Čater, 2015).

The methods used in each essay and the underlying theoretical background are presented in Table 1. The following section describes the research designs of each paper in more detail.

4.1. Research Design

As the literature review has shown, the utility of the ecosystem lens within platform research is insufficiently elaborated, which is also accompanied by conceptual ambiguities. Therefore, Paper I aims to systematize the discourse on platform-based ecosystems by adopting an ecosystem perspective and exploring both the conceptual and the intellectual structure. To this end, it is not sufficient to conduct a simple literature review. Rather, bibliometric methods are needed to analyze and visualize the structures in the cited references as well as the terms used within the text corpora. Bibliometric studies become increasingly important, as they allow the study of structures related to authors, publications, and journals, the analysis of themes within fields, and the identification of the most relevant articles (Aria & Cuccurullo, 2017). The bibliometric database was extracted from the *ISI Web of Science* database by *Thomson Reuters* and complemented with sources drawn from *Google Scholar* using *Publish or Perish*.[11] The *ISI Web of Science* database is frequently used to conduct bibliometric analyses due to the rich availability of metadata (Waltman, 2016). However, some scholars emphasized the underrepresentation of proceedings articles (Meho & Yang, 2007), which are particularly relevant in information systems research. *Google Scholar* was found to provide a complementary source to close this gap (Mayr & Walter, 2007). By using both databases to retrieve documents, Paper I provides a more accurate picture of the literature on platform-based ecosystems as most previously conducted systematic literature reviews do, which build their bibliometric databases solely on *ISI Web of Science* (e.g., Gomes et al., 2018; Tsujimoto et al., 2018). While bibliometric analyses can show the underlying structures of the literature, they suffer ambiguities in terms of how references are cited and terms are used (Zupic & Čater, 2015). The aim of content analysis is to complement bibliometric analyses by including the actual content of the articles, thereby revealing its relation to the structures. Hence, the combination with content analysis can help to identify frequently studied research contexts, the use of terms, and any gaps that may exist (Gomes et al., 2018). The systematic literature review covers 112 documents (i.e., journal articles, proceedings articles, and book chapters) that matched the query “platform* AND ecosystem*” as well as research questions.

[11] https://harzing.com/resources/publish-or-perish

Table 1: Overview of methodological approaches adopted in the essays.

Paper	Research Question(s)	Methodology	Key References
I	How is the intellectual foundation of research on platform-based ecosystems structured? What are the key concepts and how are they interrelated? How does platform research reflect key properties of ecosystems?	Conceptual: Bibliometric and content analysis to review literature	• Ecosystem concept (Adner, 2006, 2017; Gawer, 2014; Jacobides et al., 2018; Moore, 1993; Tiwana et al., 2010) • Bibliometric analysis (Cobo et al., 2011; Zupic & Čater, 2015) • Content analysis (Krippendorff, 2004)
II	How do platform sponsors choose the platforms to promote with respect to technology standards and platform type (i.e., giant vs non-giant)?	Empirical (Quantitative): Network analysis based on exponential random graph model	• Platform openness (Mosterd et al., 2021; West, 2003) • Platform competition (Katz & Shapiro, 1985; Rietveld et al., 2019) • Exponential random graph models (Pattison & Wasserman, 1999; Wasserman & Pattison, 1996)
III	How do dynamics across competing standard bodies affect product certifications? How do orchestrators contribute to the set of certified products?	Empirical (Quantitative): Panel data analysis based on zero-inflated negative binomial regression model	• Innovation ecosystem (Adner, 2017; Bogers et al., 2019) • Standardization (David & Greenstein, 1990) • Organizational networks (Ahuja et al., 2011) • Panel data analysis (Lambert, 1992; Wooldridge, 2010, chapter 18)
IV	What are the factors motivating individuals to affiliate with and contribute to peer production platforms?	Conceptual: Literature review	• Commons-based peer production (Benkler, 2002) • Self-determination theory (Deci & Ryan, 1985, 2000) • Social practices (MacIntyre, 1981)

Source: Own illustration.

The bibliometric analysis covers a co-citation and citation analysis to identify major references as well as their research groups, and a co-word analysis based on the 10 most frequently used platform terms and the 10 most frequently used ecosystem terms per article to reveal thematic clusters and sub-strands. The content analysis is used to extract information on applied methods, research objectives and questions, main constructs and theories, research contexts, and definitions. In addition, the content analysis is used to identify key properties of ecosystems studied to systematize the articles reviewed. Theoretically, the article builds on seminal works on the ecosystem concept (Adner, 2006, 2017; Gawer, 2014; Jacobides et al., 2018; Moore, 1993; Tiwana et al., 2010), which are among the most cited references, highlighting different properties of ecosystems.

Paper II and III both address issues in a broader environment around the platform-based ecosystems studied. While most previous studies predominantly examined the same contexts of mobile platforms such as Android and iOS and video game consoles, as outlined above, I have aspired to create a unique dataset that can capture hundreds of organizations within a market and examine open technology standards. Therefore, both articles rely on a comprehensive dataset created by applying machine learning techniques to collect information from the Internet and preprocess it for statistical inference. The data collection and preprocessing procedure is described in more detail in the following section. Methodologically, the two articles differ in that the research question addressed in Paper II requires network analysis to predict the formation of relationships between platforms (i.e., edge formation). We[12] could not simply use a logistic regression with compatibility promotion as the dependent variable, since a platform company's decision to cooperate with other platforms depends partly on structural characteristics of the network itself, e.g., on how many other actors promote compatibility with a given actor (Albert & Barabási, 2002) due to network effects. Consequently, observations are not independent, violating a fundamental assumption of general linear models (Pattison & Wasserman, 1999; Robins, 2014). Drawing on network analysis as method allows not only to estimate social processes and structural features that govern network formation, but also to visualize relationships and simulate networks (Borgatti & Halgin, 2011; Oinas-Kukkonen et al., 2010). We use an exponential random graph model (Pattison & Wasserman, 1999; Wasserman & Pattison, 1996) to estimate the underlying processes. For the analysis, we use the *statnet* R package (Handcock et al., 2008), as it is based on an efficient Monte Carlo Markov chain maximum likelihood estimation (MCMC-MLE), taking starting values from a computationally less expensive maximum pseudo-likelihood estimation (Robins, 2014). We include nodal attributes (i.e., firm and platform attributes) to account for idiosyncratic characteristics of senders and receivers, dyadic parameters to capture social selection processes such as homophily, and topological features to account for the effect of structural features on

[12] Note that the analysis was conducted with a co-author. As such, I use "we" in the following.

actors' choices. Theoretically, Paper II builds on the literature strands of platform openness (Mosterd et al., 2021; West, 2003) and platform competition (Katz & Shapiro, 1985; Rietveld et al., 2019) on compatibility. In doing so, the focus is particularly on Mosterd et al.'s (2021) framework on platform-to-platform openness, based on which the conceptual model of the article is derived.

In contrast to Paper II, the research questions raised in Paper III require the study of the association between changes in relationships and product certifications. Therefore, Paper III requires a longitudinal dataset that spans several years. The study focuses on the dynamics of memberships in standard development bodies over the years and their impact on the number of certified products. The dependent variable of the study consists of count data, suggesting the use of a count data model (Wooldridge, 2010, chapter 18). However, the underlying process linking the independent variables with the dependent variable is not direct, but implies a two-step process. The first step is based on the decision to manufacture products for a particular technology standard in the first place and to certify them. Not all companies with memberships in standard development bodies generally intent to develop products, but may link different motives to their memberships such as learning (Leiponen, 2008). Accordingly, excess "zeros" can be observed in the dependent variable. In the second step, the effects of independent variables on the dependent variable can then be determined. Overall, this suggests the use of a zero-inflated model, which is a combined model consisting of a logit or probit and a count model (Lambert, 1992). Nevertheless, Paper III is still at an early stage, so the specific method used may be revised as it progresses. Theoretically, the paper builds on the literature strands of standardization (David & Greenstein, 1990) and organizational networks (Ahuja et al., 2011). Further, it applies an innovation ecosystem lens (Adner, 2006, 2017) that focuses on a broader technology-centric ecosystem.

Paper IV is devoted to the relatively new phenomenon of peer production and therefore takes a conceptual approach to consolidate findings. The goal of the paper is to gain an understanding of why individuals voluntarily affiliate with and contribute to peer production platforms. Unlike the intensively studied platforms in the commercial context, little attention has been paid so far to ecosystems related to the collaborative creation of commons. Therefore, the article draws on the theoretical strands of peer production systems (Benkler, 2002) and self-determination theory (Deci & Ryan, 1985, 2000) to systematize the literature in terms of motivations of individuals. In addition, the literature review builds on practice literature (MacIntyre, 1981) to provide an explanation especially for long-term contributions to peer production platforms.

4.2. Data Collection and Preparation

In this chapter, I will first discuss the empirical setting and the reasoning behind its selection, then describe data types and sources, and finally turn to data collection and preprocessing. In doing so, I will pay special attention to data triangulation.

Data for Paper II and Paper III covers the Internet of Things context and therein the smart home market. The empirical setting was chosen for at least three reasons. First, smart home products require connectivity technologies to exchange sensor data and commands (Kahle et al., 2020), and hence standard development is particularly crucial to materialize a customer-facing solution. In addition, industry consortia are perceived as important vehicles for ecosystem governance in the smart product context (Kahle et al., 2020). At the same time, the context offers a fragmented environment with several competing technology standards that have emerged in recent years (cf. Cottrell, 1994). As such, the context provides an interesting setting to study issues related to standards and standard setting. Second, within the market a number of manufacturers across different industries continue digitizing parts of their assortments, making the products "smart", while offering cloud-based solutions to steer such products, with the objective to gain a foothold in the platform business (Sandberg et al., 2020; Shin et al., 2018). At the same time, large established platform sponsors such as Apple, Amazon, Google, and Samsung entered the market to provide "meta-platforms" (Shin et al., 2018). Hence, the empirical setting allows the study of relationships between platforms at different layers (predominantly device and service layers) and with different functions. Third, the smart home market is one of the most established (consumer-facing) application areas of IoT technology (Chaudhary et al., 2021). Yet, it is also a complex setting in terms of strategic considerations and standard adoption choices, as it underlies network externalities, requiring platform sponsors to quickly reach a critical mass of users through opening the platforms (Schilling, 2002; West, 2003), where platform sponsors manufacturing smart products slide into the role of complementors to potential rivals. Therefore, the context provides an interesting setting to study trade-offs in decision-making.

The Internet was selected as the overarching data source. The Internet provides access to numerous publicly available data sources that are available in semi-structured form and can thus be extracted automatically (Braun et al., 2018). In addition, services such as *The Wayback Machine*[13] provide a comprehensive archive of web pages in the past. Accordingly, a comprehensive longitudinal data set can thus be formed relatively efficiently, allowing for multiple independent data sources for each variable. This dissertation thus joins a number of studies published in highly renowned journals (e.g., Baron & Spulber, 2018; Eaton et al., 2015; Leiponen, 2008). The dataset underlying this dissertation spans the period between 2000 and 2019, with a scope of more than 4.6 gigabytes from 14 data sources. To address the research questions, three main types of data are required: (1) membership data in industry consortia, (2) product data, and (3) company data (see Table 2). Membership data of companies in industry consortia are needed to observe dynamics in the memberships. As a starting point, the Z-Wave Alliance was chosen to determine the sample of observed companies. The alliance is one of the largest in terms of members, reflecting a larger part of the smart home market. In addition, it is built on top of the sponsored Z-Wave standard[14] and has a formal governance structure, several membership levels and a certification program for products. In addition to data on the Z-Wave Alliance, we collected data on the major competing consortia in the smart home market – namely, Thread Group, Zigbee Alliance, KNX Association, AllSeen and the Open Connectivity Foundation, as they provide competing technology standards specific to smart home applications with similar technical features. Data was obtained from archived industry consortia websites via *The Wayback Machine*, covering 11,490 annual memberships, which were constructed based on 175,041 records. Product data on certified products serves as a dependent variable in Paper III and allows identifying platform companies in Paper II. For this purpose, additional product data was obtained from Amazon.com, one of the largest e-commerce platforms, as well as data on smartphone apps from *Google Play Store*[15] and *Fnd.io*[16]. In total, 3,873 certified products were identified on the Z-Wave Alliance website, 11,733 on *Amazon.com*[17] and 1,509 apps in both app marketplaces. Additional company data were obtained to be able to construct control variables for idiosyncratic effects. These data were retrieved from the four databases *FactSet*, *Nexis Uni*, *Compustat* and *Crunchbase*, which are considered

[13] https://archive.org/web/
[14] The Z-Wave standard is a radio frequency transmission protocol, which was developed by the venture Zensys in 1999, where companies such as Intel and Cisco were among the first investors. In 2005, the Z-Wave alliance was established by the first adopting companies. Then Sigma Design acquired Zensys in 2008 and sold the Z-Wave business to Silicon Labs in 2018. The standard is implemented on semiconductors produced by the technology sponsor Silicon Labs as well as the licensee Mitsumi (for further information, see https://z-wavealliance.org/z-wave_alliance_history/).
[15] https://play.google.com/
[16] https://fnd.io/
[17] https://www.amazon.com/

inexhaustible historical data sources for company size, age and structure (e.g., Basole & Karla, 2011). For Paper II, additional company websites were downloaded to provide more detailed information on supported technology standards and advertised compatible devices.

Table 2: Data underlying empirical works in this dissertation.

Data Type	Data Source	Description	Scope	Paper
Memberships in industry consortia	Archived websites of industry consortia	Members of AllSeen Alliance, KNX Association, Open Connectivity Foundation, Thread Working Group, ZigBee Alliance, Z-Wave Alliance in the period between 2000 and 2019.	11,490 unique annual memberships	II, III
Products & Apps	Certified Z-Wave products	Certified products in Z-Wave Alliance.	3,873 certified products	II, III
	Amazon.com	Products of companies in sample offered via Amazon.com.	11,733 products	II
	Google Play, Fnd.io	Android and iOS Apps of companies in sample.	1,509 apps	II
Company data Company data	FactSet, Nexis Uni, Compustat, Crunchbase	Databases contain longitudinal firm information, including year of foundation, revenue, number of employees, sub-subsidiaries and acquisitions.		II, III
	Company websites	Company websites, graphical illustrations, and products manuals for content analysis to identify platforms.	1,439 documents	II

Source: Own illustration.

To extract the data from the web pages the scraper *Webscraper.io* was used. The tool is a browser plugin that can extract individual elements based on the code structures of the web pages and can follow links.[18] The data is then output in a structured form as comma-separated values (CSV) files. To preprocess the data, the individual files were then imported into an SQL database and homogenized in the first step by removing special characters and capitalization. Furthermore, company names were matched within and across the different data types by using URLs, logos,

[18] https://webscraper.io/

member IDs and brand names. Data from the *WIPO database*[19] was consulted to look up brand names. This procedure combined multiple data points in each data type to triangulate the data. Triangulation denotes the integration of different data sources with the aim to build a coherent justification for themes (Creswell & Plano Clark, 2011). For Paper II, additional content analysis of web content (Krippendorff, 2004; McMillan, 2000) was performed. Content analyses allow scholars to obtain a systematic, objective, and quantitative description of the content of (transcribed) conversations, articles, and other texts. In addition, it allows for the inclusion of more context in the analysis by considering graphical representations and the nature of the document (Krippendorff, 2004).

Data were then transformed into categorical and metric values for analysis in R (Paper II) and STATA (Paper III).

4.3. Quality Criteria in Quantitative Studies

To ensure truthful, applicable, consistent, and objective evidence in quantitative research, there are two broad quality criteria that are widely discussed in the literature: validity and reliability (Creswell & Plano Clark, 2011; Messick, 1989).

According to Messick (Messick, 1989, p. 6) validity refers to “the degree to which empirical evidences and theoretical rationales support the adequacy and appropriateness of interpretations and actions based on test scores.” As such, it not only covers instruments and measurements, but also includes interpretation and inferences made thereof. In this context, inferences are hypotheses, where the validation of inferences amounts to hypotheses testing. On this basis, validity can be seen as an evaluative judgement of inferences based on test scores, stating to which extent the interpretations and implications of inferences are appropriate.

One of the most important forms of validity is *construct validity* (Cronbach & Meehl, 1955). Construct validity is used to ensure that assessments made are meaningful, trustworthy, and serve the purpose of the assessment, i.e. the construct assesses what it is supposed to (Cronbach & Meehl, 1955; Messick, 1989). To ensure construct validity, authors should provide clear construct definitions and demonstrate that the empirical indicators reflect the underlying constructs (Aguinis et al., 2010). Regarding the studies conducted in this dissertation, construct validity is ensured in

[19] https://www3.wipo.int/branddb/en/

several ways. First and foremost, the constructs used to test for sources of variance of major interest and control for further sources of variance are derived from previous works, were triangulation of data from various sources allows to increase validity (Creswell & Plano Clark, 2011). In addition, we fitted a number of alternative models, using different statistical techniques prior to constructing our main models. The statistical techniques for the main models were selected based upon stochastical selection tests, particularly likelihood ratio tests, in combination with rigor goodness of fit assessments (Hunter et al., 2008). The main models were rendered and presented in hierarchical fashion with robust standard errors and variance inflation factors computed to ensure an appropriate account for multi-collinearity. Statistical significance is further verified by computing effect sizes that guide interpretation of the inferences made (Kolaczyk & Krivitsky, 2015). To check for robustness of the outcomes, various models with alternative measures were tested to ensure that plausible alternative explanations fail to be supported.

A second type of validity that is crucial to ensure quality of quantitative assessments *is external validity*. External validity refers to the extent to which an assessment can be generalized to the population and other situations (Campbell & Stanley, 1963). As such, it involves rigor definition of the population and sampling thereof (Messick, 1989). In our empirical studies, the samples are drawn based on the contextual boundaries (i.e., Z-Wave Alliance members), where the context was chosen due to its large coverage of the companies in the overall market (i.e., the population).

A concept overlapping and supporting validity is *reliability* (Messick, 1989). Reliability reflects consistency and replicability over time, which means that a number of researchers can repeat the test that will lead to consistent results under stable conditions. As such, data underlying the dissertation projects were retrieved from public sources that are conserved in an archival database. The data retrieval follows a computer-aided, systematic procedure, where the procedures underlying each of the empirical articles were documented (see A7, A8, A9, and A10) to ensure objectivity and transparency. This includes data sources, tools for data retrieval, and algorithms for data pre-processing.

5. Summary of Papers

Paper I: Ecosystem perspective in platform research: A bibliometric analysis and review of recent literature

The first of the four papers of this dissertation is conceptual in nature and conducts a systematic review of the literature by applying bibliometric and content analyses. The overall objective of the article is to promote further understanding of the concept of platform-based ecosystems. To this end, the article has two goals in particular. The first goal is to demonstrate the utility of the ecosystem lens in platform research. The second goal is to show the conceptual and intellectual structure and, on this basis, to identify essential, fundamental concepts, definitions, and distinguishing features between platforms and ecosystems. To address these goals, the article incorporates 112 studies, book chapters, and proceedings papers obtained from both *ISI Web of Science* by Thomson Reuters and *Google Scholar*. The articles reviewed span a period between 2005 and 2021, are predominantly from journals, and apply mostly qualitative methods.

In the first part of the article, a bibliometric analysis is conducted, upon which the second part of the article, i.e., the content analysis, builds.

The co-citation analysis within the bibliometric analyses shows that the cited references form three clusters: one cluster on seminal works on the ecosystem concept (i.e., Adner, 2006; Iansiti & Levien, 2004; Moore, 1993) and one cluster each around the most cited articles by Tiwana et al. (2010) and Gawer (2014). The clusters each reflect different disciplines and define platform-based ecosystems differently, which partly explains the conceptual ambiguities. Furthermore, the citation analysis shows that the articles with the highest impact (article impact factor) focus on aspects related to two-sided markets, network effects, platform strategies, modularity, platform openness and digitality that can be considered as fundamental concepts for platform-based ecosystems. Co-word analysis of the most frequently used platform and ecosystem terms in the reviewed articles was used to index conceptual strands within the literature. The analysis reveals six thematic clusters: (1) core cluster, (2) mobile platform cluster, (3) service platform cluster, (4) IoT platform cluster, (5) software platform cluster, and (6) multisided platform cluster. For these clusters, the network analysis shows that the core cluster consists of terms that are not always used consistently, reflecting conceptual ambiguities. Instead, in some articles, separate terms are introduced and used synonymously with other terms. In addition, the cluster around mobile platforms exhibits high relevance (i.e., high Callon centrality and Callon density) in that it contains important concepts for understanding the basic platform-based ecosystem concept. This could be due to the fact that much of the research has been conducted in the context of Android and iOS platforms (Rietveld & Schilling, 2021). The clusters on service and software platforms have independent definitions and can be considered as independent research groups. The clusters on IoT platforms and multisided platforms are less central, although IoT platforms seems to be an emerging topic.

In the second part, the article first derives basic ecosystem properties from the most cited articles: (1) (co-)evolution, (2) co-opetition, (3) value co-creation, (4) interdependencies, (5) governance, (6) complementarities, and (7) multilateral relationships. The content analysis then shows that the studies focus predominantly on (co-)evolution, co-opetition, and value co-creation while considering the other properties as predominantly exogenous. On this basis, the article presents a framework that also depicts the systems surrounding the platform-based ecosystems (political system, society, markets, infrastructure) and consolidates the articles' findings based on this framework. The article then discusses the definitions underlying the clusters elaborated earlier in order to then derive distinguishing characteristics between ecosystems of platforms. For this purpose, the article first elaborates the basic functions of platforms (development tool, distribution channel, interaction interface, value sharing infrastructure) and conceptions of ecosystems (community of developers, multi-stakeholder systems, network, complex system). On this basis, the four characteristics (1) centrality, (2) stability, (3) level of analysis, and (4) manageability are discussed. Finally, possibilities for further research are presented.

Paper II: Compatibility promotion between platforms: The role of open technology standards and giant platforms

The second dissertation article is empirical in nature and conducts a network analysis based on an exponential random graph model. The aim of the article is twofold. The first goal is to investigate to what extent the adoption of open technology standards has an influence on the communicated compatibility between platforms. The second goal is to examine the role of large, established platforms (Amazon, Apple, Google, IFTTT, and Samsung), particularly as they offer solutions that can bridge the boundaries of different open technology standards. The article thereby considers the dilemma of platform sponsors in the smart home market, which can potentially also be complementors for rival platforms. Therefore, the study brings together the discourses of platform openness (Mosterd et al., 2021; West, 2003) and platform competition (Katz & Shapiro, 1985) on compatibility and derives the conceptual model of the study. The framework of Mosterd et al. (2021) on decision factors on "platform-to-platform openness" as well as the concept of "selective promotion" (Rietveld et al., 2019) form a mainstay in this context. Hypotheses are formulated on the basis of this theoretical foundation.

The variable to be explained is *platform-to-platform compatibility promotion*, i.e., the targeted promotion of selected platforms that are de facto compatible with a given platform. The conceptual model contains four hypotheses on decision factors predicting platform-to-platform compatibility promotion: (1) interaction between fundamental tendency toward openness with competition, (2) complementarity between adopted open technology standards, (3) interaction of the integration with giant platforms with the number of supported open technology standards, and (4) interaction of the integration with giant platforms with multi-homing. Based on the analysis of a directed network of 157 platforms and 879 edges (i.e., platform-to-platform compatibility promotion from a sender to a receiver), the study fails to reject all but the hypothesis on complementarities in open technology standards.

Specifically, the findings suggest that advocating compatibility with other platforms can be attributed to a tradeoff between basic openness (i.e., adoption of a platform logic) and the competitive situation with the receiving platform. Furthermore, it appears that most platforms support the broader Wi-Fi standard and predominantly combine it with either the Z-Wave standard or the ZigBee standard. We believe this is the main reason why complementarity between the adopted open technology standards cannot be demonstrated as a driving factor for platform-to-platform compatibility promotion. It turns out that a large part of the network is attributed to integrations with five giant platforms (circa one third of the edges). Our empirical findings suggest that the fewer open technology standards a platform supports, the more attractive the integration with giant platforms is. We attribute this in part to the high coordination costs of integration with giant platforms and simultaneously high certification costs of open technology standards. Furthermore, the analysis shows that integrations with giant platforms predominantly take place when they happen to several giant platforms at the same time (multi-homing). As studies have previously outlined, integration with giant platforms carries the risk of platform envelopment, which can be reduced by multi-homing (Hilbolling et al., 2020). We find empirical support for this proposition.

The evaluation of the control variables shows that platforms tend to be heterophily with respect to product niches. The analysis also shows reciprocity and preferential attachment as structural effects. Some of the reciprocity is due to giant platforms, highlighting their role in shaping the market. Specifically, platforms such as Android or iOS have large installed bases of users that can spill over to smart home platforms via their advertisements. Accordingly, giant platforms not only act as converters but can also be sources of demand spillovers.

The study includes the calculation of average marginal effects and second differences reflecting effect sizes in addition to significances, performs robustness tests based on alternative measures, and discusses the goodness of fit.

The study concludes with implications for managers and researchers, noting in particular the concept of platform-to-platform compatibility promotion as a useful concept for navigating settings with potential dual roles of platform sponsors.

Paper III: Backing the Right Horse: A Study of the Effect of Membership Dynamics on Value Creation in the Smart Home Market

The third dissertation paper is empirical in nature and conducts a panel data analysis. The objective of the study is to empirically examine the impact of both membership dynamics and orchestrator roles in a technology-based ecosystem on value co-creation in the form of product certifications. The underlying premise is that decisions to join or leave an alliance – and correspondingly the ecosystem – and the adoption of an orchestrator role reflect different degrees of relative alignment of individual (i.e., firm) interests and ecosystem interests. Accordingly, the article links to recent conceptual studies in the discourse around the ecosystem concept, which focuses on the divergence of interests and its implications for value co-creation (Adner, 2017; Bogers et al., 2019). Furthermore, the article illustrates how platform-based ecosystems can be orchestrated through alliances and addresses calls for more research shedding light on the role of standard development bodies (Bogers et al., 2019; Teece, 2018).

To address the research objectives, the paper builds on literature on standards and standardization (David & Greenstein, 1990) and on organizational networks (Ahuja et al., 2011) to derive the hypotheses. In particular, the framework of Ahuja et al. (2011) on the four basic factors for dynamics in organizational networks (i.e., agency, opportunity, inertia, random factors) forms the foundation for the hypotheses. The study assumes rational actors who make decisions with respect to entering and exiting alliances based on cost-benefit trade-offs that reflect their own interests. The outcome of the decision can be observed in terms of membership dynamics. We distinguish between two dimensions of the dynamics: (1) switching, which equates to frequent switching between alliances and thus ecosystems, and (2) spanning, which equates to alignment with multiple alliances simultaneously. For the purpose of the study, we assume that switching is associated with low alignment of interests, whereas spanning is associated with moderate alignment with the interests of multiple alliances. Furthermore, companies can take an orchestrator role within the alliance by choosing the most expensive membership to get a seat on the board. For the purpose of the study, we assume this role reflects a high alignment of interests. On this basis, we propose three hypotheses regarding the impact on value co-creation in the form of certified products: (1) switching decreases the number of certifications, (2) spanning increases the number of certifications, and (3) an orchestrator role is associated with an increased number of certifications.

The analysis includes a panel dataset of 731 members in the Z-Wave Alliance as well as memberships in 5 other alliances, covering a period between 2005 and 2019. The number of certified products is used as the dependent variable, where a zero-inflated negative binomial model was fitted. Accordingly, the model consists of a logistic model, which in the first step estimates the factors influencing the basic propensity to certify products and thus discriminates the "zeros" in the dependent variable between a lack of intention to certify and low productivity. In the second step, a negative binomial model is applied to estimate which factors significantly affect the number of product certifications.

The analysis fails in rejecting the hypotheses. Specifically, the results of the negative binomial model indicate that frequent leaving of alliances (switching) is associated with a significantly reduced number of certified products. Conversely, firms that exhibit higher levels of spanning exhibit higher activity associated with product certifications. Orchestrators further show increased activity in product certifications, where they do not have to focus solely on the focal consortium, but can also be active as orchestrators in other consortia. In our dataset, it appears that some very large companies that hold board seats in some consortia simultaneously account for a large share of the certified products. Thus, the findings suggest an alternative account of roles within ecosystems that contrasts with the classic division of many small niche players generating most of the value and a few large keystones extracting most of the value (cf. Iansiti & Levien, 2004). The logistic model further suggests that especially smaller companies and companies with lower membership levels tend to have a lower intention to certify products.

The study further includes additional Poisson and OLS models to support the findings. Furthermore, robustness tests based on a random effects panel model are performed to corroborate the result.

The article concludes with implications for practitioners and researchers, suggesting avenues for further research based on the conceptual model.

Paper IV: User Motivations in Peer Production

The fourth paper of the dissertation is conceptual in nature and pursues the goal of systematizing the motivations of individuals to affiliate with and contribute to peer production platforms. Commons-based peer production systems play a particularly crucial role in contexts such as the IoT (Kwak et al., 2018; Rong et al., 2018), as they rely on the contributions of many peers to common goods such as open source software (Benkler, 2002). To systematize motivations, this paper draws on self-determination theory (Deci & Ryan, 1985), which is based on the assumption that individuals engage in certain behaviors in order to satisfy three basic needs, namely competency, social relatedness, and autonomy (Deci & Ryan, 2000, pp. 233–235). The theory distinguishes between intrinsic and extrinsic motivation. While intrinsic motivation rests on the inherently interesting and enjoyable act of performing the task itself, extrinsic motivation requires an outcome that is distinct from the task itself (Deci & Ryan, 1985, 2000). Thus, extrinsically motivated individuals satisfy their basic needs indirectly, e.g. by being monetarily rewarded (Osterloh & Frey, 2000). Some studies have extended the basic concept and have added internalized extrinsic motivation (e.g., Chandler & Connell, 1987; Deci & Ryan, 2000). Internalization of extrinsic motivation refers to “an active, natural process in which individuals attempt to transform socially sanctioned mores or requests into personally endorsed values and self-regulations” (Deci & Ryan, 2000, pp. 235–236). Thus, internalized motivation is by definition extrinsic but may be internalized by the individual and, accordingly, perceived as self-regulating rather than externally imposed behavior (Deci & Ryan, 2000; Roberts et al., 2006).

The book chapter builds on this structuring and first summarizes empirical findings on intrinsic motivations. Fun, ideology, kinship and altruism are found to be intrinsically colored motivations. Internalized extrinsic motivations include own use value, learning, reciprocity and reputation. Pay and career can be counted among the extrinsic motivations. Overall, we find that contributors to commons-based peer production systems are motivated not by a single motive, but by a whole range of intrinsic, internalized extrinsic and extrinsic motives. Empirical support is provided for almost all the discussed motives, but their effects differ significantly in magnitude. Overall, kinship amity, learning, reputation, and payment appear as significant drivers for contributions. Empirical findings for ideology vary. Own use value and reciprocity are found to be rather short-term, while altruism appears a too simple explanation.

In addition, the literature review addresses a popular effect that has often been studied, namely "crowding out" (Frey, 1997), where intrinsic motivations are undermined by the introduction of extrinsic incentives. Some of the literature also examined crowding out effects in the context of internalized extrinsic motivations. Yet, empirical studies do not yield support.

Motivations further not only influence whether an individual contributes to a peer production platform, but are also related to task characteristics. The literature review shows that peers' motivation partly determines the type of task they will self-allocate, hence, requiring a mix of various incentives and motivations to cover all tasks. In this context, extrinsic and internalized extrinsic motives seem to play a crucial role to impel individuals to perform mundane tasks.

Finally, the article seeks to answer the question as to why individuals commit to peer production platforms in the long term, as self-determination theory only provides inferences about short- and medium-term motivations (von Krogh et al., 2012). Accordingly, the article builds on the social practices literature (MacIntyre, 1981). Based on MacIntyre's (1981) definition of practices, a peer production system involves the creation of internal goods with public goods characteristics, such as source code or encyclopedia articles, which are produced by members of the practice. Institutions house these practices and provide external goods, such as status or capital that enable and extrinsically motivate contributors. By drawing attention to social practices, the focus shifts from short- and mid-term motivation – going back to direct rewards – towards the long-term motivation of participants, as the social practice becomes intertwined with their lives, creating the perception of a moral obligation associated with the pursuit of the *unity of life* (von Krogh et al., 2012). Empirical findings in the literature suggest that social exposure as well as institutional frameworks (governance structures, sponsorship, licensing) may have an impact on peers' long-term commitment to platforms.

6. Contributions

The four articles in this dissertation contribute to the current literature on digital platform-based ecosystems and technology standards, both theoretically and practically. As described at the outset, the articles can be placed within the conceptual framework based on Tsujimoto et al. (2018), Henfridsson et al. (2018) and Kwak et al. (2018), with the four articles highlighting different aspects in the environment of platforms and their ecosystems. In this regard, the articles examine different forms of value creation from the perspective of different actors.

Paper I provides a general overview of the discourse on platform-based ecosystems, revealing thematic clusters and research groups through bibliometric analysis. Furthermore, the article shows how the ecosystem perspective is applied within the literature, which key properties are studied in the process, which interactions between platforms and surrounding systems are considered, and which conceptual distinctions are made between ecosystems and platforms. Thus, the article lays the foundation for the dissertation, with the subsequent Papers II and III adopting such an ecosystem perspective. Paper II and III are both empirical, but consider different scopes, actors, and value creation mechanisms. While Paper II focuses on platform sponsors and decision factors about signaling compatibilities to other platforms and their ecosystems as a form of value creation, Paper III considers the pool of potential complementors (i.e., manufacturers of certified products) in the Z-Wave based market that spans a standard technology domain. In this context, the value creation lies in the manufacturing and certification of Z-Wave compatible products. Hence, Paper III complements the findings of Paper II by showing how dynamics at the consortium level influence the production of certified products. Just as Paper III, Paper IV takes the perspective of complementors, but focuses on the group of user innovators who organize around peer production platforms and develop open source hardware and software. The focus is on the motives and practices of individuals (i.e., user innovators) who contribute directly to the market in the form of software code or hardware configurations. This is an important addition, especially as it becomes clear in Paper II that some platform sponsors are intentionally providing development programs and developer forums for end users.

The dissertation, with its broad view of the environment of platform-based ecosystems in the four articles (i.e., surrounding systems, other platforms, standardization bodies, and peer production systems), makes some relevant contributions to theory and practice, as will be discussed in detail below.

6.1. Theoretical Contributions

By reviewing the discourse on platform-based ecosystems, Paper I connects to the discourse on the theoretical advancement of the ecosystem concept (Adner, 2017; Jacobides et al., 2018; Tsujimoto et al., 2018). In this context, it makes four major contributions to advancing the metaphor into a theory. First, it structures the fragmented discourse by grouping the terms used and showing how they are interrelated. This helps new researchers in particular to position their work within the thematic sub-strands. Second, the study uses a structured content analysis to identify the most frequently used concepts and to show their use within the literature, thus revealing the conceptual underpinnings of the platform-based ecosystem concept. Third, the study approaches the concept of platform-based ecosystems from an ecosystem perspective to highlight key properties and show how an ecosystem perspective on platforms can complement previous findings on two-sided markets and modular product architectures. Fourth, the literature review elaborates on how studies conceptualize platforms and ecosystems to highlight differentiating features between the two concepts. In essence, the literature review shows that especially co-evolution, co-opetition and value co-creation are the central properties of ecosystems in the platform literature, with these properties interacting with each other. These properties also reflect the "ecological" nature in the ecosystem metaphor by describing the processes based on the interactions of autonomous actors. In this regard, it provides an alternative, though not opposing, view to the platform-centric works of Thomas et al. (2014) and Gawer (2014) on platform-based ecosystems by highlighting the “ecosystemic” nature and demonstrating how it guides research. Furthermore, the article contributes to the conceptual distinction between platforms and ecosystems, which aims at the ease to examine interactions between the two constructs and to promote comparability between studies (de Reuver et al., 2018). As such, this dissertation makes an attempt to improve construct clarity (Suddaby, 2010). Unlike, for example, innovation ecosystems, platform-based ecosystems differ in their strong reliance on platforms. Platform-based ecosystems are superordinate constructs that resemble a dispersed set of actors and their resources, which evolve dynamically and cannot be controlled directly. Platforms are technological artifacts at a lower analytical level that affiliate actors, integrate resources, and generate exchange and interaction between them, are characterized by a relatively stable core and interfaces, and can be directly controlled by the platform sponsor. Platforms are important for developing network effects, exploiting economies of scale and scope, and generating technological generativity. In this context, the study further identifies the four possible functions of platforms for ecosystems, namely development tool, interaction interfaces, distribution channel, and open business model.

Paper II builds on the literature strands on platform-to-platform openness (Mosterd et al., 2021) and platform competition (Rietveld et al., 2019) by introducing the concept of platform-to-platform compatibility promotion. The concept reflects how platform sponsors not only establish de facto compatibility with other platform ecosystems, but also actively promote it. This allows observing the outcome of strategic trade-offs in terms of the basic preference for openness, competition and giant platforms. The article advances theory by offering insights that allow a more nuanced understanding of the relative impact of different factors driving platform-to-platform connections that are visible to end users. In addition, to the best of our knowledge, the article is one of the first to show the impact of technology standards on platform competition. While prior literature examined either dominance battles between standards or dominance battles between platforms analogous to standards (Rietveld & Schilling, 2021), this article focuses on the interaction between the two. Specifically, the article empirically demonstrates how platform sponsors predominantly incorporate widely used standards into their platforms and withdraw end-user attention from rivals by selectively promoting particular platforms. The study furthers theoretical understanding as to how different roles in larger innovation ecosystems emerge, where some actors profit from market fragmentation going back to incompatible technology standards, which they address by offering internet-based communication protocols and certification programs attracting a considerable share of promoted compatibility. Tight integrations with their platforms give them access to larger portions of the data streams in the smart home market, improving value appropriation opportunities (Henfridsson et al., 2018). Accordingly, giant platforms shape the industry architecture in such a way that they become "bottlenecks", which increases their chance of becoming platform leaders in the emerging market (Gawer & Cusumano, 2002). This insight adds to understanding not only how "keystone" roles can emerge in a new technology environment, but also how platforms gradually become infrastructures (Constantinides et al., 2018).

Paper III builds on recent conceptual works on ecosystems (Adner, 2017; Bogers et al., 2019) and conceptualizes ecosystem dynamics as a dialectic between individual and ecosystem interests, the outcome of which is observed in terms of membership dynamics. The study echoes the idea that ecosystem dynamics can be attributed to a degree of alignment among actors in terms of roles and value flows, with higher degrees leading to a stabilization of structures (Adner, 2017). To this end, Paper III studies how firm-level decisions are linked to ecosystem-level outcomes, based on the divergence of interests between the firm level and the ecosystem level, where firms face the tension between their own interests and the ecosystem interests (Wareham et al., 2014). We theorize switching costs and lock-in as well as market reach and dependence of single technologies as underlying factors. Paper III presents an approach to measure this degree of alignment and the resulting dynamics using two dimensions (spanning and switching). Furthermore, Paper III builds on research on standardization bodies and identifies factors that influence product certifications through statistical inference. To the best of our knowledge, this is the first study to explore product certification as a performance metric. Previous literature on standard consortia mostly studies innovation activities by considering patents or product announcements as an outcome of collective efforts. In addition, we adopted an innovation ecosystem lens considering dynamics within and across standard consortia to observe a larger fraction of the ecosystem forming around a focal industry consortium and to measure how individual decisions affect the common ecosystem goal of providing a large and diverse set of compatible products (Jacobides et al., 2018).

Paper IV makes evident that platform-based ecosystems do not only receive contributions from a homogeneous group of paid developers, but must also consider user innovators, who are especially salient in settings such as IoT. In this regard, Paper IV highlights the phenomenon of peer production systems, which are formed by a multitude of peers with similar interests contributing to a common goal, i.e. a public good (Benkler, 2002). In this context, the article meta-analytically consolidates the variety of motives that can make individuals contribute.

6.2. Practical Contributions

The dissertation also provides some guidance for practitioners. Paper I demonstrates the need to take a holistic view of platform management and ecosystem orchestration. The literature review shows that platforms are interwoven with a complex environment, with which they interact. Accordingly, platform sponsors should broaden their view and consider platform governance as a more comprehensive task that may include, among other things, engagement in standardization bodies or changing consumption patterns within societies by rapidly building an installed base.

Furthermore, Paper II discusses the strategy of selectively promoting compatible platforms to address the complex competitive situation due to open technology standards and a common market of hardware components. The article shows that platforms can draw end-users' attention to specific compatible platforms. Factors such as competition and complementary product niches, as well as the platforms' user base, can be included to inform decisions regardless of the de facto prevailing compatibility with other platforms. We observe platforms doing so via compatibility lists or even product marketplaces, the latter of which allows them to earn additional returns through commissions. It is further shown that compatibility promotion is characterized by reciprocity. Accordingly, promotion by many complementary platforms can also lead to promotion by many other platforms. An example in our dataset represents Fibaro, which promotes relatively many platforms and receives relatively much promotion back. Regarding the decision to adopt technology standards, we observe that the adoption of more general standards can pose a viable alternative to adopting a higher number of more specific standards, thus reducing certification and membership costs. In addition, integrations with giant platforms can be an attractive target for cloud-to-cloud integrations. Our results demonstrate that some fraction of reciprocity in promotion goes back to giant platforms, as they curate products, allowing users of these platforms to easily identify integrated platforms. Moreover, especially giant platform sponsors show high betweenness centralities, reflecting their central role in bridging between (incompatible) platforms. Nonetheless, such integrations increase dependence, as they require a tight coupling and bear the potential to sideline the initial offer of the platform, which harbors the danger of platform envelopment by the giant platform (Eisenmann et al., 2011; Hilbolling et al., 2020). Therefore, simultaneous integration with multiple giant platforms proves to be a way to reduce the risk of platform envelopment.

Paper III makes evident that standardization bodies are particularly significant in contexts where hardware products serve as complements for platforms. Standardization bodies such as industry consortia promote the development of a technology market similar to that for smart home products. Platform sponsors as part of this technology market have to choose between different industry consortia and thus themselves become part of a larger innovation ecosystem that forms around this technology. Platform sponsors can also choose their role in this process, and our research clearly shows that industry consortia are also the locus of competition between rival major platforms such as Google and Apple, which support different consortia.

7. Directions for Future Research

The findings of the dissertation offer rich avenues for future research, which I will discuss in detail below.

First, the empirical articles, i.e. Paper II and III, focus on platforms and complementors in one particular context, namely the smart home market. The smart home market is an application area of the Internet of Things technology, which has distinctive features. Internet of Things is a complex digital technology with an infrastructure character that relies heavily on open communication standards enabling the exchange of data among devices and between devices and the cloud (Rowland et al., 2015). In addition, the majority of complementary products are not made for specific platforms, but for an open technology standard, requiring platforms, on the one hand, to build their ecosystems on a shared set of complementary products in the market. On the other hand, it also ties the success of the platforms to the standardization and certification processes in industry consortia. Future research is needed to examine the extent to which the findings of Paper II and Paper III can be confirmed in other contexts within and also outside of IoT. Connected cars (Svahn et al., 2017) and Industrial Internet of Things (Sandberg et al., 2020) are only two of such contexts that provide a starting point for future research. Moreover, open technology standards such as file formats also play a role in content and service platforms, where digital contents can be transferred between platforms.

Second, despite the large amount of data from different sources our empirical studies relied on, observations are limited to publicly available information from alliance and company websites. To gain better insight into decision-making processes whose outcomes we observe, further research is needed that incorporates internal data sources. One approach may be to conduct surveys with managers to statistically evaluate motivations and beliefs (Gaski, 2015). In this case, alternative statistical methods such as structural equation modeling (Kim et al., 2015) may also help to construct more complex models of the decision-making process including latent variables. Another approach could be to use dynamic panel models to incorporate auto-regressive effects into the model, allowing to capture path dependencies and network effects, but are to date limited in that they are rather unstable, particularly in cases with complex relationships (Moral-Benito et al., 2019). In addition, further qualitative methods such as ethnographic techniques can provide insights on mechanisms and derive process models (Eisenhardt, 1989). This could particularly help to gain more insights on how executives handle the dual role of platform sponsors acting simultaneously as complementors in the smart home market. It can also help to better understand how traditional companies manage the balancing act between a manufacturer logic and a platform logic. An exemplary study is provided by (Sandberg et al., 2020), which illustrates the transition of a traditional manufacturer to a platform sponsor using ABB as a case study.

Third, examining the relationship between the adoption of multiple open technology standards and platform competition in Paper II raises further questions. In particular, it shows that established platform sponsors such as Apple are introducing their own proprietary protocols (HomeKit) and their own certification programs, which is similar to some of the functions of standardization bodies. This raises the question as to which roles and positions platforms occupy within the interwoven networks of platforms (Mosterd et al., 2021). While research exists on roles within broader ecosystems, as in the case of the mobile ecosystem (Basole & Karla, 2011) or the IoT ecosystem (Toivanen et al., 2015), it ignores the importance of standards and infrastructures. In this regard, an example of further research is provided by Kazan et al. (2018), who identify strategic positions and strategies with infrastructure in mind.

Fourth, particularly Paper III points at the relevance of standardization and standardization bodies. An observation within the dataset shows that large incumbent platform sponsors such as Apple, Google, and Samsung engage in industry consortia for standards development, sometimes taking the orchestrator role. This allows them to influence the development of standards, contribute patents, and influence the further development of the consortia. This raises questions as to the extent to which involvement in standardization bodies such as industry consortia influences the position of a platform within a technology market and the extent to which rivalries between platform sponsors are also reflected at the level of industry consortia. Industry consortia also have direct relevance for ecosystem orchestration. They can be found in other contexts, such as connected mobility (e.g., Open Automotive Alliance[20]) or cell phones (e.g., Open Handset Alliance[21]), which were launched by platform sponsors such as Google to organize their

[20] https://www.openautoalliance.net/
[21] https://www.openhandsetalliance.com/

ecosystems. Anecdotal evidence suggests that Google uses these to steer participants in the broader innovation ecosystem, as described by Karhu et al. (2018) in the case of the Open Handset Alliance, where Google uses bylaws to prevent handset manufacturers from using other operating systems. Especially in contexts that can be attributed to the broad domain of IoT, industry consortia are vital for value co-creation in platform-based ecosystems. Governance is accordingly not limited to software developers, but also includes manufacturers of devices, who can only be directly influenced in the case of proprietary standards (such as Apple's HomeKit in the smart home market). In the case of open standards, it is inevitable to consider industry consortia as a tool for governance of value co-creation.

Lastly, the dissertation, and not least Paper I, shows that a deeper understanding of the interactions between platform-based ecosystems and especially social and political systems is missing in platform research. However, as digital platform-based ecosystems often operate globally and span multiple political and social systems that are constantly changing, platforms must also adapt to these changes. For example, Bazarhanova et al. (2020) report in their study how regulatory changes in Finland, which implemented the EU Regulation 910/2014 on electronic identification and trust services for electronic transactions (European Union, 2014), led to a change in the orchestrator role at the expense of platform sponsors. In the European Union, the European Commission in 2015 passed the EU Regulation 2015/2366 (Payment Services Directive 2) obliging financial service providers to establish open interfaces in order to make it easier for companies without a banking license, such as FinTechs, to participate in the payment industry (European Union, 2015), which led banks to develop platforms. Similarly, the Digital Services Act (European Union, 2020a) and the Digital Markets Act (European Union, 2020b) promise to affect established and potential platforms in the European market. These address in particular the moderation of criminal content on platforms as well as gatekeeping in digital marketplaces by large digital corporations (more than 80 billion euros market capitalization) (European Union, 2020b, 2020a). Conversely, the example of Uber shows how platforms can also change consumer behavior in society and can thus indirectly influence the regulatory framework (Garud et al., 2022). In this context, a focus on the nested structure of ecosystems offers an approach to study such emergent processes (Barile et al., 2016). Important starting points also include the Special Issue on the regulation of platforms in *Computer Law & Security Review* (Belli & Zingales, 2020) and discussions of data sovereignty such as *in situ data rights* (Martens et al., 2021).

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Paper I:

Ecosystem Perspective in Platform Research: A Bibliometric Analysis and Review of Recent Literature

Sven Niederhöfer

Abstract

The ecosystem concept was originally introduced in the context of strategic management and includes a variety of different actors that are interdependent. The concept is also widely used in the platform literature, where it is more narrowly defined and its conceptual origin is seen in the strands of literature on market intermediaries and product families. As several reviews address platform-based ecosystems from the perspective of within platform literature, little is known as to how the ecosystem concept is applied with respect to ecosystem properties. In this article, we explore the concept of platform-based ecosystem from an ecosystem perspective, identifying the key characteristics of an ecosystem and exploring their addressing in platform research. In this context, we systematize the literature and derive a framework. We also conduct a bibliometric analysis and examine the structure of the intellectual base, identify the most frequently cited references, and conduct a content analysis to examine the use of platform and ecosystem terms using a co-word analysis. In addition, we elaborate basic definitions of related concepts and derive differentiators between platforms and ecosystems. We conclude the article by identifying research gaps concerning the role of complementarities, interdependencies, and multilateral relationships, as well as the interactions of platform-based ecosystems with their surrounding systems (political system, society, market, and infrastructure).

This paper is currently getting prepared for submission to Journal of Management together with a co-author.

1. Introduction

The business ecosystem concept was originally introduced by Moore (1993) to reinforce a strategic self-image of a company as part of an ecosystem that competes with other ecosystems. In this context, the company interacts with a variety of stakeholders within the ecosystem, which may include competitors and policy makers (Iansiti & Levien 2004b). However, the bulk of platform research deals with strategic issues from the perspective of a central company, a platform leader (Gawer 2014). This approach takes a narrow view of platforms and their environment – predominantly focusing on interactions between platform leaders and complementors (Jacobides et al. 2018; Tsujimoto et al. 2018) – that departs from the fundamental idea of the broadly defined business ecosystem concept (Adner 2017).

While the concept of a platform-based ecosystem has been predominantly defined in the platform literature by building on two-sided markets and modular product families (Gawer 2014; Thomas et al. 2014) and adopting certain properties from the general ecosystem concept, little is known about how these ecosystem properties are studied in platform research. Considering the concept from an ecosystem perspective can help identify research gaps and guide future research, as well as contribute to further developing the concept.

Beyond that, both ecosystem and platform concepts remain ambiguous, with more terms gradually being defined. To date, there is also no clear distinction between platforms and ecosystems, with some researchers using the terms interchangeably (cf. de Reuver et al. 2018). Both demonstrate the concept's interdisciplinary roots. An analysis of the conceptual structure can help identify thematic strands and concepts within the literature to guide future research and define characteristics that distinguish platforms from ecosystems.

This is not the first review of the literature on platform-based ecosystems. Some researchers focus on specific topics related to platform ecosystems. For example, Rietveld & Schilling (2021) provide a bibliometric review examining various aspects of platform competition. In addition, McIntyre & Srinivasan (2017) review the platform literature to systematize findings on network effects. A more general review by Thomas et al. (2014) provides a comprehensive overview of distinct strands within the platform literature, distinguishing organizational platforms, market intermediaries, product families, and platform ecosystems. In contrast to Thomas et al. (2014), we approach from within the ecosystem literature, focusing on general ecosystem properties and how they are addressed. We further extract key concepts and contexts related to platforms and ecosystems that underlie the research. The goal is to gain a better understanding of the concept, in particular its particularities, and to identify sub-strands.

In addition, some scholars have reviewed the ecosystem literature. Most notably, Gomes et al. (2018) provide a bibliometric review of the concept of innovation ecosystems and consider platform-based ecosystems as specific types of innovation ecosystems. They also derive basic ecosystem properties. Similarly, Tsujimoto et al. (2018) provide a systematic review to consolidate different ecosystem concepts and consider platform-based ecosystems as part of a nested structure consisting of an industrial ecosystem, an enterprise ecosystem, and a multi-agent network. However, neither review focuses on the specifics of platform-based ecosystems and how ecosystem characteristics are reflected in platform research. We build on these reviews by elaborating on the distinctive features of the platform-based ecosystem concept.

Against this background, the aim of this article is to systematize the discourse on "platform-based ecosystems" and derive a basis for future studies from an ecosystem perspective on platform research.

In particular, the following research questions underlie the work: *RQ1: How is the intellectual foundation of research on platform-based ecosystems structured? RQ2: What are the key concepts and how are they interrelated? RQ3: How does platform research reflect key properties of ecosystems?*

To answer these questions, the literature on platform-based ecosystems is reviewed, supplemented by bibliometric analysis and content analysis. The literature review includes 112 documents retrieved via *Google Scholar* and *ISI Web of Science*, including journal articles and proceedings as well as books and book chapters.

This study provides a number of contributions to platform research. First, the co-citation analysis reveals three clusters in the intellectual base, with one reflecting the foundational ecosystem articles and the other two being formed around the seminal work of Gawer (2014) and Tiwana et al. (2010). To some extent, this explains the conceptual ambiguities. Second, the thematic analysis reveals six thematic clusters, which can be understood as sub-clusters within the literature. In addition to the core cluster, which contains the essential concepts, we observe one thematic cluster each on mobile platforms, software platforms, service platforms, IoT platforms, and multi-sided platforms. In this context, software platforms and service platforms in particular exhibit distinct concepts. This shows how ecosystem and platform terms are related and identifies the key definitions. Third, the content analysis on the main ecosystem properties shows a research focus on (co-)evolution, value creation, and coopetition. Complementarities, interdependencies, and multilateral relationships are predominantly considered exogenous. Moreover, in some studies we observe the inclusion of interactions with surrounding systems (political system, society, markets, and infrastructure). Finally, we identify the four main functions of ecosystem platforms (development tool, distribution channel, interaction interface, value sharing infrastructure) and ecosystem conceptualizations (community of developers, multi-stakeholder system, network, complex system) and derive four distinguishing characteristics between platforms and ecosystems: centrality, stability, level of analysis, and manageability. We believe this can serve as a starting point for further differentiation of the two concepts.

The rest of this article is organized as follows. The following chapter describes the document retrieval and analysis process. Chapter 3 presents descriptive statistics along with the results of the bibliometric and content analyses. In the final section, we conclude the article with the main findings, discuss the limitations, and summarize further research opportunities.

2. Research design

The systematic review of the literature conducted in this study is based on bibliometric analyses. Bibliometric studies are becoming increasingly important and allow the study of structures related to authors, publications, and journals, the analysis of themes within fields, and the identification of the most relevant articles (Aria & Cuccurullo 2017). Combining bibliometric analysis with content analysis aims to identify frequently studied research contexts, the use of terms, and any gaps that may exist (Gomes et al. 2018). The overall process is illustrated in Figure 2.

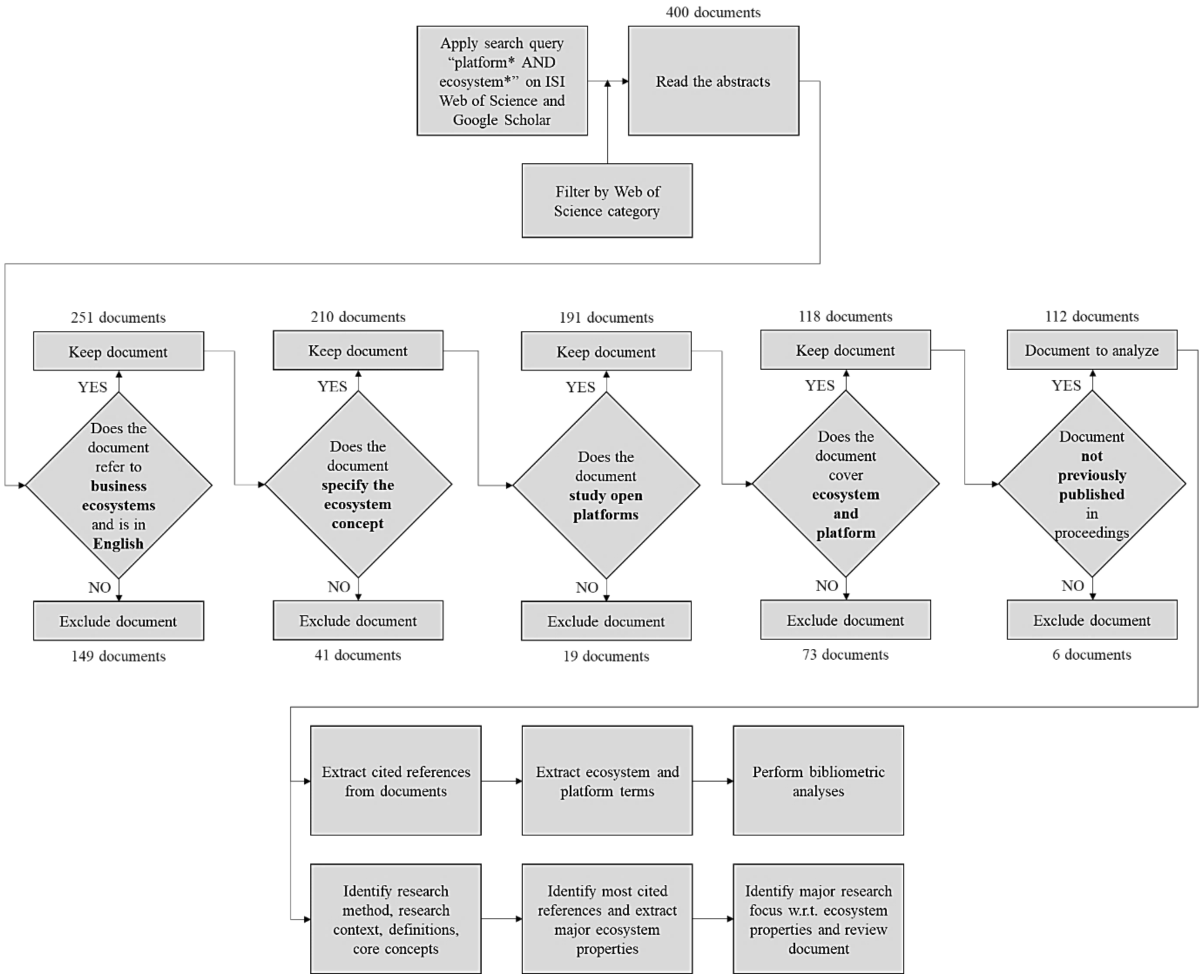
Description of sample

The bibliometric database was extracted from the *ISI Web of Science* database by *Thomson Reuters* and complemented with sources drawn from *Google Scholar* using *Publish or Perish*.[22] The *ISI Web of Science* database is frequently used to conduct bibliometric analyses due to the rich availability of metadata (Waltman 2016). However, some scholars emphasized the

[22] https://harzing.com/resources/publish-or-perish

underrepresentation of proceedings articles (Meho & Yang 2007), which are particularly relevant in information systems research. Google Scholar was found to provide a complementary source to close this gap (Mayr & Walter 2007).

Figure 2: Document retrieval and analysis process.



Source: Own illustration.

To select research articles, we searched for "platform* AND ecosystem*" in both search engines. We filtered the results returned by ISI Web of Science based on category[23]. Google Scholar does not allow for such filtering, resulting in lower precision. From both sources, we retrieved

[23] We included a broad range of categories: Computer Science Information Systems, Computer Science Theory Methods, Engineering Electrical Electronic, Computer Science Interdisciplinary Applications, Management, Telecommunications, Computer Science Software Engineering, Business, Computer Science Hardware Architecture, Information Science Library Science, Economics, Robotics, Engineering Multidisciplinary, Computer Science Cybernetics, Engineering Biomedical, International Relations, Engineering Mechanical, Engineering Chemical, Transportation.

bibliometric information on the 200 most relevant articles each. We then scanned the abstracts to identify and exclude spurious hits such as studies on biological ecosystems. We further excluded studies that were not in English, reducing the sample to 251 articles. For a more in-depth selection of articles, the studies were sourced and analyzed for relevance to our research questions using MAXQDA. For this purpose, we coded research questions, theories, and definitions. Only those articles were retained in the sample that did not use the ecosystem concept purely as a term (210 articles) or understood the platform concept as an internal or organizational platform (191 articles). This method excludes articles that examine internal platforms such as closed product platforms (e.g., brainstorming platform) or platforms as organizational entities such as open innovation platforms for exchange. In the next step, we examine whether articles include both the platform concept and the ecosystem concept, leading to 118 articles. Finally, we identified and removed proceedings articles that were published as journal articles later on. This leads to a final sample of 112 articles, of which 32 originate from Google Scholar, 45 from ISI Web of Science, and 35 from both databases.

Bibliometric analysis procedures

Different analysis tools for bibliometric analyses are discussed in literature (Cobo et al. 2011). We use the R package *bibliometrix* (Aria & Cuccurullo 2017) to conduct a co-citation analysis, citation analysis, and co-word analysis.

We start by studying the intellectual structure underlying the retrieved literature and apply a co-citation analysis of the 50 most frequently cited references. Co-citation analysis is one of the most used and validated bibliometric methods. It aims to identify commonly cited references and, thus, the structure of the scientific community (Zupic & Čater 2015). We then identify most frequently cited references. In so doing, we consider the global impact of references and include the journal impact factor to study the relative importance of references. These articles then form the foundation for the content analysis by deriving the main properties of ecosystems from them and then reviewing how these properties are studied in the articles of the sample.

Bibliometrix further allows the study of conceptual structure by conducting a co-word analysis and applying multi-level clustering to identify thematic groups. Overall, co-word analyses help identify main concepts treated in a research field and can be applied to authors’ keywords, abstracts, or entire text corpora (Cobo et al. 2011). Yet, the latter two usually introduce more noise (Zupic &

Čater 2015). As we are interested in the use of platform and ecosystem terms, we apply a lexical search to identify and extract platform and ecosystem terms together with up to two previous words from the studies.[24] We then use the 10 most frequently used terms per document as input for conceptual analysis. Clustering is then used to group the terms and identify different thematic strands within the literature. We also calculate density and centrality measures per cluster to interpret their degree of development and relative importance.

Content analysis procedures

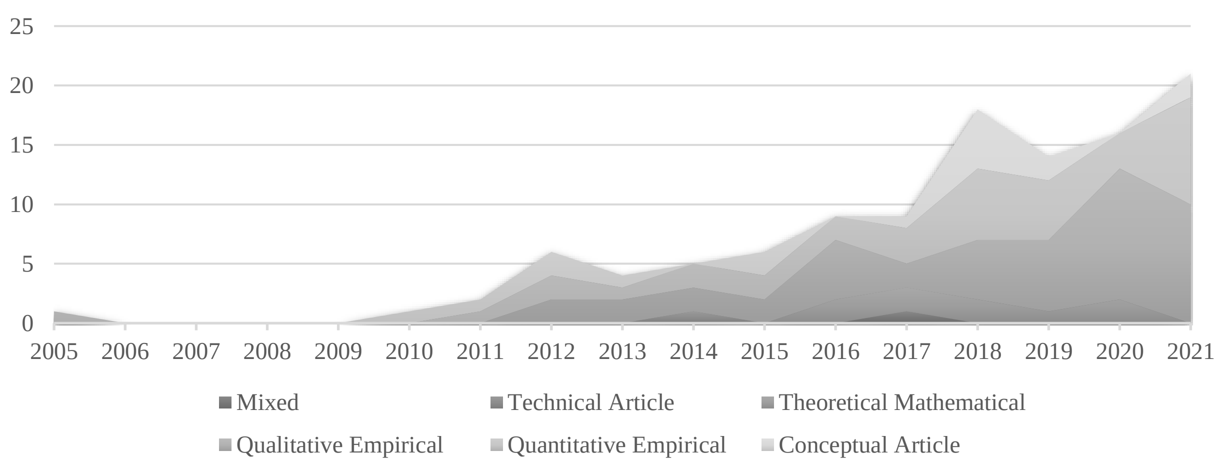
For the content analysis, we use MAXQDA to extract definitions, research contexts, platform and ecosystem terms, and methodological approaches. In addition, to identify the use of ecosystem properties, we extracted research questions and objectives as well as main constructs. To some extent, the content analysis also provides input for the bibliometric analysis in that we use extracted platform and ecosystem terms to conduct a co-word analysis.

3. Main findings and discussion

3.1. Descriptive statistics

The documents in the sample span a period between 2005 and 2021, with an average duration since publication of 4.62 years. The total of 112 documents includes 80 journal articles, 2 book chapters, 7 early access publications, and 23 proceedings papers.

Figure 3: Annual scientific production.



Source: Own illustration based on analysis.

[24] We exclude all matches from the references, as they do not reflect word choices of the authors.

The documents were cited 57.71 times on average (approximately 10.01 citations per year and document). Slightly more than half of the documents (62 of 112) were published between 2018 and 2021 (see Figure 3). The most relevant sources are Technological Forecasting and Social Change (9), MIS Quarterly (6), Strategic Management Journal (5), and Information Systems Research (4). Methodologically, qualitative approaches were predominantly chosen (42%), followed by quantitative (33%), conceptual (15%), theoretical-mathematical (8%), and mixed approaches (1%). Lastly, one article can be classified as a technical article (1%).

3.2. Bibliometric analysis

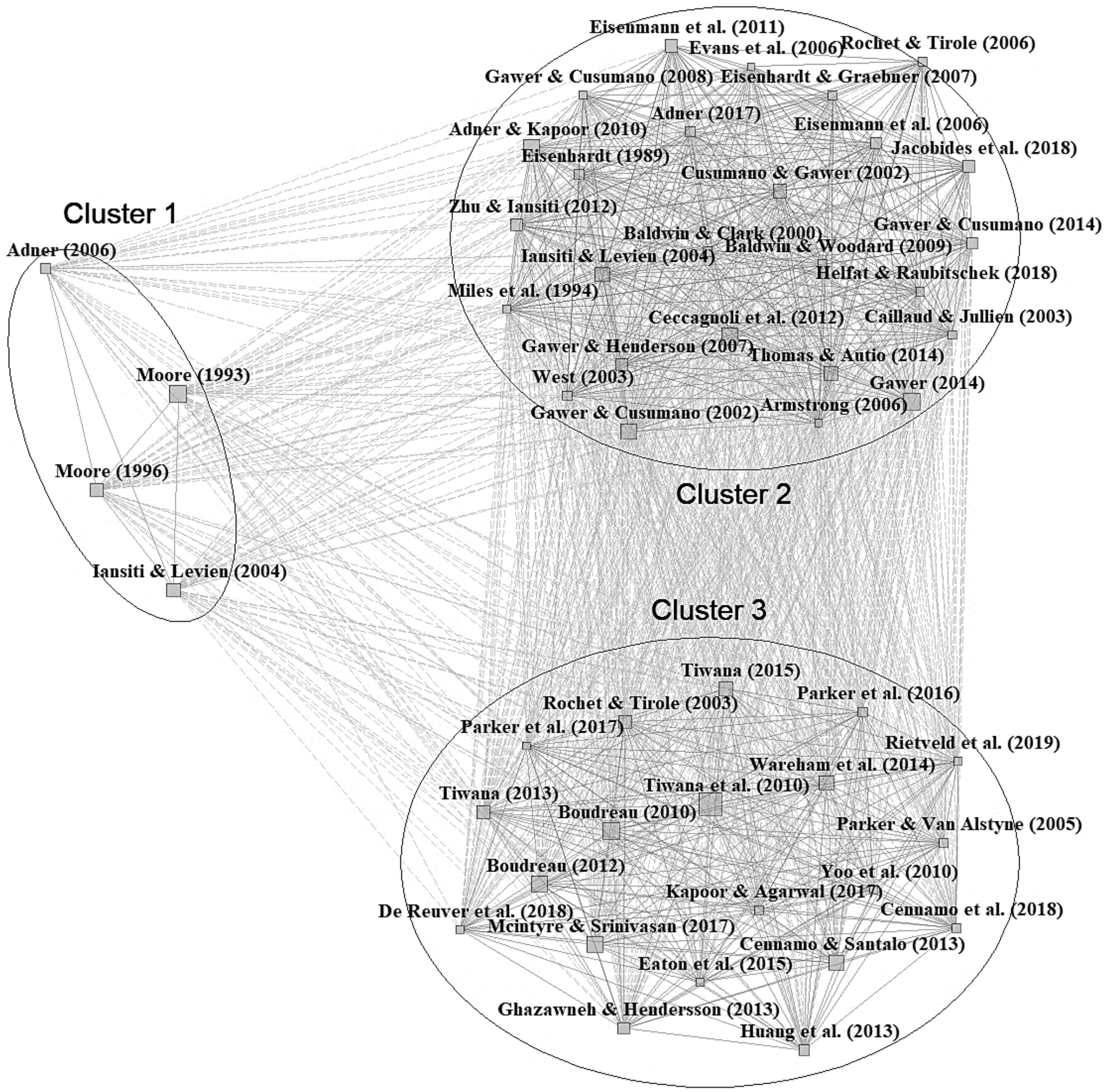
In the following sections, we present the analyses of the intellectual structure and conceptual structure, respectively.

3.2.1. Intellectual structure: Co-citation analysis and most cited references

To investigate the intellectual structure, we perform a co-citation analysis (see Figure 4) and then identify and review most cited references. In this context, we analyze the 50 most cited references and cluster the articles. Three clusters emerge, with one composed of basic ecosystem articles (cluster 1) and one cluster each around Tiwana et al. (2010) (cluster 2) and Gawer (2014) (cluster 3). Both articles have the two highest PageRank centralities of the overall references.

Cluster 1 consists of four seminal articles that introduced and successively extended the ecosystem metaphor into the business and management literature. Among them, the seminal article by Moore (1993) has the highest PageRank centrality – reflecting a high centrality within a group of frequently co-cited references – and locates the ecosystem metaphor in strategic management. Iansiti & Levien (2004b) take up the idea and extend it to include different strategic roles. Moreover, Adner (2006) emphasizes the relevance of the concept to the study of collective value creation and transfers the concept to innovation management. These three articles, along with Moore's (1996) book, form the foundation of the ecosystem concept. Adner (2006) has the highest betweenness centrality of all 50 references, indicating that the article is frequently co-cited with other references that are rarely co-cited with each other. In other words, the article is highly relevant across topics and disciplines.

Figure 4: Co-citation network of 50 most-cited references.



Source: Own illustration based on bibliometrix outputs.

Notes: Clustering based on Walktrap algorithm and graph layout based on Fruchterman-Reingold algorithm.

Cluster 2 consists of 26 articles that are located in the business and management literature as well as in economics, technology and innovation management, and strategic management. The most central article with the highest PageRank centrality is of the article by Gawer (2014), who defines a platform as a meta-organization. In addition, the cluster includes the systematic literature review by Thomas et al. (2014), who see the platform ecosystem as conceptually anchored in the literature on market intermediaries and product platforms, as well as Gawer & Cusumano's (2014) definition of an "industry platform." It further includes articles on platform leadership (e.g., Cusumano & Gawer 2002), recent conceptual articles on the ecosystem concept (Adner 2017; Jacobides et al. 2018), foundational works on network effects and two-sided markets (e.g., Rochet & Tirole 2006; Armstrong 2006), modularity (e.g., Baldwin & Clark 2000), and platform strategies (e.g., T. Eisenmann et al. 2011, 2006). Among these references, Baldwin & Clark (2000) has the highest betweenness centrality and among all 50 references the second highest . Analogous to Adner (2006) from cluster 1, this article is most relevant across topics and disciplines.

Cluster 3 consists of 20 articles from the information systems literature and management literature. The central article in this cluster is of the article by Tiwana et al. (2010), who define the platform ecosystem concept from a technical perspective and assume a software platform as its nucleus. In addition, there are articles on network effects (e.g., Rochet & Tirole 2003; Parker & Van Alstyne 2005), platform openness (e.g., Boudreau 2010), digitality (Yoo et al. 2010; de Reuver et al. 2018), boundary resources (e.g., Ghazawneh & Henfridsson 2013), and governance (e.g., Wareham et al. 2014). Among these references, Ghazawneh & Henfridsson (2013) has the highest betweenness centrality and is most relevant across topics and disciplines.

To get a better understanding of the intellectual foundation, we identify the most frequently cited references. In so doing, we first identified the most frequently cited references and in the next step identified the most relevant articles based on total citations. For this purpose, we determined the article impact factor (cf. Carvalho et al. 2013). The article impact factor (AIF) incorporates both the total citation count (TC) and the journal impact factor (JCR) and is calculated as follows: AIF = TC x (JCR + 1).[25] We analyze the articles with an AIF of more than 8,000 to extract basic ecosystem properties (see Table 4). The two most impactful articles were skipped in this context because they are methodological articles.

Following these, the article by Moore (1993) has the highest AIF. Moore (1993) introduced the ecosystem concept as a biological metaphor in strategic management to emphasize the "underlying strategic logic of change" in "complex corporate communities" (p. 75). He emphasizes concepts

[25] Citation counts were retrieved from Google Scholar to cover citations from articles not included in the Web of Science Core Collection and for articles not included in Web of Science, such as most proceedings articles. In addition, citation metrics of Google Scholar were found to be more accurate than those of ISI WoS due to higher coverage (cf. Mingers & Lipitakis 2010).

such as co-evolution of capabilities and roles, species, leadership, simultaneous competition and cooperation, and the life cycle of ecosystems. In Moore's view, companies should be considered as part of ecosystems that evolve as a whole, just like biological ecosystems. Iansiti and Levien (2004b) extend the basic concept and introduce several ecosystem roles that reflect the function of the respective actors for the ecosystem. Thus, an ecosystem member can be either a keystone, a niche player, or a value or physical dominator. While one or a few key players act as keystones, typically creating platforms to maintain overall health and providing basic resources, many niche players create most of the value. They suggest that central actors should balance value extraction and value sharing as opposed to the dominator role, which can harm the overall ecosystem.

Table 3: Network statistics, disciplines, and most cited references per cluster in co-citation network.

Cluster	N	Density	Discipline						Locally most cited article
			M	I	T	S	E	O	
1	4	1.0000	4						Moore (1993)
2	20	0.9815	11	2	4	4	3	2	Gawer (2014)
3	26	0.9895	11	7		1	1		Tiwana et al. (2010)
1-3	*50*	*0.9665*	*26*	*9*	*4*	*5*	*4*	*2*	*Tiwana et al. (2010)*

Source: Own illustration.

Notes: Discipline determined based on journal. “M” = business and management, “I” = information systems, “T” = technology and innovation management, “S” = strategic management, “E” = economics, “O” = other/methodological.

Besides, Adner (2006) emphasized the central value proposition as a binding element of the ecosystem that generates interdependencies and directs attention to value co-creation. In this context, the ecosystem can be divided into upstream and downstream activities, with interdependencies unfolding differently in the two parts (Adner & Kapoor 2010). On this basis, Adner (2017) distinguishes two ecosystem conceptions: ecosystem as affiliation and ecosystem as structure. While the former reflects a hub-and-spoke structure and focuses on centralized governance and community enhancement, the latter emphasizes relative positions and activity flows as well as alignment between actors with the goal of studying value creation. Jacobides et al. (2018) argue that an ecosystem has two fundamental requirements for its emergence: modularity and non-generic complementarity in supply and demand.

Table 1: Most-cited references with AIF above 8,000 in sample.

Article	Journal	Local citations	Total citations	% Citations	JCR 2020	AIF
Eisenhardt (1989)	Academy of Management Review	16	67332	52%	12.638	918273
Eisenhardt & Graebner (1989)	Academy of Management Journal	11	18709	15%	10.194	209429
Moore (1993)	Harvard Business Review	25	4618	4%	6.870	36344
Rochet & Tirole (2003)	Journal of the European Economic Association	20	5985	5%	4.583	33414
Adner & Kapoor (2010)	Strategic Management Journal	21	2638	2%	8.641	25433
Iansiti & Levien (2004)	Harvard Business Review	22	2509	2%	6.870	19746
Eisenmann et al. (2006)	Harvard Business Review	15	2314	2%	6.870	18211
Adner (2017)	Journal of Management	15	1408	1%	11.790	18008
Adner (2006)	Harvard Business Review	12	2192	2%	6.870	17251
Yoo et al. (2010)	Information Systems Research	13	2312	2%	5.207	14351
Gawer & Cusumano (2014)	Journal of Product Innovation Management	18	1702	1%	6.987	13594
Armstrong (2006)	The Rand Journal of Economics	11	4304	3%	1.986	12852
Jacobides et al. (2018)	Strategic Management Journal	18	1318	1%	8.641	12707
Gawer (2014)	Research Policy	28	1379	1%	8.110	12563
West (2003)	Research Policy	14	1255	1%	8.110	11433
Rochet & Tirole (2006)	The Rand Journal of Economics	12	3486	3%	1.986	10409
Parker & van Alstyne (2005)	Management Science	12	1710	1%	4.883	10060
Eisenmann (2011)	Strategic Management Journal	13	1008	1%	8.641	9718
Tiwana et al. (2010)	Information Systems Research	36	1441	1%	5.207	8944
De Reuver et al. (2018)	Journal of Information Technology	15	1019	1%	6.953	8104

Source: Own illustration.

They define an ecosystem as a set of interdependent actors, who contribute to a focal innovation by performing complementary activities.

Based on our analysis, these articles represent the most significant articles from the ecosystem literature.

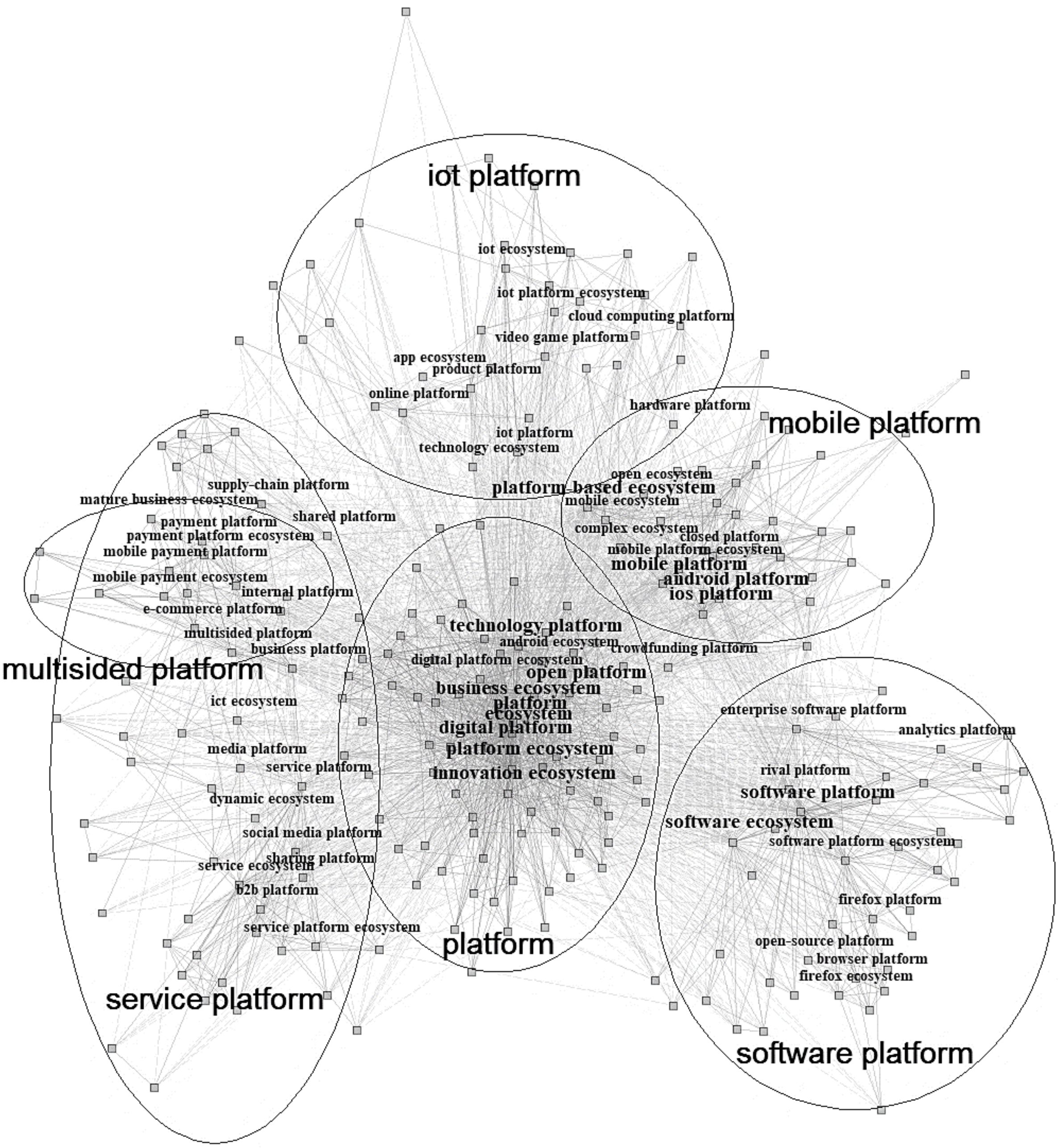
In the platform literature, Gawer (2014) defines an ecosystem as a meta-organization that allows external actors to contribute to the core technology, where these actors act autonomously, cooperate and compete, and must be guided through governance. In this context, a platform ecosystem is based on an industry platform (Gawer & Cusumano 2014) that provides resources to external actors and allows the platform sponsor to take leadership within an industry. Another group of frequently cited articles originates from research on two-sided markets and examines network effects, pricing, and multihoming (Armstrong 2006; Rochet & Tirole 2003, 2006; Parker & Van Alstyne 2005; Eisenmann et al. 2006). Some frequently cited articles discuss platform strategies such as platform envelopment (Eisenmann et al. 2011) and open platform strategies (West 2003).

A final group of frequently cited articles underscores the digital nature of some platform ecosystems. Tiwana et al. (2010) introduce a definition of software-based platform ecosystems and emphasize that governance and architecture must be in alignment. Yoo et al. (2010) extend the modular architecture to include four layers, namely network, device, service, and content to emphasize the digital nature of platforms and their role in digital innovation. The layers are loosely coupled through standards and common protocols so that software and hardware platforms, as well as other digital artifacts, can be combined in different ways at different layers that support these standards. De Reuver et al. (2018) derive a general definition of digital platforms, building on the definition of Tiwana et al. (2010), and describe a research agenda. They further identify social, technical, and socio-technical conceptualizations of platform ecosystems in the literature.

3.2.2. Conceptual structure: platform and ecosystem terms in text bodies

To investigate the conceptual structure, we perform a co-word analysis based on platform and ecosystem terms. Figure 5 shows the resulting network graph including the conceptual clusters. The network consists of 250 terms extracted from the text corpora of the 112 documents in the sample. For each document, the 10 most used platform terms and the 10 most used ecosystem terms were used. Table 5 summarizes the key parameters (Callon density, Callon centrality, size, and five most common terms). Callon centrality and density provide two measures that describe a cluster's contribution to the structuring of the overall network through its relative position and links to other clusters and internal coherence, respectively (Callon et al. 1991).[26]

Figure 5: Thematic network of 250 platform and ecosystem terms across 112 articles.



Source: Own illustration based on topic analysis in bibliometrix.

Notes: Layout based on multi-level clustering. Top 10 most frequently used terms per cluster illustrated as node labels.

[26] The higher the Callon centrality, the more a cluster describes a set of concepts considered crucial by the scientific community. The greater the Callon density, the more the concepts corresponding to the cluster form a coherent and integrated whole.

Based on this co-word analysis, we identify six thematic clusters: (1) platform, (2) mobile platform, (3) service platform, (4) IoT platform, (5) software platform, and (6) multisided platform.

Table 5: Thematic clusters of platform and ecosystem terms.

Cluster	Callon centrality	Callon density	# Terms	5 most frequent terms (frequency in brackets)
1 Platform	50.20	184.46	61 (35.7%)	Platform (108) Ecosystem (102) Platform ecosystem (77) Business ecosystem (40) Digital platform (34)
2 Mobile platform	29.48	191.12	28 (16.4%)	Android platform (15) Mobile platform (15) Platform-based ecosystem (14) Mobile ecosystem (11) iOS platform (11)
3 Service platform	28.94	317.33	24 (14.0%)	Service platform (11) Service ecosystem (8) Social media platform (7) Dynamic ecosystem (4) Media platform (4)
4 IoT platform	26.18	194.28	23 (13.5%)	IoT platform (7) Product platform (7) Online platform (6) IoT ecosystem (4) Technology ecosystem (4)
5 Software platform	23.65	275.98	25 (14.6%)	Software platform (31) Software ecosystem (16) Software platform ecosystem (9) Enterprise software platform (7) Rival platform (7)
6 Multisided platform	11.38	218.20	10 (5.8%)	Multisided platform (7) Business platform (5) E-commerce platform (4) Internal platform (4) Mobile payment ecosystem (3)

Source: Own illustration.

Platform. The most central cluster (Callon centrality: 50.20) represents the core cluster and comprises the central concepts “platform”, “ecosystem”, “platform ecosystem”, and the conceptually superordinate concepts “innovation ecosystem” and “business ecosystem”. It also includes the concepts of “open platform”, “technology platform”, and “digital platform”. The conceptual cluster is the largest one, as it comprises 61 terms; however, at the same time it is the cluster with the lowest density (Callon density: 184.46), suggesting a weak development of the relationships between the terms. In other words, many similar concepts exist alongside the main concepts in the cluster.

Mobile platform. The second cluster encompasses the context around mobile platforms and ecosystems such as Android and iOS. It includes concepts such as mobile platform ecosystem, software-based platform, and industry ecosystem. It is the second largest cluster with 28 (16.4%) terms and has the second highest Callon centrality (29.48) with a Callon density (191.12) similar to that of cluster 1. Based on these two measures, the second cluster can also be classified as a basic theme, containing important concepts for understanding the basic platform ecosystem concept. In fact, much of the research on platform ecosystems is based on data on Apple's iOS ecosystem or Google's Android ecosystem (see Table 8).

Service platform. The third cluster comprises platforms and ecosystems in a service-oriented context. This includes social media platforms, streaming platforms, media platforms, B2B platforms, and healthcare ecosystems. It is conceptually grounded in the stream around service platforms and service ecosystems. This cluster is the densest (Callon density of 317.33) with Callon centrality (28.94) and size (24 terms / 14.0%) similar to that of the mobile platform cluster. Generally, clusters with a relatively high Callon density and a relatively high Callon centrality are well developed and important to structure the research field.

IoT platform. Cluster 4 thematically represents platforms in the broader internet of things context. Conceptually, it includes IoT platform, IoT ecosystem, hardware platform, video game platform, 3D printing ecosystem and app ecosystem. It predominantly covers open product platforms with complementary software extensions such as IoT apps or video games. It further comprises platform terms in the industrial context. The cluster includes a total of 23 terms (13.5%) with a Callon density of 194.28 and a Callon centrality of 26.18, both being in the middle range. Callon density and centrality point to an emerging theme.

Table 6: Most central platform and ecosystem terms per cluster in co-occurrence network.

Term	Cluster	Betweenness centrality	Closeness centrality
platform	1	1858.650	0.002
ecosystem	1	2136.646	0.002
platform ecosystem	1	3290.913	0.002
business ecosystem	1	2398.176	0.002
digital platform	1	1353.127	0.002
open platform	1	866.107	0.002
technology platform	1	592.410	0.002
innovation ecosystem	1	857.347	0.002
digital platform ecosystem	1	660.135	0.002
digital ecosystem	1	438.364	0.002
mobile platform	2	467.009	0.002
platform-based ecosystem	2	850.694	0.002
mobile ecosystem	2	604.605	0.002
service platform	3	498.427	0.002
service ecosystem	3	379.235	0.002
iot platform	4	259.757	0.002
product platform	4	249.120	0.002
software platform	5	1059.710	0.002
software ecosystem	5	859.373	0.002
multisided platform	6	358.632	0.002
business platform	6	218.890	0.002

Source: Own illustration based on thematic analysis in bibliometrix.

Software platform. The cluster around software platforms and software ecosystems includes platforms in the open-source software, software application, and enterprise software context. Platforms in this cluster are, for example, the Firefox browser platform or app development platforms. The cluster contains 25 (14.6%) terms and has the second highest Callon density (218.20). The Callon centrality is 23.65. Based on these two values, the cluster can be considered a niche theme, being a fairly well developed topic without major relevance to the overall stream.

Multisided platform. Cluster 5 forms the smallest group with 10 (5.8%) terms and the lowest Callon centrality (11.38). It has a relatively high Callon density (218.20). Thematically, it mainly represents e-commerce and mobile payment platforms and is conceptually based on multisided platforms and business platforms. The cluster is almost entirely contained within the cluster of service platforms. Similar to the cluster around software platforms, this cluster is also a niche theme.

3.3. Content analysis

While bibliometric analyses can show the underlying structures of the literature, they suffer ambiguities in terms of how references are cited and terms are used (Zupic & Čater 2015). The aim of content analysis is to complement bibliometric analyses by including the actual content of the articles, thereby revealing its relation to the structures.

Specifically, we will first follow the analysis of intellectual structure and extract most significant properties of ecosystems from the most cited references. We will then build on this to examine the extent to which the articles in our sample address these ecosystem properties. In so doing, we develop a framework for systematizing the studies. We then follow up on our analysis of the conceptual structure to highlight definitions and differences of the most central platform and ecosystem concepts. We also address differences between platforms and ecosystems.

3.3.1. Platform-based ecosystem: major ecosystem properties and their addressing in research

Based on the most-cited references, seven major characteristics of ecosystems can be derived that drive research ambitions:

- i. *Evolution*. A fundamental property of ecosystems is their dynamic nature. Ecosystems are subject to constant change, with social structures (roles, value flows, relationships), institutional aspects (rules, processes), and technical aspects (platform architecture, variety, and quality of complementary products) changing. These changes at the ecosystem level are influenced by the evolution of its components and their interaction (e.g. platform and complementary products or capabilities of the actors) (Moore 1993; Tiwana et al. 2010).
- ii. *Simultaneous competition and cooperation* represent another characteristic (Moore 1993). Driven by their own interests and the simultaneous dependence on the cooperation of others, actors within an ecosystem try to balance cooperation and competition in their interactions (Moore 1993). In so doing, the maximization of value appropriation as well as the balancing of interests are in the foreground.

- iii. *Value co-creation*. A frequently discussed property is value co-creation within an ecosystem. Actors within an ecosystem contribute specific capabilities and resources to collectively materialize a central value proposition. Value co-creation is subject to a certain structure (Adner 2017) and is influenced by governance and co-opetition, among other factors.
- iv. *Interdependencies*. Actors within an ecosystem are held together by interdependencies (Iansiti & Levien 2004b; Adner 2017).
- v. *Governance*. Some researchers further highlight the orchestration or governance of an ecosystem as a key activity of a technology owner (Iansiti & Levien 2004b; Gawer 2014). The use of control mechanisms, rules, and boundary resources is intended to influence the behavior of platform users (Tiwana et al. 2010).
- vi. *Complementarities*. In particular, Jacobides et al. (2018) highlight complementarities as a key characteristic of ecosystems. The offerings of individual contributors within an ecosystem complement each other and together form a set of products and services designed to address the heterogeneous needs of consumers (Boudreau 2010). Complementarity is non-generic in nature and fosters interdependence between different contributors as their offerings depend on the availability of complementary offerings from others (Jacobides et al. 2018).
- vii. *Multilateral relationships*. In particular, Adner (2017) highlights multilateral relationships between ecosystem actors as a characteristic of ecosystems. In this context, relationships cannot be viewed and managed in a dyadic manner, but must include dependencies on other relationships.

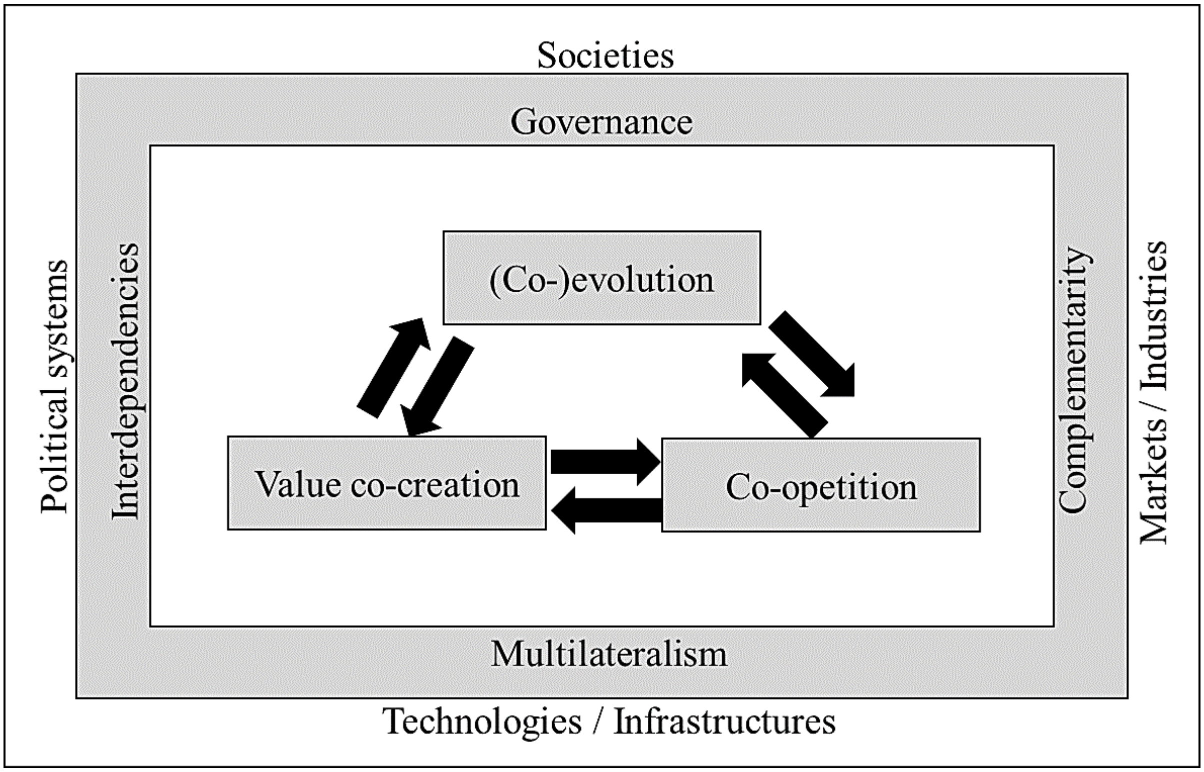
Based on these seven ecosystem characteristics, a content analysis of the articles in the sample was carried out to elaborate how these characteristics were addressed in the platform literature.

Our coding approach of the main research foci with respect to the identified ecosystem properties shows dominance in three of these properties: (1) co-evolution, (2) value co-creation, (3) simultaneous competition and cooperation (i.e., co-opetition). Multilateralism, interdependencies, and complementarity appear primarily as conditional factors, i.e. they are assumed to be predominantly exogenous. Governance often plays an important role by influencing value co-creation across ecosystem evolution and in the face of co-opetitive dynamics. Therefore, it represents a medium through which the central properties are to be influenced and is rarely itself the central focus of the studies.

The review of the studies further reveals four overarching systems in which the platforms and their ecosystems are embedded: (1) political systems, (2) societies, (3) industries, and (4) infrastructures.

We discuss the articles' findings in light of this insight, which is visualized in Figure 6.

Figure 6: Conceptual framework for systematizing studies by centrality of ecosystem properties and surrounding systems.



Source: Own illustration.

Governance. Starting with the conditioning factors, in our sample, governance is treated as the main focus in 7 articles (6%): 3 broad literature reviews in the context of digital platform ecosystems (Mukhopadhyay & Bouwman 2019) and service platforms (Smedlund et al. 2018) as well as the key challenges of governance (Mukhopadhyay & Bouwman 2018); 2 articles discussing the use of blockchain technology for decentralized governance (Schmeiss et al. 2019; Yu et al. 2018); and 1 article each on data governance (Lee et al. 2018) and learning about governance through boundary resources (Weiß et al. 2018).

Multilateral relationships. Another 9 articles (8%) deal with addressing multilateral relationships with a variety of complementarities. At their core, studies focusing on multilateral relationships consider ecosystem-wide rules and the impact of changes in individual platform-complementor relationships on the relationships between the platform sponsor and other complementors. There is a particular focus on platform openness, which is examined by four articles in the sample (Teixeira 2015; Mukhopadhyay et al. 2016; Choia et al. 2017). Platform openness is seen as a means to ensure uniform and controlled access to platform resources for a group of users (usually developers), where openness can comprise multiple dimensions (Benlian et al. 2015; Teixeira 2015). With similar intent, one article discusses various metrics for assessing outputs of complementors in partner programs (Engert et al. 2020).

The remaining four studies focus on selective deviations from ecosystem-wide rules with the goal of increasing the value of the platform ecosystem by seizing opportunities. Of these, two articles address the conditions under which platform sponsors can deviate from ecosystem-wide rules on a case-by-case basis (Hurni et al. 2022; Huber et al. 2017), one study proposes the promotion of specific complements (Rietveld et al. 2019), and one study highlights the option of tiered models for self-selection by partners (Wareham et al. 2014).

Co-evolution. 41 articles (37%) in our sample are centrally concerned with the co-evolution of actors within the platform ecosystem, between platforms within a larger market or industry, or the evolution of the ecosystem as a whole along a lifecycle, where some studies focus on the initial emergence. Of these, 12 studies examine the co-evolution of a central platform and its ecosystem or groups of actors within the ecosystem, constituting the first group. A central problem in this context is the technical evolution of the platform core, as complements depend on its properties. They particularly study the effect of intergenerational platform technology transitions (Ozalp et al. 2018), their frequency (Song et al. 2018; Zhou et al. 2018), and relative timing between app releases and platform core updates (Soh & Grover 2020), or the evolution of certain characteristics of the platform core such as the app permissions model (Wei et al. 2012). The focus is on the impact of platform core evolution on value creation in the platform ecosystem, for example, in terms of cross-side network effects (Song et al. 2018), innovativeness (Ozalp et al. 2018), app performance (Zhou et al. 2018; Soh & Grover 2020), and quality (Wei et al. 2012). In addition, two articles in our sample investigate the co-evolution of user groups in terms of user preferences for innovativeness and its impact on the number of complementors (Panico & Cennamo 2022), or of the part of the ecosystem for further development of the core and the part for development and commercialization of third party complements (Isckia et al. 2020).

In addition to the previously discussed studies that focus more on technical aspects and innovation, the remaining 5 of the 12 studies adopt a strategic focus. The main focus is on conflicting interests of different ecosystem actors that influence the evolution of the ecosystem. Accordingly, these studies show the connection between evolution and co-opetition. In this context, the enforcement of interests of the platform sponsor influences the ecosystem. For example, the platform ecosystem as a whole may be submerged by an overly dominant role of the sponsor (West & Wood 2014) or the sponsor's decision to enter a new market (Inoue & Tsujimoto 2018). In addition, the success of the ecosystem also depends on the interests of other players, such as the platform provider. For example, strategic considerations of the platform provider may influence the diffusion of platform core updates by the platform sponsor (Oh & Hong 2018). In addition, platform sponsor decisions may also be influenced by ecosystem evolution, such as the degree of openness (Parker et al. 2017), which in turn may have an impact on the financial performance of complementors (Yun et al. 2017). These studies further offer some insights on interdependencies between actors.

The second group comprises five of the forty-two articles and examines the co-evolution of platforms with other platforms or players in the market or industry. In this context, two studies use network analyses to show how platforms network and position themselves within the broader IoT ecosystem (Toivanen et al. 2015) or mobile ecosystem (Basole & Karla 2011). Two other studies address the mechanisms of ecosystem evolution by adopting a sociocultural perspective to propose an evolutionary model on service platform ecosystems based on selection and retention of platform variants (Xu et al. 2021) or by adopting a socio-economic position to demonstrate how co-existence, co-learning, co-production, and co-evolution influence the evolutionary trajectories of over-the-top platform ecosystems (Lee et al. 2020). One study in this group highlights the complementary relationship between platforms in the context of 3D printers (Kwak et al. 2018). In this context, platforms perform different functions for 3D printer users and thus build a common installed base of users.

The third group contains eight of the forty-two articles and uses a lifecycle model to examine different stages of platform ecosystem development, typically reflecting increasing complexities. The studies consider one or a few cases. Five studies of these focus on service platforms. Most notably, Rong et al. (2021) examine the development of sharing economy platforms from a socio-economic perspective and distinguish between the following: community stage, scaling-up stage, and legitimation stage. Besides, Nieborg & Helmond (2019) show the evolution of Facebook from an online college directory to a service development platform and, finally, to a mobile messaging infrastructure. Similar evolutions are shown for a platform in agriculture (Jha et al. 2016) and TripAdvisor (Alaimo et al. 2020). A mathematical model reflecting most of the trajectories is discussed by (Yan et al. 2020), which, based on the Lotka-Volterra model, shows the evolution from a bilateral platform (two-sided market) via a core platform (core-periphery structure) to a platform ecosystem with a nested structure. Lastly, one article each examines the change in platform strategy over the ecosystem lifecycle (Rong et al. 2013), the impact of policy changes on the evolution of the Finnish e-identification ecosystem (Bazarhanova et al. 2020), and the transformation of a traditional service company to a platform company (Shi 2019). As such, some scholars consider the role of the regulator and examine how orchestrator roles change due to policy changes (Bazarhanova et al. 2020).

The fourth group, which consists of the remaining 17 of the 42 articles on platform ecosystem evolution, addresses specific aspects related to the incipient stage of the ecosystem. Of these, four studies address the transition of a software or hardware product toward a platform ecosystem. In this context, the product may be an app (Costa et al. 2013), industrial software (Kilamo et al. 2012), or a modular product platform (Sandberg et al. 2020; Slinger Jansen 2015). In an attempt to formalize, (Thomas & Autio 2015) introduce a process model for the emergence of platform ecosystems. The other 12 studies within the group address specific aspects in emergence, such as legitimacy (Garud et al. 2022; Khanagha et al. 2022), alliance formation (Quaadgras 2005), roles and structures (Dedehayir et al. 2018; Breznitz et al. 2018; Saarikko et al. 2016; Kapoor et al. 2021; Pang & Tian 2014; Dupont et al. 2017), the role of architectural knowledge (Attour & Barbaroux 2016), platform scope choices (Murthy & Madhok 2021), and dynamic capabilities (Sun et al. 2020).

Value co-creation. Thirty-two articles (29%) in our sample focus centrally on the co-creation of value in terms of specific complementary characteristics, roles and structures, technological generativity, boundary resources, and organizational as well as institutional factors. The first and largest group (13 of the 32 studies) addresses the impact of ecosystem properties or platform sponsor decisions on certain characteristics of the products and services developed by external complementors, or the development itself. These characteristics include composability (Eklund & Bosch 2012), quality (Hilbolling et al. 2021; Goldbach et al. 2018), performance or success of complementary goods (Tiwana 2015; Inoue 2021; Yin et al. 2014), availability and diversity of complements (Xu 2017; Kim 2016; Lee & Hwang 2018), innovativeness of complementors (Foerderer et al. 2018), and value perceptions by end users (Dunn et al. 2021). In this context, the studies explore the effects of governance measures (e.g., Eklund & Bosch 2012; Hilbolling et al. 2021), platform openness (e.g., Inoue 2021; Scholten & Scholten 2012), marketplace characteristics (e.g., Yin et al. 2014), platform strategies (e.g., Foerderer et al. 2018), or policy changes (e.g., Wessel et al. 2017). Accordingly, co-opetitive dynamics also play a role, such as the decision of a platform sponsor to enter a complementary market (Foerderer et al. 2018) or the market power of a platform sponsor (Lee & Hwang 2018).

The second largest group (8 of 32 articles) refers to the roles and structures underlying value co-creation. In this context, some studies address the role of specific actors or groups such as beta tester communities (Mäkinen et al. 2014) or downstream distributors (Inoue et al. 2019) in the context of value generation and delivery. Other studies refer to the structure as a whole and discuss different roles and their activity flows among each other (Sun et al. 2018; Presenza et al. 2019), with two studies using network analysis to highlight positions of specific actors (Riasanow et al. 2021; Lee & Kim 2017). Two studies address processes in value creation to develop complementary applications (Zeng et al. 2010) or to select strategic patterns of innovation (Zhong & Nieminen 2015).

The third group, with 5 out of 32 studies, focuses on technological generativity. Technological generativity occurs when resources (usually delivered via APIs) from one or more sources (e.g., platforms) can be integrated with each other in an uncountable number of ways, allowing developers to independently generate value for the platform. Most of the studies in this group consider integrations of resources from multiple platforms, examining patterns of integrating internal with external APIs (Um et al. 2013), cross-platform interoperability (Deshmukh et al. 2021), or the process of developing mashups (Stecca & Maresca 2011). In addition, one study addresses the relationships between developers that are created by recombining apps and services (Kourtesis et al. 2012). Another article studies the effect of generativity on system reputation (Cennamo & Santaló 2019). In this sense, this group of studies also highlights the importance of complementarities between platforms.

Another 5 of the 32 studies explicitly address the role of boundary resources. These resources are made available to complementors and thus shape both the relationships between platform and complementors and the creation of value. Different types of boundary resources are investigated (Petrik & Herzwurm 2019) such as social boundary resources, e.g., developer conferences, (Foerderer 2020; Fang et al. 2021), knowledge boundary resources such as information portals (Foerderer et al. 2019), or a combination of several different types (Bonina & Eaton 2020).

The last 4 of the 32 articles examine organizational or institutional factors that influence value co-creation. The studies deal with institutional logics (Schulz et al. 2020; Qiu et al. 2017), organizational capabilities (Schreieck et al. 2021), or value co-creation practices (Hein et al. 2019).

Co-opetition. Twenty-one articles (19%) in our sample focus centrally on co-opetitive dynamics, which appear as divergence of interests between different stakeholders in the platform ecosystem. In this context, individual interests (value appropriation) are usually set against collective interests (value creation and ecosystem survival), whereby these can be aligned to varying degrees. We observe co-opetitive dynamics between platform leaders and complementors, platform leaders and actors in the broader ecosystem, between complementors, and between platform leaders and consumers. Most studies (14 out of 21) in our sample consider co-opetitive dynamics between the platform leader and complementors. Some studies examine power dynamics among them (e.g., Johnson et al. 2021), where some take the perspective of the platform leader, for example, focusing on locking in complementors (Kim et al. 2016), while others adopt the perspective of complementors, for example, linked to how they can use multihoming to maintain bargaining power (Wang & Miller 2020). Other studies distinguish between different models of relationships between platform leaders and complementors based on the degree of predation (Yao & Zhou 2016; Ding et al. 2019) as well as frictions that can be caused by platform governance (Chen et al. 2021). These studies relate to value co-creation by studying the effects of these models. Further studies address the difficulties and motivations associated with ecosystem participation of entrepreneurs or SMEs and address role conflicts (Nambisan & Baron 2021), managerial challenges regarding interdependencies (Altman 2016), and intentions towards participation (Wei et al. 2021; Ceccagnoli et al. 2012). Some studies focus on ecosystem health and various factors that promote it (Chen & Sun 2021), or ecosystem resilience (Floetgen et al. 2021). One study examines the interaction of relative position in the ecosystem with the decision to adopt or reject a platform model and its effect on performance (Pellizzoni et al. 2019).

The second group of studies (4 out of 21) examines co-opetitive dynamics between the platform leader and actors in the broader ecosystem, exploring different gradations on the continuum between collaboration and competition: with more collaborative relationships, where partners collectively build an infrastructure around a platform (van der Vlist & Helmond 2021), co-opetitive relationships, where the platform leader negotiates boundaries with other actors (Saarikko et al.

2016), and more competitive relationships, where the platform leader occupies bottlenecks (Ondrus 2015) or digital platforms challenge traditional incumbent producers (Cozzolino et al. 2021).

Table 7: Overview of key properties of ecosystems and research issues.

Property	**Research issues**	**Key references**
Evolution	• Intergenerational transition of technology core and its co-evolution with the surrounding ecosystem • Role of platform sponsor's strategic choices and characteristics on evolution and the influence of complementors on platform sponsors' choices • Co-evolution of platforms within markets • Evolutionary stages of platforms and ecosystem emergence	Moore (1993), Tiwana et al. (2010), Basole & Karla (2011)
Value co-creation	• Effect of platform and ecosystem characteristics (e.g., governance regimes, platform strategies) on characteristics of complementary products and services or on development itself • Definition and emergence of roles and structures underlying value co-creation • Technological generativity due to resource integration within and across ecosystems and its facilitation • Role of boundary resources for value co-creation • Organizational and institutional factors influencing value co-creation	Adner (2017), Cennamo & Santaló (2019), Qiu et al. (2017)
Co-opetition	• Between platform leader and complementors • Between platform leaders and actors in a broader ecosystem • Between complementors • Between platform leader and consumers	Moore (1993), Wang & Miller (2020), Nambisan & Baron (2021)
Governance	• Governance dimensions • Data governance • Decentralized governance	Gawer (2014)
Multilateral relationships	• Platform openness • Selective deviation from ecosystem-wide rules and values • Tiered partnership programs	Adner (2017), Huber et al. (2017), Wareham et al. (2014)

Table 7 (*Continued*)

Property	Research issues	Key references
Interdependencies	• Interdependencies between platform sponsors and platform providers • Interdependencies between complementors and platform sponsors	Adner (2017), Oh & Hong (2018)
Complementarities	• Complementarities between platforms • Implicitly assumed complementarities between products, services, and capabilities provided by third-parties	Jacobides et al. (2018), Kwak et al. (2018)

Source: Own illustration.

The third group comprises 2 out of 21 studies and addresses co-opetitive dynamics between complementors. In this context, one study examines how complementors must position themselves in competition with each other to improve their sales (Roma & Vasi 2019). The other study examines how complementors establish inter-firm relationships (van Angeren et al. 2016).

The last study examines the relationship between platform leader and consumer, examining consumer lock-in (Zanescu et al. 2021).

Overall, several research aspects for each ecosystem property have been explored in the literature. The ecosystem properties, along with the research aspects and key references, are summarized in Table 7.

3.3.2. Definitions of main concepts and distinguishing features between platforms and ecosystems

3.3.2.1. Most commonly used definitions: platforms and ecosystems

Building on the co-word analysis of commonly used platform and ecosystem terms, we analyze the use of the 14 most central terms in the articles studied (see Table 6). In the following, we discuss common definitions of the concepts and their relation to each other and to further concepts.

The general term *platform* is used in various ways. Drawing on Iansiti and Levien (2004a, 148), some studies define a platform from an ecosystem-centric perspective as “a set of solutions to problems that are made available to the members of the ecosystem through a set of access points or interfaces” (e.g., Xu 2017). Building on this definition, Rong et al. (2013) argue that a platform can serve three main functions for the ecosystem, namely interaction interface, value creation, and network formation. Other studies take a more platform-centric viewpoint and consider them as technical architectures or business models. For example, some studies follow Baldwin & Woodard (2009) or Tiwana et al. (2010) and consider a platform as a technical architecture such as modular products or software code (e.g., Sandberg et al. 2020; Choia et al. 2017). In particular, this view emphasizes its function in promoting value creation and determines the division of labor and thus the structure at the ecosystem level (Jacobides et al. 2006). Alternatively, some studies consider platforms as a particular business model based on exchanges between different user groups, as in the case of mobile payments (Kim et al. 2016). Therefore, a platform is considered as an interaction interface within the ecosystem (e.g., Ding et al. 2019; Rong et al. 2013). In addition, Gawer's (2014) definition of a platform as a meta-organization, born out of the platform literature, includes both a modular architecture and actors that generate value. Thus, this definition can be understood synonymously with *platform ecosystem*.

The term *technology platform* goes back to Gawer & Cusumano (2002), who introduced the concept in the context of high-tech industries such as mobile telecommunications and personal computers to emphasize the influence of central platform providers on a network of participants. They define a technology platform as "an evolving system composed of interdependent parts, each of which can be renewed." (p. 2). Thus, the concept combines a business ecosystem with a complex technology and is sometimes used to refer to the technological foundation that underlies innovation activities in an ecosystem (e.g., Qiu et al. 2017; Choi et al. 2019). Examples of technology platforms include, in particular, operating systems (e.g., Quaadgras 2005) or cloud technology platforms (e.g., Khanagha et al. 2022).

The term *open platform* emphasizes the property of a platform to invite external parties to participate (Mukhopadhyay & Bouwman 2018). It is closely linked to open standards and open source and determines the degree of access to a platform and its resources (West 2003; Boudreau 2010). In this context, the openness of a platform can be defined for different roles (cf. Eisenmann et al. 2009). The concept of open platform is in contrast to proprietary or closed platforms and corresponds to the concept of "industry platform" (Gawer & Cusumano 2014). The term is used to draw attention to different roles (Choi et al. 2019) and to the permeability of boundaries (e.g., Wessel et al. 2017; Parker et al. 2017).

Digital platforms denote technical artifacts that differ in their re-programmable nature (de Reuver et al. 2018). The concept is a more general version of software-based platforms (Tiwana et al. 2010) and is related to interoperability (e.g., Smedlund et al. 2018), application programming interfaces (e.g., Hilbolling et al. 2021; van der Vlist & Helmond 2021), and technological generativity (e.g., Um et al. 2013). It originates from the IS literature and emphasizes the socio-technical nature of innovation activities in platform-based ecosystems (Bazarhanova et al. 2020) and is used to study innovation of digital services (Petrik & Herzwurm 2019) and distribution of information goods (e.g., Wang & Miller 2020). In the sample, it is particularly used in contexts of enterprise software (Schreieck et al. 2021), internet of things (Smedlund et al. 2018; Deshmukh et al. 2021), social media (van der Vlist & Helmond 2021; Alaimo et al. 2020), and mobile phones (Dunn et al. 2021). The term is usually used together with the terms *digital platform ecosystem* and *digital ecosystem*.

The general term *ecosystem* refers to either a set of complementary products and services connected to a central platform (e.g., Fang et al. 2021; Weiß et al. 2018), a set of interconnected actors that interact (e.g., Zanescu et al. 2021), or both (e.g., Kapoor et al. 2021). Overall, the ecosystem concept is related to several concepts we discussed in the previous chapter, and is used as a synonym for several ecosystem concepts, in particular "business ecosystem", "innovation ecosystem", "platform ecosystem", and "digital ecosystem", which are also part of the core cluster. Conceptually, it is based on the concepts of *business ecosystem* by Moore (1993) and *innovation ecosystem* by Adner (2006).

Definitions of the term *platform ecosystem* vary across the articles reviewed, considering platform ecosystems as a collection of systems or architectures and complementary assets (e.g., Weiß et al. 2018; Choi et al. 2019), a collection of a platform core, actors, and their offerings (e.g., Kapoor et al. 2021), a group of actors that includes the platform owner, complementors, and end users (e.g., Smedlund et al. 2018), or platform owners and complementors (e.g., Hurni et al. 2021; Zanescu et al. 2021). In particular, the technical definition is close to that of a platform as a modular architecture, where different complementary products and services are connected via interfaces to a stable core (Baldwin & Woodard 2009). In part, the differences go back to the cited definition, which is mostly by either Tiwana et al. (2010) or Gawer (2014).

All of these terms form the core of the platform ecosystem concept, and most articles use a subset of these terms together, which leads to the emergence of the core cluster. From the core cluster, several strands have formed that additionally incorporate other key concepts.

The concepts of *mobile platform* and *mobile ecosystem* reflect the contextual environment of the mobile telecommunications industry (Costa et al. 2013; Qiu et al. 2017). Mobile platforms (i.e., smartphone operating systems) represent software platforms with one of the largest user bases (Soh

& Grover 2020). Google's Android and Apple's iOS platforms are among the most studied platforms in the literature (Rietveld & Schilling 2021), which also holds true for the studies reviewed (see Table 8). While most studies focus on software and related topics, mobile ecosystems also include hardware (Oh & Hong 2018). Thus, they are related to both the IoT cluster and the software ecosystem cluster. Some scholars also consider mobile platforms as important distribution infrastructures for entrepreneurs and their ventures (Kim et al. 2016; Soh & Grover 2020).

Table 8: Overview of identified research contexts in articles studied.

Context	Count	Fraction
not specified	19	17%
mobile phones	18	16%
internet of things	8	7%
enterprise software	6	5%
video games	6	5%
multiple	5	4%
cloud computing	4	4%
software application	4	4%
health care	3	3%
manufacturing	3	3%
social media	3	3%
sharing economy	3	3%
technology standard	3	3%
18 further	27	24%
Total	*112*	*100%*

Source: Own illustration.

The concepts of *service platforms* and *service ecosystems* draw on service-dominant logic and originate from marketing literature (Lusch & Nambisan 2015). Service ecosystems are defined as “a relatively self-contained, self-adjusting system of resource-integrating actors that are connected by shared institutional logics and mutual value creation through service exchange” (Lusch & Vargo 2014, 161). Service ecosystems can be built on top of service platforms, which Lusch & Nambisan (2015) view as “a modular structure that comprises tangible and intangible components (resources) and facilitates the interaction of actors and resources.” (p. 166). In this context, value creation is seen as an act of resource exchange between actors (Lusch & Nambisan 2015), where resources of actors are liquefied by the service platform, which promotes technological generativity (Hein et al. 2019). A particularly important question in this context is which and how (service) companies offer microservices to open up resources for mashup development (Stecca & Maresca 2011). Furthermore, institutional logics are highlighted as factors moderating value co-creation (Lusch & Nambisan 2015). From a contextual perspective, service platforms encompass a wide range of domains that are integrated into daily life (Smedlund et al. 2018) and intersect with larger domains such as social media (Alaimo et al. 2020; Kim 2016) and the sharing economy (Xu et al. 2021). From a business-centric perspective, it addresses the "servitization" of traditional businesses, e.g., in the manufacturing industry (Kapoor et al. 2021), and considers service innovation (Hein et al. 2019).

The concepts of *IoT platforms* and *IoT ecosystems* direct the focus to digital products ("smart things") and the multi-layered modular architecture of digital technologies (Yoo et al. 2010). While covering both physical (hardware) and virtual (software, digital content) domains, issues related to technological standards and interoperability (Deshmukh et al. 2021), B2B service co-creation (Hein et al. 2019; Petrik & Herzwurm 2019), and the digitization of traditional product platforms (Sandberg et al. 2020) play a dominant role. In this context, platforms are embedded in larger ecosystems of device manufacturers, gateway manufacturers, network operators, and application developers (Toivanen et al. 2015).

A *software platform* refers to “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 et al. 2010, 675). While this definition is used by many studies in the sample as it applies to digital platforms in general, the sub-strand on software platforms focuses mainly on software applications (Foerderer et al. 2019; Kilamo et al. 2012; van Angeren et al. 2016). These can be consumer platforms or more complex enterprise software platforms (Foerderer et al. 2019) as well as commercial and open source solutions (van Angeren et al. 2016). The articles in the sample examine web browser applications (Zhou et al. 2018; van Angeren et al. 2016; Song et al. 2018), cloud-based productivity suites such as Microsoft Office365 (van Angeren et al. 2016), and enterprise software (Foerderer et al. 2019). In addition, some studies take a software engineering perspective, where a software application is designed to allow external developers to provide extensions such as "plug-ins" or "add-ons" (van Angeren et al. 2016) while sharing development costs (Kilamo et al. 2012). The focus is thus shifting from traditional in-house development to interorganizational collaborations (van Angeren et al. 2016). A key question is how companies can manage the transition from a standalone software application to a software platform ecosystem (Kilamo et al. 2012). Software platforms form the basis of *software ecosystems* (Eklund & Bosch 2012), which are defined as "a set of businesses functioning as a unit and interacting with a shared market for software and services, together with the relationships among them" (S. Jansen et al. 2009, 187–88). Thus, the ecosystem is conceived as a community of developers, excluding users, and is similar to that of a developer ecosystem (van Angeren et al. 2016).

The concept of a *multi-sided platform* emphasizes the multi-sided structure of platforms and draws on the concepts of multi-sided markets and network effects. It views platforms as business models that create value primarily by enabling interactions between actors (Zhong & Nieminen 2015). Accordingly, the value created can be determined threefold, in the production process on the supply side, matching between supply and demand and its perception on the demand side (Scholten & Scholten 2012). The term *business platform* is used to reflect an economic imperative focused on growth and an underlying multi-sided market logic (Nieborg & Helmond 2019), while it refers to the production part of a platform as opposed to the consumption part (van der Vlist & Helmond 2021).

3.3.2.2. Conceptual differences between platforms and ecosystems

Since the concept of platform-based ecosystems is composed of two concepts that are sometimes used interchangeably, clarity is needed about their distinguishing characteristics. We suggest that a conceptual distinction between both concepts can help promote understanding of mechanisms for evolution, value co-creation, and co-opetition going back to the platform and the ecosystem and studying interactions between platforms and ecosystems. It further helps to improve comparability across studies.

We start by examining the use of platforms and ecosystems across the studies. Overall, most studies emphasize different functions of platforms.[27] The definitions discussed earlier point to four main functions of platforms, namely development tool, distribution channel, interaction interface, and value sharing infrastructure:

[27] Note that platforms do not necessarily have to perform all of these functions.

- *i. Development tool.* A platform provides the basic functionality and development tools for third parties to create their own complementary products and services (Iansiti & Levien 2004b). Participation and development are subject to certain rules and so is value co-creation (Tiwana et al. 2010). The platform integrates complements by ensuring compatibility, thus providing complementarities to its users (Jacobides et al. 2018) and promoting generativity and value.
- *ii. Distribution channel.* Platforms provide distribution channels or marketplaces for the exchange of resources, information, or goods (Qiu et al. 2017; Benlian et al. 2015). They thus serve as an infrastructure for the commercialization of innovations and enable network effects to unfold, as users on the supply side interact with users on the demand side.
- *iii. Interaction interface.* Platforms provide space for interaction between their users and can therefore be regarded as interaction interfaces (Thomas et al. 2014). A platform thus fulfills an organizational function by providing space for interaction, such as social boundary resources ("hackathons", see Fang et al. 2021) or community forums (Qiu et al. 2017).
- *iv. Value sharing infrastructure.* Platforms function as an open business model that determines how value is created and delivered, but also how it is shared between actors (Yun et al. 2017; Mukhopadhyay & Bouwman 2018). In this respect, the platform sponsors usually exercise architectural control in order to have greater bargaining power (Thomas et al. 2014).

In addition, we observe that different structures of ecosystems are adopted in the studies: developer communities, multi-stakeholder systems, networks, or complex systems:

- *i. Community of developers.* The conceptualization of ecosystems most commonly used in the studies reviewed follows the definition of Gawer & Cusumano (2002) and Gawer (2014), who consider a central platform surrounded by an ecosystem of firms providing complementary assets. Complementary products are connected through standardized interfaces (Baldwin & Clark 2000), which allows complementors to form arm's-length relationships with the central platform (Tiwana et al. 2010; Boudreau 2010), resembling a "hub-and-spoke" structure (Baldwin & Woodard 2009).
- *ii. Multi-stakeholder system.* Some scholars emphasize the heterogeneity of ecosystem members, as originally proposed by Iansiti & Levien (2004b), and consider a range of actors such as end-users, research institutes, downstream distributors, telecom operators, and policy makers who align or interact with a platform (e.g., Kilamo et al. 2012; Riasanow et al. 2021). Some scholars further highlight differences in complementors, such as module contributors and mashup developers (Bonina & Eaton 2020) or internal and external developers (Kilamo et al. 2012). In addition, some studies further consider activity and asset flows among actors within an ecosystem including their roles (e.g., Sun et al. 2018; Riasanow et al. 2021), as proposed by Adner (2017).
- *iii. Network.* Some studies consider platform-based ecosystems as networks of actors, drawing on either the literature on two-sided markets (Rochet & Tirole 2003; Katz & Shapiro 1986) or network theory (Freeman 1978; Wasserman & Faust 1994) and interorganizational networks (Ahuja 2000). While the former emphasizes the role of network externalities (e.g., Song et al. 2018; Kim 2016), the latter is used to study positions and clusters within the ecosystem and their evolution (e.g., Basole & Karla 2011; van Angeren et al. 2016).

- *iv. Complex system*. Some scholars highlight the systemic nature of platform-based ecosystems, drawing on the literature on socio-technical systems (Lyytinen & Newman 2008; Garud et al. 2013), multi-level and nested systems (Barile et al. 2016; Muegge 2013), and service systems (Barrett et al. 2015; Lusch & Nambisan 2015) to examine interactions and interdependencies of subsystems or competing systems (e.g., Lee et al. 2020; Kapoor et al. 2021).

Based on these observations, we discuss four distinguishing features between platforms and ecosystems: (1) centrality, (2) stability, (3) level of analysis, and (4) manageability. The findings are summarized in Table 9.

Centrality. An ecosystem is a dispersed group of autonomous entities (actors and/or technical artifacts) that provide resources and may be affiliated with multiple platforms (Ghazawneh & Henfridsson 2013; Hurni et al. 2021). A platform, in contrast, is a central aggregation point that brings actors together, enables exchanges between them, integrates the resources they provide, and provides a set of rules (Thomas et al. 2014; Lusch & Nambisan 2015). Although it is not necessarily the center of a given ecosystem, as multiple platforms may exist in the same ecosystem (Kwak et al. 2018; Lee et al. 2020), it is most certainly the center for certain interactions (Lusch & Nambisan 2015).

Stability. Ecosystems are highly evolvable due to competitive dynamics (Foerderer et al. 2018; Moore 1993), niche creation (Iansiti & Levien 2004b), or network effects (Song et al. 2018; Inoue & Tsujimoto 2018). In contrast, a platform is a relatively stable technology with relatively stable interfaces (Baldwin & Clark 2000). Its evolution is driven by carefully executed generative innovations of the technology core that ensure backward compatibility to some degree (Ozalp et al. 2018). Modularity and boundary resources bridge the varying degrees of stability between platforms and ecosystems.

Level of analysis. An ecosystem is a superordinate construct (e.g., Petrik & Herzwurm 2019) in which network effects unfold and technological generativity emerges. Actors seeing themselves as part of an ecosystem are bound by a common vision, while interdependencies make their fate to some extent dependent on the fate of the ecosystem as a whole (Wareham et al. 2014; Iansiti & Levien 2004b). Ecosystems can therefore be understood as complex adaptive systems (Sandberg et al. 2020). In contrast, platforms are lower-level constructs with less complexity. In particular, a platform is the locus where generativity is harnessed through its modularity and network effects are created through the provision of a central point of interaction (Thomas et al. 2014). A platform thus connects activities and resources at the individual level with the entire ecosystem level (Petrik & Herzwurm 2019; Lusch & Nambisan 2015), where technological generativity and network effects act as backbone.

Table 9: Overview of distinguishing features of platforms and ecosystems.

Distinctive feature	Platform	Ecosystem	Key references
Centrality	• Aggregation point that brings actors together • Enables resource exchange • Integrates resources of third parties • Provides regime of ecosystem-wide rules and values	• Dispersed group of autonomous entities (actors and/or technical artifacts) • Actors may be affiliated with multiple platforms	Thomas & Autio (2014)
Stability	• Relatively stable technology that provides relatively stable interfaces parties	• Evolving set of interconnected actors and technical artifacts	Baldwin & Woodard, (2009)
Level of analysis	• Lower level construct that connects individual level (micro) with ecosystem level (macro) • Technological generativity is harnessed through modularity and network effects created through provision of an interaction interface	• Superordinate construct • Actors to some extent share common visions and objectives • Due to interdependencies, individual actors' fate depends on the whole ecosystem • Source of technological generativity as well as source and target of network effects	Muegge (2013), Lusch & Nambisan (2015)
Manageability	• Manageable object whose architecture and governance regimes can be designed	• Orchestrated through platform governance	Gawer & Cusumano (2014)

Source: Own illustration.

Manageability. An ecosystem cannot be managed directly, but is orchestrated or managed because there are no formal relationships between the central actor and the other actors (Tiwana et al. 2010).

In contrast, a platform is a "manageable object" (Gawer & Cusumano 2014) whose architecture can be designed (Ghazawneh & Henfridsson 2013; Dupont et al. 2017), whose degree of openness can be determined (Benlian et al. 2015; Goldbach et al. 2018; West 2003), and whose participation conditions can be defined (Qiu et al. 2017; Huber et al. 2017).

3.3.3. Research opportunities

By now, our analysis has revealed most impactful references, research groups within the intellectual base, thematic strands, the addressing of main ecosystem properties, definitions of main platform and ecosystem concepts, and conceptual differences between platforms and ecosystems. In this section, we aim to discuss some research gaps and opportunities for future research based on previous findings.

Our conceptual framework of the current state of the art of research with respect to ecosystem properties shows that little is known about complementarities, interdependencies, and multilateral relationships. Despite some scholars considering complementarities as a precondition for ecosystem emergence (Jacobides et al. 2018), research is scarce as to how different levels of complementarities between third-party products and services can be stimulated, how such differences affect ecosystem evolution, and which role complementarities between resources of different platforms play. An example is the study of (Stecca & Maresca 2011) that shows how to provide a development platform for mashup creation. A better understanding of complementarities can also help promote research with respect to value co-creation, as it affects technological generativity (e.g., Um et al. 2013). Similarly, interdependencies are rarely the focus of research ambitions despite their relevance for ecosystem emergence (cf. Adner 2017). Little is known about differences in interdependencies, for example, with respect to different parts of the ecosystem (Kapoor 2018), how they affect evolution and are affected by evolution. Furthermore, little is known, for example, about the role interdependencies play for stabilizing the ecosystem. Lastly, multilateral relationships are usually assumed between a central hub and affiliated complementors (Hurni et al. 2021; Huber et al. 2017). Little is known about multilateral relationships faced by complementors. A starting point is multi-homing, where complementors need to manage relationships with multiple platforms and their end-users. Similarly, the effects between distinct groups of developers (Bonina & Eaton 2020; Kilamo et al. 2012) may provide an additional avenue for further research.

We further noticed a scarce consideration of the surrounding environment in which a platform-based ecosystem is embedded. However, some scholars provide viable starting points for further research with respect to interactions between platform-based ecosystems and political systems (e.g., Xu et al. 2021; Wessel et al. 2017; Garud et al. 2022), societies (e.g., Xu et al. 2021), market structures (e.g., Khanagha et al. 2022; Cozzolino et al. 2021), and infrastructures (e.g., Nieborg & Helmond 2019). For example, Garud et al. (2022) show how Uber was focusing on building up a large installed base of users to create legitimacy and force policy makers to accept their market entry. Wessel et al. (2017) showed in their study how policy changes may affect platform openness and in turn value co-creation in platform-based ecosystems. Cozzolino (2021) show how digital platforms disrupt industry structures. Nieborg & Helmond (2019) show the transition of Facebook from a platform provider to a messaging infrastructure provider.

In this respect, the adoption of an interdisciplinary perspective on the phenomenon such as a socio-economic perspective (Rong et al. 2021; Panico & Cennamo 2022) or a socio-cultural perspective (Khanagha et al. 2022) may help widen the scope and study such interactions.

4. Conclusion, limitations, and further research

The aim of this article has been to review the literature on platform-based ecosystems, focusing on the properties of ecosystems to shed light on the ecosystem lens as such and its use in platform research. In addition, this study examined the underlying intellectual and conceptual structures.

The co-citation analysis reveals three clusters in the intellectual base, with one reflecting the basic ecosystem articles and the other two each forming around the seminal papers by Gawer (2014) and Tiwana et al. (2010). This division reflects, in part, the different definition of ecosystem from a socio-technical perspective (Gawer, 2014) and a predominantly technical perspective (Tiwana et al., 2010). On the other hand, both clusters have different disciplinary focuses, with the cluster around Gawer (2014) being more anchored in strategic management and technology and innovation management, while the cluster around Tiwana et al. (2010) has stronger references to information system research.

The thematic analysis reveals six thematic clusters that can be understood as sub-strands within the literature. In addition to the core cluster, which contains the essential terms such as technology platform, digital platform, and business ecosystem, we observe one thematic cluster each on mobile platforms, software platforms, service platforms, IoT platforms, and multi-sided platforms. In this context, software platforms and service platforms in particular have distinct definitions.

The content analysis on the main characteristics of ecosystems shows a research focus on (co-)evolution, value co-creation, and co-opetition. Complementarities, interdependencies, and multilateral relationships are mainly considered exogenous and, accordingly, appear in our framework only as conditioning factors that can influence the three aforementioned properties. Furthermore, in some studies we observe the inclusion of interactions with surrounding systems (political system, society, markets, and infrastructure).

Finally, we identify the four main functions of platforms for ecosystems (development tool, distribution channel, interaction interface, value sharing infrastructure) and the conceptualizations of ecosystems (community of developers, multi-stakeholder system, network, complex system, infrastructure) and we derive four differentiators between platforms and ecosystems: centrality, stability, level of analysis, and manageability.

Overall, the article carried out a systematic literature review on platform-based ecosystems. Despite the systematic nature of the review, which reduces selection biases, it comes with some limitations. An important aspect in this regard is the possible absence of important articles in the selected databases ISI Web of Science and Google Scholar, as they may not be complete. Nevertheless, our approach allows for a more comprehensive sample than some other reviews because, in addition to articles from ISI Web of Science, it also includes documents from Google Scholar as well as other document types such as book chapters and proceedings articles. In addition, the bibliometric analysis allows us to include important articles that were not covered in the original sample.

The review identifies research gaps with respect to the role of complementarities, interdependencies, and multilateral relationships. Furthermore, few researchers study the interactions between platform-based ecosystems and their enclosing systems.

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Paper II:

Compatibility Promotion Between Platforms: The Role of Open Technology Standards and Giant Platforms

Sven Niederhöfer & Sebastian Späth

Abstract

Background Most platform literature focuses on individual platforms and their governance, e.g. with respect to app developers. We believe this ignores platform-to-platform relationships and the role of standards. Nonetheless, platforms are increasingly forming connections with each other and building complex constellations.

Aim Therefore, the goal of this study is to investigate how platform sponsors select compatible platforms to promote, with our focus on open standards and giant platforms.

Method To address these questions, we construct a unique data set covering 157 platforms in the smart home market. We conduct a network analysis based on an exponential random graph model (ERGM) to incorporate platform features, dyadic characteristics, and structural processes.

Result We find that platform-to-platform compatibility promotion comes down to a careful selection of platforms with dissimilar industry sectors and ecosystem niches. We test two efficient strategic approaches to select compatible platforms to promote based on standard complementarity and size of installed base. We find that platforms more often promote other platforms with similar supported standards. The majority of endorsements are directed at giant platforms, allowing platforms to support a smaller number of standards and thus reduced degree of openness at the technology level. Nevertheless, platforms usually only integrate several giant platforms at the same time. Our study makes two major contributions to the literature. First, we extend the concept of selective promotion (Rietveld et al. 2019) to include inter-platform compatibility and studying open technology standards. Second, we demonstrate how platform sponsors compensate accessibility at the technology level with transparency at the marketplace level.

This paper is currently under review for the Special Issue on “Standardization in Platform Ecosystems” in Electronic Markets (third round).

1. Introduction

Digital product platforms (Hilbolling et al., 2020; West, 2003), which comprise physical devices with embedded digital functions and are organized along a layered modular architecture (Yoo et al., 2010), enable the building of vibrant ecosystems of interconnected products and services around a platform (Henfridsson et al., 2018). Platform ecosystems consist of a relatively stable core - the platform - and a set of complementary products and services in the periphery that are connected to the platform via standardized interfaces (Baldwin & Woodard, 2009). In the area of home automation within the Internet of Things (IoT), such complex product systems are installed in the homes of end users, forming local infrastructures of "smart" devices from multiple vendors that are interconnected via communication standards (Rowland, 2015a, 2015b).

The platform business model has become the dominant model in some industries (Rietveld & Schilling, 2021), changing their structures and driving their convergence. In the smart home market, even manufacturers of conventional products try to launch digital product platforms to gain a foothold in the platform business (Shin et al., 2018). Examples include lighting manufacturers such as Signify and home appliance manufacturers such as LG Electronics. They are offering platform solutions in order to control a wide range of complementary smart home devices, including their own.

Smart home systems encompass many application areas (cf. Shin et al., 2018) that exceed a single company's product portfolio. At the same time the value of the entire platform depends on the availability of various complementary products (Boudreau, 2010; Gawer, 2009), as a consequence interdependencies arise between the actors in the smart home market. These interdependencies are exacerbated by users' desire for cross-vendor compatibility (Shin et al., 2018).

Therefore, platform sponsors often need to open their platforms to third-party participation - including competitors - in order to provide a comprehensive offering to their customers. Access to a platform includes not only access to technical resources such as the code base, but also access to a market of users of the platform through its distribution channels (Benlian et al., 2015). Platform openness generally refers to the extent to which external actors have access to a platform's resources and the constraints on their use (Boudreau, 2010; West, 2003) and comprises two broad dimensions: accessibility and transparency (Benlian et al., 2015).

An often-overlooked factor in previous research, is the choice of open technology standards (West, 2003), which determine the subset of products and platforms that are compatible at the hardware level. In the case of smart home products, wireless communication protocols such as ZigBee, Z-Wave, or Bluetooth Low Energy are of particular importance because they are embedded in hardware and are certified and promoted to consumers through the alliances behind those standards. In addition, wireless communication protocols are often open standards (West, 2003).[28] By selecting a set of supported technology standards, a platform sponsor can specify in the design phase of the platform and products with which third-party products and platforms they can interoperate.

Platform openness implies a strategic dimension: while it is necessary to leverage the capabilities of external complementors in order to increase variety of complements, it also requires some loss of control, which Boudreau (2010) calls the tradeoff between variety and control. Particularly, open technology standards that enable communication between smart devices allow platform providers to make devices from other platform providers compatible without collusion (West, 2003). As a result, digital product platforms are increasingly interconnected, forming complex platform constellations (Mosterd et al., 2021) or "ecologies of platforms" (Hilbolling et al., 2020). Platform providers on the smart home market thus simultaneously act in the role of complementary providers for other platforms, intentionally or unintentionally.

This dual role of platform providers as complementors to other platforms enables some tactics to signal openness to end users while diverting their attention from direct competitors. This strategic tension can be addressed through endorsement (Rietveld et al., 2019). For example, it can be observed that platform providers, such as Samsung only promote third-party products as compatible, which are not in their own product portfolio.

At the same time, large platforms established in other markets, such as Apple, Google or Amazon, have entered the smart home market and offer certification programs to establish interoperability between platforms. Previous literature has highlighted the importance of such giant platforms in cross-platform compatibility considerations (e.g., Hilbolling et al., 2020).

[28] This study refers to open wireless communication standards that are integrated into many smart home products. A table with the standards considered and their properties can be found in appendix A10.

Taken together, it becomes apparent that it is vital to understand the role of open technology standards in platform ecosystems and how platforms promote compatibility with one another in light of platform openness and platform competition. Against this backdrop, we address the following research question:

RQ1: How do platform sponsors choose the platforms to promote with respect to technology standards and platform type (i.e., giant vs non-giant)?

To address this question, we perform two consecutive content analyses on data retrieved from several web-based sources, accompanied by a network analysis of relationships between platform sponsors. In doing so, we construct a unique data set covering 157 platforms in the smart home market.

This study is expected to contribute to extant literature on several fronts. First, we extend the research on platform strategy by introducing the concept of compatibility promotion as a particular form of selective promotion (see Rietveld et al., 2019). In contrast to selective promotion, compatibility promotion is used by platform sponsors to sift through the shared stock of complementary devices that goes back to different platform ecosystems to make a considerate decision about which devices to promote, taking into account the characteristics of the platform in each of these ecosystems, in order to strike a balance between adoption and appropriability. We test two strategic approaches to promoting selected platforms as compatible, based on (1) standard complementarity and (2) size of the installed base of the platform (giant platforms). We find strong support for the second approach, with giant platforms receiving most of promotions, while the likelihood to promote giant platforms is conditioned by the number standards and the number of giant platforms with which promoting platforms integrate. In particular, platforms promoting giant platforms support fewer open technology standards, reducing the degree of openness at the technology level and overall costs. At the same time, we observe a strong preference to integrate with multiple giant platforms simultaneously, which we believe serves to mitigate potential platform envelopment. As such, two strategic preferences arise contingent on the number of standards supported: (1) integrating with multiple giant platforms for fewer standards, and (2) promoting more non-giant platforms with similar sets of supported technology standards when supporting more standards. Overall, platforms in our sample can be divided into two groups, with one group integrating at most two standards and one group integrating more than two standards.

We identify further factors driving compatibility promotion. Second, we extend platform research on platform openness, particularly focusing on the multidimensionality of openness. We find empirical evidence to promote compatible platforms based on dissimilarity in primary industry sector and ecosystem niches, suggesting that platforms compensate higher accessibility at the technology level due to open technology standards with adjusting transparency about compatibilities to end users at the marketplace level.

The paper is organized in six sections. In the following section, we derive our research model for platform-to-platform compatibility promotion, drawing on literature of platform openness and platform competition on compatibility. Next, we elaborate our research setting, describing the content analyses and network analyses as well as our research context before passing on to the presentation of our results from the network analysis. The last section concludes the paper by discussing our contributions and the limitations of our study and ponder possible future research.

2. Theoretical background and hypotheses development

2.1. Platform-to-platform compatibility promotion

A platform's value is determined by the availability of various complements, their quality, and the end users' perception of these (Boudreau, 2010; Gawer, 2009; Schilling, 1998). Previous literature has discussed various approaches to platform openness to manage ecosystem value, including governance measures such as control mechanisms and information policies (Benlian et al., 2015), partner programs (Wareham et al., 2014), and boundary resources (Ghazawneh & Henfridsson, 2013), predominantly considering openness towards developers. Recent literature highlights the multifaceted nature of openness in relation to different activities and actors (e.g., Benlian et al., 2015; Boudreau, 2010; Broekhuizen et al., 2021). As such, openness can be defined with respect to different roles (Eisenmann et al., 2009), including competing platforms (e.g., Karhu et al., 2018) and accordingly determines how platforms connect and interact (Mosterd et al., 2021). Platform-to-platform openness offers the potential to extend the functionality of a (complementary) platform and its connected complements (Mosterd et al., 2021). Ondrus et al. (2015) also point out that interoperability between platforms can lead to higher market potential.

Openness is closely related to network externalities, particularly in the initial phase (Ondrus et al., 2015), requiring platform sponsors to achieve a certain degree of openness that fosters adoption by leveraging network effects, while maintaining enough control for value appropriation (West, 2003;

Eisenmann et al., 2009; Landsman & Stremersch, 2011). West (2003) describes this tension as 'adoption vs appropriability'. Vast literature highlights the role of network externalities underlying competitive dynamics between platforms, which can lead to a tipping of the market and thus a winner-take-all outcome (e.g., Farrell & Saloner, 1992; Katz & Shapiro, 1985; Schilling, 2002). In markets with strong network externalities, platform companies may therefore be particularly inclined to rapidly build an installed base to gain a competitive advantage (Cennamo & Santalo, 2013; Parker & Van Alstyne, 2005). In this context, fostering network effects by offering sufficient complementary products is particularly important to overcome initial barriers to adoption (e.g., Armstrong, 2006; Caillaud & Jullien, 2003).

In an attempt to balance adoption and appropriability, Ondrus et al. (2015) derived a framework, distinguishing three levels of openness - provider, technology, and end users – that reflect restrictions imposed to each of these groups. At the technology level, platforms may establish compatibility to other platforms through the adoption of common technology standards (Ondrus et al., 2015; Farrell & Saloner, 1992).[29] Generally, platform sponsors face the decision whether or not to make their platform compatible with that of competitors (Besen & Farrell, 1994).

As such, even if de facto compatibility exists, platform sponsors have a stake in steering (prospective) end users' attention away from rivals' offers. We draw on Rietveld et al.'s (2019) concept of selective promotion to derive our theoretical concept of compatibility promotion. Selective promotion denotes a strategic approach of deliberately choosing a subset of compatible (software) complements to promote, with the aim of increasing perceived value of a focal platform ecosystem. In contrast, compatibility promotion involves screening of a shared stock of complementary devices that goes back to different platform ecosystems and making a considerate choice as to which devices to promote in light of the platform's characteristics in each of these ecosystems in order to balance adoption and appropriability.[30]

While compatibility may be promoted to complements and platforms alike (Mosterd et al., 2021), we focus on platform-to-platform compatibility promotion, where platform sponsors deliberately choose platforms and their complements to promote. As such, platform-to-platform compatibility

[29] Compatibility denotes "the ability of machines, especially computers, or computer programs to work successfully with other machines or programs." (https://dictionary.cambridge.org).
[30] This also comprises software complements, but is not within the focus of this study, as we are interested in the role of wireless communication protocols connecting complementary hardware devices.

promotion reflects the coopetitive nature of relationships in ecosystems (Bogers et al., 2019), appearing as established and promoted compatibility. This implies that platform sponsors combine openness at the technology level (adoption of open technology standards) with openness in their marketplaces (which categories and brands to curate) with transparency as the dominant dimension (Benlian et al., 2015; Broekhuizen et al., 2021).

Specifically, the consideration of compatibility between competing platforms is crucial, as it makes it easier for consumers to substitute platforms (David & Greenstein, 1990). Thereby, particularly open technology standards make it easier to build up a large and diverse set of complementary products and services across platforms, but make it more difficult for an individual platform to reach the critical mass (Ruutu et al., 2017). By adopting open technology standards, a platform devolves some control to industry committees that decide on these standards (West, 2003).

While a lower level of compatibility makes it easier for platform sponsors to differentiate from competing platforms, weakening its competitive position, a higher degree of visible compatibility (cf. Besen & Farrell, 1994) increases the value perceived by users, making the platform more useful, which may facilitate adoption. Thus, platform sponsors may address this tension by decreasing the level of compatibility by adjusting openness of boundary resources (Eaton et al., 2015; Karhu et al., 2018) or promoting certain complementary products and services in a favorable way (Rietveld et al., 2019). The level of compatibility between platforms and their respective ecosystems is hence influenced by strategic tradeoffs concerning platform openness and competition.

Especially in the IoT area, platforms predominantly go back to manufacturers of conventional products who digitize them and often offer complementary cloud services for them. Despite the introduction of a platform, not all manufacturers necessarily then adopt a platform logic that provides access to manufacturers of complementary products by opening up the platform to stimulate overall growth (Pellizzoni et al., 2019; Sandberg et al., 2020). Instead, some may choose to follow a product manufacturer's logic and maintain the focus on selling their complementary products due to the market position of the firm (Eisenmann et al., 2009) or maturity of the firm or platform (Boudreau, 2010), resulting in a rather closed platform.

Both openness to complementors and to platforms will often be correlated, since companies do not necessarily distinguish between different forms of openness (Mosterd et al., 2021). Still, a higher degree of openness exposes a platform to threats from competitors (Eaton et al., 2015; Ghazawneh & Henfridsson, 2013; Karhu et al., 2018), making competition between platforms an important factor influencing openness decisions (Mosterd et al., 2021). This is likely to be particularly evident in the IoT sector with product manufacturers subject to certain competitive structures within their industries. Accordingly, we expect to observe platform-to-platform compatibility promotion to be an approach to balance openness and competition, and hypothesize:

H1: Platform-to-platform compatibility promotion is positively related to the degree of marketplace openness of a platform, negatively moderated by the level of competition.

2.2. Compatibility promotion to platforms with complementary standards

There is at least two approaches to establish and promote compatibility, either in a direct fashion to certain platforms or indirectly by leveraging converters (Mantera & Sara, 2012; Ondrus et al., 2015). In a direct fashion, a platform can establish compatibility to another platform at two different levels: (1) software level and (2) hardware level. At the software level, interoperability can be established through direct cloud-to-cloud integrations, usually by opening application programming interfaces (APIs) to specific partners (Rowland, 2015b). APIs are typically based on more general standards such as the Internet Protocol, and are based on flexible software frameworks that provide platform sponsors with greater design freedom. As such, platform sponsors can implement control mechanisms to regulate access to and use of platform resources (Ghazawneh & Henfridsson, 2013; Karhu et al., 2018).

At the hardware level, interoperability can be achieved through common interoperability standards that allow two platforms to understand each other semantically (Rowland, 2015a). In this context, platform sponsors can provide gateway devices that act as converters between more specialized standards used locally by devices and more general standards such as Wi-Fi or the Internet Protocol for connecting to the Internet (Rowland, 2015b). Overall, compatibility decisions at the hardware level can be described as adoption decisions related to open technology standards (West 2003).

Generally, a technology standard can be understood as "a set of specifications to which all elements of products, processes, formats, or procedures under its jurisdiction must conform" (Tassey, 2000, p. 588). Standards can vary in the degree of openness, with proprietary and open source representing the extremes (West, 2003). West (2003) assumes that proprietary standards are developed by a platform sponsor for its own use, with an appropriation regime. In contrast, more open technology standards are subject to fewer constraints on their integration into products, their certification, and their commercialization (West, 2007; Boudreau, 2010).[31]

Adopting open technology standards eliminates the need to identify and grant access to complementors because interoperability is de facto established (Funk, 2003; West, 2003). Any firm that integrates the standard into a product inevitably becomes a complementor to that platform. As such, it contributes to the formation of "arm's length relationships" (Boudreau, 2010) where platform sponsors cannot exercise direct control over complementors.

At the same time, a platform ecosystem that supports certain open standards and thus practices openness at the hardware level also makes its own complementary products available to other platforms, which affects platform competition (cf. Besen & Farrell, 1994; Farrell & Gallini, 1988). The more standards two platforms share, the greater the overlap in complementary products that both support, leading to multi-homing in offerings (Armstrong, 2006) and reducing differentiation between platforms (Hagiu & Lee, 2011), gradually driving consumers indifferent between competing platforms but increasing overall incentives for adoption (Landsman & Stremersch, 2011). While standard adoption choices usually go back to characteristics of the standard and the alliance developing the standard (Leiponen, 2008; Baron & Spulber, 2018) and drive openness at the technological level, transparency about the resulting cross-platform compatibility at the marketplace level positions the platform within the network of platforms (Henfridsson et al., 2018). However, firms face resource constraints, affording efficient strategic choices.

As such, in order to differentiate their platforms from those of competitors by selecting how dissimilar the complements in two ecosystems should be (Cennamo & Santalo, 2013), while facing a fragmented market consisting of several competing, yet complementary standards, an efficient way to cover most of the technology standards and thus devices, can be achieved by promoting platforms with a complementary set of supported technology standards. Particularly, different technology standards usually serve different purposes and thus come with different technical

[31] Please note that a distinction between proprietary and open standards is not easy, as there are different perceptions with respect to criteria for openness West (2007). For our study, we consider open standards as communication standards that can be adopted by interested parties and are thus shared by many firms, leading to compatibility. We leave further criteria such as restrictions with respect to participation in standard development and royalty fees out of scope.

specifications (Chaudhary et al., 2021), fitting different use cases unequally well (Rowland, 2015a)[32], and thus drive technology standards complementary to some extent.

Taken together, this could lead platform sponsors favoring other platforms with a certain degree of difference in standard configuration, appearing as an inverted-U shape relation between standard overlap and platform-to-platform compatibility promotion:

H2: Platform-to-platform compatibility promotion exhibits an inverted U-shaped relationship to the standard overlap between two platforms.

2.3. Compatibility promotion to giant platforms

Alternative to promoting compatibility in a direct fashion to certain platforms, platform sponsors can choose to promote giant platforms (Hilbolling et al., 2020). Particularly, for smaller platforms, one viable approach is to establish compatibility with a platform that has a larger installed base of users (Katz & Shapiro, 1985, 1992; Venkatraman & Lee, 2004). Empirical results show that this can lead to demand spillover effects (Li & Agarwal, 2017), or at least awareness spillover effects where a third party gains increased awareness by offering complementary goods on a well-known platform (Song et al., 2021). Compatibility with larger platforms is particularly critical in markets with "excess inertia," i.e., the market is biased toward existing products (see Katz & Shapiro, 1992). Some scholars therefore argue that compatibility with dominant players is preferable (Cusumano & Gawer, 2002; Xie & Sirbu, 1995). For example, Venkatraman & Lee (2004) demonstrate that game developers in the video game industry are more inclined to join a dominant platform.

Platforms seeking platform leadership within the market must fulfill a fundamental function for the industry (Cusumano & Gawer, 2002). Addressing fragmentation in standards by creating interoperability between platforms represents such a function, allowing a broader platform to concentrate many interconnections from more specialized platforms and improve its value appropriation capabilities (Henfridsson et al., 2018). Accordingly, they can influence the industry architecture in their favor and become a “bottleneck” (Jacobides et al., 2006). This is especially the case for digital technology markets, where platforms occupy different positions in the technology stack (Yoo et al., 2010) and can jointly create a market by offering different complementary functions (Kwak et al., 2018).

[32] For example, Wi-Fi achieves higher data rates than ZigBee and can transmit video data, but also has higher power consumption and is therefore unsuitable for battery-powered devices such as light switches.

Hence, to overcome the adoption barrier of fragmentation, platform sponsors seeking compatibility with a larger set of devices may choose to certify their products with one or multiple giant platforms. This yields three predominant benefits: First, by certifying the interoperability of all devices and platforms that integrate with the giant platforms, they act as a de facto “converter” (Farrell & Saloner, 1992) within the network of connected platforms. This reduces the need to adopt multiple technology standards and the associated costs, since integrations with giant platforms are typically implemented via cloud-to-cloud connections over the Internet Protocol (Hou et al., 2017; Rowland, 2015b). Second, platform sponsors do not need to promote compatibility with direct rivals, but can establish an indirect path via giant platforms. Third, as giant platforms offer co-branded certification programs (i.e., "works-with" logos)[33] while having large installed bases of users, the potential of demand spill-overs opens up (Li & Agarwal, 2017). Accordingly, platform sponsors can signal users of giant platforms a quick and easy entry in using their platform, lowering perceived barriers to adoption.

Yet, integrations with giant platforms drive up coordination costs as they require technical changes to the devices and platforms and increase the platform’s dependence on the giant platform (Hilbolling et al., 2020). These costs are in addition to the cost of memberships and product certifications with standards development organizations. For some giant platforms, in addition to certifications with all standard development organizations, products must then go through the certification process with the giant platform before it can be launched into the market.[34]

Hence, we expect integrations with giant platforms to be particularly attractive for platforms not supporting many open technology standards natively. Therefore, we hypothesize as follows:

H3: Platform-to-platform compatibility promotion towards giant platforms negatively interacts with the number of open standards a promoting platform supports.

While integrations with giant platforms offer benefits, it harbors the danger of “platform envelopment” (Eisenmann et al., 2011) by the giant platforms. In particular, by integrating with giant platforms and obtaining demand spillovers, the user bases of the integrating and giant platforms become gradually more similar, which improves the conditions of platform envelopment

[33] https://partnermarketinghub.withgoogle.com/brands/google-assistant/, https://developer.apple.com/homekit/, https://developer.amazon.com/en-US/alexa/devices/connected-devices/business-resources/works-with-alexa
[34] https://developers.google.com/assistant/smarthome/concepts/fulfillment-authentication, https://smartthings.developer.samsung.com/docs/devices/hub/hub-connected-device.html

by the giant platform. In addition, users can draw on applications of the giant platform, sidelining the initial offer of the integrated platform and further increasing the risk.

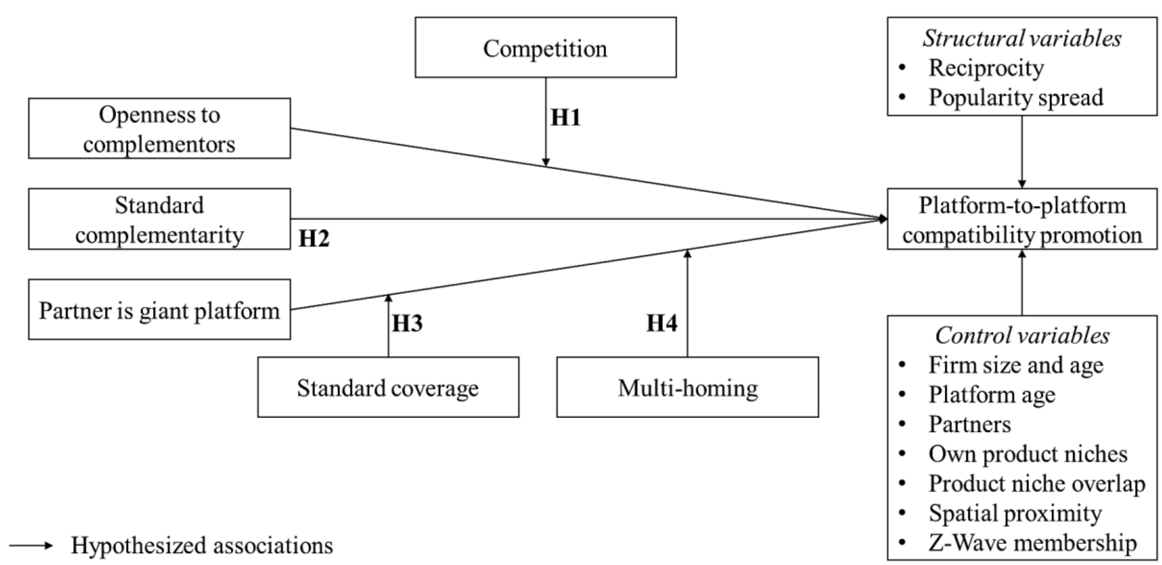
One way to mitigate the risk of envelopment by a giant platform is to integrate with several giant platforms (Hilbolling et al., 2020). This way, a platform sponsor can reduce dependency on one particular platform and increase the leeway to respond to hostile approaches by a giant platform. In addition, platform sponsors also increase potential benefits of such integrations with multiple giant platforms as these may host installed bases of users that may complement one another (e.g., Android users versus iOS users), increasing potential spillover effects. Taken together, we thus posit that:

H4: Platform-to-platform compatibility promotion towards giant platforms is conditioned by multi-homing to multiple giant platforms.

2.4. Research model

Based on our literature review, we have derived our research model as illustrated in Figure 7.

Figure 7: Research model.



Source: Own illustration based on Mosterd et al. (2021).

Note: Arrows denote associations. Competition, standard complementarity, product niche overlap spatial proximity are edge covariates, whereas all the other variables are nodal attributes.

The premise of the model is that platform-to-platform compatibility promotion reflects transparency at the marketplace level about de facto established compatibility at the technology level, balancing adoption and appropriability (H1). The model therefore tests two efficient strategic approaches to cover most of the standards, compatibility promotion to platforms with different standards in a direct fashion (H2) and to giant platforms reaching the market in an indirect fashion (H3, H4). As such, the model reflects some of the factors underlying openness decisions at the technology level as identified by Mosterd et al. (2021), providing the starting point for promoted compatibility in the marketplace. To this end, we focus first on the fundamental decision to open up (organizational factor) and second on competition between firms (market level factor).

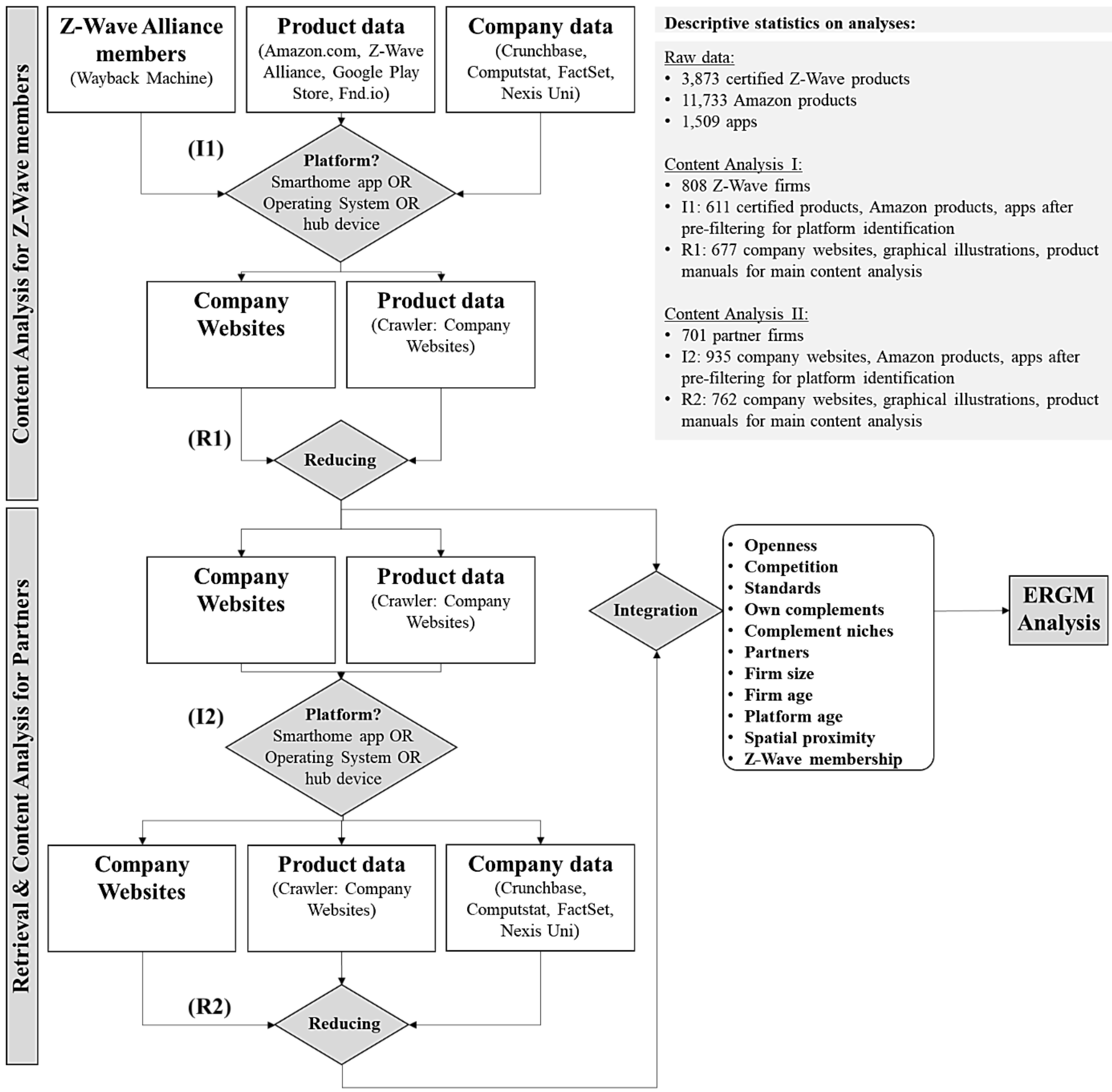
3. Research methodology

3.1. Data sources and content analyses

We chose the context of the Internet of Things because it offers a fragmented environment with several competing technology standards that have emerged in recent years and covers a variety of platforms. We focus on the smart home market as one of the most established (consumer-facing) application areas of IoT technology (Chaudhary et al., 2021). This environment provides an interesting context for exploring our research question, as there are network externalities that force companies to quickly establish connections to complementary products and services to gain a competitive advantage (Katz & Shapiro, 1985; Schilling, 2002). At the same time, they share a common stock of devices that support the same standards, making competition more difficult (Landsman & Stremersch, 2011). Although platform providers aspire to leadership within a market (Cusumano & Gawer, 2002), no single market leader has yet emerged (Ali & Yusuf, 2018), while at the same time giant platforms like Google and Amazon have entered the playing field (Shin et al., 2018).

The entire data collection process is guided by two successive web-based content analyses (Krippendorff, 2004; McMillan, 2000), as illustrated in Figure 8 and described in more detail in the online appendix. Content analyses allow scholars to obtain a systematic, objective, and quantitative description of the content of (transcribed) conversations, articles, and other texts. In addition, it allows for the inclusion of more context in the analysis by considering graphical representations and the nature of the document (cf. Krippendorff, 2004).

Figure 8: Overview of data collection and analysis.



Source: Own illustration.

As a starting point, we expanded a data sample we had previously created by crawling (Baron & Spulber, 2018; Leiponen, 2008) member companies of the Z-Wave Alliance, a consortium of more than 800 companies that manufacture products based on the Z-Wave standard.[35] The Z-Wave standard provides a relevant research context, as it is embedded in more than 3,000 smart home

[35] The data sample comprises all member firms between 2005 and 2019, aggregated to one list. All data on products and apps as well as all documents for the content analyses and network analysis were collected in 2020.

products, constituting a larger part of the overall market, with a tiered membership structure allowing an easy adoption and certification.[36]

Overall, we consider a firm to be a platform firm if it offers (1) a smart home app, (2) home automation software, and/or (3) a standalone device that can be used to connect and control a variety of smart home products. We exclude pure cloud service providers as we are interested in consumer-facing platforms where network effects are particularly relevant.

In total, 157 firms meet at least one of our criteria, of which 81 are Z-Wave firms and 76 are partner firms.

3.2. Network analysis

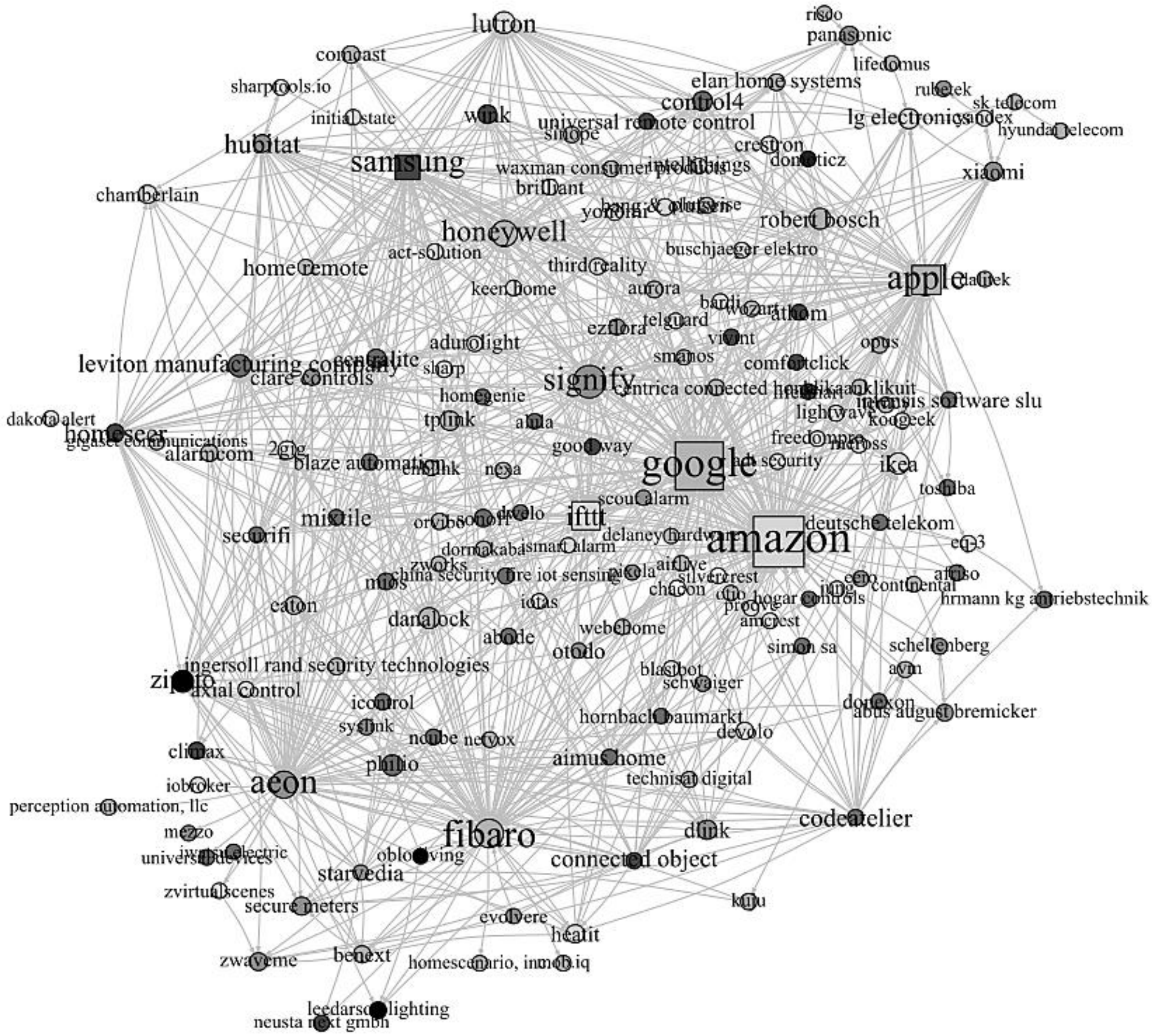
We conducted a network analysis in order to tackle our research questions. We could not simply use a logistic regression with compatibility promotion as the dependent variable, since a platform company's decision to cooperate with other platforms depends partly on structural characteristics of the network itself, e.g., on how many other actors promote compatibility with a given actor (Albert & Barabási, 2002) due to network effects. Consequently, observations are not independent, violating a fundamental assumption of general linear models (Pattison & Wasserman, 1999; Robins, 2014).

To account for the structural features that underlie firms' decisions, we rely on network analysis as a method that allows us not only to estimate social processes and structural features that govern network formation, but also to visualize relationships and simulate networks (Borgatti & Halgin, 2011; Oinas-Kukkonen et al., 2010).

We use an exponential random graph model (Pattison & Wasserman, 1999; Wasserman & Pattison, 1996) to estimate the underlying processes. In recent algorithms (such as in the "*statnet*" R package we used), ERG models are usually estimated using Monte Carlo Markov chain maximum likelihood estimation (MCMC-MLE), taking starting values from a computationally less expensive maximum pseudo-likelihood estimation (Robins, 2014).

[36] https://z-wavealliance.org/

Figure 9: Network graph of platform-to-platform compatibility promotion in the Z-Wave-based smart home market.



Source: Own illustration based on the network data.

Note: Network plot of all 157 platforms positioned using Multi-Gravity ForceAtlas2 algorithm. Node size reflects in-degree, node color corresponds to number of supported standards (white = 0, black = 7). Node shape reflects whether it is classified as giant platform (square shape) or not (circle).

Generally, an ERGM is modeling an observed network by weighting hypothesized network statistics (parameters) using the following form

$$\Pr(\boldsymbol{X} = \boldsymbol{x}) = \left(\frac{1}{k}\right) exp\left[\sum\nolimits_{A} \eta_A g_A(x)\right]$$

where $\boldsymbol{X}$ and $\boldsymbol{x}$ are the adjacency matrices of the predicted and observed networks; A refers to different network configuration types (i.e., triangle, reciprocated tie, etc.) to be included in the estimation; η_A reflects the relative importance of each configuration type in A, $g_A(x)$ is the network statistic (i.e., edge count, triangle count, number of reciprocated ties, etc.) for each type in A; k normalizes the exponential function to fit a proper probability distribution (cf. Robins, 2014).

For our analysis, we construct a network graph consisting of platform firms as nodes connected by directed (unweighted) edges, indicating whether a platform sponsor (sender) promotes compatibility with another platform ecosystem (receiver). The edges here include listed partners, manufacturers of listed complementary hardware, and integrations to platforms ("works-with" logos, see Hilbolling et al., 2020). The network consists of 157 nodes and 879 directed edges, as shown in Figure 9. For our analysis, we resorted to the statnet package for R (Handcock et al., 2008).

We include nodal attributes and edge covariates to capture platform-specific and relational effects. Nodal attributes (i.e., firm and platform attributes) capture differences in selection (out-degree) or attraction (in-degree) arising from differences in idiosyncratic characteristics of a sender or receiver, respectively. Dyadic parameters capture social selection processes such as homophily (heterophily), in which actors in a network form edges with actors who are similar (different) in certain characteristics (McPherson et al., 2001; Robins, 2014). Structural effects generally capture decisions based on an actor's perception of topological features. We follow the general recommendation to incorporate at least one parameter for network density and parameters for degree distributions and triad closure to account for the network structure at different levels (Robins et al., 2009; Snijders et al., 2006).

3.3. Variables and measures

In our model, we predict *Platform-to-platform compatibility promotion* (PCP), which is reflected by the formation of a directed edge in the network graph. We consider several parameters in our analysis. An overview of parameters and measures included in our model is presented in Table 10.

Main parameters. To measure the effect of a platform's underlying tendency to be open, we introduce the network statistic *Sender(Openness)*, which reflects the number of platforms with a product marketplace or compatibility list published on their websites. We measure the effect of competition via the Standard Industrial Code (SIC), introducing a network statistic *Competition* that reflects the number of platform firms that are active in the same primary industry. We test Hypothesis 1 by the interaction of *Sender(Openness)* and *Competition*.

To account for selection preferences going back to heterophily in standards (H2), we construct a valued sociomatrix with edge weights corresponding to the overlap in the standard sets S_i and S_j of two nodes i and j, defined as the Jaccard Index $S_i \cap S_j / S_i \cup S_j$. We then introduce a network statistic *Standard overlap* that computes the edge covariates to determine the relationship between standard overlap and compatibility promotion.[37] We also add a network statistic *Standard overlap^2* to test for the existence of a maximum in standard overlap, which is analogously incorporated and defined as $(S_i \cap S_j / S_i \cup S_j)^2$. We do this by using open technology standards rather than all standards (i.e., also proprietary standards), as they better reflect baseline interoperability of a platform.[38]

In addition, we incorporate the network statistic *Receiver(Giant platform)*, which counts the number of platforms that are classified as giant and receive compatibility promotion, to measure the basic propensity to promote compatibility with giant platforms. We classify a platform as giant if it provides a certification program to address the bottleneck of incompatibility and offers co-branding in the form of a "work-with" logo. Following these criteria, we classify Apple (HomeKit), Amazon (Alexa), Google (Google Assistant), Samsung (SmartThings), and IFTTT as giant.[39]

To capture the effect of the number of supported technology standards on the propensity to promote compatibility, we include a nodal covariate *Sender(Standards)*. We use the count of open standards to construct these measures. To measure the propensity for edge formation from a platform to a giant platform, which is conditional on the number of technology standards supported by the sending platform (H3), we add the *Sender(Standards) x Receiver(Giant platform)* interaction as a network statistic in our model.

[37] In easier terms, we can think of it as constructing an additional network for each variable, consisting of edges (i → j) that – reflected by their edge weights – measure the degree of homophily between i and j for a given attribute (e.g., standards). Yet, we do not add these edges to our actual network, as this would drastically change network statistics, such as degrees. In contrast, we compare the network of actual relationships to the homophily networks by computing correlations for edges connecting the same nodes.
[38] See A10 for an overview of considered standards.
[39] See A10 for an overview of considered giant platforms.

Table 10: Overview of effects included in the ERGM estimation for P2P compatibility promotion.

Parameter	Diagram	Hypotheses	statnet term
Main parameters			
Sender(Openness)			nodeofactor(Openness)
Competition			nodematch(SIC)
Sender(Openness) x Competition		H1	nodeofactor(Openness): nodematch(SIC)
Standard overlap *Standard overlap^2*		H2	edgecov(Standard overlap) edgecov(Standard overlap^2)
Receiver(Giant platform)			nodeifactor(Giant platform)
Sender(Standards)			nodeocov(Standards)
Sender(Standards) x Receiver(Giant platform)		H3	nodeocov(Standards): nodeifactor(Giant platform)
Sender(Multi-homing)			nodeofactor(Multi-homing)
Receiver(Giant platform) x Sender(Multi-homing)		H4	nodeifactor(Giant platform): nodeofactor(Multi-homing)
Control parameters			
Sender(Niches) *Receiver(Niches)*			nodeocov(Niches) nodeicov(Niches)
Niche overlap *Niche overlap^2*			edgecov(Niche overlap) edgecov(Niche overlap^2)
Sender(Partners) *Platform age*			nodeocov(Partners) nodecov(Platform age)
Sender(Firm size) *Sender(Firm age)*			nodeocov(log emp) nodeocov(Firm age) nodeocov(Integrations)
Structural parameters			
Spatial proximity			nodematch(Country)
Sender(Z-Wave) *Receiver(Z-Wave)*			nodeifactor(Z-Wave) nodeofactor(Z-Wave)
Arc			edges
Reciprocity			mutual
Giant platform reciprocity			edgecov(Giant platform reciprocity)
Popularity spread			gwidegree

Source: Own illustration.

Furthermore, we introduce a network statistic *Sender(Multi-homing)* that reflects the number of endorsing platforms with integrations to more than one giant platform. To test hypothesis 4, we include the interaction *Receiver(Giant platform) x Sender(Multi-homing)*.

Control parameters. As prior literature has highlighted that platforms tend to carefully populate their niches (Boudreau, 2012; Inoue & Tsujimoto, 2018), we introduce three control parameters *Sender(Niches)*, *Receiver(Niches)*, *Niche overlap*, and *Niche overlap^2*, analogously defined to our measures on standards.

Since the basic probability of endorsing compatibility to platforms is also likely to depend on the total number of partners (platforms and non-platforms) endorsed by platforms, we capture the effect due to differences in partner numbers with a variable *Sender(Partners)*.

Moreover, platforms that were launched earlier also had more time to build relationships with other companies (Parker et al., 2017). Hence, we introduce a parameter *Sender(Platform age)* calculated as the difference between 2020 and the year of introduction. Similarly, we introduce the two controls *Sender(Firm age)* and *Sender(Firm Size)* that measure the effect of age as well as $log\ (number\ of\ employees)$, as larger firms tend to have larger asset stocks (Sierzchula et al., 2015; Sørensen & Stuart, 2000). We also include a variable that measures spatial proximity of the headquarters of two platform firms on the formation of edges (*Spatial proximity*).

We further add two parameters to account for membership in the Z-Wave Alliance on both in-degree (*Receiver(Z-Wave)*) and out-degree (*Sender(Z-Wave)*). Partner firms may show lower in-degrees due to the nature of data collection and potential differences in compatibility choices among Z-Wave members.

In addition, platform firms may enter into formal partnership agreements, unfolding in mutual signaling of compatibility. Thus, we account for *Reciprocity*[40] (Pattison & Wasserman, 1999). To control for the extent to which this effect is due to the excess connections to and from giant platforms, include the network statistic *Giant platform reciprocity*, capturing dyad-wise covariates.[41]

[40] That is, the propensity to form an edge from a node i to a node j, which is higher when there is already an edge from j to i.
[41] Therefore, we construct a binary sociomatrix corresponding to a subgraph containing only edges from incumbent platforms.

A commonly observed effect is preferential attachment (Venkatraman & Lee, 2004; Weiss & Gangadharan, 2010), reflecting the tendency of nodes with low degrees to form edges to nodes with high degrees and vice versa (Albert & Barabási, 2002). Following Snijders et al. (2006), such preferences can be incorporated into the model by using geometrically weighted degrees, where the measure reflects anti-preferential attachment (Hunter, 2007), i.e., the coefficient estimate is positive if the degrees tend to be similar for all nodes. The parameter *Popularity spread* is used to captures this effect.

4. Results

4.1. Descriptive statistics and network statistics

Before turning to our analysis, we want to present some network statistics together with descriptive statistics on our main variables and measures to provide more insights.

Table 11: Descriptive statistics on network characteristics and key measures.

Measure	Value
Size (Nodes)	157
Connections (Edges)	879
Integration Edges	280
Density	0.036
In-Degree Centralization	0.577
Out-Degree Centralization	0.222
Betweenness Centralization	0.188

Parameter	Min.	Max.	Mean	Std. Dev.
Openness	0	1	0.401	0.492
Edge-wise competition	0	1	0.137	0.344
Number of Standards	0	7	2.573	1.464
Edge-wise standard overlap	0	1	0.359	0.253
Giant platform	0	1	0.032	0.176
Multi-homing	0	1	0.541	0.500

Source: Own illustration.

Note: Table 11 (a) on the left reports graph-level measures; Table 11 (b) presents descriptive statistics on key measures for statistical inference.

The network consists of 157 nodes (i.e., platforms) that are connected by 879 directed edges (i.e., compatibility signaling), resulting in a relatively low density of 3.6%. Of 879 directed edges, 280 (i.e., 31.9%) go back to integrations with large general smart home platforms (i.e., Apple, Amazon, Google, IFTTT, and Samsung).

The Freeman's graph centralization measures[42] provided in the table reflect the degree of inequality in degrees, i.e., how heterogeneous a population is in terms of structural positions (Freeman, 1978; Hanneman & Riddle, 2014, p. 365). The in-degree and out-degree centralities of 0.577 and 0.222, respectively, indicate a substantial concentration in the network, particularly for in-degrees. The betweenness centralization[43] on average equals to 0.188, which reflects a relatively homogeneous betweenness centrality of the platforms.

Looking at the descriptive statistics of the main parameters, we observe that about 40.0% of the platforms are classified open. 13.7% of the edges are between firms that are active in the same industry. Platforms on average support 2.57 standards, ranging from 0 to 7, while edge-wise there is a mean overlap in standards of 35.9%, ranging from 0% to 100%. About 3.2% of the platforms meet our definition of giant platforms, and 54.0% of platforms integrate with multiple giant platforms.

4.2. Findings: Platform-to-platform compatibility promotion

As part of our analysis, we computed five models, including (1) only control variables (base model), (2), the impact of openness and competition (3) the effect of standards, (4) integration with giant platforms, and (5) a combination of all previous models (full model). We interpret the full model (5).

As the MCMC-ML algorithm of the *statnet* package computes log-odds, which are generally difficult to interpret and compare (Hoetker, 2007), we further computed average marginal effects (King et al., 2000) for the full model, which we describe together with coefficient estimates. Our results are reported in Table 12 (see p. 126), together with the Akaike information criterion (AIC), the Bayesian information criterion (BIC) to evaluate model fit, and MCMC standard errors (MCSE) as a measure for additional uncertainty induced by the MCMC estimation procedure.[44] Overall, our

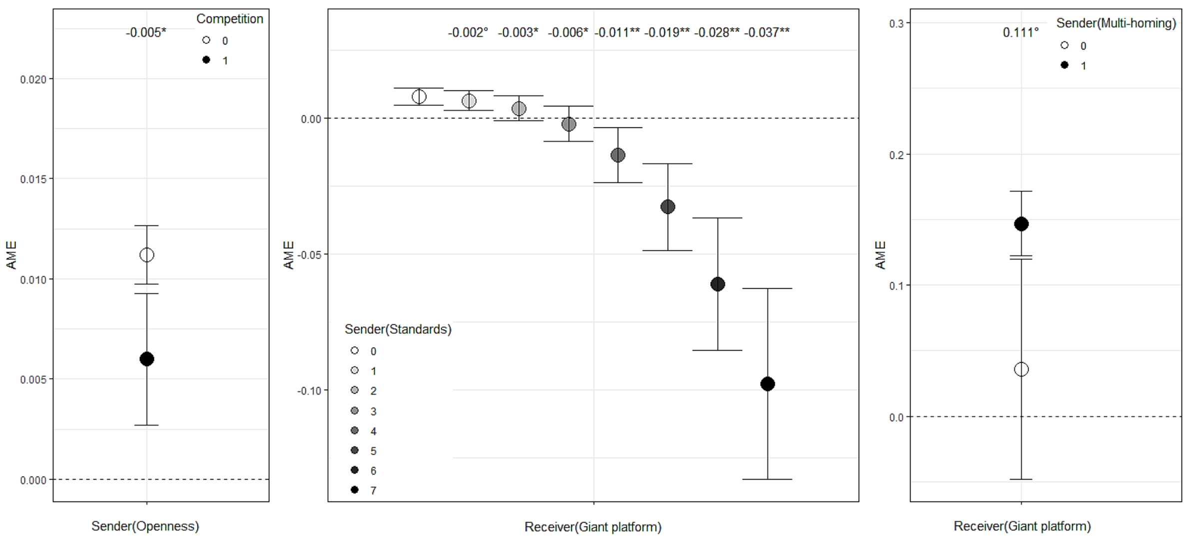
[42] Degree centrality generally provides a measure for node connectivity, reflecting the importance of nodes based on many "one-hop"-edges they hold to all other nodes in a graph, and is closely related to the notion of "social capital" (Borgatti & Everett, 2006; Hanneman & Riddle, 2014, p. 24). A high in-degree centrality reflects popularity (i.e., frequently getting promoted as compatible), while a high out-degree centrality reflects a broader compatibility (i.e., promoting compatibility with many platforms). It equals to 1, if one node has all degree (star graph) and 0, if all nodes have equal degrees (circle graph).

[43] Betweenness centrality generally measures the number of times a node is on the shortest path (geodesics) between all other node pairs, and thus acts as a "bridge", while usually having access to a larger fraction of information flows (Borgatti & Everett, 2006).

[44] Given that AIC and BIC were generally developed to assess the fit of models meeting the criterion of independence of observations, scholars suggest that these measures are not most accurate for dyad-dependent ERGMs (Harris, 2014).

full model provides the best fit with respect to AIC and BIC, where the MCMC standard error of 0.5806 is relatively low.

Figure 10: Interaction plots for H1, H3, and H4.



Source: Own illustration.

Note: Interaction plots for average marginal effects for *Sender(Openness) x Competition* on the left (a), *Receiver(Giant platform) x Sender(Standards)* in the middle (b), and *Receiver(Giant platform) x Sender(Multi-homing)* on the right (c). 95%-confidence intervals are shown for (a) and (b), and 90%-confidence interval for (c). Second differences presented at the top of the graphs.

Parameter estimates of the full model (5) show that platform-to-platform compatibility promotion (PCP) is significantly associated with the basic tendency of openness, where an open-appearing platform (*Sender(Openness)*) exhibits a significantly (p<0.01) increased baseline probability of PCP, with average marginal effects of 1.2% for open platforms. No significant main effect emerges for competition. In fact, the statistically significant difference is due to the interaction effect with openness (p<0.05), supporting H1. Accordingly, platforms do not necessarily exhibit a lower tendency to promote compatibility with platform firms in the same industry, but do so in interaction with their decision to open their marketplaces to external complementors. The interaction plot in Figure 10 (a) shows that the average marginal effects for PCP are 0.5% (p<0.05) lower for open

We thus complement our analysis by running the MCMC diagnostics procedure and the goodness-of-fit procedure provided by the *statnet* package. We discuss the latter at the end of this section.

platforms that consider links to industry competitors, compared to open platforms that do not match primary industries.

Moreover, the probability of PCP increases with the similarity of the standard configurations (*Standard* overlap; $p<0.05$), where platforms with full overlap of the supported standards show a 1.1% ($p<0.05$) higher probability of PCP. Nevertheless, we do not find a statistically significant estimator for the squared standard overlap (*Standard overlap^2*), albeit the estimator is negatively pronounced. The AME is also not statistically significant. A deeper look into the dataset reveals that most platforms focus on the broader Wi-Fi standard, sometimes in combination with Z-Wave or ZigBee. It is therefore not surprising that it is more likely to achieve a greater similarity in the standard configurations. We therefore find no support for hypothesis 2.

Turning to the number of open technology standards a platform supports (*Sender(Standards)*), the analysis shows a significant positive ($p<0.05$) relationship with the likelihood of PCP (AME: 0.1 %; $p<0.05$). Looking at giant platforms(*Receiver(Giant platform)*), we observe a statistically significant ($p<0.05$) and positive correlation between being a giant platform and being a target of PCP (AME: 0.8%; $p<0.05$). The interaction of the number of supported open standards of the sender on one side and a receiving giant platform being on the other side (*Receiver(Giant platform) x Sender(Standards)*) exhibits a significant negative ($p<0.05$) relationship. The negative estimate reflects a decrease in propensity to promote compatibility with giant platforms with an increasing number of standards the sending platform supports. The interaction plot in Figure 10 (b) shows that the average marginal effect of *Receiver(Giant platform)* is significantly positive for sending platforms that support less than three open technology standards, while then gradually becoming more negative. Put differently, compatibility promotion towards giant platforms more frequently occurs for platforms supporting lower numbers in supported standards. The finding indicates that integrations with giant platforms are particularly interesting to platform sponsors that focus only on a few standards due to resource constraints or strategic considerations. The estimate conforms to hypothesis H3.

Table 12: Propensity to promote compatibility to other platforms.

Parameter	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**
Sender(Openness)		0.85** (0.08)			1.10** (0.10)
Competition		0.00 (0.17)			0.15 (0.19)
Sender(Openness) x Competition		-0.38° (0.22)			-0.51* (0.24)
Standard overlap			0.68° (0.34)		1.04* (0.46)
Standard overlap^2			-0.11 (0.35)		-0.39 (0.45)
Receiver(Giant plat.)				1.26** (0.28)	0.74* (0.29)
Sender(Standards)				0.15** (0.03)	0.09* (0.03)
Receiver(Giant plat.) x Sender(Standards)				-0.23** (0.07)	-0.27** (0.07)
Receiver(Giant plat.) x Sender(Multi-homing)				2.47** (0.25)	2.66** (0.26)
Sender(Multi-homing)	0.81** (0.09)	0.81** (0.09)	0.84** (0.09)	0.35** (0.10)	0.32** (0.10)
Sender(Niches)	-0.03* (0.01)	-0.01 (0.01)	-0.02° (0.01)	-0.07** (0.01)	-0.05** (0.01)
Receiver(Niches)	0.02** (0.01)	0.02** (0.01)	0.02** (0.01)	0.01 (0.01)	0.01 (0.01)
Niche overlap	0.91* (0.34)	0.91* (0.35)	0.77* (0.35)	2.23** (0.46)	2.33** (0.47)
Niche overlap^2	-1.95** (0.49)	-1.90** (0.49)	-1.84** (0.50)	-2.66** (0.58)	-2.80** (0.58)
Sender(Partners)	0.01** (0.00)	0.01** (0.00)	0.01** (0.00)	0.01** (0.00)	0.01** (0.00)
Platform age	0.01° (0.00)	0.01* (0.00)	0.01* (0.00)	0.00 (0.01)	0.00 (0.00)
Sender(Firm age)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Sender(Firm size)	-0.07** (0.02)	-0.07** (0.02)	-0.07** (0.02)	-0.09** (0.02)	-0.09** (0.02)
Spatial proximity	0.29** (0.06)	0.29** (0.06)	0.27** (0.06)	0.34** (0.07)	0.26** (0.07)
Sender(Z-Wave)	0.47** (0.08)	0.35** (0.08)	0.44** (0.08)	0.39** (0.10)	0.27* (0.10)
Receiver(Z-Wave)	-0.11** (0.03)	-0.10** (0.04)	-0.16** (0.04)	-0.08° (0.05)	-0.16** (0.04)
Popularity Spread	-4.10** (0.13)	-4.09** (0.13)	-4.05** (0.13)	-3.28** (0.14)	-3.44** (0.12)
Reciprocity	1.53** (0.13)	1.44** (0.12)	1.50** (0.13)	1.58** (0.15)	1.36** (0.14)
Giant platform	1.33** (0.23)	1.17** (0.23)	1.34** (0.23)	0.81** (0.25)	0.74** (0.25)
Arc	-3.34** (0.12)	-3.76** (0.13)	-3.58** (0.14)	-3.67** (0.16)	-3.78** (0.19)
Nodes	157	157	157	157	157
Edges	879	879	879	879	879
AIC	5773.58	5664.59	5747.58	5111.53	4818.26
BIC	5903.28	5818.61	5893.49	5273.65	5020.91
MCMC Std. Err.	0.7412	0.691	0.7888	0.6535	0.5806
DoF	24476	24473	24474	24472	24467
LogLikelihood	-2870.79	-2813.30	-2855.79	-2535.76	-2384.13

Source: Own illustration.

Note: ERGM estimations on sample with 157 platform sponsors and 879 compatibility promotions among them. Standard errors in parentheses. Significance levels: ° $p < 0.1$, * $p < 0.05$, ** $p < 0.01$.. Mean variance inflation factor equals 7.11.

Also, compatibility promotion is associated with a significant (p<0.01) tendency to multi-homing (*Sender(Multi-homing)*), with the baseline probability being 0.3% (p<0.01) higher. When looking at the interaction between being receiving giant platform on one side and the multi-homing tendency with respect to integrations by the sender on the other side (*Receiver(Giant platform) x Sender(Multi-homing)*), we observe a statistically significant (p<0.01) and positive relation. Accordingly, H4 finds support. The interaction plot in Figure 10 (c) shows that the average marginal effect of *Receiver(Giant platform)* is 11.1% (p<0.10) higher for promoting platforms that simultaneously integrate with multiple giant platforms.

Next, we consider the control parameters. Looking at parameters related to product categories in the ecosystems, there is a significantly (p<0.01) lower tendency of PCP with a higher number of market niches that can be served by the sending platform with its own products. We further observe that platforms show heterophily in terms of categories of complementary products, where compatibility promotion increases with the number of common product categories (*Niche overlap*; p <0.01) but where, however, the correlation shows diminishing returns (*Niche overlap^2*; p<0.01). The results suggest that platforms are more inclined to promote compatibility with platforms with a moderate level in category overlap (mean: 26.5%), leaving sufficient potential for complementarity.

Our further firm-level controls show that rather smaller firms (*Sender(Firm size);* p<0.01) show a higher activity to promote compatibility. Yet, we do not observe a significant difference as to platform age (*Platform age*) and firm age (*Sender(Firm age)*). We believe this goes back to relative similar platform and firm ages in our sample. Besides, a significant positive (p<0.01) relationship between the number of partners (*Sender(Partners)*) of an endorsing platform and PCP is shown. In addition, we observe a significant correlation in *Spatial proximity* (p<0.01). Considering Z-Wave memberships, we observe differences in activity for Z-Wave members (*Sender(Z-Wave)*) showing a higher propensity to promote compatibility (p<0.05) and a lower propensity to be target of compatibility promotion (*Receiver(Z-Wave);* p<0.01).

Turning to the basic structural features, the parameter estimate for *Popularity spread* is negative and significant (p<0.01), indicating the presence of dispersion in the in-degree distribution. The negative estimate suggests that some platforms in our sample are listed as compatible disproportionately often. Indeed, in our sample, we observe that the highest in-degrees go back to giant platforms, underscoring their importance within the market and reflects the network's in-degree centralization measure.

In addition, we observe a higher significant ($p<0.01$) tendency towards *Reciprocity* in PCP, which is even higher in the case of giant platforms (*Giant platform reciprocity*; $p < 0.01$) and equals an average marginal effect of 0.8% ($p<0.01$). Accordingly, promoting compatibility with giant platforms leads to reciprocity, allowing sending platform sponsors to gain visibility of their installed bases.

Furthermore, the parameter estimation for *Arc* is strongly negative and statistically significant ($p<0.01$), reflecting that the basic propensity to promote compatibility is overly low. In other words, platforms would not promote compatibility with other platforms if it were not for structural features, such as preferential attachment or the need for complementary devices, as discussed above.

4.3. Goodness of fit assessment

As ERGM parameter estimations occasionally do not produce simulated networks similar to the original one, it is necessary to visually inspect distributional fit on at least in-degrees, out-degrees, edge-wise shared partners, and geodesic distance (Hunter et al., 2008). The plots are generated by simulating 1,000 network graphs using the estimated parameters to then infer confidence intervals. The distributions are presented in Figure 11.

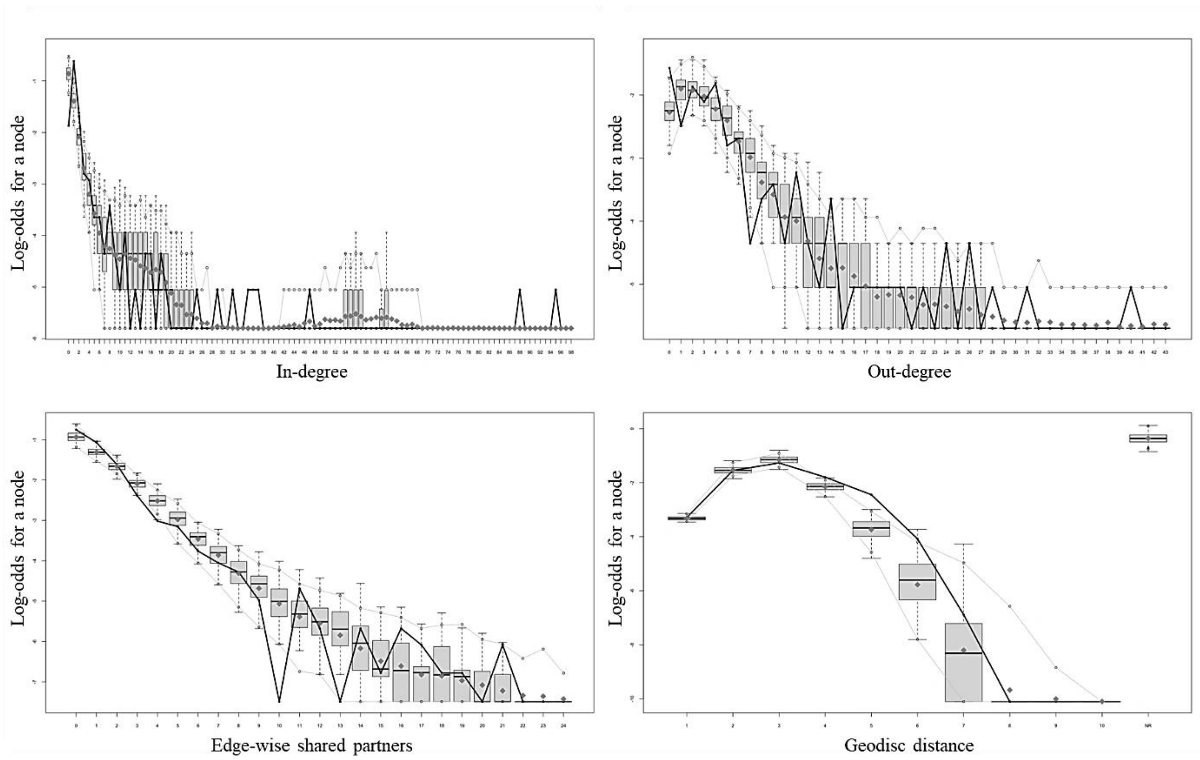
The four plots compare the log-odds for each value in the distributions of in-degree, out-degree, edge-wise shared partners, and geodesic distance in the observed network to the range of log-odds in the simulated networks. Overall, the full model shows a fair similarity between the simulated networks and the observed network, increasing our confidence in the model.

4.4. Robustness

Next, we discuss alternative measures to inspect robustness of our findings against different sets of standards and size variables. The robustness tests are reported in A11.

First, our parameter on the openness of a platform only covers the existence of a compatibility list or marketplace. To map a somewhat stricter definition of the term, we use an alternative measure that captures openness based on the relation of own complements to third-party complements (model (1)). Accordingly, a platform is assumed to be open if a platform has more third-party complements than own complements. The results do not differ significantly from those of our main model.

Figure 11: Goodness-of-fit plots for the full model.



Source: Own illustration.

Second, the main model incorporated only open technology standards, as they can potentially be adopted by any platform, in contrast to proprietary standards. Yet, some platform sponsors offer proprietary standards, which may shield rivals from establishing compatibility. This may introduce a selection bias. Therefore, we construct an alternative model, incorporating all standards we initially coded (model (2)). The results are close to that of the main model.

Finally, an alternative explanation for the moderation of the number of standards may be differences in firm size. Accordingly, we replace standard measures in the interaction terms with a firm size parameter. The results are reported in model (3), (4), and (5). The estimates are consistent with our main model, suggesting that firm size differences do not explain the differences.

5. Discussion

Digital product platform providers such as those in the smart home market face a complex decision in terms of opening up to complementaries that offer their own platforms. One promising approach to balancing the tension between opening up to create adoption and safeguarding against competition is to endorse certain compatible offerings.

5.1. Theoretical implications

This study provides theoretical contributions to research on the management of ecosystems value (Benlian et al., 2015; Rietveld et al., 2019; Boudreau, 2010; Inoue & Tsujimoto, 2018). Most of previous studies focused on software complements that are developed for particular platforms (e.g., Benlian et al., 2015; Rietveld et al., 2019), with deliberate choices by developers to port their complements to other platforms as well (Landsman & Stremersch, 2011). This study examines how platform sponsors manage their ecosystems in settings with hardware complements developed for a shared technology market, with industry consortia coordinating development efforts and providing the certification infrastructure. To this end, the study shows that platform sponsors address the devolution of control going back to the integration of open technology standards by selectively promoting complementary products and platforms, thus balancing the tension between openness and competition. As such, the study extends the concept of selective promotion. We observe that about 60% of the platforms in the sample promote compatibility to certain partners and even 70% integrate with giant platforms. The study examines two complementary approaches to balance openness and competition: (1) complementarity in standards as a way to seek differentiation and cover a wider array of standards, and (2) integrations with giant platforms to seek indirect connections with fewer standards. Our study lends particular support for the second approach, with similarity in standards driving promoted links among platforms. We believe, while it is an efficient strategy to cover most of the underlying standards with a few promoted links, complementarity in standards does not play a major role in this setting. We rather observe that platforms tend to focus on other platforms within the same standards, underscoring the relevance of alliances to identify (potential) partners (Leiponen, 2008), with the number of standards two platforms support considerably driving the likelihood to promote cross-platform compatibility.[45]

[45] Note that in our sample, the combinations of standards the platforms are integrated with vary considerably. Hence, there is no single combination dominating adoption choices. However, Wi-Fi/IP denotes the most widely adopted standards. Overall, our sample is divided into two approaches, one where platforms adopt one standard (mostly Wi-Fi) or two (mostly Wi-Fi + X), and one where platforms support three or more standards. Overall, the standard domains

The study identifies a range of factors that are associated with compatibility promotion that are in line with previous findings, including spatial proximity (Sierzchula et al., 2015), preference for heterogeneity in ecosystem niches (Hagiu & Lee, 2011), and dissimilarity in primary industry sector (Mantena & Saha, 2012). Compatibility promotion can be viewed as a strategic approach to manage an ecosystem's value through balancing value creation by end users and value capturing by the platform sponsor. In particular, the study shows one form of how platforms make use of what Henfridsson et al. (2018) call 'path channeling'. Following their framework, platform sponsors create value connections to digital resources of other platform sponsors by integrating the same set of open technology standards or opening APIs (i.e., value creation through design recombination). While end users create value through combing digital resources of various suppliers – even in undesired forms – (i.e., value creation through use recombination), compatibility promotion denotes a form of path channeling, aiming at capturing more value by steering value connections made by end users. Particularly giant platforms attract much of the value connections defined by platform sponsors. In line with previous research (Weiss & Gangadharan, 2010), we observe a power law distribution in promoted links between platforms. Together, the five giant platforms account for almost one third of all promoted compatibility in our network graph of 157 platforms. As such, our study supports anecdotal evidence of how giant platforms make their digital resources more center-stage in the smart home market, allowing them to capture more value (Henfridsson et al., 2018). Even more so, as tight integrations with their platforms give them access to larger portions of the data streams in the smart home market. Accordingly, giant platforms shape the industry architecture in such a way that they become "bottlenecks" (Jacobides et al., 2006), which increases their chance of becoming platform leaders in the emerging market (Cusumano & Gawer, 2002).

Second, the study contributes to literature on platform openness by considering platform-to-platform openness (Mosterd et al., 2021). As such, the study addresses recent calls to advance understanding on openness (Mosterd et al., 2021; Broekhuizen et al., 2021; Ondrus et al., 2015), where it particularly considers platform sponsors as the target of openness decisions. Most of previous literature focused on developers as the target of openness decisions by platform sponsors, largely ignore the inclusion of customers, while rarely specifying sub-dimensions of openness (cf.

in which a platform is located determine its links to other platforms. As such, platform competition and openness also to some extent depends on the alliances behind open technology standards.

Broekhuizen et al., 2021). Our study considers open technology standards as a source of platform openness at the technology level (Ondrus et al., 2015; West, 2003), with more standards corresponding to a higher degree of openness. Overall, the platforms in our sample can be divided into two groups of almost same size, with one group integrating at most two standards and the other group integrating more than two standards in their platforms.[46] We find empirical evidence that with an increase in technological openness in terms of number of open standards, the likelihood to promote compatibility to more platforms increases as well. Those platform sponsors that integrate with giant platforms, however, support fewer technology standards, which also reflects higher degree of openness at technology level. While open technology standards determine the degree of openness in technical terms by defining with which and to what extent platforms interoperate, compatibility promotion addresses the perception of platform openness, rather than changing the actual degree of interoperability. Similar to Benlian et al.'s (2015) framework of developers' perception of platform openness, the study shows how platform sponsors influence the end users' perception of platform openness by varying the degree of transparency. However, in contrast to transparency about the market mechanisms of the distribution channels faced by developers, platform sponsors in our study vary the degree of transparency about the categories and brands that can be used in conjunction with their platforms. Hence, compatibility promotion corresponds to 'category openness' (Broekhuizen et al., 2021), which complements technological openness (i.e., accessibility in terms of interoperability). In this regard, the study adds to the body of literature on the multidimensionality of platform openness (Broekhuizen et al., 2021; Benlian et al. 2015; Ondrus et al., 2015) by showing how platform sponsors compensate undesirable effects of accessibility at the technology level with transparency at the marketplace level. More specifically, while most of the platforms in our sample support Wi-Fi/IP standards and many support Z-Wave, only a fraction of interoperability between these platforms is promoted, particularly between platform sponsors with dissimilar sectors and high niche complementarity.

Previous studies created a profound understanding of the mechanisms underlying platform competition, stressing differences in pricing schemes and technology core (Katz & Shapiro, 1985; Mantena & Saha, 2012). Yet, as studies on compatibility between platforms usually apply mathematical models, conceptualizing platforms as two-sided markets, they are limited to dyadic

[46] That is, 26% support one open standard only, 30% support two open standards, and 44% support three and more open standards. While configurations of adopted standards differ across platforms, 134 of 157 platforms support the more general Wi-Fi/IP standards, allowing to establish cloud-to-cloud connections.

relationships (two platforms). As our approach is based on an exponential random graph model estimation, it helps us capture structural features that go beyond dyads that otherwise would have imposed a bias on our estimation (Pattison & Wasserman, 1999; Robins, 2014).

5.2. Managerial implications

Our study also yields practical contributions by offering a strategic perspective on platform openness, informing design considerations, and, more broadly, by helping to better understand the underlying mechanisms driving inter-connections between platforms. Our study offers concrete recommendations.

First, our study shows that platforms can draw end users' attention to specific compatible platforms, particularly those in other sectors that are complementary in terms of device niches, regardless of the de facto prevailing compatibility. We generally observe considerable differences in form (i.e., partner curation, product curation, promotion of system/platform integration) and magnitude (i.e., number of platforms promoted as compatible) platform sponsors promote other platforms as compatible. It is further shown that compatibility promotion is characterized by reciprocity. Accordingly, promotion by many complementary platforms can also lead to promotion by many platforms. An example in our dataset represents Fibaro, which promotes relatively many platforms and receives relatively much promotion back. Overall, promoting compatibility can lead to three relevant outcomes. First, a user adopts the focal platform and uses compatible complementary devices of another platform. Second, a user adopts the other platform and uses complementary devices of the focal platform. Third, the user adopts both platforms and uses both together with their complements. The first case depicts the ideal case, which allows a platform sponsor to offer superior services, such as smart phone applications or cloud services, making the focal platform the “daily driver” of a user. The second case depicts a scenario in which the competing platform is superior and degrades the focal platform to a mere complement provider and possible converter. In the last case, different platforms symbiotically coexist in the consumers’ homes, as access to APIs fosters demand-side multi-homing, making it more important to offer different services and/or device niches (Boudreau, 2012; Inoue & Tsujimoto, 2018). By promoting certain platforms and their complements, platform sponsor influence the position within the network of interconnected platforms and as such the value paths to and from other digital resources of which it becomes part (Henfridsson et al., 2018).

Second, integrations with giant platforms can be an attractive target for cloud-to-cloud integrations. While some platforms are surrounded by larger existing installed-bases from adjacent markets and offer proprietary standards based on widely adopted Internet-based standards, integrations with these platforms offer a fruitful avenue to overcome constraints imposed by incompatible standards, while avoiding to advertise rival platforms and drawing on the potential to receive demand spillovers (Li & Agarwal, 2017) or awareness spillovers (Song et al., 2021). Our results demonstrate that some fraction of reciprocity in promotion goes back to giant platforms, as they curate products, allowing users of these platforms to easily identify integrated platforms. Moreover, especially giant platform sponsors show high betweenness centralities, reflecting their central role in bridging between (incompatible) platforms. Nonetheless, such integrations increase dependence, as they require a tight coupling, and bear the potential to sideline the initial offer of the platform, which harbors the danger of platform envelopment by the giant platform (Eisenmann et al., 2011; Hilbolling et al., 2020). Therefore, simultaneous integration with multiple giant platforms proves to be a way to reduce the risk of platform envelopment. As such, multi-homing in terms of integrations with multiple giant platforms can be a third viable strategy to defend against platform envelopment, additional to opening to find many allies and making the own bundle similar to that of the attacker (Eisenmann et al., 2011). In addition, combing the integration with multiple giant platforms with fewer open technology standards integrated with the focal platform appears as preferred approach by many platforms. We believe this goes back to reduction in costs.

5.3. Limitations and directions for future research

All research designs imply tradeoffs. A usually mentioned issue in network analysis considers the selection of nodes (Laumann et al., 2017). An "incorrect" node selection, possibly includes "irrelevant" nodes, while excluding potentially important nodes. This is especially crucial as networks generally do not possess well-defined boundaries (in contrast to formal groups), which makes it difficult, if not impossible, to determine the complete set of actors (Borgatti & Halgin, 2011). Our extensive triangulation of platform stakeholders through web searches, standards memberships and Amazon product pages we believe we included most important actors relevant to the study. As standardization plays a dominant role in our study, we started with a relatively well-defined group of firms, i.e., Z-Wave Alliance members, and captured promoted compatibilities directly at other actors inside and outside this group, getting a fair picture of relations from and to Z-Wave platforms. Yet, we did not include software extensions ("apps") in our network, as we are interested in communication protocols that are embedded in devices. Future research may extend this study and analyze differences in relations going back to promoting compatible devices and third-party software extensions. Specifically, the different approaches of incumbent platforms provide an interesting starting point to study strategic implications with respect to compatibility promotion in platform ecosystems spanning a larger fraction of the layered modular architecture. In addition, future studies may verify the findings of this study for platforms outside the Z-Wave Alliance. Similar settings can be found for service firms providing APIs where complements are mashups for Android or iOS, such as banks or insurances (Weiss & Gangadharan, 2010; Kazan et al., 2018).

A related concern focusses on the definition of "platform" in our study. We, on purpose, defined platforms in a rather narrow way to study similar platforms (i.e., offering stand-alone solutions for the consumer mass market). Consequently, this study covers smart home platforms, which are perceived by end users and deemed most relevant in the industry. Platform firms offering back-end solutions in a business-to-business manner usually have a different view on network effects with respect to consumers. As such, B2B platforms show different behaviors, as they are either pure cloud platforms running in the background without visible connections or merely provide white label solutions with a generic tendency towards creating as many edges as possible. Both cases create upward or downward biases. However, future research may also consider behaviors of back-end solution providers to determine their role in standardization and compatibility choices (Papert & Pflaum, 2017).

Another concern, considering network analysis, is the argument that one cannot accurately predict the observable network structure without considering the network's full trajectory, as it is the result of a longer evolutionary process (Borgatti & Halgin, 2011). Robins (2014) serves a defense for analyzing snapshot data: "because of the relative constancy of network organizing principles, a single network observation captures the accumulation of social processes, like an archaeological trace. Stable organizing principles will result in patterns of network ties that can be observed in the data, even when data are from a single instance in time. These patterns of network ties are indeed the structural signature of the network and provide evidence from which we may infer something of the social processes that build the network." (p. 484). Yet, a longitudinal study on the evolution of compatibility structures over time provides an interesting space for further research. Especially cascading effects within networks (Borgatti & Halgin, 2011) can be studied, such as how platform competition unfolds and propagates through the network.

Particularly web repositories such as The Wayback Machine prove a good source to construct unique datasets covering several years in the past. Also, directories such as the ProgrammableWeb can provide good starting points, as demonstrated in Weiss & Gangadharan's (2010) study.

6. Conclusion

Embedded in digital infrastructures, platforms increasingly form interconnections between each other, driven by the employment of boundary resources such as application programming interfaces. As platform sponsors seek to balance adoption and appropriability in an attempt to defend platforms against competition, this study introduces the concept of platform-to-platform compatibility promotion. Constructing a unique dataset covering 157 platforms, we conducted a network analysis based on an exponential random graph model (ERGM) to incorporate platform features, dyadic characteristics, and structural processes. Our results suggest that platforms' compatibility promotion choices with respect to other platforms reflects a tradeoff between openness and competition, compensating access at the technology level with transparency at the marketplace level. We find a strong tendency to integrate with giant platforms (about 70%), allowing to support lower numbers of standards (i.e., openness at the technology level) but multi-homing to several giant platforms to address the threat of platform envelopment. We do not find evidence for a pronounced preference towards platforms with dissimilar sets of supported standards. Platform sponsors rather prefer to promote platforms with higher similarity in supported standards. Overall, platforms tend to focus on a smaller number of standards, most often including the broader Wi-Fi/IP standards allowing to establish direct cloud-to-cloud connections.

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Paper III:

Backing the Right Horse: A Study of the Effect of Membership Dynamics on Value Creation in the Smart Home Market

Sven Niederhöfer & Sebastian Späth

Abstract

Innovation ecosystems usually form around complex product systems that cannot be materialized by one firm alone but requires cooperation among a diverse set of firms. This requires a certain level of coordination to collectively create value. Standard consortia provide a forum to achieve the required level of coordination, while revealing some fraction of the roles and dynamics within and across the underlying innovation ecosystems. In our study, we draw on recent studies on standard consortia and innovation ecosystems to examine the effect of dynamics across competing ecosystems and prominent ecosystem roles on product certifications in the smart home sector. Our framework is based on the dialectic of own interests and ecosystem interests, bridging the affiliation perspective and structure perspective described by Adner (2017). We derive two dimensions of visible membership dynamics, switching and spanning. This paper draws on a unique longitudinal dataset comprising more than 700 firms and their memberships in six standard consortia between 2006 and 2019. We focus on the Z-Wave alliance to study value creation in form of product certifications. The analyses show that firms switching more often in previous periods tend to contribute less to value creation to the Z-Wave alliance, also showing a shorter membership in the Z-Wave alliance as well as across all standard consortia, reflecting a lower level of alignment. In contrast, we find a positive association between higher spanning in multiple alliances in previous periods and value creation towards in Z-Wave alliance. Theoretical and practical implications are discussed.

The article has been published on SSRN as working paper.

1. Introduction

Innovation ecosystems form around certain technologies, usually complex value propositions that cannot be materialized by one firm alone but requires cooperation among a diverse set of firms (Adner, 2017; Adner & Kapoor, 2010). Previous literature on innovation ecosystems addressed ecosystems of different scope, covering ecosystems forming around software-platforms such as iOS (Qiu et al., 2017) or Android (Karhu et al., 2018), complex hardware products such as semiconductor lithography (Adner & Kapoor, 2010) or aircrafts (Ritala et al., 2013), and larger settings in the realm of the entire mobile ecosystem (Basole, 2009) or API mashup ecosystem (Weiss & Gangadharan, 2010).

Despite their differences in the analytical levels, they share their focus on direct firm relationships and collective actions, while omitting external vehicles such as standard bodies. Recent research draws attention towards consortia and standard organizations as crucial value creation mechanism (Bogers et al., 2019; Ritala et al., 2013; Teece, 2018). Such organizations provide forums to find consensus between different parties, including close rivals (Rysman & Simcoe, 2008; Simcoe, 2012) and manifest coopetitive behaviors during standard setting (Toh & Miller, 2017) and adoption of competing technologies (Besen & Farrell, 1994; Farrell & Saloner, 1986a). Also, technology sponsors such as Google in the case of the Open Handset Alliance make use of statutes as a leverage to impede certain unwanted behaviors by device manufacturers (Karhu et al., 2018).

Especially in markets with increasing returns in the number of firms adopting the same technology (Axelrod et al., 1995) and where market success depends on interoperability of products (Baron & Pohlmann, 2013), standard setting becomes a crucial strategic driver to orchestrate a larger set of firms. As Besen and Farrell (1994, p. 117) note:

> *"In these [computer, telecommunications, and consumer electronics] industries, standard-setting has been transformed from an internal matter for individual firms to a subject of cooperation and competition among independent players. The strategic issues raised by these developments include both policies towards vertically related firms and policies toward horizontal competitors."*

This is especially true for markets with distributed leadership among many firms, making coordination more complex (Rysman & Simcoe, 2008).

Firms controlling certain technologies underlying these consortia face considerable benefits (Besen & Farrell, 1994). As such, the formation of consortia around certain standards becomes increasingly popular (Baron & Pohlmann, 2013).

Especially in information technology intensive markets such as those connected to internet of things technologies the fate of innovation ecosystems largely depends on the fate of the underlying technology standard, raising the need to better understand the ecosystem dynamics manifested around standard bodies.

While innovation ecosystem literature points to "ecosystem dynamics", the majority of literature considering dynamics across competing standards considered network effects (Katz & Shapiro, 1985, 1986), compatibility (Farrell & Saloner, 1992; Katz & Shapiro, 1985), and multi-homing (Cennamo et al., 2018; Ranganathan et al., 2018). Moreover, some literature addressed governance issues (Chiao et al., 2007; Stoll, 2014). Yet, most empirical research adopted a static view not accounting for changes of decision-making of firms over time. We adopt an ecosystem lens, considering dynamics observable in standard consortia that follow coopetitive logics involving assessment of features of the focal technology, governance mechanisms within the community, and features of the community such as size and the presence of rivals.

Also, literature highlighted distinctive roles, most prominently the central keystone role (Iansiti & Levien, 2004a) and platform providers (Gawer & Cusumano, 2002). Teece argues that "complementarity is the essence of platforms, and platforms help enable ecosystems. Because of the progress and diffusion of digital technologies, platforms are becoming pervasive" (Teece, 2018, p. 1375). In contrast to the literature on platform ecosystems, we consider platform providers as complementors to an underlying standard and assess their role as niche players. While most of the literature on innovation ecosystems considers a static keystone or hub, we contemplate a case with changes in this role and control for their effects. Against this backdrop, we ask the following questions: *RQ1: How do dynamics across competing standard bodies affect product certifications? RQ2: How do orchestrators contribute to the set of certified products?*

We construct a longitudinal dataset, spanning a period of 15 years and covering roughly 700 members in the Z-Wave alliance as well as their memberships in four competing consortia. Our results show that firms switching more often in previous periods tend to contribute less to value creation in terms of product certifications to the Z-Wave alliance, while they also show a shorter membership in the Z-Wave alliance as well as across all consortia, reflecting a lower level of alignment. In contrast, we find a positive association between higher spanning in previous periods and a higher number of product certifications, where spanning is associated with certifications across a higher number of consortia. Also, we find significantly higher product certification activities after taking an orchestrating role.

Apart from our empirical results, we make several contributions. First, we take a dynamic view and observe changes in memberships over a longer period occurring between competing standard consortia. Second, we examine the effect of these dynamics, namely switching and parallel memberships, on the succeeding certification behavior of firms. Third, we consider differences for commonly highlighted roles in ecosystem literature, i.e., of keystones. In doing so, we contribute to the literature stream on standard organizations by shedding light on coopetitive dynamics between consortia and their effect on product certifications. In addition, we extend innovation ecosystem literature by showing how firms sponsoring particular technologies can leverage standard consortia to align complementors to collectively compete with firms supporting other technologies. We particularly analyze changes in the underlying structure of the ecosystem as the keystone role changes over the course. This allows us to observe the effect on contributions.

The article is structured as follows. In the next section, we provide a brief overview of literature on innovation ecosystems and standard organizations to derive our testable hypotheses. This is followed by the description of research methodology including data source and measures. A chapter on results provides evidence in support of our hypotheses and underlying assumptions, followed by separate post-hoc analyses to provide additional insights for decision making, and ends with a battery of robustness checks. The paper concludes with a discussion of our results and provides a conceptual framework on how firm-level decisions are linked to ecosystem-level outcomes. We discuss the implications for scholars and practitioners, important limitations, and make suggestions for future research in the last section.

2. Theoretical framework

2.1. Innovation ecosystems

Innovation ecosystems depict "the collaborative arrangements through which firms combine their individual offerings into a coherent, customer-facing solution." (Adner, 2017, p. 2). The concept of ecosystems was introduced to reflect firms' interdependencies with respect to complex technological systems (Gawer & Cusumano, 2002; Moore, 1993; Teece, 2007). These interdependencies require different actors to cooperate, as only collectively they are able to provide a customer-facing value proposition (Adner, 2017; Adner & Kapoor, 2010). Adner (2006) invokes to identify and manage the risks associated with these interdependencies. Interdependencies may arise among complementary goods (downstream) and between complementary goods and components required to assemble them (upstream) (Adner & Kapoor, 2010; Kapoor, 2018). For technology pioneers central to the ecosystem, interdependencies between complementary goods are particularly crucial as challenges may diminish overall pioneer advantage allowing rivals to catch up (Adner & Kapoor, 2010). Bogers et al. (2019) further distinguish different forms of interdependencies ranging from rather cooperative such as in the case of platform ecosystems, and coopetitive requiring close rivals to cooperate, to competitive such as crowdedness in certain ecosystem segments or for ecosystem participation. The categorization reflects different levels of competitiveness between different parties within and across the same ecosystems. Interdependence in the structural relationship among the actors is further connected to complementarity among the products and services provided (Jacobides et al., 2018; Kapoor, 2018).

Moreover, ecosystems are shaped by their underlying industry architecture (Jacobides et al., 2006; Luo, 2018), involving several roles (Iansiti & Levien, 2004a) and multilateral relationships among them (Adner, 2017; Jacobides et al., 2018). One or a few companies within these ecosystems take a leading role and orchestrate the ecosystem (Gawer & Cusumano, 2002; Moore, 1993), while they have the opportunity to obtain a larger share of the value capture (Iansiti & Levien, 2004a; Oh et al., 2015) in exchange for access to critical assets they provide (Iansiti & Levien, 2004b). Aside from these so-called 'keystones' further roles were identified, where niche players are said to create most of the ecosystem's value in the form of a diverse set of complementary products and services (Iansiti & Levien, 2004a). The distribution among these roles tends to follow a power law with only a few companies taking the keystone role and a larger number of niche players (Weiss & Gangadharan, 2010). Roles and relationships among firms may further change over time (Basole, 2009; Hannah & Eisenhardt, 2018; Moore, 1993).

While bound together by interdependencies, firms still pursue their own interests (Bogers et al., 2019; Moore, 1993), thus facing the dialectic between their own goals and the shared ecosystem goals (Eaton et al., 2015; Wareham et al., 2014). Most notably, value creation and delivery denotes an overall ecosystem goal, while value capture is rather located at the individual level (Gomes et al., 2018; Ritala et al., 2013). Thus, different dynamics have been reported in previous research reflecting this coopetitive logic at different stages of the collective innovation efforts. Research focusing on innovation in ecosystems covers different aspects including collective technology management (Adner & Kapoor, 2016; Adner & Snow, 2010), the emergence of innovation ecosystems (Dattée et al., 2018), partnership structures (Davis, 2016; Kapoor & Lee, 2013), knowledge exchange (Alexy et al., 2013; Toh & Miller, 2017), platform governance (Gawer, 2014; Wareham et al., 2014), niche crowding (Venkatraman & Lee, 2004), multi-homing (Cennamo et al., 2018), and roles and activities (Adner, 2017; Moore, 1993). They all have in common that the success of the ecosystem highly depends on the degree of alignment between self-interested actors with a certain degree of interest divergence (Adner, 2017; Bogers et al., 2019).

As most of the literature focuses on dynamics within a particular ecosystem, dynamics across ecosystems are under-researched. Previous research addressing dynamics across ecosystems usually focuses on price competition between platforms (Rochet & Tirole, 2003) or multi-homing by developers (Cennamo et al., 2018). In our study, we consider participation dynamics over time that unfold between competing communities (Ranganathan, Ghosh & Rosenkopf 2017) forming around competing technologies while organizing in industry consortia as a central forum to align activities (Adner, 2017). We thereby leverage the explicit organization of industry consortia to observe some part of the underlying innovation ecosystems[47], while we follow Leiponen's (2008) approach considering firm-consortia relationships, i.e., memberships.

2.2. Standard organizations

Standard organizations usually emerge in response to some coordination problem, i.e., there are diverging interests as to which technology should be used within or across industries (Markus et al., 2006; Rysman & Simcoe, 2008). This is particularly the case in the absence of a dominant firm, such as a platform leader (Gawer & Cusumano, 2002) aligning actors around their technology (Gawer, 2014; Gawer & Cusumano, 2002). It is noticeable in the context of internet of things technologies, where connectivity is a vital characteristic of the products to function while there is

[47] Ecosystems are difficult to identify, specifically due to the challenge to define and observe boundaries (Iansiti & Levien, 2004b). While they are distinct concepts, we use industry consortia to observe some part of the innovation ecosystem, as companies – particularly in IT-intensive markets – tend to organize in such standard bodies to adopt, develop, and disseminate certain technologies at the center of these innovation ecosystems (Adner, 2006). This approach allows us to identify changes in memberships across a set of consortia – and thus innovation ecosystems – reflecting dynamics in technology choices.

a plentitude of options. Then potential rivals are often required to form standard organizations (Axelrod et al., 1995).

These standard organizations allow firms to find consensus, resolve issues related to overlapping intellectual property rights and endorse and promote a particular technology (Rysman & Simcoe, 2008; Simcoe, 2012). They thus provide a focal point for orchestrating major change when leadership is distributed among firms and coordination is hence more complex (Rysman & Simcoe, 2008).

Standard organizations can engage in a range of activities. They usually foster the diffusion of particular technologies aiming to establish these as technological standards (Baron & Spulber, 2018), i.e., “any technology or product incorporating specifications that provide for compatibility” (Weitzel et al., 2006, p. 491). Furthermore, they may or may not set or develop standards themselves (Baron & Spulber, 2018; Leiponen, 2008), certify the compliance of products with the technical specifications (Farhi et al., 2005; Lerner & Tirole, 2006) or act as interfaces between governments and private standard organizations such as in the case of the American National Standards Institute (ANSI) (Baron & Spulber, 2018).

In our study, we focus on a sponsored industry consortium (David & Greenstein, 1990). Industry consortia play a crucial role in standardization as firms can join forces to collectively improve their position against competing standards (see e.g., Axelrod et al., 1995; Leiponen, 2008) or coordinate with rivals to reduce the risk of duplicate R&D efforts by upfront coordination (Baron & Pohlmann, 2013; Delcamp & Leiponen, 2014). Thus, standardization reflects some degree of coopetition among actors (Baron & Pohlmann, 2013; Leiponen, 2008). To provide the required level of coordination among these actors, standard consortia must implement appropriate governance mechanisms to regulate memberships and voting rights (Axelrod et al., 1995; Markus et al., 2006), address ownership of intellectual property rights through IP and licensing policies (Chiao et al., 2007) and ensure compliance with technical specifications, usually through certification (Lerner & Tirole, 2006). Governance approaches differ considerably across organizations (Lemley, 2002) and essentially influence the actors’ behavior (Stoll, 2014), especially with respect to the selection of a certain organization and certification, which we will discuss subsequently.

2.3. Adoption and certification of technology standards

Whether or not a firm joins a certain standard consortium depends on an evaluation of the costs against the expected benefits (Farhi et al., 2005; Weitzel et al., 2006). The relation between costs and benefits in turn depends on several factors. An intensely researched factor is the size of the consortium as a larger group of complementors, thus also including complementary products and services, which makes adoption more attractive for end users and also increases the expected benefits of firms (Farrell & Saloner, 1986a, 1986b; Katz & Shapiro, 1986). This corresponds to the perspective taken by Lerner and Tirole (2006), who consider consortia as certification bodies and argue that firms prefer the consortium to better persuade end users to adopt the technology.

Another factor discussed in some literature is the presence of rivals within a consortium (Axelrod et al., 1995; Baron & Pohlmann, 2013). Axelrod et al. (1995) argue that firms may prefer to join a coalition if there are less close rivals in terms of firm size in order to maximize their own benefits. In contrast, the findings of Baron & Pohlmann (2013) suggest that especially consortia can provide a forum for rivals to coordinate upfront in order to reduce duplicate R&D efforts, thus rather preferring consortia with higher levels of firms with similar patent portfolios.

Additionally, for potential technology sponsors the decision to either join an existing consortium or promote their own proprietary technology crucially depends on symmetry in terms of relative market power (Axelrod et al., 1995; Besen & Farrell, 1994) and on their preference to compete between standards or within a standard including the agreement on one particular standard (Besen & Farrell, 1994). Besen and Farrell (1994) argue that firms with relatively similar power may rather prefer to sponsor their own technologies and then either compete between their standards or negotiate over one and compete within. Agreement particularly depends on concessions such as low-cost or zero-cost licensing (Farrell & Gallini, 1988) towards the other, and commitments to their own standard such as R&D investments making the adoption of the other technology less attractive (Besen & Farrell, 1994).

Being a member of a consortium does not necessarily imply product certifications by that firm. Some firms may rather intend to learn about competitors' technologies (Rosenkopf et al., 2001) or improve impact on formal standard setting (Leiponen, 2008).

Certifications usually involve a formal certification procedure and may or may not entail certification fees. During this process, products of one company are tested against technical specifications and interoperability with products of other companies. As more and more companies choose to develop products incorporating the technical standard and applying for technical certification, these companies increase the set of complementary products to the technology at hand, making it increasingly more attractive to consumers.

Especially in markets with information asymmetries, certifications reveal some information about the quality of products (Farhi et al., 2013; Lizzeri, 1999). While Chiao et al. (2007) argue that a stronger focus on the interests of end users improves the effectiveness of certifiers, some research stresses that firms usually prefer certifiers who do not disclose failed applications and thus do not reveal information about lower product quality (Farhi et al., 2013; Lizzeri, 1999).

Apart from testifying compliance with the technical specifications, and thus signaling interoperability with certain devices, certification can further serve branding purposes helping firms to leverage a potentially strong brand of the consortium (Jacoby & Kyner, 1973; Updegrove, 2007).

To conclude, empirical evidence on certifications in standard organizations is scarce, and research on standard organizations mainly takes a static view (c.f. Baron & Spulber, 2018) while foregoing adjustments of decisions over time. We thus adopt an ecosystem lens considering adoption dynamics over several years and consider the impact on certifications as contributions to the overall community. Building on this context, we develop testable hypotheses as follows.

3. Development of research hypotheses

3.1. Switching

According to the framework of Ahuja et al. (2011), dynamics within organizational networks go back to four factors, namely *agency*, *opportunity*, *inertia*, and *random* factors. *Agency* denotes the deliberate decision-making based on e.g. homophily or prominence attraction. *Opportunity* goes back to convenience guiding a firm’s ties through features such as proximity, common goals, or identities. *Inertia* occurs when a firm develops certain routines or habits inhibiting change. In other words, firms adapt to their environment, while internal and external structures may limit their possible choices. Overall, firms’ choices are guided by a continuous assessment of expected costs for adjusting a set of memberships against potential benefits of such an adjustment (Farhi et al., 2005; Weitzel et al., 2006). If switching costs are lower than expected benefits, firms prefer to adjust their memberships.

The costs of switching crucially depend on the engagement of a firm within a certain community. First, contributions by means of complementary products and services requiring investments and at some point causing “excess inertia” (Zhu et al., 2006). Second, investments by means of membership fees or technology disclosure and sponsorship (Toh & Miller, 2017) making it less profitable to leave. Third, the formation of a network of relationships with others (Rosenkopf et al., 2001) increase social embeddedness of the actor (Granovetter, 1985). All these factors increase the bond of a firm to a certain consortium, limiting changes of memberships. Considering the dialectic of shared interests at the ecosystem level and self-interests, this case reflects a higher alignment of both (von Krogh et al., 2012).

In contrast, firms with a relatively low lock-in to a certain set of memberships prefer to adjust this set if opportunities emerge elsewhere, increasing potential benefits of changing, or if undesired changes occur in the respective consortia, decreasing initially assumed benefits. This is the case when fees (Farrell & Gallini, 1988) or IP and licensing policies change (Stoll, 2014), niche crowding occurs driving prices down, the installed base of competing technologies becomes relatively larger (Farrell & Saloner, 1986a), or the technological core changes causing a competitive disadvantage for a firm (Kapoor & Agarwal, 2017). In addition, firms may deliberately decide to join certain consortia aiming to learn about competitors’ technologies (Leiponen, 2008; Toh & Miller, 2017), increase impact for formal standard setting (Leiponen, 2008), or search for capabilities required for their own innovation habitat (Selander et al., 2013; Teece, 2007). In any case, interests within the ecosystem are misaligned and overall switching costs must be relatively low, which is then observable in adjustments to the set of memberships. We expect that firms with a lower alignment with the shared interests and relatively low switching costs (i.e., binding) are also less inclined to contribute to value creation in form of certified and thus interoperable products. Accordingly, we formulate

H1: *A more intense adjustment of consortia memberships is associated with an overall lower product certification activity in the focal consortium.*

3.2. Spanning

The second dimension of ecosystem dynamics we study is spanning, i.e., participating in several competing ecosystems at the same time. Participation in several competing ecosystems requires higher investments through membership fees, but also offers firms the opportunity to increase market access and thus revenues (Cennamo et al., 2018; Landsman & Stremersch, 2011) as well as political capital to influence peers (Leiponen, 2008). Furthermore, it allows firms to form sustainable relationships across several communities (Rosenkopf et al., 2001), stay updated on technological changes, and leverage the brands of the consortia (Jacoby & Kyner, 1973; Updegrove, 2007).

As described above, these motives go along with higher investments over time and increase the bond to the set of memberships, thus inducing firms to release products to benefit from their multiple memberships. As such, one behavior going along with participating in several ecosystems is multi-homing (Cennamo et al., 2018; Landsman & Stremersch, 2011), as membership is required to get access to the technical specifications and certification program , allowing firms to efficiently market their products in a fragmented market.

Certifying products for several technologies signals end-users interoperability across a larger set of devices as they can be combined freely (Yoo et al., 2010), improving the firm's competitive position. At the same time, it decreases differentiation between both sets of complementary products (Hagiu & Lee, 2011; Landsman & Stremersch, 2011), thus gradually driving end-users indifferent between both technologies but overall increasing inducements for adoption (Landsman & Stremersch, 2011). Moreover, multi-homing may go along with a loss of quality performance in complements, especially when they are ported to more complex technologies (Cennamo et al., 2018).

Firms counting on multiple consortia become more independent from a single technology shifting the focus towards improving the technology's own value capture. Considering the dialectic of shared interests at the ecosystem level and self-interests, this case reflects an alignment with several competing communities. Firms indeed contribute to value creation by contributing compatible products and thus serving ecosystem-level interests. At the same time, they leverage several memberships to reduce interdependence with one particular set of companies and gain access to a larger part of the market. We thus posit:

H2: *A higher number of simultaneously held consortium memberships is associated with a higher product certification activity in the focal consortium.*

3.2. Orchestration

As outlined above, different ecosystem roles are usually associated with differences in value capturing opportunities and contributions to value creation (Iansiti & Levien, 2004a; Oh et al., 2015). One highlighted role is that of orchestrators, who establish a favorable position within the ecosystem and thus usually can capture a larger fraction of value created (Moore, 1993; Oh et al., 2015).

Ecosystem orchestrators usually promote an ecosystem vision as well as an architectural "blueprint" (Dattée et al., 2018; Ozcan & Eisenhardt, 2009), may recruit actors that are required to create and deliver value (Adner, 2012), manage knowledge mobility and network stability (Dhanaraj & Parkhe, 2006) and provide services, tools and technologies required for value creation (Gawer, 2014; Iansiti & Levien, 2004a). While ecosystems formed by a platform leader are usually orchestrated by one actor, the platform sponsor[48], industry consortia allow to formally devolve a larger fraction of control to other participants (Boudreau, 2010). As such, formal board committees allow interested parties to participate in governance decisions, while usually paying higher membership fees (Baron & Spulber, 2018). Albeit, previous literature took a rather static view on the orchestrator's role. In contrast, we consider changes as firms may choose to join or leave the boards across consortia, thus reflecting changes in their interests in competing technologies and their surrounding community of firms.

Orchestrating firms have the opportunity to impact decisions in a favorable way for themselves such as aligning policies and technological changes with their own technologies, making it easier to market their products. In addition, higher membership fees required to get access to the board committee also increase the motivation to provide and certify products. Accordingly, an orchestrator role allows strengthening self-interests and increasingly intertwines the orchestrator with the ecosystem over time. Hence, we expect that firms involved in the board committee also engage more in product certification and hypothesize as follows:

H3: *Firms that held a board seat in the focal consortium within the observation period show a higher product certification activity in the focal consortium.*

[48] Examples include but are not limited to Apple (Qiu et al., 2017), Google (Karhu et al., 2018), SAP (Wareham et al., 2014), and Mozilla (Tiwana, 2015).

4. Methodology

4.1. Sample and data collection

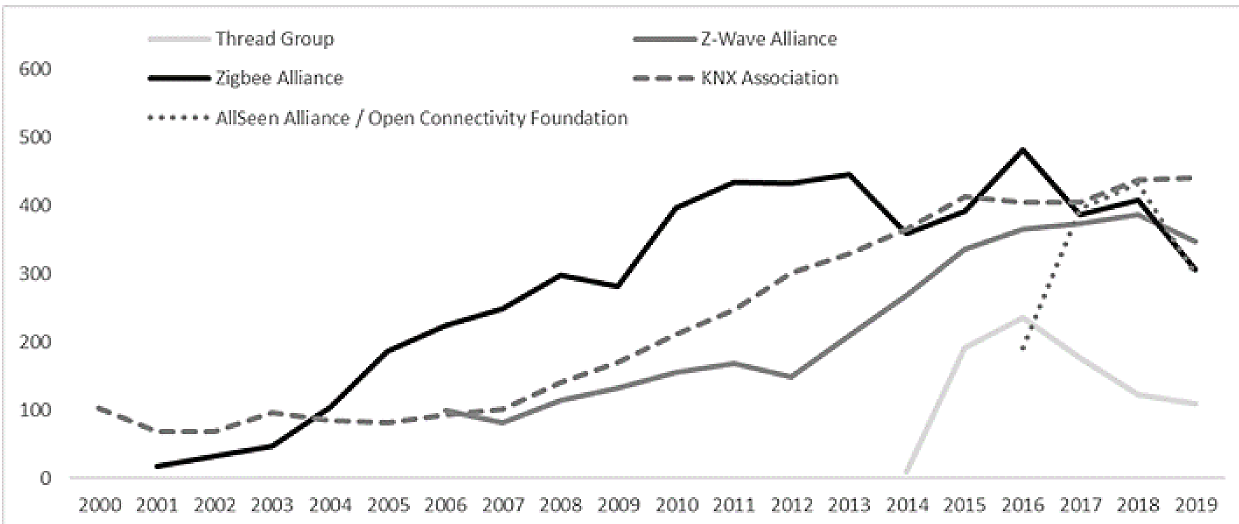
While ecosystem boundaries are difficult to determine (Iansiti & Levien, 2004b), roles and positions of firms are challenging to observe within ecosystems. We leverage formal standard organizations with publicly available information to make some part of the innovation ecosystem's structure and evolution visible. While a larger part of the literature on innovation ecosystems focuses on firm-centric (Li, 2009), platform-centric (Qiu et al., 2017) or smaller technology ecosystems (Adner & Kapoor, 2016), we focus on technological standards as the binding element within the ecosystems as they determine the set of interdependent actors and at the same time provide a forum for consensus building. Industry consortia in particular provide an institution that governs the technological evolution within technical committees, addresses IP rights, ensures interoperability of products, provides a shared vision, and fosters technology adoption. As such, it allows firms to orchestrate an innovation ecosystem together.

We chose the smart home market as our research context to study ecosystem dynamics for several reasons. First, smart home products require connectivity technologies to exchange sensor data and commands (Kahle et al., 2020), and hence standard development is particularly crucial to materialize a customer-facing solution. In addition, industry consortia are perceived as important vehicles for ecosystem governance in the smart product context (Kahle et al., 2020). Second, the market is highly fragmented with a continuous emergence of additional standards (cf. Cottrell, 1994). This fragmentation seems to sustain, as there is no "tipping" visible in the number of members between 2005 and 2019 (see Figure 12). Specifically, most of the consortia grow without taking over shares of the others, while almost all of them lost members in 2019, most probably due to increases in fees. Also, some firms have teamed up to create additional standards, increasing the fragmentation even further.[49] Third, each standard is accompanied by a larger ecosystem of hundreds of companies from various industries (Peine, 2008) providing complementary products and services.

[49] For example, Amazon, Google and Apple recently announced to collaborate with Zigbee on a new standard (https://www.apple.com/newsroom/2019/12/amazon-apple-google-and-the-zigbee-alliance-to-develop-connectivity-standard/).

In this context, we focus on the Z-Wave alliance[50] to study product certifications. The alliance is built on top of the sponsored Z-Wave standard and has a formal governance structure, several membership levels and a certification program for products, allowing us to observe a larger fraction[51] of the underlying ecosystem affiliated with the Z-Wave standard – in particular, firms taking leading roles, changes in memberships, and their resulting contribution in form of complementary products.

Figure 12: Evolution of total consortia memberships between 2000 and 2019.



Source: Own illustration.

The Z-Wave standard is a radio frequency transmission protocol, which was developed by the venture Zensys in 1999, where companies such as Intel and Cisco were among the first investors. In 2005, the Z-Wave alliance was established by the first adopting companies. Then Sigma Design acquired Zensys in 2008 and sold the Z-Wave business to Silicon Labs in 2018. The standard is implemented on semiconductors produced by the technology sponsor Silicon Labs as well as the licensee Mitsumi. Product certifications follow a formal certification process that requires a paid membership of a certain level, the submission of an application form containing product and company/brand information, a compliance test conducted by an authorized testing lab, and the grant of trademark licenses accompanied by announcement of compatibility within a product registry. Z-Wave's process differs in that it divides the process into two sub-processes, a technical

[50] https://z-wavealliance.org/.

[51] We do not account for end-users (Autio & Thomas, 2014) or the provision of additional services (Papert & Pflaum, 2017), but focus on the hardware and software part of the innovation ecosystem, where they cooperate to foster the adoption of the underlying technology while pursuing their own interests.

certification, which is managed by the technology sponsor, and a marketing certification, managed by the consortium.[52] Completion of the marketing certification is required to receive technical certification and ensures that the issuing company holds the trademark rights to the brand under which the product is to be sold. Yet, the overall Z-Wave certification process does not encompass additional requirements that exceed those by competing consortia (consider A12 in the appendix for an overview of the considered consortia). Completion of the overall process is mandatory in order to be allowed to sell products incorporating Z-Wave technology. Hence, announced product certifications in the Z-Wave alliance reflect companies' contributions of complementary products of reasonable quality to the overall innovation ecosystem formed around Z-Wave.

In addition to data on the Z-Wave alliance, we collect data on the major competing consortia in the smart home market – namely, Thread Group, Zigbee Alliance, KNX Association, AllSeen and the Open Connectivity Foundation – to reconstruct the firm-consortia affiliations (Leiponen, 2008). We chose these consortia, as they provide competing technology standards specific to smart home applications with similar technical features. In order to analyze the dynamics in membership between the underlying ecosystems (Tsujimoto et al., 2018), we carried out longitudinal data collection between 2005 and 2019. We include three types of data: 1) firm memberships in standard consortia, 2) products and apps, and 3) additional firm information (see Figure 13 for an overview).

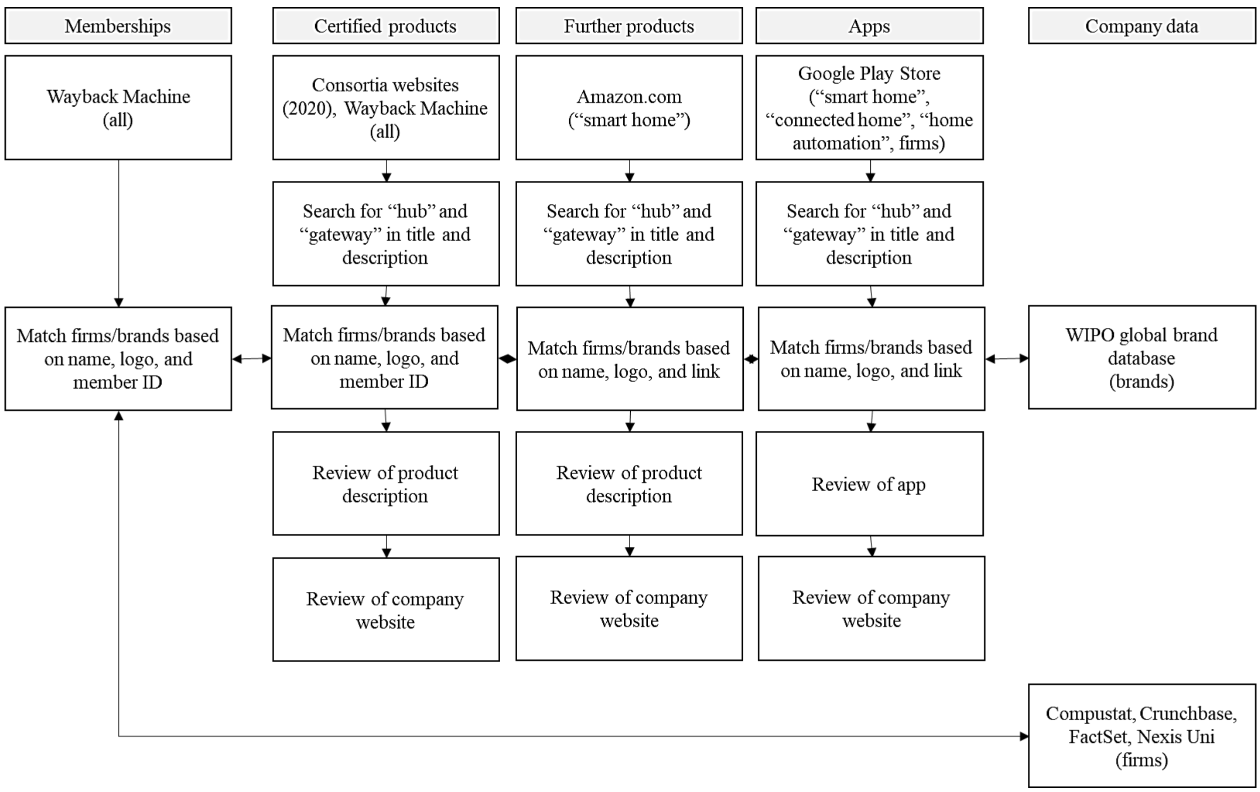
To collect the historical membership data, we followed the approach of Leiponen (2008) and Baron and Spulber (2018) and crawled the archived consortia websites using the *The Wayback Machine* (www.archive.org). The data covers the period between 2005 and 2019, consisting of 175,041 records, whereby several copies of the same website were retrieved per year. This allowed us to cross-validate the data and fill in gaps caused by the archiving or crawling process.

We retrieved and triangulated company data such as the standard industrial classification (SIC) sector code, the number of employees or the acquisitions from Crunchbase, Nexis Uni, Compustat and FactSet. We used the data to identify rebranding, acquisitions and subsidiaries. By including such data, we can account for firms' decision to acquire other firms within the sample allowing us to control for effects stemming from M&A and labor division in larger corporate groups.

[52] The division of the product certification process into a technical and a marketing certification allows to divide control over certification between the technology sponsor and the consortium. Yet, the marketing certification consists of the registration of an issuer's brand as well as a product category under which the product is to be sold and does not encompass requirements that exceed certification by competing consortia such as Zigbee.

Particularly, rights and obligations associated with membership in the Z-Wave alliance of a company do also apply to its subsidiaries, while the reverse is precluded.

Figure 13: Overview of data collection and evaluation.



Source: Own illustration.

We imported these datasets into a database, homogenized the firm names and matched the manufacturers across the three data types, based on website links, names, logos, and member IDs. Also, we used the WIPO Global brand database[53] to link brands to companies.

This led to a full dataset of 766 firms and 11,490 unique membership years with a total of 3,036 certified products. As acquisitions may have changed overall decision processes of firms that were acquired, we exclude them from our sample, leaving us with 731 firms.

4.2. Dependent variable

Previous studies mainly focused on the number of patents granted (Artz et al., 2010), innovative sales productivity (Tsai, 2009), and product announcements (Artz et al., 2010) to measure

[53] https://www3.wipo.int/branddb/en/#

innovation outcomes at the firm level or market shares (Bogers et al., 2019) and market penetration at the ecosystem-level (Sandström, 2016). In platform-centric ecosystems, app releases have been used to reflect value creation (Foerderer et al., 2018). In a similar fashion, we consider product certification as one type of value creation by member firms choosing to adopt a certain technology, develop complementary products, and certifying them making the central technology standard more attractive to consumers as the set of complementary devices grows.

Table 13: Overview of annual memberships and certified products across the observation period.

Year	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Product certifications	0	0	6	3	7	32	46	85	77	109
Member count	0	0	0	0	0	0	104	84	117	136
Year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Product certifications	52	134	104	200	176	333	400	468	389	476
Member count	159	171	150	213	274	341	372	379	392	350

Source: Own illustration.

As firms must certify all products that incorporate the standard – including software – and certified products receive a unique certification number depicting the certification year, this measure allows us to reliably observe all complements across the years. We collected data on certified products from the consortia's websites in 2020 while using the certification number to extract the year for Z-Wave products.[54] As visible in Table 13, some products were certified within the period of standard invention and formation of the consortia (2002 - 2005), which resolves in inconsistent member counts. Hence, we focus on the periods after 2005 (covering 3,049 certified products) to compute our dependent variable $products\, certified_i$ as the accumulated count of products certified between 2006 and 2019 for each firm i.

4.3. Independent variables

To measure switching behavior across the consortia we count the number of exits $Exits_i$ between 2006 and 2019 per firm i. An exit is identified, if firm i is a member in consortia c in period t ($member_{ict} = 1$), but not a member in the same consortia in $t + 1$ ($member_{ict+1} = 0$), where

[54] Z-Wave certification numbers follow one of five formats beginning with the Z-Wave version followed by the 2-digit year, 2-digit month and a 4-digit number (c.f. https://www.silabs.com/documents/login/miscellaneous/INS10638-Z-Wave-Certification-Overview.pdf, section 2.8).

$exit_{ict} = -(member_{ict} - member_{ict-1})$. The auxiliary variable $member_{ict}$ is a dichotomous variable reflecting whether a membership is existing or not. The overall measure is then the sum of all annual exits: $Exits_i = \sum_{t=2006}^{2019} \sum_c^5 exit_{ict} = \sum_{t=2006}^{2019} \sum_c^5 -(member_{ict} - member_{ict-1})$. We chose exits as they reflects the outcome of the decision-making process not to remain in a consortium and thus not supporting the further evolution of the underlying technology.

Analogously, we measure spanning across consortia by considering the mean annual memberships across all five consortia c and years t between the first year ($2006 \leq First\ year_i \leq 2019$) of the firm's occurrence in our dataset and its disappearance ($2006 \leq last\_year_i \leq 2019$). Mathematically, we apply the formula: $Spanning_i = (\sum_{t=First\ year_i}^{Last\ year_i} \sum_c^5 member_{ict}) / (Last\ year_i - First\ year_i + 1)$.

To identify orchestrators, we use a dummy variable *orchestrator*$_i$ set to 0 if firm i never held a seat in the Z-Wave Alliance and set to 1 if firm i held a board seat in at least one period in Z-Wave.

4.4. Control variables

First, we control for the *First year* of appearance in our sample, as over time the technology sponsor changed two times, prices were adjusted, and new technology generations were released, changing conditions for firms that joined later.

In addition, as differences in firm size and age may be associated with different certification behaviors as large firms usually have access to more resources yielding more opportunities to bear development and certification expenditures. Accordingly, we include ln(number of employees) as a measure for firm size (Tsai, 2009) and the firm age as further controls.

Also, we add a variable *Mean Z-Wave level* that reflects the average membership level in Z-Wave, because the lowest level is not allowed to certify products.

Finally, count outcomes are usually influenced by the differences in the duration an individual is exposed to the underlying data generating process. As membership lengths of firms in our sample differ, we define a variable $ZWave\_membership\_years_i = \sum_{t=first\_year_i}^{last\_year_i} member_{it,Z-Wave}$, storing the sum of membership-years in the Z-Wave Alliance for firm i, which we use as an exposure factor in our model. Also, we add dummies for 1-digit sector codes based on the standard industrial classification system to account for different probabilities to develop and certify products across industries.

5. Analysis and results

5.1. Measurement model

The majority (64 %) of the firms in our sample never certify any product, which is reflected by excess zeros.

Table 2: Descriptive statistics and pairwise correlations.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
(1) Products certified								
(2) Exits	-0.01							
(3) Spanning	0.23	0.30						
(4) First year	-0.11	-0.38	-0.02					
(5) Firm age	0.15	0.23	0.23	-0.20				
(6) Firm size (ln(emp))	0.16	0.23	0.37	-0.07	0.59			
(7) Mean Z-Wave level	0.18	0.04	0.14	-0.08	0.16	0.20		
(8) Z-Wave membership duration	0.34	0.00	0.18	-0.48	0.21	0.15	0.04	
N	731	731	731	731	731	731	731	731
Mean	3.98	0.83	1.16	2013.04	25.41	3.90	1.70	4.17
Standard Deviation	15.19	0.77	0.40	4.19	28.33	2.70	0.49	2.86
Minimum	0.00	0.00	0.23	2006.00	1.00	0.00	0.00	1.00
Maximum	213.00	5.00	3.21	2019.00	209.00	12.62	14.00	14.00

Source: Own illustration.

Note: Values larger than |0.01| are significant at $p < 0.05$. Mean variance inflation factor equals 1.33.

This goes back to two reasons. First, our sample contains firms that have a focus other than developing and certifying products such as universities or certification institutes. Second, some firms do develop products, but did not develop Z-Wave products, which they could certify in our sampling period. To capture this process, we use a zero-inflated model (Lambert, 1992). Zero-inflated models are usually preferred over hurdle models, if there are excess structural zeros in addition to sample zeros (Rose et al., 2006). Furthermore, we observe overdispersion in our sample (mean = 3.98, variance = 230.96), suggesting to use a negative binomial model. We thus compared a zero-inflated Poisson model to a zero-inflated negative binomial model, of which the latter yields the more efficient coefficient estimates.

We report a hierarchical regression approach, where our interpretation is based on model 5, the full model. Further, we estimate robust standard errors and report McFadden's R^2, adjusted McFadden's R^2 and log likelihoods as measures for model fit, apart from average marginal counts for the full model. Descriptive statistics and pairwise correlations are reported in Table 14.

On average, firms in our sample certify 3.98 products between 2006 and 2019. Yet, as stated before, certification counts differ significantly across firms, reflected by a relatively high standard deviation. Also, firms in our sample, on average leave 0.83 times a consortium and on average span 1.14 consortia, both reflecting the large fraction of firms in our sample choosing to only commit to Z-Wave. On average firms, join our sample in 2013, close to the middle of our observation period, are 25 years old, and stay 4.17 years in the Z-Wave Alliance.

5.2. Hypotheses testing

The full model (5) reported in Table 15 explains 11.2% of the overall variance, while alpha, the dispersion parameter, is significantly different from 0, that is ln(alpha) is larger than 1 ($p< 0.001$). Hence, the zero-inflated negative binomial model is the better choice for the data.

Turning to the logistic model predicting whether a firm is not inclined to develop and certify products in the first place, we see that the average membership level in Z-Wave is the strongest predictor, suggesting that the likelihood to certify products increases with the level ($p < 0.001$). In addition, firm size is good predictor, suggesting that the likelihood to certify products increases with the number of employees ($p < 0.10$). While an earlier Z-Wave membership (*First membership year*) and higher firm age show similar effects, they are not statistically significant.

Table 15: Zero-inflated negative binomial regressions of product certification counts.

Product certification counts	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**Average marginal counts**
Count model (NB)						
First membership year	0.12^{**}	0.10^{**}	0.11^{***}	0.12^{***}	0.08^{**}	0.33^{*}
	(0.04)	(0.04)	(0.03)	(0.04)	(0.03)	(0.17)
Firm age	0.01	0.01^{*}	0.01	0.01	0.01°	0.05°
	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)	(0.03)
Firm size	0.07	0.10°	0.01	0.02	0.01	0.12
	(0.05)	(0.05)	(0.05)	(0.06)	(0.06)	(0.27)
Exits		-0.29^{*}			-0.60^{***}	-2.85°
		(0.14)			(0.17)	(1.62)
Spanning			0.98^{**}		1.16^{***}	5.54°
			(0.30)		(0.31)	(3.10)
Z-Wave board member				0.92^{**}	0.53°	3.00
				(0.34)	(0.31)	(2.21)
Other board member				1.04^{*}	1.66^{*}	14.42
				(0.50)	(0.78)	(13.76)
Constant	-232.57^{**}	-210.29^{**}	-213.22^{***}	-246.40^{***}	-163.89^{**}	
	(70.72)	(70.21)	(61.16)	(73.29)	(62.90)	
Logit model						
First membership year	0.31	0.31	0.30	0.31	0.32	
	(0.21)	(0.21)	(0.22)	(0.21)	(0.22)	
Mean membership level	-8.27^{***}	-8.27^{***}	-8.28^{***}	-8.28^{***}	-8.28^{***}	
	(1.90)	(1.84)	(1.96)	(1.98)	(1.95)	
Firm age	-0.01	-0.01	-0.01	-0.01	-0.01	
	(0.02)	(0.02)	(0.02)	(0.03)	(0.03)	
Firm size	-0.28	-0.27°	-0.29	-0.31°	-0.29°	
	(0.17)	(0.16)	(0.19)	(0.18)	(0.16)	
Constant	-606.22	-620.79	-595.59	-618.99	-624.63	
	(412.86)	(411.46)	(431.55)	(420.49)	(432.33)	
Industry dummies	Yes	Yes	Yes	Yes	Yes	Yes
Ln(alpha)	1.36^{***}	1.34^{***}	1.30^{***}	1.33^{***}	1.22^{***}	
	(0.10)	(0.10)	(0.10)	(0.11)	(0.10)	
McFadden R2	0.094	0.097	0.102	0.098	0.113	
McFadden R2 adj.	0.079	0.081	0.086	0.082	0.095	
Degrees of freedom	3	4	4	5	7	
LL Null	-1129.027	-1129.027	-1129.027	-1129.027	-1129.027	
LL Full	-1112.921	-1109.482	-1103.574	-1107.678	-1089.843	
Firms	731	731	731	731	731	731

Source: Own illustration.

Notes: Robust standard errors in parentheses. Significance levels: $^{\circ}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The full model (5) of the second part, the negative binomial count model, of the mixed model show similar estimates for the control variables, suggesting that older firms ($p < 0.10$) and firms that appeared later in our dataset ($p < 0.01$) are more likely to show higher product certification counts. Our main variable *Exits* is negative and statistically significant ($p < 0.001$). This is consistent with our expectation (H1) that firms more often adjusting their memberships are less inclined to certify a higher number of products. Average marginal counts suggest that for each additional exit of a consortium in our sample, the product certification count declines on average by 2.8 ($p < 0.10$). In addition, the variable *Spanning* is positive and statistically significant ($p < 0.001$). On average the product certification count increases by 5.5 products for each additional consortium a firm holds a membership in next to its other consortium memberships ($p < 0.10$). This result is consistent with our expectation that firms engaging with more consortia simultaneously are inclined to certify more products (H2). Lastly, coefficient estimates for Z-Wave board membership ($p < 0.05$) and board seat in other consortia ($p < 0.05$) are positive and significant. Yet, average marginal counts are not statistically significant as reported in the last column of Table 15.

To measure our assumptions underlying the hypotheses, we conduct further analyses to predict: the number of consortia a firm certified products in using a Poisson model (6), the mean Z-Wave membership level using an OLS model (7), and the membership duration within Z-Wave measured in years using a Poisson model (8). The results are reported Table 16.

The regression of the number of consortia firms certified products with (6) allows us to obtain more insight as to how firms certify across all consortia in our sample, complementing our results on the focal consortium, Z-Wave. We can see that a higher exit count is associated with a lower number of consortia ($p < 0.001$). In contrast, a higher mean in held memberships (spanning) is associated with a higher number of consortia a firm certified products with ($p < 0.001$). This suggests that firms more frequently adjusting their memberships not only certify significantly less products in Z-Wave but also certify across a fewer number of consortia. Hence, there is no evidence that firms hop between several consortia, certifying products in each of these. Rather, firms hold memberships in multiple consortia simultaneously with the intention to certify products. Firms that held a board seat in at least on period do not show a significant association with the number of consortia, neither for Z-Wave board members nor for board members in other consortia.

Table 16: Cross-sectional regressions for the underlying mechanisms.

	(6) *No. consortia with certification*	(7) *Mean Z-Wave membership level*	(8) *Z-Wave membership years*
Exits	-0.280***	-0.035	-1.190***
	(0.065)	(0.027)	(0.163)
Spanning	0.762***	0.099°	1.652***
	(0.086)	(0.057)	(0.255)
Z-Wave board member	0.227	0.759***	2.874***
	(0.152)	(0.121)	(0.724)
Other board member	0.262	-0.217	-2.975***
	(0.257)	(0.185)	(0.753)
First membership year	-0.031**	-0.007	-0.352***
	(0.011)	(0.005)	(0.033)
Firm age	0.003°	0.000	0.007
	(0.002)	(0.001)	(0.005)
Firm size	0.058**	0.018*	0.011
	(0.021)	(0.008)	(0.043)
Constant	62.039**	15.868°	711.556***
	(22.010)	(9.141)	(66.055)
Industry dummies	Yes	Yes	Yes
McFadden R2	0.118	0.110	0.085
McFadden R2 adj.	0.095	0.078	0.076
Degrees of freedom	15	15	15
LL Null	-689.224	-508.934	-1788.140
LL Full	-607.938	-453.135	-1636.731
Firms	731	731	731
Model	Poisson	OLS	Poisson

Source: Own illustration.

Notes: Cross-sectional regressions on 731 firms. Robust standard errors in parentheses. Mean variance inflation factors from left to right: 4.07, 4.21, 4.21.
Significance levels: ° $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Considering the mean Z-Wave membership level reported in model 7 provides insights as to how observable dynamics and board seats are associated with the commitment to Z-Wave. Different membership levels come with different fees and privileges. The variable *Exits* is negatively correlated with the mean Z-Wave membership level (p < 0.001), while spanning shows a positive but not significant coefficient estimate. Hence, firms leaving consortia more often tend to show a lower membership level averaged across the membership years, yet not statistically significant. In contrast, firms with higher mean annual memberships (spanning) tend to hold higher average membership levels (p < 0.10), reflecting a slightly higher commitment. A strong association between Z-Wave board membership and the mean membership level in Z-Wave ($p < 0.001$) underlines their overall higher commitment across their membership.

Model 8 reported in Table 16 allows us to gain more insights on how membership dynamics and board membership are linked to membership duration in Z-Wave. We observe that *Exits* are strongly negatively associated ($p < 0.001$) and *Spanning* is strongly positively associated ($p < 0.001$) with the duration in Z-Wave in years. These are consistent with our assumptions that firms leaving overly consortia more often do it consistently with Z-Wave, while spanning reflects rather more sustainable Z-Wave memberships. Similarly, firms that held board seats in Z-Wave show significantly longer Z-Wave membership durations ($p < 0.001$), while firms that held board seats in competing consortia show significantly shorter Z-Wave membership durations ($p < 0.001$), underlining their strong commitment to their respective consortia.

5.3. Robustness tests

Although our further analyses already provide more insight into the mechanisms underlying our results and, to some extent, prove validity, there may be alternative explanations. Next, we discuss five approaches to ensure robustness of our findings.

To measure causality rather than correlations to address a possible endogeneity issue between product certifications and spanning as well as product certifications and exit, we construct a panel.[55] The panel model regresses annual product certification counts on *exits* and *spanning* within a rolling time window of three previous years, *Z-Wave board seat* and *other board seat* in the previous period, and firm size and age as further time-invariant control variables. We also must include a dummy variable *member* that states whether a firm held a membership in Z-Wave in period *t*, as this is mandatory for product certification. We form interactions between *member* and all time-varying independent and control variables and include year dummies. The model is presented in Table 17. Overall, the results are consistent with our models on aggregate values discussed previously, yet changes in product certifications directly follow changes in dynamics. We get similar results for alternative windows sizes of four and five periods.

[55] Applying the Breusch-Pagan Lagrange Multiplier (Breusch & Pagan, 1980) implies using a panel regression rather than a pooled OLS model. Thus, to study dynamics over time, we use a panel regression with year-fixed effects (Wooldridge, 2010, p. 300 ff.).

Table 17: Random-effects panel regression between 2006 and 2019.

Product certifications$_t$	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
Member$_t$	0.50***	0.50***	0.51***	0.22*	0.10	0.45***	0.08
	(0.06)	(0.06)	(0.07)	(0.11)	(0.16)	(0.06)	(0.14)
Firm age	0.00	0.00	0.00	0.00	0.00	0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Firm size	0.03°	0.03°	0.03°	0.01	0.01	0.03*	0.02
	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)
Exits (window=3)		-0.03	-0.00				-0.04
		(0.03)	(0.03)				(0.04)
Member x Exits			-0.15				-0.40**
			(0.20)				(0.15)
Spanning (window=3)				0.36**	0.20		0.23°
				(0.12)	(0.12)		(0.14)
Member x Spanning					0.25		0.20
					(0.18)		(0.16)
Z-Wave board member						0.29	0.19
						(0.20)	(0.21)
Member x Z-Wave board member						2.16**	2.19**
						(0.79)	(0.75)
Other board member						0.11	-0.26
						(0.24)	(0.33)
Member x Other board member						0.83	0.14
						(1.61)	(1.70)
Constant	-0.16°	-0.16°	-0.16*	-0.08	-0.08	-0.11*	-0.05
	(0.08)	(0.08)	(0.08)	(0.07)	(0.07)	(0.05)	(0.04)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R2 within	0.024	0.024	0.024	0.027	0.028	0.037	0.041
R2 between	0.105	0.106	0.102	0.136	0.146	0.125	0.158
R2 overall	0.039	0.039	0.039	0.049	0.050	0.057	0.068
Degrees of freedom	16	17	18	17	18	19	23
Sigma u	0.614	0.613	0.607	0.604	0.598	0.649	0.627
Sigma e	1.547	1.547	1.546	1.544	1.543	1.533	1.530
Rho	0.136	0.136	0.133	0.133	0.130	0.152	0.144
RMSE	1.549	1.549	1.550	1.546	1.546	1.534	1.532
Observations	10234	10234	10234	10234	10234	9503	9503
Firms	731	731	731	731	731	731	731

Source: Own illustration.

6. Discussion, conclusions and implications

6.1. Discussion

Our aim has been to study the dynamics across competing innovation ecosystems and roles to better understand the associated product certification activities as a form of value creation within innovation ecosystems. Complex technology products such as smart home systems require firms to collaborate in order to provide consumers with an attractive set of compatible products and services. Yet, the emergence of incompatible and competing technology standards leads to fragmentation (Cottrell, 1994), requiring firms to decide in which ecosystems they participate and create value in form of compatible products and services.

As in such a setting, firms usually form industry consortia as a vehicle to form consensus and develop one technology standard that allows interoperability as well as provide a shared governance regime (Baron & Spulber, 2018; Kahle et al., 2020), with observable structures, we use these to observe dynamics in memberships between the underlying (unobservable) innovation ecosystems.

We constructed a longitudinal dataset across a 15-year period, covering more than 700 members in the Z-Wave alliance as well as their memberships in four competing consortia to observe the formal structures and affiliations of firms of the underlying ecosystems.

Our statistical analyses lend support to our framework, showing significantly lower product certifications for firms that adjust their ecosystem affiliations more often. Consistent with our expectation, firms showing a more frequent adjustment in their ecosystem affiliations also affiliate significantly shorter with Z-Wave, reflecting an overall lower alignment between the firm's and the ecosystem's interests. Consistently, firms that on average leave ecosystems more often across the entire period in our sample also certify products for a significantly lower number of competing technologies and thus do not contribute to the stocks of complementary products and services of the respective innovation ecosystems.

In contrast, firms spanning across a higher number of competing consortia and thus participating in the underlying ecosystems show a subsequently higher product certification count for Z-Wave. We further observe a significant association between spanning across the entire period and certifications across a higher number of consortia, underscoring our theoretical assumption. While spanning and multi homing constitute drivers for higher product certifications, the majority of Z-Wave firms in our sample that certify products limit their certification activities to Z-Wave (about 79.1%).

Further building on our results, we consider one prominently discussed role in ecosystems, orchestrators as they should show a higher interest in the fate of the ecosystem, which should be expressed in an overall higher involvement in product certifications. In our sample, ecosystem orchestrators typically occupy positions with high influence on the overall evolution of the ecosystem. Thus, we consider board memberships as a proxy for orchestrators.

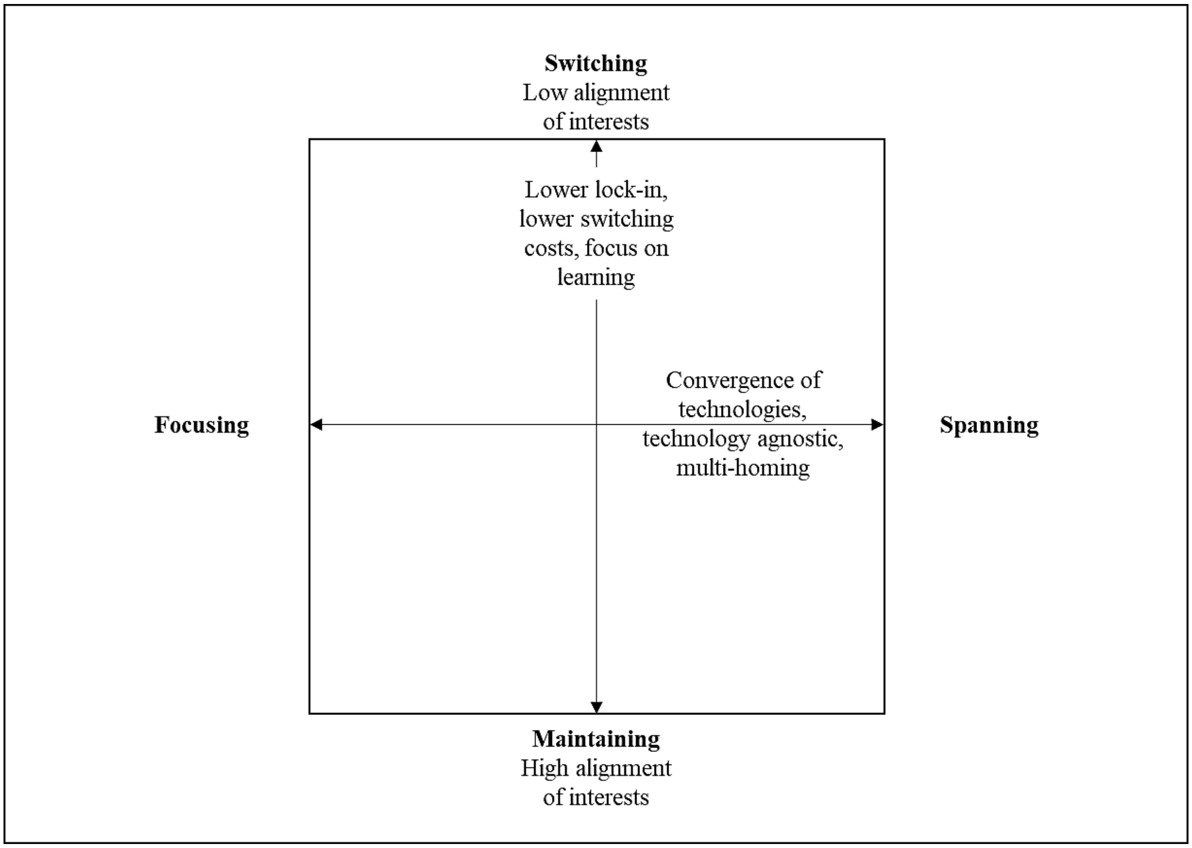
Our results show that Z-Wave orchestrators, i.e., firms holding a board seat in the Z-Wave alliance, display a significantly higher product certification count. Furthermore, we consider orchestrators of competing technologies, also showing a significantly higher product certification count. While previous literature pointed towards the superior bargaining power to extract a higher fraction of the returns (Iansiti & Levien, 2004a; Oh et al., 2015), we additionally show that these firms also fundamentally contribute to value creation by manufacturing and certifying products. We thereby consider shared governance (Boudreau, 2010) with changing orchestrators (Moore, 1993) in contrast to the majority of studies considering a central hub. Consistent with previous literature, we observe a small amount of firms governing the community (Weiss & Gangadharan, 2010).

6.2. Implications

Previous literature on innovation ecosystems neglected the role of standard consortia as forums to orchestrate innovation ecosystems by allowing a diverse set of (competing) firms to find consensus, populate a variety of product niches and build up a common brand. While innovation ecosystem literature points to "ecosystem dynamics", the majority of studies focuses on either dynamics within an ecosystem or multi-homing and network effects across ecosystems. In addition, literature on standard consortia mostly studies innovation activities by considering patents or product announcements as an outcome of collective efforts. We adopted an ecosystem lens considering dynamics within and across standard consortia to observe a larger fraction of the underlying ecosystem and the common ecosystem goal of providing a large and diverse set of compatible products (Jacobides et al., 2018). This allowed us to study how firm-level decisions are linked to ecosystem-level outcomes.

Building on our results, we present a theoretical framework (see Figure 14) based on the divergence of interests between the firm level and the ecosystem level (Adner, 2017), where firms face the tension between their own interests and the ecosystem interests (Wareham et al., 2014). We consider switching costs and lock-in as well as market reach and dependence of single technologies to derive two dimensions of visible membership dynamics, i.e., switching and spanning. While switching crucially depends on the lock-in to a certain ecosystem and the costs associated with switching from one to another technology and ecosystem, it further reflects a lower alignment between the firm's own and the ecosystem's interests. Spanning reflects the concurrent participation in several ecosystems, allowing a firm to become more independent of the fate of a single ecosystem and gain a larger market reach at the expense of higher membership fees. A higher number of concurrent memberships thus reflects a higher interest in convergence of incompatible standards and a higher motivation to provide standard agnostic products by means of multi homing.

Figure 14: Theoretical framework of participation strategies and alignment of interests.



Source: Own illustration.

Note: Theoretical framework based on the alignment of interests covering two dimensions of dynamics across ecosystems, i.e., switching and spanning.

6.3. Research limitations and future research

Our findings need to be qualified by our study's limitations. First, our data collection procedure using crawling techniques on archived snapshots of websites raises concerns about completeness and accuracy of our dataset. To address this issue, we included a number of different data sources and applied different perspectives to our dataset. Specifically, we collected various records per data point for validation. In addition, we estimated different models prior to our study to gain a better understanding of the underlying mechanisms.

Second, our study focuses on the Z-Wave alliance raising concerns about generalizability. Yet, the consortium shows an organizational structure, technology, and policies similar to that of the other consortia. Thus, we believe that Z-Wave does not constitute a special case.

In ecosystem literature, a general concern raised is the use of the concept of "ecosystems". While research does not present a clear picture of what constitutes an ecosystem in the business and innovation context, it needs to be questioned what justifies the use of this perspective. This is further connected to the issue of unclear boundaries of ecosystems (Santos & Eisenhardt, 2005). In our study, we present an approach to observe a fraction of the ecosystems' structure and dynamics by crawling historical records on the web (Baron & Spulber, 2018) concerning affiliations with competing standard consortia. Specifically, we do not directly observe the overall ecosystem but leverage the organization of standard consortia, as we know that they play a crucial role in coordination and help firms to occupy certain positions within the underlying ecosystem. We thereby bridge what Adner (2017) calls the affiliation perspective with the structure perspective on ecosystems. We consider dynamics stemming from coopetition and focus on value creation as a major common goal of innovation ecosystems. According to our understanding, it requires a certain alignment between individual interests and common interests for ecosystems to collectively produce a central value proposition. Yet, the alignment drives changes in the affiliations across competing ecosystems and thus also the memberships in standard consortia.

This study shows a venue for further research. As our study focuses on hardware and software certifications, further research may consider services and further roles (Papert & Pflaum, 2017) across the ecosystems as well as dynamics over time. In addition, it allows to study the co-evolution of governance mechanisms between competing communities, whereby a comprehensive dataset by Baron and Spulber (2018) covering 60 consortia and standard setting bodies may essentially contribute. Finally, we focus on a subset of reasons for misalignment of interests, which does not embrace the overall concept of the "alignment structure" described by Adner (2017) and thus leaves room for further research.

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Paper IV:

User Motivations in Peer Production

Sebastian Späth & Sven Niederhöfer

Abstract

Peer production systems often attract larger communities of paid and unpaid volunteers, who contribute to their respective projects. This chapter examines different underlying motivations that fuel these contributions. It thereby takes a tripartite form and summarizes current literature on 1) individual motivations to participate, 2) selection of tasks and 3) participation in peer production as a social practice. In the first two parts, we draw on self-determination theory, which discusses various intrinsic (the joy performing the task itself), extrinsic (rewards such as pay), and internalized extrinsic motives (internalized mores and values). The discussed literature shows that contributors are motivated not by a single motive, but by a whole range of interacting intrinsic, internalized extrinsic and extrinsic motives with different magnitudes. It further shows that peers' motivation partly determines the type of task they will self-allocate, whereby (internalized) extrinsic motives seem to play a crucial role in impelling individuals to perform mundane tasks. In the third part, we view peer production systems as social practices, which conceptualizes these systems as collectives of contributors with shared general principles, whose lives increasingly become intertwined with these communities. Reviewed literature suggests that motivation may be influenced by factors such as social exposure and institutional frameworks.

This article has been published as part of The Handbook of Peer Production.

1. Introduction

The advantages of "commons-based peer production" (Benkler, 2002, p. 375) on a national or firm level seem obvious: 1) it is better at identifying and assigning human resources to production processes, 2) increasing returns allow huge clusters of potential contributors to interact with huge clusters of information resources and 3) it achieves lower transaction costs by not relying on property and contract as the organizing principles of collaboration" (Benkler, 2002, p. 376). By reducing transaction costs through peer self-selection, Benkler argues an economic case for a commons-based peer production process. This does not explain why individuals would volunteer to contribute to such a system, though. Olson famously stated: "Indeed, unless the number of individuals in a group is quite small, or unless there is coercion or some other special device to make individuals act in their common interest, *rational, self-interested individuals will not act to achieve their common or group interest*" (Olson, 1965, p. 2 emphasis in original). In the case of public goods, this is the classic consequence of under-provisioning and overuse: the tragedy of the commons (Hardin, 1968).

Yet, various forms of peer production obviously thrive, ranging from the obscure (such as proof-reading of scanned classic texts) to industry-wide dominant solutions (e.g. Wikipedia). Thousands of volunteers, both unpaid and paid, act in and contribute to their respective projects. Here, we examine what motivates these individuals to contribute on an individual level.

In 2000, the economists Lerner & Tirole called these peers' behavior "startling" and succinctly condensed their dilemma in the oft-cited question "Why should thousands of top-notch programmers contribute freely to the provision of a public good?" (Lerner & Tirole, 2000, p. 2). Similar questions have been asked about other forms of peer production besides free and open source software creation, such as Wikipedia contributors (Schroer & Hertel, 2009) as well as participants in electronic networks of practice in the legal professions (who are not famous for their altruism) (Wasko & Faraj, 2005).

In this chapter, we summarize current research on user and peer motivations in peer production systems, focusing on the following: 1) individual motivations to participate, 2) selection of tasks and 3) participation in peer production as a social practice, which influences motivations and highlights the critical role of institutions in enabling peer production. Generally, we focus on motivation at the individual level (that is, not addressing the question of why organizations choose to partake in peer production).

2. Individual Motivation

Most early studies on user motivations in peer production settings have adopted a form of self-determination theory (Deci & Ryan, 1985), which rests on the assumption that individuals exhibit certain behaviors in order to satisfy three basic needs, namely competency, social relatedness, and autonomy (Deci & Ryan, 2000, pp. 233–235). The theory distinguishes between intrinsic and extrinsic motivation. While intrinsic motivation rests on the inherently interesting and enjoyable act of performing the task itself, extrinsic motivation requires an outcome that is distinct from the task itself (Deci & Ryan, 1985, 2000). Thus, extrinsically motivated individuals satisfy their basic needs indirectly, e.g. by being monetarily rewarded (Osterloh & Frey, 2000). Some studies have extended the basic concept and have added internalized extrinsic motivation (e.g., Chandler & Connell, 1987; Deci & Ryan, 2000). Internalization of extrinsic motivation refers to "an active, natural process in which individuals attempt to transform socially sanctioned mores or requests into personally endorsed values and self-regulations" (Deci & Ryan, 2000, p. 235-236). Thus, internalized motivation is by definition extrinsic but may be internalized by the individual and, accordingly, be perceived as self-regulating behavior rather than externally imposed (Deci & Ryan, 2000; Roberts, Hann, & Slaughter, 2006).

Table 18: Overview of individual-level motivations in open source software production.

Intrinsic	Internalized extrinsic	Extrinsic
• Enjoyment & fun Ideology	• Own-use value	• Pay
• Kinship amity	• Learning	• Career
• Altruism	• Reciprocity	
	• Reputation	

Source: Own illustration based on von Krogh et al. (2012).

Much of the early research was conducted in the context of open source software programming (von Krogh, Haefliger, Spaeth, & Wallin, 2012) and online community contributions (such as Wikipedia contributors). Generally, surveys have identified a diverse set of motivations for starting and continuing engagement in peer production (Benkler, 2017) spanning intrinsic, internalized extrinsic and extrinsic motivations. Table 18 provides an overview of identified individual-level motivations, based on von Krogh et al. (2012).

2.1. Intrinsic Motivation

Fun

One major intrinsic motivation discussed is enjoyment (Moilanen, 2012; Torvalds & Ghosh, 1998). It drives efforts due to the joy, creativity, and challenges associated with performing the task (Shah, 2006). Fun deriving from participating, creating objects or "hacking" software has been consistently cited as important drivers of effort (Hausberg & Spaeth, 2018; Lakhani & Wolf, 2005; Moilanen, 2012). This holds true even for contracted and paid contributors (Hars & Ou, 2002).

While these studies focus on the quantitative impact of fun and enjoyment on contributions, Shah (2006) further argued that they play an important role for sustained long-term contribution.

Ideology

Besides enjoyment and fun, many report that ideology-based intrinsic aspects are important factors driving contributions (David & Shapiro, 2008; Ghosh, Glott, Krieger, & Robles, 2002; Lakhani & Wolf, 2005). Ideology is typically based on certain norms, values, and beliefs (K. J. Stewart, Ammeter, & Maruping, 2006). Especially requirements such as freedom of use and modification as well as publication of source code or the overall conviction that open source is the best way to develop software are typically strongly supported (David & Shapiro, 2008).

Empirical findings, however, suggest that the impact of ideology-driven motivation may differ between peer production systems. For instance, Hertel et al. (2003) find a positive and significant relationship between social and political motives and code contributions within the Linux developer community. In contrast, Xu and Li (2015) do not find a significant relationship between ideology-based motivation and participation levels for Wikipedia. Thus, they argue that individuals may choose to participate in multiple encyclopedic communities, diminishing the effect of strong ideological beliefs on the overall contribution level.

Kinship

Similarly to ideological motives, kinship amity has been identified as an intrinsic inducement. Kinship amity is associated with the desire to belong to a certain group or community where members are treated as "kin" (Hars & Ou, 2002). Thus, they exhibit an altruistic behavior as they do not expect something in return for their contributions. However, it differs from altruism in that it is limited to a specific community (von Krogh et al., 2012). Some surveys document kinship motives as respondents report a desire to interact with like-minded people (David & Shapiro, 2008; Hertel et al., 2003; Moilanen, 2012). This driver can be quite strong. As such, self-identification as a Linux developer appears to be the strongest predictor for the average hours spent per week on Linux-related activities (Hertel et al., 2003).

Altruism

Some literature also discusses the role of altruism as an intrinsic motivation (e.g., Hars & Ou, 2002; Ke & Zhang, 2008). Altruism refers to the behavior where peers seek to increase the welfare of others at their own expense without necessarily expecting something in return (Hars & Ou, 2002). Thus, it is often considered in the context of open source projects since participants contribute to a public good while investing their own time or bearing opportunity costs (Osterloh & Rota, 2007; von Krogh & von Hippel, 2006). While there is some empirical support for altruism for a minority of survey participants, especially students and hobby programmers (Hars & Ou, 2002; Hemetsberger, 2004), it seems that altruism is too simple an explanation to account for the occurrence of peer production.

2.2. Internalized Extrinsic Motivation

Own use value

Between intrinsic and extrinsic inducements, research also identified a set of internalized extrinsic motivations. For instance, Raymond suggested that individuals might be motivated to contribute to public goods in pursuit of “scratching a personal itch” (Raymond, 1999), that is, they have a personal need that needs solving. The sometimes termed “own-use value” has been widely documented in surveys (Hars & Ou, 2002; Hemetsberger, 2004; Lakhani & Wolf, 2005). While most studies find a strong positive relationship between personal need and successful participation (Hars & Ou, 2002; Hertel et al., 2003), a few studies identify a negative relationship between personal need and the amount of one’s contribution (Hausberg & Spaeth, 2018; Roberts et al., 2006). These argue that a personal need may only serve as a temporary driver to contribute, with peers stopping their contributions as soon as their need is sufficiently addressed. Consequently, they might leave the community after a short period.

It is interesting to note, though, that motivations are dynamic. Shah (2006) reminds us that peers’ motivations evolve over time, moving from utility driven to more intrinsic motives.

Learning

A second internalized intrinsic motivation often identified is learning (David & Shapiro, 2008; Shah, 2006; Ye & Kishida, 2003). It typically includes aspects such as the acquisition or improvement of new skills or knowledge and is associated with feedback on peers' work (Ye & Kishida, 2003).

Several studies find support for learning motivations. Some show a positive impact on individual contribution levels, such as hours per week spent on open source software or hardware contribution (Hars & Ou, 2002; Hausberg & Spaeth, 2018) or lines of code written (Roberts et al., 2006). Other studies show significant relations between learning motivations and a higher intention to participate in the future (Spaeth, Haeflinger, Von Krogh, & Renzl, 2008; Wu, Gerlach, & Young, 2007).

Ye & Kishida (2003) argue that learning is one of the major forces that motivate developers to contribute as it may create the intrinsic satisfaction and the opportunity to earn a higher rank within the community. Some scholars, moreover, link learning with future job opportunities as it may increase human capital (Hars & Ou, 2002; Xu, Jones, & Shao, 2009).

Reciprocity

Besides own-use and learning, the literature frequently discussed reciprocity as internalized extrinsic motivation. Reciprocity is based on a "give and get mentality" of individuals (Alexy & Leitner, 2012), which is embedded in a gift culture (Bergquist & Ljungberg, 2001; Zeitlyn, 2003). As such, individuals are motivated to contribute as they have already received something and feel the obligation to give something back to the community or they expect to receive something in return for their contribution (Lakhani & von Hippel, 2003). Moderate support for reciprocity as a motive was reported in several studies covering hackerspaces (Moilanen, 2012), virtual consumer communities (Hemetsberger, 2004), and open source projects (Lakhani & Wolf, 2005). In a similar vein, some studies suggest that individuals who received help from other contributors are more inclined to return help once they have gained more experience and knowledge (Ghosh et al., 2002; Hertel et al., 2003).

Further, Shah (2006) finds that individual contributions associated with obligation-based activities were rather small and limited to a shorter term. Specifically, she finds that individuals driven by this motivation tended to contribute in pursuit of releasing themselves from the obligation, and then retreated. Thus, reciprocity – similar to need-based motivation – might not necessarily lead to a sustaining motivation to contribute.

Reputation

Further, some scholars investigated individual reputation as driver for peer production. In this regard, von Krogh et al. (2012) identify two types of reputation discussed in the literature, namely peer reputation and outside reputation. Peer reputation is directed toward peers within the community. It is associated with demonstrating skills and capabilities to other contributors by making contributions of high quality and earning a corresponding status (Raymond, 1999; Roberts et al., 2006; D. Stewart, 2005). It thus serves as an indicator of community membership in the absence of hard and formal membership criteria (von Krogh, Spaeth, & Lakhani, 2003) and may be linked to learning motivations (Ye & Kishida, 2003). Peer reputation is also what drives other famous peer production systems, such as the production of academic knowledge (von Krogh & Spaeth, 2007).

Outside reputation is concerned with the anticipated reactions of related people outside the community and the resulting prestige (Shah, 2006; von Krogh et al., 2012). Research on open source software production has frequently found a link between peers' motivation and outside reputation (Hars & Ou, 2002; Hemetsberger, 2004; Hertel et al., 2003; Roberts et al., 2006). Outside reputation also overlaps with the extrinsic motivation of potential career benefits as elaborated in the following.

2.3. Extrinsic Motivation

In addition to intrinsic motivations, individuals can be motivated by extrinsic motives such as direct compensations or expected career benefits (e.g., Hars & Ou, 2002; Lerner & Tirole, 2002; Wu et al., 2007).

Pay

Indeed, contributors in peer production systems such as open source communities do not necessarily work for free. Rather, for some, contributing is part of their job or at least their supervisor knows about and tolerates such engagements during working hours (Hertel et al., 2003; Lakhani & Wolf, 2005). Regarding direct compensation, some scholars find that developers motivated by payment on average spent more time working on open source software than their voluntary contributors (Hertel et al., 2003; Lakhani & Wolf, 2005; Roberts et al., 2006). However, Alexy & Leitner (2012) only found an overall positive effect of payment on total motivation in cases where contributors did not show a strong norm against payment.

Career

Apart from financial incentives, signaling theory (Spence, 1976) provides an additional framework for extrinsic motivation, which was taken up by Lerner & Tirole (2002). Their original argument that peers' behaviors may be driven by anticipated career benefits in an attempt to signal their skills and abilities to the labor market has been validated in numerous studies. As such, positive relations have been reported with respect to contribution intensity (Hars & Ou, 2002) and participation intention (Hertel et al., 2003).

Complementary findings show that signaling indeed may lead to a higher average wage (Hann, Roberts, & Slaughter, 2013). In their study, they report a positive and significant relation between the developers' rank within the Apache foundation and their average wage and argue that employers may use a developer's rank as a measure of productive capabilities.

However, one question remains open as to the causality of the observed links: Do peers attempt to become employed so they can continue to do what they love to do, or do they participate in peer production as part of a rational signal to the labor market?

To sum up the above discussion, one may note that the general picture shows a range of user motivations (Benkler, 2017; David & Shapiro, 2008), whereas individual motivation is not based on a single motive but rather on a dynamic mix of several interacting inducements. Accordingly, some scholars started to research the links and mutual influences among different motivations within what Roberts et al. (2006) call the "system of motivations".

2.4. Crowding out

One popular effect often considered in peer motivation is "crowding out" (Frey, 1997), i.e., the undermining of intrinsic motivations through the introduction of extrinsic incentives. An early meta-analysis by Deci et al. (1999), considering 128 studies in the field of psychology, finds evidence for crowding out intrinsic motivation, especially in those cases where individuals affected by external interventions perceived them as controlling. In contrast, external factors perceived as supportive can lead to the opposite effect of crowding in (Frey & Jegen, 2001).

Crowding effects caused by extrinsic motives

For open source software, Osterloh & Rota (2007) had suggested that extrinsic rewards may impede voluntary sharing of software and knowledge. However, much of the empirical research finds no evidence of a crowding out Roberts et al. (2006). Studies rather identify a positive effect of pecuniary rewards on overall contribution levels in various open source communities (Alexy & Leitner, 2012; Krishnamurthy, Ou, & Tripathi, 2014; Lakhani & Wolf, 2005; Roberts et al., 2006). Thus, financial (extrinsic) rewards seem to crowd in intrinsic motivation if they are perceived as supportive rather than controlling (Frey & Jegen, 2001; Krishnamurthy et al., 2014). Crowding-in denotes a positive effect of external interventions (such as pay) on intrinsic motivation (Frey & Jegen, 2001).

As these results appear counterintuitive, Alexy & Leitner (2012) examine the role of payment norms and find that crowding in is related to a community's and an individual's norms against payment and commercial involvement. In the face of strong anti-commercial and anti-payment norms, intrinsic motivation tended to be crowded out. Indeed, the results of a study by Krishnamurthy et al. (2014) examining the acceptance of monetary rewards in open source software development suggests that even intrinsically motivated participants might be willing to accept financial rewards without loss of intrinsic motivation. Individuals exhibiting a higher kinship-based motivation who are thus more exposed to social norms have a lower propensity to accept financial rewards. These findings reflect the contingency associated with crowding effects.

Crowding effects caused by internalized extrinsic motives

Further studies dealing with crowding effects consider the impact of internalized extrinsic motives on intrinsic motivation. A few studies find a crowding-in effect of reputation on intrinsic motivation (Gallus, 2016; Roberts et al., 2006). Gallus explains this effect as the result of an increase in the identification with the community, which can be caused by symbolic reward systems as, for example, in the case of Wikipedia (Gallus, 2016). Further studies find a crowding in effect of learning on enjoyment-based motivation (Hausberg & Spaeth, 2018).

The effects are not clear-cut though: some studies in this field also find negative effects arising from internalized extrinsic inducements. Hausberg and Spaeth (2018) find in their study on user motivations in the open source hardware context a crowding out of enjoyment-based intrinsic motivation when makers were highly motivated by reputational benefits. The study of Roberts et al. (2006) unveils a negative effect of own-use value on contribution levels in open source software development.

2.5. Summary of Self-Determination Theory

Overall, we can say that contributors to commons-based peer production systems are motivated not by a single motive, but by a whole range of intrinsic, internalized extrinsic and extrinsic motives. Further, motivation is not static: there is instead an evolution of motives over time (Shah, 2006).

Empirical support is provided for almost all the discussed motives. However, differences regarding their magnitude can be observed. While kinship amity is found to be a strong driver of intrinsic motivation, the effects of ideology vary significantly between different peer production systems. Furthermore, altruism appears a too simple explanation in the context of peer production.

Similarly, in the case of internalized extrinsic motives, own use value and reciprocity are widely documented (Hars & Ou, 2002; Hemetsberger, 2004; Lakhani & Wolf, 2005), but do not necessarily lead to more contributions as some studies find a short-term pursuit of quickly solving personal needs (Hausberg & Spaeth, 2018; Roberts et al., 2006) or fulfilling obligations of giving something back to the community (Shah, 2006). Learning and reputation appear as sustainable drivers (Hars & Ou, 2002; Roberts et al., 2006; Shah, 2006; Ye & Kishida, 2003).

Regarding extrinsic motives, payment can lead to an increased overall motivation, especially when the individual and the community are not principally against payments (Alexy & Leitner, 2012). Moreover, signaling effects are discussed in the literature as a further motive, which is linked to anticipated career benefits (Hars & Ou, 2002; Lerner & Tirole, 2002).

As motivations may interact (Roberts et al., 2006), several scholars suggested crowding out effects of extrinsic factors in intrinsic motivation (Haruvy, Prasad, & Sethi, 2003; Osterloh & Rota, 2007). However, empirical investigations cannot confirm the assumptions, but find instead the opposite effect of crowding in (Alexy & Leitner, 2012; Krishnamurthy et al., 2014; Lakhani & Wolf, 2005; Roberts et al., 2006). For internalized extrinsic motives, the effects vary significantly.

3. Choosing a Task to Work On

Peer production systems, such as open source software or hardware communities, typically cover plenty of different tasks (Hausberg & Spaeth, 2018; Moilanen, 2012), which can coarsely be categorized into creational tasks and community-related tasks (Xu & Li, 2015). While creational tasks include direct contributions to the public good, such as writing source code of software or editing content (e.g., Wikipedia articles), community-related tasks cover duties such as administration issues or technical user support (Lakhani & von Hippel, 2003; Xu & Li, 2015).

As the individual's motivation depends on the characteristics inherent in the task (e.g., creative or challenging), variations might also be reflected by differences in the tasks' attractiveness and selection (Lakhani & von Hippel, 2003). Benkler (2002) postulates that task self-allocation in peer production systems is based on more or less well-informed assessments of the individual's own fit to the respective task or job.

3.1. "Sexy" Tasks

The reasons for individuals to take on attractive – "sexy" – creational tasks are obvious. Individuals performing such tasks may receive direct or indirect rewards such as fun and enjoyment (Hausberg & Spaeth, 2018), learning benefits (Roberts et al., 2006), the enhancement of reputation (Lakhani & von Hippel, 2003), or the satisfaction of a personal need (Shah, 2006) as elaborated above. In addition, this self-selection might lead to neglecting less attractive but vital tasks, because peer production systems heavily rely on the self-selection of tasks by volunteers, potentially jeopardizing the survival of individual peer production systems (Benkler, 2002; Lakhani & von Hippel, 2003; von Krogh et al., 2012).

While specifically creational tasks exhibit high popularity among peers (Moilanen, 2012), covered by a variety of motivations (Lakhani & von Hippel, 2003; Roberts et al., 2006; Shah, 2006), some scholars are especially concerned with community-related tasks as they may be mundane or tedious, without providing obvious direct or indirect benefits.

3.2. Mundane Tasks

Some articles suggest that long-term contributors are more inclined to take on community-related tasks. For instance, Shah (2006) finds that they take on mundane and unattractive tasks such as rewriting source code in order to keep code simple and extensible, while newcomers tend to work on attractive and creative tasks. Hence, these groups appear to form a symbiotic relationship: new need-driven participants tend to provide new directions and challenges, while an old core provides support, creates the requested features and integrates them into the source code, while also taking on further maintenance duties. Similarly, some studies suggest that participants may be inclined to take on more challenging tasks the more experienced they are within a specific project and the more knowledge they have gained over time (Hann et al., 2013; Hertel et al., 2003). Certain project governance structures can help to make community-related and mundane work more manageable: O'Mahony & Ferraro (2007) argue that peer production systems structure themselves in ways that are beneficial for community-related tasks such as coordination of efforts and integration.

The necessity of performing mundane community-related tasks leaves space for the involvement of commercial actors providing extrinsic incentives, such as payment, or providing internalized extrinsic incentives. For instance, Alexy & Leitner (2012) conclude that using financial rewards could compensate for the absence of intrinsic motivation. *Bounty programs* (Krishnamurthy & Tripathi, 2006) where users pledge financial support for someone else performing certain tasks are another way of providing such extrinsic motivation. In some open source communities with defined roles, individuals accept certain mundane tasks by occupying respective (more or less formal) roles (Hann et al., 2013).

Some studies find internalized extrinsic motives to be drivers to perform mundane or tedious tasks. For instance, some scholars consider peer reputation and kinship as major drivers to motivate "Wikipedians" to perform community-related tasks (Gallus, 2016; Kittur, Pendleton, & Kraut, 2009; Xu & Li, 2015). Another study finds learning to be a major driver (Lakhani & von Hippel, 2003). Specifically, they examine the reasons why contributors in the Apache community are providing technical support to others. They find that answering questions on Usenet help forums was mainly driven by anticipated learning benefits. Accordingly, community members spent considerable time scanning and reading questions in forums that may also have been relevant for their own projects.

3.3. Summary of Findings

Altogether, we can see that peers' motivation partly determines the type of task they will self-allocate. In order to perform all required tasks (both creative and community-related) a mix of various incentives and motivations is required in a healthy commons-based peer production system, as it is a mix of a diverse set of actors. Specifically, extrinsic and internalized extrinsic motives seem to play a crucial role to impel individuals to perform mundane tasks in peer production systems.

4. Peer Production as a Social Practice

While self-determination theory provides some insights into the psychological processes that may adopt impulses external to the individual as inputs, leading to immediate observable behaviors, it neglects the wider context that may explain, for example, why individuals maintain their participation and contributions over time (von Krogh et al., 2012). Peer motivations are not detached from influences springing from an individual's environment, as shown by the dynamically evolving motivations of peers embedded in the social structure of a peer production system (Shah, 2006). Rather than identifying individual-level motivations in isolation, an alternative promising approach is to view peer production systems from a practice perspective (Feldman & Orlikowski, 2011).

Some theoretical approaches started to view peer production systems as social movements (McCarthy & Zald, 1977) or linked them to the collective action literature (Ostrom, 1990, 1999) as they share many traits. By becoming part and member of a social practice, contributions stop being seen as expensive investments and collaboration instead become part of the intrinsic incentive itself. In this regard, Jon Elster remarks:

> *"Cooperation reflects a transformation of individual psychology so as to include the feeling of solidarity, altruism, fairness, and the like. Collective action ceases to become a prisoner's dilemma because members cease to regard participation as costly: It becomes a benefit in itself, over and above the public good it is intended to produce" (1986, p. 132).*

One comprehensive approach considers peer production as social practice, which explicitly accounts for the interrelation of collective activities with institutions (Ostrom, 1990; von Krogh et al., 2012). The approach builds upon MacIntyre's seminal work, which describes a practice as

> *"any coherent and complex form of socially established cooperative human activity through which goods internal to that form of activity are realized in the course of trying to achieve those standards of excellence which are appropriate to, and partly definitive of, that form of activity, with the result that human powers to achieve excellence, and human conceptions of the ends and goods involved, are systematically extended" (1981, p. 187).*

Following this view, peer production involves the creation of internal goods with public goods characteristics, such as source code or encyclopedia articles, which are produced by members of the practice. The collective of contributors follows certain general principles (so-called *standards of excellence*) that are determined and shared by the whole collective (von Krogh et al., 2012). As individuals decide to contribute, they gradually adopt the general norms and principles of the social practice (Rullani & Haefliger, 2013) and over time collectively adapt them. Internal goods are defined by the social practice and do not only benefit individual contributors but also other members in the social practice as well as the wider community (von Krogh et al., 2012).

Institutions house these practices and provide external goods, such as status or capital that enable and extrinsically motivate contributors (MacIntyre, 1981; von Krogh et al., 2012). Institutions can be seen as “sustainable forms of human cooperation” (von Krogh et al., 2012, p. 660), including companies and foundations, that are governed by certain organizations (e.g., the community), rules (e.g., coordination), and routines (von Krogh et al., 2012).

By drawing attention to social practices, the focus shifts from short- and mid-term motivation – going back to direct rewards – towards the long-term motivation of participants, as the social practice becomes intertwined with their lives, creating the perception of a moral obligation associated with the pursuit of the *unity of life* (von Krogh et al., 2012). In particular, the theory postulates that individuals attempt to reach and maintain the uniformity of their actions, forming a consistent journey that emphasizes values such as personal development (c.f. von Krogh et al., 2012). In this way, peer production as a social practice explains interview statements, such as “this is just how open source programmers are supposed to act” or “it is kind of a moral obligation to contribute”. Social practices frame peer production as a school of virtue in which norms, attitudes and standards are concurrently being created with the internal goods themselves. Peer production becomes a lifestyle.

4.1. Social exposure

Research suggests that social exposure in a peer production community is crucial. Community participation and kinship are powerful drivers aligning individuals’ activities with overall goals and social norms inherent in the community. Thus, the exposure to the community may positively affect the overall contribution level of participants (Rullani, 2007).

As such, literature considers the architecture of social practices as comprising a core and a periphery, where individuals start as passive lurkers and observers situated at the periphery, eventually starting to make small contributions while gradually tending to be dragged towards the core (Rullani, 2007; Rullani & Haefliger, 2013; Ye & Kishida, 2003). Reaching the core, they tend to focus more on maintaining the social practice by taking supportive tasks or helping to educate new members (Shah, 2006).

In the process of joining, an individual socializes with the community (Rullani & Haefliger, 2013) and acquires an identity related to the social practice that intertwines individual motivation with experiences related to the membership (von Krogh et al., 2012). While membership is typically granted by a consensus vote by the core group, studies found a tendency of lurkers to attempt to prove their abilities to that core (Midha & Bhattacherjee, 2012). Specifically, Misha & Bhattacherjee (2012) find that lurkers tried to complete assigned mundane maintenance tasks as quickly as possible to get attention and acceptance.

Further, on one hand, the community core may exert social pressure by using collective sanctions to enforce certain social norms and standards of excellence (Sagers, 2004). As outlined before, norms within the group such as the refusal of payments can have a significant effect on certain motives (Alexy & Leitner, 2012). On the other hand, communities may reward members for their past performances, i.e., meritocratic self-organization. In this regard, Roberts et al. (2006) find that promotions within the Apache meritocracy led to higher intrinsic and extrinsic motivation and to higher participation levels as status increases.

Apart from that, some scholars illuminated the effects of two socialization outcomes, namely social identification and social integration, on motivation. Social identification refers to the extent to which an individual identifies with a certain community, whereas social integration denotes the perception of being accepted and trusted by the community. Several studies demonstrate that they can positively influence contributors' behaviors within the community towards kinship amity and lead to an increase in task performance (Carillo, Huff, & Chawner, 2017; Gallus, 2016; Spaeth, von Krogh, & He, 2015).

4.2. Institutional Frameworks

In a social practice, institutions and institutional frameworks impact on the peers' behavior, with impacts ranging from the enabling (by providing infrastructure and support or by remunerating them) to the corrupting (by introducing conflicts of interests or formal restrictions).

Governance structures

One such institutional framework is the governance structure of a peer production system. It plays a crucial role in influencing individuals' motivations. Governance can be defined as "the means of achieving the direction, control, and coordination of entirely or partially autonomous individuals and organizations on behalf of a [peer production] project to which they jointly contribute" (Markus, 2007, p. 152). Markus (2007) highlights the importance of governance as it may solve collective action problems as well as coordination problems and determines the climate for contributors.

The relevant literature identified different governance structures and examined their relation with individual motivation (Di Tullio & Staples, 2013; Klapper & Reitzig, 2018; Shah, 2006).

In this regard, studies show that the formalization of conflict management and development processes can lead to a higher task performance and a better community climate, if overall goal-definition remains within the decision-making scope of the project members (Di Tullio & Staples, 2013; Klapper & Reitzig, 2018). A complementary study by Ho & Rai (2017) shows a further positive effect of input and output control on the continued participation intention of contributors. Specifically, they argue that a formal accreditation process of members and leaders based on their skills (input control) as well as a careful code review and acceptance (output control) can effectively signal high standards of excellence, attracting further volunteers to the social practice.

Sponsorship

Moreover, the organizational integration of the peer production system into a private firm appears crucial. In that regard, research distinguished two governance structures, namely "open" and "gated" communities. While open communities produce true public goods, gated communities constitute hybrid forms of collective development and private ownership and are controlled by a focal company (c.f. Shah, 2006; Spaeth et al., 2015). A study by Shah (2006) found that particularly in the long run, developers who were primarily motivated by use-value were more inclined to contribute to gated communities, whereas developers motivated by enjoyment (i.e., hobbyists) tended to contribute to open communities. Furthermore, the sponsor's specific characteristics as well as their perception by the contributors can play a crucial role in influencing their motivation by affecting social identification (Spaeth et al., 2015; Stewart et al., 2006). Contributors may assess institutions such as sponsoring companies or foundations and consider them as either supportive or restrictive depending on their adherence to the standards of excellence (von Krogh et al., 2012). For instance, attributes such as expertise and trustworthiness as well as an attitude towards mutual knowledge exchange were found to have a positive impact (Spaeth et al., 2015). Overall, scholars suggested that firm sponsors should avoid extracting too much benefit from the peer production community as this may depress community morale and work (Haruvy et al., 2003; von Krogh et al., 2012).

Licensing

Another institutional framework to consider are the licenses of the goods produced. Generally, research focusses on the restrictions embedded in the applied license. The famous GNU General Public License (GPL) imposes two restrictions: 1) modified versions of the source code need to be open as well (*copyleft*), and 2) the code can only be combined with programs distributed under the same license (*viral* provision). The intuition that more intrinsically motivated individuals tend to prefer more restrictive licenses, while less restrictive licenses attract more extrinsically motivated ones is reflected by empirical findings (Allyn, Misra, & Kozyreva, 2008).

Furthermore, contributions may differ across both types of licenses. For instance, Fershtman & Gandal (2007) find that output per contributor in open source projects is much higher when licenses are less restrictive and more commercially oriented, such as the Berkeley Software Distribution (BSD) type license, while the number of contributions is higher when licenses are more restrictive such as the GPL. It highlights the differences among individual motivations and the role of appropriate protection mechanisms for intellectual property in influencing contributors' behaviors.

It is noteworthy, however, that the effect of licenses may depend on the type of sponsor. In particular, Stewart et al. (2006) find that the presence of non-market sponsors such as non-profit foundations may reduce concerns about the project's future. Thus, development activity and user interest were the highest when the application was distributed under a non-restrictive license and the sponsor was a non-market organization.

4.3. Summary of Social Practice View

Altogether, we can say that a social practice perspective complements an isolated analysis of peers' individual motivations as it allows investigating the social practice and the influence it has on individuals. Thus, we showed that social pressure exerted by the community may either sanction or promote certain behaviors, influencing individual motives. Furthermore, social integration and identification seem to be crucial factors influencing the individuals' behavior as well as performance. The social practice view further allows to identify institutions (such as financial sponsors) and institutional arrangements, such as the project governance structure and the produced good's license as well as their impact on peers' motivation.

As the social practice view stresses the overall social context surrounding an individual, one should observe that participation in peer production systems as reflected by the reviewed studies is a privilege of Global North nations.

5. Conclusion

Peers are motivated by a number of individual motivations, ranging from the intrinsic (ideology, altruism, kinship amity, enjoyment & fun), to the internalized extrinsic (reputation, reciprocity, learning, own-use value), to the purely extrinsic (pay, career benefits) although boundaries between these categories can be somewhat blurry at times. Studies have generally found a mix of motivations in various empirical peer production systems. Diversity is high though, and motivations have been shown to change over time (e.g. from own-use problem solving to pure enjoyment and kinship amity), which can be explained by considering peer production systems as a social practice (the self-given term "Wikipedians" nicely illustrates the strong community identification in such systems). Commercial involvement in these systems is not necessarily bad *per se*, as we have shown, and empirical evidence of crowding out of intrinsic motivation is scarce. However, domination of a gated community by a commercial entity and controlling core aspects of processes and goods produced can indeed prevent voluntary contributions in the first place.

Most individuals will be consumers and free-riders of commons-based peer production systems. Still, in many cases and under the right conditions enough peers can be motivated to achieve impressive output. Success seems to depend on the right mix of motivations and types of peers in peer production settings. Fortunately, as Elinor Ostrom (2000, p. 138) succinctly put it, "the world contains multiple types of individuals, some more willing than others to initiate reciprocity to achieve the benefits of collective action."

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Appendix

A1 Summary of Dissertation

While platforms as a phenomenon and strategic tool are not new to research and practice, recent literature considers industry platforms that act as central control points or hubs within ecosystems. Platforms stand out as they allow to leverage economies of scope in production, innovation, and transaction, with network effects allowing to quickly grow and potentially achieve a monopoly position. Not least due to these characteristics, platforms have emerged as a popular form of business model, allowing to draw on external resources and capabilities, opening up considerable potential for value creation. In digital platform-based ecosystems, value arises through combination and recombination of resources within or across platforms. Albeit there has been a proliferation of research on various issues related to value co-creation in digital platform-based ecosystems, there are still a number of gaps in the literature. Particularly, many findings are limited to a few platform-based ecosystems and neglect the environment. As such, value creation has been predominantly studied as the outcome of combining resources within platform-based ecosystem.

This cumulative dissertation pursues the overarching target to study how strategic considerations and motives influence value creation in terms of product certifications, cross-vendor compatibility, and contributions by user innovators. In doing so, the thesis is based on a conceptual framework that considers the environment of digital platform-based ecosystems in the context of the Internet of Things, studying industry consortia, peer production platforms, and interactions between digital platform-based ecosystems that collectively create the underlying market. Methodologically, the dissertation relies on both a conceptual and empirical, quantitative research approach. The first dissertation paper conducts a systematic review of the literature by applying bibliometric and content analyses to further understanding of the concept of platform-based ecosystems. The second paper conducts a network analysis based on an exponential random graph model to study the influence of technology adoption choices and the role of giant platforms in cross-platform compatibility signaling. The third dissertation paper conducts a panel data analysis to empirically examine the impact of both membership dynamics and orchestrator roles in a technology-based ecosystem on value co-creation in the form of product certifications. The fourth paper of the dissertation pursues the goal of systematizing the motivations of individuals to affiliate with and contribute to peer production platforms, which play a crucial role in the Internet of Things context.

The findings of the four articles show that a narrow view of platform-based ecosystems that only considers the interactions between platform sponsors and a homogeneous set of complementors falls short. Instead, the dissertation shows that external entities such as standardization bodies or peer production platforms are particularly significant and, in the context of the Internet of Things, constitute a broader innovation ecosystem. By expanding both theoretical and practical knowledge about value creation in digital platform-based ecosystems, the dissertation contributes to the current literature on platforms and standardization.

A2 Zusammenfassung der Dissertation

Während Plattformen als Phänomen und strategisches Instrument in Forschung und Praxis nicht neu sind, werden in der neueren Literatur Industrieplattformen betrachtet, die als zentrale Kontrollpunkte oder Knotenpunkte innerhalb von Ökosystemen fungieren. Plattformen zeichnen sich dadurch aus, dass sie die Nutzung von Verbundvorteilen bei Produktion, Innovation und Transaktion ermöglichen und durch Netzwerkeffekte schnell wachsen und potenziell eine Monopolstellung erreichen können. Nicht zuletzt aufgrund dieser Eigenschaften haben sich Plattformen zu einer beliebten Form von Geschäftsmodellen entwickelt, die es ermöglichen, auf externe Ressourcen und Fähigkeiten zurückzugreifen, was ein erhebliches Wertschöpfungspotenzial eröffnet. In digitalen plattformbasierten Ökosystemen entsteht der Wert durch die Kombination und Rekombination von Ressourcen innerhalb oder zwischen Plattformen. Obwohl es eine Vielzahl von Forschungsarbeiten zu verschiedenen Themen im Zusammenhang mit der gemeinsamen Wertschöpfung in digitalen plattformbasierten Ökosystemen gibt, weist die Literatur noch immer eine Reihe von Lücken auf. Insbesondere beschränken sich viele Erkenntnisse auf einige wenige plattformbasierte Ökosysteme und vernachlässigen die Umwelt. Daher wurde die Wertschöpfung vorwiegend als Ergebnis der Kombination von Ressourcen innerhalb plattformbasierter Ökosysteme untersucht.

Diese kumulative Dissertation verfolgt das übergreifende Ziel zu untersuchen, wie strategische Überlegungen und Motive die Wertschöpfung in Bezug auf Produktzertifizierungen, herstellerübergreifende Kompatibilität und Beiträge von Nutzerinnovatoren beeinflussen. Dabei stützt sich die Arbeit auf einen konzeptionellen Rahmen, der das Umfeld digitaler plattformbasierter Ökosysteme im Kontext des Internets der Dinge betrachtet und Industriekonsortien, Peer-Produktionsplattformen und Interaktionen zwischen digitalen plattformbasierten Ökosystemen untersucht, die zusammen den zugrunde liegenden Markt etablieren. Methodisch stützt sich die Dissertation sowohl auf einen konzeptionellen als auch auf einen empirischen, quantitativen Forschungsansatz. Das erste Dissertationspapier gibt einen systematischen Überblick über die Literatur, indem es bibliometrische und inhaltlsanalytische Techniken anwendet, um das Konzept der plattformbasierten Ökosysteme besser zu verstehen. Im zweiten Papier wird eine Netzwerkanalyse auf der Grundlage eines exponentiellen Zufallsgraphenmodells durchgeführt, um den Einfluss zu untersuchen, den Adoptionsentscheidungen mit Blick auf Technologiestandards und die Rolle von große, etablierten

Plattformen auf die Signalisierung von Kompatibilität zu (rivalen) Plattformen hat. Im dritten Papier wird eine Paneldatenanalyse durchgeführt, um die Auswirkungen der Mitgliederdynamik und der Rolle des Orchestrators in einem technologiebasierten Ökosystem auf die gemeinsame Wertschöpfung in Form von Produktzertifizierungen empirisch zu untersuchen. Die vierte Aufsatz der Dissertation verfolgt das Ziel, die Motivationen von Individuen zu systematisieren, sich Peer-Produktionsplattformen anzuschließen und zu ihnen beizutragen, die im Kontext des Internets der Dinge eine entscheidende Rolle spielen.

Die Ergebnisse der vier Artikel zeigen, dass eine enge Betrachtung plattformbasierter Ökosysteme, die nur die Interaktionen zwischen Plattformsponsoren und einer homogenen Gruppe von Komplementären berücksichtigt, zu kurz greift. Stattdessen zeigt die Dissertation, dass externe Instanzen wie Standardisierungskörpern oder Peer-Produktionsplattformen von besonderer Bedeutung sind und im Kontext des Internet der Dinge ein breiteres Innovationsökosystem darstellen. Durch die Erweiterung des theoretischen und praktischen Wissens über die Wertschöpfung in digitalen plattformbasierten Ökosystemen trägt die Dissertation zur aktuellen Literatur über Plattformen und Standardisierung bei.

A3 List of Publications

Published

Spaeth, Sebastian/Niederhöfer, Sven (2020): User Motivations in Peer Production. In: M. O'Neil, C. Pentzold & S. Toupin (Eds.), The Handbook of Peer Production (pp. 123-136). Malden, MA: Wiley-Blackwell. ISBN 9781119537106.

Niederhöfer, Sven/Späth, Sebastian (2022): Backing the Right Horse: A Study of the Effect of Membership Dynamics on Value Creation in the Smart Home Market, on SSRN. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4080862.

Submitted or under review

Niederhöfer, Sven (2022): Ecosystem perspective in platform research: A bibliometric analysis and review of recent literature, in: Journal of Management (Status: preparation for submission).

Niederhöfer, Sven/Spaeth, Sebastian (2022): Compatibility promotion between platforms: The role of open technology standards and giant platforms, in: Electronic Markets (Status: 3. Round).

Conference papers and presentations

Niederhöfer, Sven/Spaeth, Sebastian (2021): Digital platforms and infrastructure: How platform providers form interconnections across standards in the smart home market. Submitted to and accepted by Academy of Management, Online Conference 2021. *Paper designated for "Best Paper Award" in Technology and Innovation Management*.

Niederhöfer, Sven, Spaeth, Sebastian (2021): Digital platform ecosystems and digital infrastructure: How platform providers populate their ecosystems across standards in the smart home market. Submitted to and accepted by European Academy of Management, Online Conference 2021.

Niederhöfer, Sven/Spaeth, Sebastian/Pakura, Stefanie (2020): The more, the merrier: Alliance memberships of platform firms in the Smart Home market. Submitted to and accepted by European Academy of Management, Online Conference 2020.

Niederhöfer, Sven/Spaeth, Sebastian/Pakura, Stefanie (2020): Ecosystem Selection Strategies: An Empirical Investigation of Memberships in Standard-based Ecosystems in the Smart Home Market. Paper presented at Research Policy Workshop on Innovation Ecosystems and Ecosystem Innovation, Online Conference 2020.

Niederhöfer, Sven (2019): Platform Organizations as Ecosystems: A Systematic Literature Review. Paper presented at European Academy of Management at ISCTE-IUL, Lisbon 2019.

A4 Teaching Experience

Lehrveranstaltungen (Bachelorniveau)

WS 2021/2022	Seminar „Digitale Plattformen und die Plattformökonomie“ (2 SWS, ca.35 Stud.)
SS 2021	Seminar „Digitale Plattformen und die Plattformökonomie“ (2 SWS, ca.30 Stud.)
WS 2020/2021	Seminar „Digitale Plattformen und die Plattformökonomie“ (2 SWS, ca.20 Stud.)
SS 2020	Übung zur Vorlesung „Strategische Unternehmensführung“ (2 SWS, ca. 60 Stud.)
WS 2019/2020	Übung zur Vorlesung „Strategische Unternehmensführung“ (2 SWS, ca. 60 Stud.)
SS 2019	Übung zur Vorlesung „Strategische Unternehmensführung“ (2 SWS, ca. 40 Stud.)
WS 2019/2018	Seminar „Building a Start-Up” (2 SWS, ca. 30 Stud.)
SS 2018	Übung zur Vorlesung „Grundkurs Betriebswirtschaftslehre“ (4 SWS, ca. 160 Stud. in 2 Gruppen)

Abschlussarbeiten

seit 11/2017	Betreuung von 17 Bachelor- und einer Masterarbeit in deutscher und englischer Sprache.

A5 Curriculum Vitae

Der Lebenslauf ist aus datenschutzrechtlichen Gründen nicht enthalten.

A6 50 most-cited references in bibliometric analysis

Reference	Cluster	Betweenness Centrality	Closeness Centrality	PageRank Centrality
Gawer (2014)	1	0.0000	0.0071	0.0327
Ceccagnoli et al. (2012)	1	0.0000	0.0063	0.0261
Gawer & Cusumano (2002)	1	0.0000	0.0060	0.0254
Iansiti & Levien (2004)	1	3.6247	0.0088	0.0203
Adner & Kapoor (2010)	1	0.0000	0.0058	0.0243
Gawer & Cusumano (2014)	1	2.2675	0.0081	0.0216
Jacobides et al. (2018)	1	0.1667	0.0072	0.0249
Thomas & Autio (2014)	1	0.1813	0.0074	0.0249
Cusumano & Gawer (2002)	1	0.6330	0.0076	0.0195
Eisenhardt (1989)	1	4.7895	0.0083	0.0165
Gawer & Henderson (2007)	1	2.3891	0.0075	0.0181
Adner (2017)	1	9.1532	0.0088	0.0199
Eisenmann et al. (2006)	1	7.4839	0.0086	0.0192
Eisenmann et al. (2011)	1	45.2098	0.0091	0.0159
West (2003)	1	17.1335	0.0092	0.0159
Zhu & Iansiti (2012)	1	0.4667	0.0066	0.0229
Baldwin & Clark (2000)	1	155.5082	0.0109	0.0131
Baldwin & Woodard (2009)	1	2.6645	0.0078	0.0174
Caillaud & Jullien (2003)	1	5.3005	0.0085	0.0162
Gawer & Cusumano (2008)	1	22.3017	0.0098	0.0148
Rochet & Tirole (2006)	1	18.354	0.0091	0.0143
Armstrong (2006)	1	61.883	0.0098	0.0161
Eisenhardt & Graebner (2007)	1	92.4478	0.0098	0.012
Evans et al. (2006)	1	70.6503	0.0101	0.0126
Helfat & Raubitschek (2018)	1	19.1796	0.0094	0.0157
Miles et al. (1994)	1	36.9841	0.0096	0.0137
Tiwana et al. (2010)	2	0.0000	0.0051	0.0338
Boudreau (2010)	2	0.0000	0.0059	0.0312
Boudreau (2012)	2	0.0000	0.0072	0.0300
Mcintyre & Srinivasan (2017)	2	0.0000	0.0071	0.0297

(*Continued*)

Cennamo & Santalo (2013)	2	0.0000	0.0057	0.0307
Tiwana (2013)	2	0.0000	0.0076	0.0227
Wareham et al. (2014)	2	4.5887	0.0085	0.0259
Rochet & Tirole (2003)	2	0.0000	0.0073	0.0258
Ghazawneh & Hendersson (2013)	2	65.1355	0.0091	0.0200
Tiwana (2015)	2	3.3926	0.0088	0.0239
De Reuver et al. (2018)	2	17.4928	0.0093	0.0150
Eaton et al. (2015)	2	34.4983	0.0096	0.0173
Huang et al. (2013)	2	19.3196	0.0090	0.0174
Parker et al. (2016)	2	0.5584	0.0076	0.0179
Yoo et al. (2010)	2	0.0833	0.0068	0.0175
Parker & Van Alstyne (2005)	2	4.5556	0.0070	0.0179
Cennamo et al. (2018)	2	5.8514	0.0093	0.0181
Parker et al. (2017)	2	53.5943	0.0102	0.0156
Kapoor & Agarwal (2017)	2	22.1872	0.0089	0.0146
Rietveld et al. (2019)	2	34.3571	0.0096	0.0147
Moore (1993)	3	5.6633	0.0076	0.0222
Iansiti & Levien (2004)	3	57.4386	0.0095	0.0173
Moore (1996)	3	38.6284	0.0093	0.0161
Adner (2006)	3	251.508	0.0108	0.0106

A7 Coding Scheme and excerpt of data sample in Paper I

No.	Code	Description	Example
1.1	Autocode: Ecosystem	Lexical search based on regular expression to code all occurences of “[<term>] [<term>] ecosystem”.	E.g., innovation ecosystem
1.2	Autocode: Platform	Lexical search based on regular expression to code all occurences of “[<term>] [<term>] platform”.	E.g., cloud-based platform
2.1	Definition	Concept definitions for platforms and ecosystems and their references.	-
2.2	Ecosystem features	Discussed properties, components, and conceptualizations of ecosystems.	E.g., network of complementors
2.3	Platform function	Discussed role and function of platforms studied.	E.g., business model
3.1	Mixed	The method described in the article covering qualitative and quantitative techniques.	E.g., multiphase design
3.2	Technical	The method described in the article covering design approaches for software or hardware prototypes.	E.g., prototype study
3.3	Theoretical	The method described in the article covering simulations and mathematical models.	E.g., mathematical model
3.4	Qualitative	The method described in the article covering qualitative techniques such as exploratory case studies.	E.g., in-depth case study
3.5	Quantitative	The method described in the article covering quantitative techniques such as regressions, ANOVA, or network analysis.	E.g., Structural equation model
3.6	Conceptual	The method described in the article covering conceptual designs such as literature reviews and research commentaries.	E.g., literature review
4.1	Motivation	The problem statement underlying the study.	-
4.2	Research Question	The research question or declared objectives of the study.	-
4.3	Concepts	Main theoretical concepts or theories.	E.g., platform openness
4.4	Context	The research context such as company, platform/product, industry, market, if available.	E.g., Internet of Things

Authors	Year	Keywords	Concepts	Context	Major ecosystem property	Methodology	Journal
SJ Maekinen, J Kanniainen...	2014		new product development, beta testing	Nokia Beta Labs	value co-creation	Quantitative	Journal Of Product Innovation Management
A Zanescu, M Lajeunesse...	2021	Steam; Value; DOTA 2; Gamblification; Platformization; Consumer studies; Game studies; Platform studies	gamblification, addiction	Valve Corporation, Steam	co-opetition	Qualitative	Journal Of Consumer Culture
K Kapoor, AZ Bigdeli, A Schroeder, T Baines	2021	Advanced services; Platform ecosystems; Servitization	socio-technical (S-T) systems	servitization, manufacturing	evolution	Qualitative	Technovation
JHJ Yun, DK Won, KB Park, JH Yang...	2017	Platform business model; Economic ecosystem; Regional innovation system; Open business model; Regional development	dynamics, Open innovation, causal loop	online hotel market, Booking.com, Hotels.com	evolution	Mixed	European Planning Studies
A Attour, P Barbaroux	2016	Architectural knowledge; Life-cycle theory; Platform-ecosystem; Near field communication services	architectural knowledge, ecosystem life-cycle	Near-Field Communication,Nice Futur Campus	evolution	Qualitative	Journal Of Innovation Economics Management

A8 Data collection and analysis in Paper II

In this section we describe the data collection and analysis process. The process covers two content analyses: one for the initial set of Z-Wave members (hereafter "Z-Wave firms") and the second for companies with which they signal compatibility (hereafter "partner firms"). The inclusion of partner firms is required because they include platform companies that we would not otherwise consider. Each of these content analyses, in turn, consists of two phases: (1) the identification of platforms (I1 & I2) and (2) the extraction of variables for the network analysis (R1 & R2). In the first phase, we determine whether companies and their product meet our criteria for a platform company. The second phase is based on the data from the first phase and additionally on company websites that were collected through a purposive sampling approach (Riffe et al., 1996, p. 86). In total, we have collected 1439 web pages, product manuals and graphic illustrations for Z-Wave companies, of which 677 are from Z-Wave companies and 762 are from partner companies.. The goal of this phase was to obtain variables as input for network analysis. For this phase, we derived a coding scheme from our literature review to group platform sponsors with similar characteristics in terms of their architectural features, supported technology standards, complementary hardware devices and niches, and compatible devices and selected partners. The coding scheme can be found in A9. We consider only the websites of the companies themselves (rather than taking a broader view that includes bloggers and other third-party web content), as this better reflects what the company is communicating to consumers and how it is thus actively promoting partnerships and compatibilities while accounting for network effects.

Overall, collected data on more than 800 firms with memberships in the Z-Wave Alliance, 3,873 Alliance-certified products, 11,733 smart-home products listed on Amazon.com[56], and 1,509 Android and iOS apps[57] as well as company data[58].

Our initial data set derived from a previous study consists of 3,352 firms with memberships in six major standard consortia in the smart home market, namely the Z-Wave Alliance, Zigbee Alliance, Open Connectivity Foundation, and Thread Group between 2001 and 2019. For data retrieval, we

[56] We used the search term "smart home".
[57] We used the search terms "smart home" and "home controller" on the Google Play Store and Fnd.io (https://www.fnd.io), a website allowing to search the App Store in a web browser.
[58] Company data was retrieved from Compustat, Crunchbase, FactSet, and Nexis Uni, covering the number of employees and years of foundation. We triangulated the records to get a more reliable picture of the size and age of the companies.

followed the approaches of Leiponen (2008) and Baron and Spulber (2018) using a crawler. We used website snapshots of these alliances archived by the Wayback machine[59], crawling several snapshots per year to cross-validate our altogether 174,987 data points. We then imported the data into a MySQL database to homogenize the names and match companies based on IDs, logos, and links.

Of this dataset, we use a sub-sample including the firms that were listed at least one period as member in the Z-Wave alliance.

1. Content analysis I: Data sources and pre-analysis for platform identification

For our first content analysis to identify platform sponsors, we used apps, products, and certified products.

Apps. We retrieved 1,509 Android and iOS apps. We matched developers of apps with companies in our sample, using a Levenshtein string matching algorithm[60] to identify the best match. This led us to 171 records of which we subsequently retrieved the app store page as pdf to review app names, descriptions, and pictures to determine whether it is a smart home app.

Products. We retrieved 11,733 product names, descriptions, feature lists, pictures, model numbers, and names of manufacturers and offerers from Amazon.com matching our keywords. As matching manufactures on Amazon with companies in our dataset is inefficient for such a large dataset, we first filter all products and then apply an analogue company matching procedure as described above. Accordingly, we searched for "hub OR gateway" in product names, descriptions and feature lists, returning 3,011 products by 834 companies. Matching led us to 149 products we analyzed.

Certified products. We retrieved 3,873 certified Z-Wave products, which we filtered for product categories containing the keyword "controller", returning 702 records. We then filtered product descriptions and product names using the keywords "hub" and "gateway", returning 303 records.

Analysis. On all these matches, we performed content analyses on the websites we retrieved. Specifically, we coded those products and apps as smart home platforms, which allow controlling

[59] https://www.archive.org

[60] The algorithm counts the number of necessary character changes in one string to match another string. By dividing the resulting integer by the string length of the first string, one obtains the fraction of mismatch. Accordingly, a Levenshtein index of 0 is a perfect match, while higher values reflect a lower chance of a match. For values greater than zero, we additionally used a first letter match as an additional filter to then manually check for matches.

a set of smart home products. This means that we do not consider product apps for particular devices as platforms. We identified 81 companies with products and apps meeting our criteria.

2. Content analysis II: Main content analysis

Our major content analysis is based on Krippendorff's (2004) framework, while we employ computer software to facilitate our analysis. In its core, the framework consist of (1) unitizing, (2) sampling, (3) recording, and (4) reducing.

Unitizing and sampling. "Unitizing is the systematic distinguishing of segments of text – images, voices, and other observables – that are of interest to an analyst" (Krippendorff, 2004, p. 83). We choose entire websites as units, as we want to consider a larger fraction of the context surrounding our codes. Accordingly, we also review graphical illustrations on websites and hyperlinks.

Sampling units are "units that are distinguished for selective inclusion in an analysis" (Krippendorff, 2004, p. 98), which is usually referred to as "observations" in inferential statistics. Our initial sample consists of group members (i.e., Z-wave member firms). To collect documents, we applied a purposive sampling approach (Riffe et al., 1996, p. 86) using a common search engine and several search queries per platform sponsor reflecting the features of interest for each firm.

Purposive sampling aims to identify all textual units that contribute to answering the research question (Krippendorff, 2004, p. 119). Accordingly, the sampling strategy follows a two-step process consisting of (1) the systematic search of textual units (web pages) that could be relevant and (1) the manual screening of the resulting web pages with regard to relevance. Since a web-based search engine was used, search results are already displayed in descending order of relevance. If there are hits for the respective search term, e.g. "API" in combination with the company name, and if they originate from the company, the web page was retrieved. Accordingly, our sample consists of all web pages found by the search engine (including forum posts and developer portals, product manuals, documentations) of the companies. In order to systematically search for sources of information to extract our variables, different search terms were defined and searched for each company using a search engine.

Specifically, we searched for "<FIRM> smart home", "<FIRM> smart home hub", "<FIRM> compatible devices", "<FIRM> works with", "<FIRM> partners", "<FIRM> API", "<FIRM> Developer", "<FIRM> smart home cloud", "<FIRM> apps", "<FIRM> extensions" and "<FIRM> plugins" with <FIRM> representing the respective firm name. We visited the top search results and retrieved them using the MAXQDA browser plug-in, and we downloaded further material such as manuals. Overall, we retrieved 677 websites and further documents.

In addition, we used web-scraping[61] to retrieve certain elements from websites containing compatible products, partnering companies, and integrations of platforms facilitating the identification of relationships between platform ecosystems. We imported the scraped website into a MySQL database to clean the data and match companies.

Recording and reducing. The recording step serves to extract and document relevant information from the sampling units through coding (Krippendorff, 2004, pp. 125–127). In this step, we imported the collected websites into MAXQDA 2020 and coded the contents based on our pre-defined code set (see A9). Codes were derived based on reviewing literature and by pre-screening documents in the sample. The structuring premise underling our coding scheme is that platform management is based on two dimensions that need to be aligned, architecture and governance (Tiwana, 2014; Tiwana et al., 2010). The architecture dimension (Extension Marketplace, Cloud, Operating System, Getway/Hub Device, Published API) is based on technical articles on generic IoT platform architectures (Aswale et al., 2019). The governance dimension is based on research from management and technology management literature discussing integrative (closed) strategies (Rowland, 2015) as an approach, emphasizing platform integration (Hilbolling et al., 2020), partner selection (Dattée et al., 2018), and marketplaces (Ghazawneh & Henfridsson, 2013). This dimension primarily reflects how platform sponsors advertise compatibility.

Codes 1.1 to 1.5 are used to identify architectural features (extension marketplace, cloud, operating system, gateway/hub device, published API), while 2.1 to 2.6 reflect the context, i.e., where the data such as a complementary product stems from to help understand the relationship type (own product, platform integration, selected partner, product curation, compatibility list, product marketplace).

For standards, we apply an open coding (inductive) approach to ensure completeness, where we used computer-based keyword search (Krippendorff, 2004, chapters 12.4, 12.5.1) after finishing our content analysis. In a similar vein, we coded products to distinguish different niches, where we classified the products themselves using sub-codes and grouped these into similar application

[61] We used the browser plugin www.webscraper.io to extract all elements of a certain type from websites. The tool also allows clicking trough websites with pagination and retrieving the unique resource links.

purposes to derive three different abstraction levels for product niches in order to remove potential biases going back to combined products (e.g., a dimmer plug). In the main analysis, we use the medium level and validate our model using the other two category levels.

We exported our coding results to a MySQL database to integrate it with our scraping results and further write MySQL scripts for text search and reducing. For scraped products, we identified product niches using a computer algorithm based on keyword-searches together with a manual review. Finally, we cleaned our data from partner companies being mere consulting firms or manufacturers in industries that are entirely different from smart home product manufacturers. In addition, we identified duplicates or wrongly scraped website elements such as table headings and removed them from our dataset.

According to Krippendorff (2004), "[r]educing data serves analysts' need for efficient representations, especially of large volumes of data" (p. 84). In the reducing step, we used relationship codes (1.2 – 2.6) to construct our network edges. All further codes were used to construct dummy variables and metric count variables. An additional variable was added by collecting data on platform introduction as an outcome of the triangulation between the app introduction in the Google Play Store, the website appearance on The WayBack Machine, and the product introduction on Amazon.com.

3. Content analysis II: Identification of partner platforms and main content analysis

To identify platforms among the partners, we searched the websites of the firms, while we used the brand database by World Intellectual Property Organization[62] to identify the actual companies behind the brands. We then repeated the process steps reported above in sections 1 and 2 for partner firms. We identified 76 further platforms in the second content analysis.

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A9 Coding scheme and excerpt of data sample in Paper II

No.	Code	Description	Example
1.1	Extension Marketplace	A list or overview offering compatible own and/or third-party extensions for free and/or sale. Extensions can be plug-ins, add-ons, or apps.	E.g., Homey Apps
1.2	Cloud	Offering of cloud service(s) (such as cloud recording, data analytics, energy management, or remote control) or providing an architectural blueprint showing a cloud.	E.g., SmartThings cloud
1.3	Operating System	Offering of a home automation software for the computer or handheld devices or firmware installed on a hub or gateway device.	E.g., HomeSeer HS4, Control4 OS3
1.4	Gateway/Hub Device	Offering of a physical device to which smart home sensors and other appliances can be connected. May or may not connect to the Internet, similar to a router. Often, but not always named "hub" or "gateway".	E.g., Wink Hub 2
1.5	Published API	An application programming interface ("API") that is published on the website and meant to be used in connection to their smart home system.	E.g., SmartThings API, Apple HomeKit API
2.1	Offer Own Products	Offering of one or more complementary (i.e., non-gateway and non-hub) stand-alone smart home devices such as sensors, cameras, or door locks.	E.g., water leak sensor
2.2	Platform Integration	Integrates with established platforms having certification programs. Compatibility is usually signaled using certification logos.	E.g., "works with Apple HomeKit"
2.3	Selected Partners	A list of corporate partners with compatible products. May be written or depicted in the form of logos.	E.g., trusted partners websites
2.4	Product Curation	An overview page or table with compatible third-party products. There is no explicit description of a testing or certification process.	E.g., product lists
2.5	Compatibility List	A list of compatible third-party products explicitly resulting from a formal testing or/and certification process.	E.g., PDF lists or tables showing compatibility with certain devices
2.6	Product Marketplace	A list or overview offering compatible own and/or third-party products for sale.	E.g., online shop

Nodes

Company	API	Marketplace	Compatibility List	Niche Access	…	Niche Windows	Platform Introduction	HQ Location	Founded	Firm size
ABODE	0	0	0	1	…	1	2014	Europe	2014	13.5489375
ABUS AUGUST BREMICKER	0	1	0	6	…	3	2016	Europe	1924	21.4875626
ADT SECURITY	0	0	0	3	…	0	2018	North America	1974	21.9969513
ALARMCOM	1	0	0	7	…	0	2000	North America	2000	19.8557653
ALULA	1	0	0	3	…	3	2018	North America	2007	16.5880993
AIMUS HOME	1	0	1	0	…	0	2015	Europe	2015	11.6581248
APPLE	1	0	1	0	…	0	2014	North America	1976	26.2846165
ATHOM	1	0	0	0	…	0	2014	Europe	2014	14.4869411
BENEXT	1	0	1	1	…	1	2011	Europe	2007	16.7599495
BLAZE AUTOMATION	0	0	0	0	…	3	2017	Asia	2006	11.3909612

Edges

Origin	Target	Standard Overlap	Niche Overlap
ABUS AUGUST BREMICKER	ABODE	0.7500	0.8000
ADT SECURITY	ABODE	0.2500	0.5455
ALARMCOM	ABODE	0.5000	0.4000
ALULA	ABODE	0.6000	0.6000
AIMUS HOME	ABODE	0.6000	0.1250
APPLE	ABODE	0.2000	0.0000
ATHOM	ABODE	0.5000	0.1250
BENEXT	ABODE	0.5000	0.5000
BLAZE AUTOMATION	ABODE	0.6000	0.7778

A10 Overview of open standards and giant platforms covered in Paper II

Open Technology Standards

Standard	Sponsor	Product categories	Adopters[63]	Certified products[64]	URL
Bacnet (Wire)	ASHRAE	Interfaces, controllers, routers	208	1,100+	http://www.bacnet.org/
Bluetooth (Radio)	Bluetooth Special Interest Group	Mainly file transfer, audio/headsets, HID, device synchronization, access control	36,560+	250,000+	https://www.bluetooth.com/
DECT ULE (Radio)	ULE Alliance	Security, energy, cordless telephones	130+	50+	https://www.ulealliance.org/
DMX (Wire)	ESTA	Lighting	100+	N/A	https://my.esta.org/directory
EnOcean (Radio)	EnOcean Alliance Inc.	Lighting, temperature, air quality, security, smart metering	400+	1,400+	https://www.enocean-alliance.org/
GSM (3G, 4G, 5G) (Radio)	GSM Association	Mobile connectivity	400+[65]	N/A	https://www.gsma.com
KNX (Both)	KNX Association	Security, energy, light	500+	5,000+	https://www.knx.org/
Modbus (Wire)	Modbus Organization Inc.	Controllers	40+	80+	https://modbus.org/
Thread (Radio)	Thread Group	Gateways, semiconductors	300+	35+	https://www.threadgroup.org/
Wi-Fi (Radio)	IEEE, Wi-Fi Alliance	Local networks, mainly phones, routers, and TVs certified	750+	61,900+	https://www.wi-fi.org/
X10 (Radio)	X10 (USA) Inc.	Controllers	N/A	N/A	https://www.x10.com/
Zigbee (Radio)	Zigbee Alliance	Light, security, energy	300+	2,600+	https://zigbeealliance.org/
Z-Wave (Radio)	Z-Wave Alliance	Security, light, energy	160+	3,300+	https://z-wavealliance.org/

Note: All information consolidated in this table as of December 2020.

[63] Only provided for formal members of, e.g., an alliance.
[64] Only if certification program available.
[65] Only counting device manufacturers, excluding telecommunication network operators.

Giant Platforms

Platform Sponsor[66]	In-Degree	Listed complements / partners / apps	User Base	Primary industry
Amazon	95	121 / 83 / 828	• 46 mil. Amazon echo users • 100,000 Alexa skills • 60,000 supported devices • Alexa voice assistant	E-Commerce
Google	88	0 / 0 / 230	• 27.1 mil. Google Home users • 2.8 bn. Android users • Google assistant	Mobile phones
Apple	37	563 / 190 / 127	• 2.5 mil. Home Pod users • 1 bn. iPhone users • Siri voice assistant	Mobile phones
IFTTT	35	0 / 0 / 666	• 18 mil. users • 650 partner services	Web service
Samsung	25	1109 / 89 / 0	• 37.1% Android market share • Bixby voice assistant	Mobile phones, appliances

[66] Sources: Amazon (https://www.statista.com/statistics/794480/us-amazon-echo-google-home-installed-base/, https://www.statista.com/statistics/912856/amazon-alexa-skills-growth/), Google (https://www.statista.com/statistics/794480/us-amazon-echo-google-home-installed-base/, https://www.businessofapps.com/data/android-statistics), Apple (https://www.statista.com/statistics/794480/us-amazon-echo-google-home-installed-base/, https://backlinko.com/iphone-users#iphone-users), IFTTT (https://www.computerworld.com/article/3239304/what-is-ifttt-how-to-use-if-this-then-that-services.html), Samsung (https://www.businessofapps.com/data/android-statistics/).

A11 Robustness tests in Paper II

Parameter	(1)	(2)	(3)	(4)	(5)
Sender(Openness)		1.11** (0.10)	1.22** (0.18)	1.09** (0.10)	1.09** (0.10)
Sender(Openness to complementors)	0.88** (0.10)				
Competition	-0.04 (0.17)	0.16 (0.19)	0.16 (0.19)	0.21 (0.18)	0.16 (0.19)
Sender(Openness to complementors) x Competition	-0.23 (0.23)				
Sender(Openness) x Competition		-0.50* (0.24)	-0.53* (0.24)	-0.49* (0.23)	-0.52* (0.24)
Sender(Openness) x Sender(Firm size)			-0.02 (0.03)		
Standard overlap	0.90* (0.44)		1.07* (0.46)	1.05* (0.47)	1.06* (0.46)
Standard overlap^2	-0.29 (0.44)		-0.41 (0.46)	-0.38 (0.46)	-0.40 (0.45)
All standard overlap		1.28* (0.47)			
All standard overlap^2		-0.59 (0.46)			
Abs. firm size diff.				0.05** (0.01)	
Receiver(Giant platform)	0.65* (0.29)	0.75* (0.29)	0.73* (0.29)	0.68* (0.29)	0.65° (0.35)
Receiver(Giant platform) x Sender(Multi-homing)	2.66** (0.26)	2.65** (0.26)	2.67** (0.26)	2.67** (0.26)	2.66** (0.26)
Sender(Standards)	0.11** (0.03)		0.09* (0.03)	0.10** (0.03)	0.09* (0.03)
Receiver(Giant platform) x Sender(Standards)	-0.25** (0.07)		-0.27** (0.07)	-0.28** (0.07)	-0.27** (0.07)
Receiver(Giant platform) x Sender(Firm size)					0.02 (0.03)
Sender(Multi-homing)	0.40** (0.10)	0.32** (0.10)	0.31** (0.10)	0.34** (0.10)	0.32** (0.10)
Giant platform reciprocity	0.67* (0.25)	0.71* (0.26)	0.76** (0.25)	0.61* (0.26)	0.75** (0.25)
Sender(Niches)	-0.03* (0.01)	-0.05** (0.01)	-0.05** (0.01)	-0.05** (0.01)	-0.05** (0.01)
Receiver(Niches)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)	0.01 (0.01)
Niche overlap	2.25** (0.48)	2.29** (0.48)	2.34** (0.48)	2.38** (0.48)	2.33** (0.48)
Niche overlap^2	-2.72** (0.60)	-2.78** (0.59)	-2.80** (0.59)	-2.86** (0.59)	-2.81** (0.58)
Sender(Partners)	0.01** (0.00)	0.01** (0.00)	0.01** (0.00)	0.01** (0.00)	0.01** (0.00)
Platform age	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)
Sender(Firm age)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)

(*Continued*)

Sender(Firm size)	-0.07** (0.02)	-0.09** (0.02)	-0.07** (0.02)	-0.09** (0.02)	-0.09** (0.02)
Spatial proximity	0.25** (0.07)	0.26** (0.07)	0.27** (0.07)	0.27** (0.07)	0.26** (0.07)
Sender(Z-Wave)	0.31** (0.10)	0.27* (0.10)	0.27* (0.10)	0.28* (0.10)	0.27* (0.10)
Receiver(Z-Wave)	-0.15** (0.04)	-0.17** (0.04)	-0.17** (0.04)	-0.19** (0.04)	-0.16** (0.04)
Popularity Spread	-3.45** (0.12)	-3.43** (0.12)	-3.44** (0.12)	-3.40** (0.12)	-3.44** (0.12)
Reciprocity	1.33** (0.14)	1.38** (0.14)	1.36** (0.14)	1.39** (0.14)	1.36** (0.14)
Arc	-3.79** (0.19)	-3.81** (0.19)	-3.85** (0.21)	-4.01** (0.20)	-3.77** (0.19)
Nodes	157	157	157	157	157
Edges	879	879	879	879	879
AIC	4870.82	4814.66	4820.60	4798.20	4820.66
BIC	5073.47	5017.31	5031.36	5008.96	5031.42
MCMC Std. Err.	0.5307	0.7499	0.7338	0.7119	0.3329
DoF	24467	24467	24466	24466	24466
LogLikelihood	-2410.41	-2382.33	-2384.30	-2373.10	-2384.33

Note: ERGM estimations on sample with 157 platform sponsors and 879 compatibility promotions among them. Standard errors in parentheses.

Significance levels: $^{\circ}$ $p < 0.1$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

A12 Industry consortia considered in Paper III

	KNX	ZigBee	Z-Wave	OCF	Thread
Alliance					
Year founded	1999	2002	2005	2013	2014
Alliance members	500+	300+	160+	500+	100+
Certified products	8,000+	3,000+	3,300+	120+	40+
Certification					
Membership required for certification?	Yes	Yes	Yes	No	Yes
Annual membership fees	2,500-12,500 EUR or 1% of KNX sales (min. 1,000 EUR)	7,000-75,000 USD	10,000-65,000 USD	2,000-150,000 USD	5,000-65,000 USD
Certification fee (hardware)	600 EUR	1,000 EUR	1,000-8,000 EUR	0 EUR for members 5,000 EUR annually for non-members	N/A
Certification fee (software)	180 EUR	-	-	-	-
Certification process	1. Become member 2. Application (KNX Association) 3. Optional: Certified Product Logo (up to 6 months before testing) 4. Optional: pre-testing 5. Compliance Test (Test provider) 6. Certified Product Logo	1. Become member 2. Optional: pre-testing 3. Compliance Test (Test provider) 4. Application (ZigBee Alliance) 5. Certified Product Logo	1. Become member 2. Pre-testing 3. Application (Silicon Labs) 4. Compliance Test (Test provider) 5. Market certification (Z-Wave Alliance) 6. Certified Product Logo	1. Optional: Become member 2. Application (OCF) 3. Compliance Test (Test provider) 4. Certified Product Logo	1. Become member 2. Application (Thread Group) 3. Optional: pre-testing 4. Compliance Test (Test provider) 5. Certified Product Logo
Technology					
Standardization	ISO/IEC 14543-3	IEEE 802.15.4	ITU-T G.9959	ISO/IEC 30118-1:2018	IEEE 802.15.4
Radio / Wired	Radio + Wired	Radio	Radio	Radio + Wired	Radio
Data transmission rate	1.2 kbit/s	250 kbit/s	100 kbit/s	N/A	N/A

A13 Excerpt of data sample underlying Paper III

id	Product certs.	Spanning	Exits	Z-Wave orchestrator	Orchestrator in others	Z-Wave memberships	First year	Log(Employees)	Founded	SIC
0	7	1.2500	0	0	0	2	2012	6.5511	1924	34
1	0	1.6667	2	0	0	2	2014	4.3820	1992	73
2	0	1.2857	2	0	0	6	2006	5.3936	1991	87
3	16	2.1429	0	1	1	10	2005	10.7994	1994	34
4	0	1.4545	2	0	0	11	2005	10.1576	1833	73
5	0	2.1429	3	0	0	2	2013	12.2815	1995	48
6	0	1.7857	0	0	0	11	2005	2.7081	1989	73
7	3	1.0000	0	0	0	6	2014	2.6391	1990	73
8	16	2.5714	2	0	0	8	2001	11.6440	1906	38
9	0	1.7778	0	0	0	9	2008	10.0698	1919	50
10	6	1.4000	1	0	0	3	2015	7.4662	1976	87
11	2	2.4286	1	1	1	4	2013	6.4085	2000	36
12	0	3.2143	1	0	0	6	2000	10.5552	1961	36
13	12	2.5000	3	1	1	7	2003	10.5374	1947	50