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Joining forces to create value: The emergence of an innovation ecosystem

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ABSTRACT

During periods of discontinuous technological change (DTC), firms seek alliances to obtain new resources and competences. The concept of innovation ecosystems is increasingly used to address joint value creation endeavours. Interactions within an innovation ecosystem are typically organized around a technology platform consisting of shared assets, standards, and interfaces. Yet, few empirical studies explain how innovation ecosystems emerge. Based on a longitudinal case study of autonomous drive technology development at Volvo Car Group, this paper aims at showing how alliances for developing a new technology leads to the emergence of an innovation ecosystem. In the context of a DTC, the paper underlines how the initial resource constraints can be a blessing in disguise that drives a firm to seek new alliances. We identify that the alliances had a significant influence on the technology platform, transitioning it from an internal to a modular technology platform. This triggered the emergence of an innovation ecosystem, consisting of actors co-creating value and organizing around the technology platform. Further, the paper highlights the subtle distinction between modularization for outsourcing and modularization for co-creating value.

1. Introduction

In the early 90s, Intel faced a major impediment to its growth as customers bought PCs, not microprocessors. The key to selling more computers, i.e., more microprocessors, was contingent on the ability of users to connect their PCs to other hardware. That is, Intel's success depended on the establishment of an architectural standard for PCs that facilitated the development of complementary products and coordinate innovation outside of Intel (Gawer et al., 2002). The Intel Architecture Lab was created to advance both system hardware and software, and thus redefined the technical architecture of the PC. The universal serial hub (USB) developed in the mid-90s provided an interface between the PC and external devices such as keyboards, printers, and digital cameras. Intel's success was closely tied to its foresight in developing this interface, stimulating complementary innovations, and coordinating innovation activities with other actors in the PC industry.

The lack of universal standards and interfaces between products (or technologies) is common during a discontinuous technological change (DTC) and triggers alliance formation. According to Rothaermel and Boeker (2008, p. 47), "Established firms use alliances with new entrants to adapt to technological change, while new entrants benefit from the ability of established players to commercialize the new technology." In an industry facing a DTC, innovation activities are often distributed and

involve firms from different industries along with customers and even competitors in a collective development process (Brusoni and Prencipe, 2013; Iansiti and Levien, 2004).

Such collaborative arrangements can be likened to an ecosystem, a metaphor first used by Moore (1993) to introduce the concept of business ecosystems. Since then, scholars have developed the concept of ecosystem to address the process of joint value creation and appropriation (e.g., Adner and Kapoor, 2016; Dedehayir et al., 2018; Gawer and Cusumano, 2014; Gomes et al., 2018; Hannah and Eisenhardt, 2016; Jacobides et al., 2018). In a broad sense, an ecosystem is a network of actors that "co-evolve their capabilities and roles and tend to align themselves with the directions set by one or more central companies" (McIntyre and Srinivasan, 2017, p. 143).

The interactions within an innovation ecosystem is generally organized around a technology platform consisting of shared assets, standards, and interfaces (Dattée et al., 2018). The presence of a technology platform allows actors to combine their individual offerings to provide a complete value proposition to customers (Dattée et al., 2018; Gawer and Cusumano, 2014). However, some scholars have also studied innovation ecosystems without a technology platform at the core. For instance, Holgersson et al. (2018) studied the mobile telecommunications ecosystem where standardization facilitated interoperability, enabling actors to collaborate and develop complementarities. The starting point

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for ecosystems, according to Kapoor (2018), is the focal offer, whereas networks research focuses on the focal firm and interorganizational relationships (see Shiplov and Gawer, 2020, p. 93).

Furthermore, an important distinction between an innovation ecosystem and other conceptualizations such as “innovation systems” is the concomitant collaborative and competitive behavior exhibited by its participants (Granstrand and Holgersson, 2020). Innovation systems are often based on geographical boundaries, labelled using constructs such as national or regional innovation systems (Carlsson et al., 2002; Granstrand and Holgersson, 2020; Lundvall, 2007). In contrast, innovation ecosystems allow for cross-sectoral and cross-regional examination of innovation activities.

Jacobides et al. (2018) suggest that modularity and non-generic complementarities are important ecosystem underpinnings. Although the literature acknowledges the importance of modular platforms¹ to allow for ecosystem emergence, not all modular platforms manifest into ecosystems. The question of leadership has also gained attention as firms that lead the ecosystem can shape its development to their own advantage (see Adner, 2006, p.9). However, there is no clear picture of how a firm may use its modular platform to orchestrate the emergence of an ecosystem and occupy a leadership position. (Dattée et al., 2018; Gawer and Cusumano, 2014; Jacobides et al., 2018). This is perhaps due to the methodological difficulty of investigating a system that is emerging, as this can take many years. Adner (2006) underlines that occupying the leadership position entails risks for a firm, as it necessitates investments over long periods of time, yet it provides no guarantee of success. Several scholars have called for further research explaining the process of ecosystem emergence (Dattée et al., 2018; Dedehayir et al., 2018; Gawer and Cusumano, 2014; Jacobides et al., 2018).

This paper aims at providing new insights on the emergence process of innovation ecosystems based on a four-year longitudinal case study at Volvo Car Group (hereafter Volvo). The automotive industry is currently witnessing a period of discontinuous technological change with new technologies, such as autonomous drive (AD) and battery electric vehicles (BEVs), threatening the competitive advantage of incumbent automotive firms. Numerous alliances have been forged between the established automotive firms, new entrants, and non-automotive firms to develop the new technologies. Using rich field and archival data from AD technology development activities at Volvo, this paper investigates the alliances set-up to develop AD technology. Our paper seeks to answer the following question: How does a firm use its internal platform to orchestrate the emergence of an innovation ecosystem?

The paper contributes to the literature on innovation ecosystem by identifying the transformation of an internal (firm specific) platform into a modular platform. The paper focuses on alliances established to develop a new technology. In particular, we highlight the importance of the mutual dependence between the case firm and its subsidiary. We show how this delicate interdependence led to the development of a modular technology platform (cf. Gawer et al., 2014, p. 420), facilitating the emergence of an innovation ecosystem. Extant research on the automotive industry highlight outsourcing (Jacobides et al., 2016) and vertical disintegration (Argyres and Bigelow, 2010) as the main drivers for modularization. This case study shows how the seeming disadvantage of not having resources and competences to single handedly develop the new technology platform pushed the case firm to establish

alliances, which in turn instigated the modularization of its technology platform. We argue that modularity was a consequence of the technology-sourcing alliances and had unintended implications in the emergence process of the innovation ecosystem.

In this paper, the term “innovation ecosystem” includes all value creating activities performed by an evolving network of actors integrating their products and services on a technology platform (cf. Dattée et al., 2018). In such collaborative networks, interaction among firms is both complex and critical, and combines cooperation and competition (Gawer and Cusumano, 2014; Gomes et al., 2018; Granstrand and Holgersson, 2020a; Hannah and Eisenhardt, 2018).

2. Frame of reference

2.1. Discontinuous technological change

Economic theories and literature on industry dynamics explain the role of technology in shaping innovation (Christensen and Rosenbloom, 1995; Klepper, 1997). Previous studies on discontinuous technological change (DTC) use the term inconsistently to address various types of change, ranging from technology generation shifts (e.g., disk drives) to shift from analog to digital (e.g., digital photography) Eggers and Park (2018). This lack of clarity leads to challenges in understanding if – and to what extent – findings from one context (or industry) will hold in another context (or industry). The emergence of a new technology attracts new entrants and intensifies competition amongst firms to establish a dominant design for future products (Anderson and Tushman, 1990; Henderson and Clark, 1990; Lambe and Spekman, 1997; Utterback and Suarez, 1993). The dominant design is a specific path that firms in a particular industry take in order to establish an advantage over other design paths (Suárez and Utterback, 1995). The dominant design is based on the prevailing technology and is inevitably a major impediment to the adoption of a new technology. Hence, collaborations in the form of strategic alliances are needed as the adoption of a new technology requires industry-wide consensus (Abernathy and Utterback, 1978; Brem et al., 2016).

Dominant design also affects standards; Brem (2016, p. 80) notes that: “The interrelation of standards, standardization, or dominant design and innovation seems to be a major contributor to a firm’s competitiveness.” However, the influence of standardization on innovation has been rather overlooked (Brem et al., 2016). Suárez and Utterback (1995, p. 417) define standards as, “the result of a battle among different technical alternatives (such as different computer architectures)” This suggests that standards are based on technical paradigms although dominant design is not based solely on technology. An example of a standard that is a well-entrenched in a dominant design is the QWERTY² keyboard. When a dominant design is accepted as the industry standard (i.e., the dominant design is synonymous with a standard or a set of standards for a complex assembled product), non-technical factors such as government interventions, industry regulation or network externalities play a major role. Additionally, government agencies can regulate innovation activity by institutionalizing the dominant design as the industry standard.

2.2. Alliances during a discontinuous technological change

The need for organizations to innovate and renew themselves has been widely acknowledged since Schumpeter’s classical work (1942), and today the need to cope with technological change is more important than ever before (Amabile and Pratt, 2016; Danneels, 2002). The search for technology sourcing alliances is a recurring pattern related to the

¹ Gawer et al. (2014) identify two types of platforms: internal (or company specific) platforms, and external platforms. They define external platforms as “products, services or technologies developed by one or more firms, and serve as a foundation upon which a large number of firms can further build complementary innovations and potentially generate network effects” (Gawer et al., 2014, p. 420). Building on Gawer and her colleagues, we refer to such external platforms as ‘modular technology platforms’ to emphasize the modular architecture which allows other firms to develop complementary innovations for a technology platform.

² The QWERTY keyboard has survived largely due to the “presence of strong technical interrelatedness, scale economics and irreversibilities due to learning and habituation” (David, 1985, p. 336).

concept of creative destruction which no industry (or firm) can evade (Lambe and Spekman, 1997; Rothaermel and Boeker, 2008). Tripsas (1997) argues that the possession of relevant complementarities allows incumbent firms to survive competence destroying technological change. To be successful, both incumbents and new entrants – beyond superior technology – need to possess necessary specialized and cospecialized assets (Teece, 1986; Tripsas, 1997). However, the continuous compression of the technology life cycle (Phillips et al., 1999) and the increasing costs to develop complementary products and services has made it increasingly difficult for a single firm to develop these complementarities, requiring inter-firm collaboration beyond traditional value chains.

During a DTC, incumbent firms can acquire the new technology in three main ways: through mergers and acquisitions, by developing the technology in-house using existing resources, or by establishing some type of alliance (Lambe and Spekman, 1997). Alliances are frequently used by established firms to develop a new technology (Rothaermel and Boeker, 2008). Lambe et al. (1997, p. 103) define an alliance as “a collaborative relationship among firms to achieve a common goal that each firm could not easily accomplish alone.” Extant literature highlights that alliances play significant roles during DTC (Ahuja, 2000; Hagedoorn, 1993, 2002; Lambe and Spekman, 1997). The numbers of alliances that are established, increase during the early stages of a DTC and then drop as the technology matures (Lambe and Spekman, 1997). Typical alliance forms include joint ventures (JV), R&D consortia and technology sourcing agreements (Lambe and Spekman, 1997).

Extant literature indicates that alliances are formed for two main reasons (Ahuja, 2000). First, due to the firm’s strategic resource needs, suggesting that firm behavior is shaped by the search for competences and resources that will provide competitive advantage (Ahuja, 2000; Wernerfelt, 1984). Second, because of existing interfirm linkages based on previous collaboration experiences, implying that new alliances are based on the firm’s position in the network structure (Ahuja, 2000). Thus, the firm’s willingness to establish an alliance is driven by the need to secure resources and competences not easily purchased in the market or developed internally. According to Martinez et al. (2017, p. 56), “R&D alliances are an ideal platform for learning as external partners bring diverse knowledge and resources that firms can integrate into new products and services.”

A JV is a business agreement between two partners (sometimes involves more partners) to establish a standalone entity (Harrigan, 1988). JVs are often established to undertake engagement in risky technology development projects in which the standard business objectives such as market attractiveness or profitability are unclear (Anderson, 1990). A JV reduces risks and costs for each of the participating firms (Kamien et al., 1992), eliminates duplication of research efforts and reduces competition which could slow the rate of technological advancement. A JV allows economies of scale and rapid acquisition of new resources, and can help overcome foreign trade barriers (Kamminga and Van der Meer-Kooistra, 2007). Rather than being aimed at generating revenue or increasing the customer base, JVs are created to develop new technology or allow entry to a new industry or market.

However, the existence of multiple parent firms can lead to control issues in a JV (Kamminga and Van der Meer-Kooistra, 2007). An appropriate control structure that aligns the JV’s activities to the parent firms’ strategies, will increase the parent firms’ competitive advantage. For example, Gong et al. (2007), p. 1022 suggest that, “In any joint venture, the structure and the process of exchange are the two central constructs affecting venture development and growth.” Kumar and Seth (1998) state that the parent firms’ control depends on the degree of uncertainty in the environment and the strategic interdependence between the parent firms and the JV. Also, JVs with multiple owners are governed by contracts which reduce the moral hazard and the potential for opportunistic behavior. Typically, a JV is in a hierarchical relationship with its parent firms which in turn, are involved in an interfirm relationship (Kamminga and Van der Meer-Kooistra, 2007).

2.3. The innovation ecosystem concept

The notion of an ecosystem has become the subject of much research attention in top strategy and innovation journals (Gomes et al., 2018; Jacobides et al., 2018; Scaringella and Radziwon, 2018; Granstrand and Holgersson, 2020). In extant research, the concept of ecosystem is used to describe value co-creation involving actors connected to a platform or a focal firm in a non-linear system and includes participants from both the production and user sides (Adner and Kapoor, 2010; Dodgson et al., 2013; Granstrand and Holgersson, 2020). Jacobides et al. (2018, p. 2264) suggest that “an ecosystem comprises of a set of actors with varying degrees of multilateral, non-generic complementarities that are not fully hierarchically controlled.” The activities of the actors within an ecosystem are orchestrated by the ecosystem leader(s) or keystone firm (s). A keystone firm is responsible for the ecosystem’s overall ‘health’ and ensures that value is shared amongst the ecosystem participants (Adner, 2017; Clarysse et al., 2014; Furr and Shipilov, 2018; Iansiti and Levien, 2004; Jacobides et al., 2018; Williamson and De Meyer, 2012). Clarysse et al. (2014, p. 1166) suggest that the “keystone firms create platforms such as services, tools, or technologies, which are open for other players in an ecosystem to enhance their own performance.”

The ecosystem notion is encompassed in other constructs such as business ecosystem, innovation ecosystem, knowledge ecosystem and entrepreneurial ecosystem (Aarikka-Stenroos and Ritala, 2017; Scaringella and Radziwon, 2018). Jacobides et al. (2018) identifies three main ecosystem types: innovation ecosystem, business ecosystem and platform ecosystem. An innovation ecosystem focuses mainly on a particular innovation or value creating activity; a business ecosystem tends to be focused on value appropriation; and a platform ecosystem refers to the platform on which the actors develop their solutions (Aarikka-Stenroos and Ritala, 2017; Adner, 2006, 2017; Gomes et al., 2018; Jacobides et al., 2018; Oh et al., 2016). In a platform ecosystem, actors are primarily attracted to the platform due to network effects. For example, the Sony Playstation or Nintendo Wii serve as platform for independent gaming companies to reach their customers (Cennamo and Santalo, 2013). The platform owners and complementors do little value co-creation, as is the case in an innovation ecosystem.

An innovation ecosystem enables the actors to access resources and complementary assets which are beyond the scope and capabilities of a single firm (Adner and Kapoor, 2010; Gawer and Cusumano, 2014; Iansiti and Levien, 2004; Kelly, 2015). Jackson (2011, p. 2) defines an innovation ecosystem as consisting of “complex relationships that are formed between actors and entities whose functional goal is to enable technology development and innovation.” In traditional value chains, actors organize their activities in a hierarchical buyer-seller relationship (Peppard and Rylander, 2006). However, in an innovation ecosystem, value is created in a network of shared assets, interfaces, and standards (Dattée et al., 2018; Jacobides et al., 2018; Peppard and Rylander, 2006), in which all actors create and deliver value simultaneously rather than sequentially. Several scholars use the concept of innovation ecosystem to capture the complexity of innovation activity that spans industries and national boundaries (Adner and Kapoor, 2010; Brusoni and Prencipe, 2013).

The wide-ranging use of the concept has also raised scholarly debate regarding the usefulness of the concept (Oh et al., 2016). In order to improve conceptual rigor, reduce ambiguous postulations and increase consensus amongst academics, (Granstrand and Holgersson, 2020) reviewed various definitions of innovation ecosystem (and related concepts) to develop a synthesized definition. They propose that “an innovation ecosystem is the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors” (Granstrand and Holgersson, 2020, p.3). Several other scholars have also proposed definitions and identified key features of an innovation ecosystem (Adner, 2006; Gawer and Cusumano, 2014; Ritala and Almpantopoulou, 2017). For instance,

Almpanopoulou et al. (2019) identify important characteristics of an ecosystem, namely: “actor interdependence within a particular context”, “co-evolution of actors”, and “typically include private firms developing new technologies, universities, research institutions and complementary firms providing components, inputs and market access”.

In a critique of the innovation ecosystem concept, Oh et al. (2016) find the concept to be insufficiently distinct from *national* and *regional* innovation systems (see Chung, 2002; Lundvall, 2007). They opine that the ecosystem concept has several inconsistencies when compared to other established notions such as innovation system, triple-helix, and clusters. While acknowledging the contributions of this literature, they see little need for the use of the “eco” qualifier. Coming to the defense of “eco” in innovation ecosystem, Ritala and Almpanopoulou (2017) argue for the distinction of the concept, emphasizing the co-evolution properties of networks or communities meant for innovation. In aggregate, they claim that the important distinction and usefulness of the ecosystem concept is the emphasis on the co-evolution, and cooperative and competitive properties of networks of communities meant for innovation.³

2.4. The role of modularity in innovation ecosystems

Typically, the interactions in an innovation ecosystem are organized around a technology platform with a modular architecture (Dattée et al., 2018; McIntyre and Srinivasan, 2017). However, literature on modularity focuses almost exclusively on either the generic complementarities leading to market transactions or business-to-business coordination where OEMs and suppliers (often belonging to the same industry) use modularity to standardize interfaces (Adner, 2017; Jacobides et al., 2016). Yoo et al. (2010) address an important distinction between the modular architecture of physical products and digital products platforms. They argue that a firm developing a digital platform with a “layered modular architecture” can utilize the platform to serve its own installed base at one layer and serve as a component at another layer to an external firm (Yoo et al., 2010, p.6).

In the context of an innovation ecosystem, a modular architecture allows actors to specify explicitly how components, technologies, subsystems, etc. interface with its platform (Autio et al., 2016; Cusumano and Gawer, 2002; Yoo et al., 2010). This reduces innovation costs and facilitates the development of specialized platform complementarities. For instance, both iPhone and Android rely on external actors to create value across their platform. The entire iOS and Android platforms are constructed to enable external suppliers to innovate and “take full advantage over the built-in features and sensors, such as touch screen, GPS positioning, camera recorders, WI-FI, calibration tools etc.” (Remneland-Wikhamn et al., 2011, p.217). Thus, platform modularization and development of non-generic complementarities create the necessary conditions for the coordination of independent actors and allow the ecosystem to flourish (Jacobides et al., 2018).

The firm that establishes a modular platform architecture and successfully uses it to the development of non-generic complementarities may become the ‘keystone’ in the ecosystem (Gomes et al., 2018; Iansiti and Levien, 2004; Jacobides et al., 2018). This differs from the concept of modularity in engineering where modularity promotes innovation through breaking down complex systems into discrete units with known interfaces to enable integration (Baldwin and Clark, 1997; Gawer and Cusumano, 2014; McIntyre and Srinivasan, 2017). This type of modularity has been heavily used in the automotive industry to cut costs and outsource parts of the manufacturing.

However, in innovation ecosystems, modularity is required not only to enable transactions between firms within an industry but also to

facilitate the development of complementarities outside the industry or value chain. In their study on modularity and ecosystems, Jacobides et al. (2018) confirmed that modularity and reduced transaction costs can lead to numerous market-based innovation activities. It is only when modularity is exploited to develop non-generic complementarities, not managed hierarchically, that it results in the emergence of an ecosystem. Thus, modularity and non-generic complementarities are important attributes of an ecosystem as they facilitate significant levels of coordination (in an ecosystem), which can be difficult in a market transaction.

2.5. The emergence of an innovation ecosystem

The concept of innovation ecosystem is widely debated, adding to the difficulty in establishing an overarching understanding of what triggers the emergence of an innovation ecosystem (see Oh et al., 2016; Ritala and Almpanopoulou, 2017). To date, innovation ecosystem literature has predominantly focused on examining the structure and dynamics of existing ecosystems, providing an ex-post understanding of value co-creation and value appropriation (Adner, 2017; Adner and Kapoor, 2010; Gawer and Cusumano, 2014; Jacobides et al., 2018). Despite the increasing popularity of the ecosystem concept in innovation and strategy journals, only a few empirical works have explored the emergence of an ecosystem (see Dedehayir and Seppänen, 2015; Holgersson et al., 2018). According to Almpanopoulou et al. (2019, p. 6357), “a comprehensive understanding of barriers and constraining mechanisms is largely absent in the innovation ecosystem literature”.

Several scholars have described the lifecycle of an innovation ecosystem as consisting of four phases, namely: *birth*, *expansion*, *leadership*, and *self-renewal* (Dedehayir et al., 2018; Moore, 1993). Thomas and Autio (2014) elaborate that the early stage of an ecosystem perhaps involves a technological development. Further, some scholars attribute that the emergence of an ecosystem can take place in multiple ways (Thomas et al., 2014). Dedehayir et al. (2018), find that the emergence phase of an ecosystem may involve activities related to acquiring resources, developing a technology, implementing rules of engagement and framing regulations. Extant literature somewhat explains the conditions (such as a new technology, changes in regulations or shifting customer behaviours) that prevail during the pre-formation phases of innovation ecosystems. Yet, a detailed account on the process of ecosystem emergence, especially on how prospective ecosystem leaders or keystones commit resources, share activities, and organize interactions, remains absent (Dattée et al., 2018; Dedehayir et al., 2018; Gawer and Cusumano, 2014; Jacobides et al., 2018).

Despite efforts by academics and practitioners in furthering the understanding of innovation ecosystem, several questions remain unanswered. Dedehayir et al. (2018) put forth questions pertaining to the emergence of an innovation ecosystem, including the roles of various actors during ecosystem emergence, and the actions that shape innovation ecosystems. Scholars have underlined the importance of modular platforms and non-generic complementarities. However, it is still not clear why some platforms evolve into flourishing ecosystems, whilst others fail (Adner, 2017; Jacobides et al., 2018). Thus, a burgeoning question amongst scholars, practitioners and policy makers is how do innovation ecosystems come into being? (see Dattée et al., 2018).

3. Method

3.1. Research design

This paper explores the development of a new technology by an incumbent firm during a period of a DTC. The case was chosen because it allows investigation of processes that evolve over time. Also, case study research is recognized as a way to understand an evolving phenomenon within a real-life context (Eisenhardt, 1989; Eisenhardt and Graebner, 2007; Hobday and Rush, 1999; Yin, 2009). A longitudinal case design is appropriate for obtaining a deep understanding of the specific context,

³ Although this paper makes a distinction between innovation systems and innovation ecosystems, scholarly works do not always make this distinction, resulting in confusion around the two concepts.

allowing exploration of dynamic aspects, flows of activities and the relationship among the variables (Perks and Roberts, 2013). Studying the case over a long period of time further allows proximity to the nucleus of the case (Mulhall, 2003). Our longitudinal study thus allowed a better understanding of the sequence of events and activities as they emerged. The data were collected by the first author who acted as a participant observer at the case firm for almost four years, as part of a PhD research project. This type of data collection, where the researcher is immersed in the case setting, is commonly described as an ethnographic approach (Aktinson and Hammersley, 1998; Anderson, 2009; Yin, 2009). The emergence of an innovation ecosystem is a complex phenomenon, unfolding in multiple layers at both the organizational and systems level which makes it difficult to identify an unambiguous unit of analysis. The authors adopted a process approach (see Langley, 1999) to take into account the context and the multiple levels of analysis which at times were difficult to separate.

3.2. Research setting: autonomous drive technology development at Volvo Cars

The automotive industry has been relatively stable over the last century, involving incremental innovations within a well-defined value chain. However, over the past two decades, the increased use of embedded systems in modern vehicles, coupled with connectivity and information and communication technology (ICT), has shifted the innovation landscape considerably (Coronado Mondragon et al., 2006; Townsend and Calantone, 2014). The industry is on the verge of the next major transformation: AD technology (Yun et al., 2016). AD technology has the potential to transform the entire automotive industry and transportation infrastructure (Greenblatt and Saxena, 2015; Lee et al., 2016; Yun et al., 2016). However, vehicle safety standards and the established dominant design (including the transport infrastructure, regulations, etc.) hampers the adoption of AD technology. Such problems are common during periods of technological change (Abernathy and Utterback, 1978; Anderson and Tushman, 1990; Yun et al., 2016).

The emergence of AD technology is creating a space for firms outside the automotive industry to disrupt the entire industry, and firms outside the traditional automotive value chain are posing a significant threat to the OEMs. Incumbent firms are required to interact with firms outside the industry to capture the relevant competences. However, collaboration for innovation involves coordination challenges; traditional automotive firms are entrenched in the value chain mode of operation. Further, AD technology still lacks standards (and/or a dominant design) which would allow widespread adoption (c.f. Abernathy and Utterback, 1978; Anderson and Tushman, 1990; Brem et al., 2016). The development of AD technology at Volvo was thus considered a suitable case to investigate the challenges faced by established firms during a DTC.

Volvo is a premium car manufacturer based in Gothenburg, Sweden, and a market leader in the area of safety (Liu et al., 2004). In 2010, the Chinese firm Geely Holding Group acquired Volvo Group's passenger vehicles business.⁴ The transfer of intellectual assets was carefully reviewed and several contracts were established in this area (Granstrand and Holgersson, 2013). In recent years, Volvo has invested hugely in its AD program (VolvoCars, 2019b). Its strong safety record and competence in advanced driver assistance systems (ADAS) made development of AD technology a natural step for the firm. Their objective is to develop AD technology, incorporating the software and hardware systems required to produce a fully autonomous car (VolvoCars, 2019b).

⁴ One of the major issues during Ford's sale of Volvo Car Corporation to Geely was the concern that Chinese competitors could gain access to Ford's technologies (Granstrand and Holgersson, 2013).

From 2013 to 2020, Volvo's AD program was based on three main research initiatives: the Drive Me project (a research initiative); Zenuity (a JV with Veoneer) and the Uber project (a redundant system platform⁵). Drive Me involved several research platforms on which Volvo collaborated with various partner organizations to develop autonomous cars for the urban environment, with a focus on safety, traffic flow and energy efficiency (Victor et al., 2017). Drive Me allowed Volvo to engage with both public and private actors, beyond its traditional value chain and included customer involvement and co-creation activities. Further, Volvo planned a unique public trial where 100 families were to be provided with autonomous cars for their daily commute. At the time, Volvo's Drive Me was touted to be one of world's first automotive firms to engage customers in its development activities. Further, in 2016 and 2017, Drive Sweden hosted a Co Creation lab on connected transport systems involving several actors (including Volvo, City of Gothenburg, residents from the city etc.).

Zenuity was an ADAS and AD software development firm, created in 2017 as a 50:50 JV between Volvo and Veoneer (Volvo, 2019a). Veoneer is a major automotive supplier (a spin-off of Autoliv) with expertise in safety electronics, ADAS and AD. The two parent firms combined their intellectual property, know-how and personnel to form the JV (Volvo Cars, 2017) and numerous engineers from Volvo's safety division and from Veoneer were moved to Zenuity to form the JV. Despite the shared ownership, Zenuity was launched as an independent firm and positioned itself as an AD and ADAS software supplier, developing software solutions in close collaboration with Volvo. Through the JV with Veoneer, Volvo's AD program acquired new resources and competences needed to develop automotive safety solutions. In April 2020, Volvo and Veoneer announced their decision to dissolve the joint venture and to focus on their respective strategies (Volvo, 2020b). In July 2020, Volvo created a new subsidiary, Zenseact, based on their part of the previous JV⁶.

The Uber project involves the delivery of base vehicles by Volvo with the required safety redundant system and core autonomous drive technology (VolvoCars, 2016). Uber is a global leader in the ride-sharing transport business and was a new partner for Volvo. According to the CEO of Volvo, the Uber partnership was in line with Volvo's intention to be a supplier of AD ride-sharing services globally (Volvo, 2017). The CEO said, "The alliance [with Uber] places Volvo at the heart of the current technological revolution in the automotive industry (VolvoCars, 2016)". Volvo also launched several other initiatives related to its AD program (Volvo, 2018a), for instance a partnership agreement with Baidu in 2018 to develop electric and fully autonomous cars for the Chinese market (Volvo, 2018b). Table 1 summarizes Volvo's AD program between 2013 and 2020.

3.3. Data sources

The qualitative data were collected between November 2016 and December 2020. In the first two months, a pilot study was conducted to understand the case context and develop the research protocols and observation routines. Observations and interviews during the pilot study focused on processes, facts and events, instead of seeking meanings and interpretations, to facilitate the understanding of both AD technology and Volvo's activities related to developing the technology (cf. Miller et al., 1997; Overholm, 2015).

The data were collected mainly by the first author from field observations, semi-structured interviews, and archival data. The presence

⁵ A redundant system consists of two or more independent systems to ensure safety goals. Highly automated driving (HAD) requires redundant systems to ensure safety.

⁶ Although the JV alliance has been rescinded, the original vision of Zenuity to be a hardware agnostic developer of AD software solution remains. Today, Zenuity's former AD software development unit is reincorporated as Zenseact, a fully independent firm owned by Volvo Car group.

Table 1
Timeline of important events in the AD program between 2013 and 2020.

2013	Volvo Car Group sets up Drive Me project. It consists of many research and development projects that cover multiple areas, from legislation to parking issues. One of the main goals of Drive Me was to run a large scale public autonomous driving experiment. The city of Gothenburg's Traffic and Public Transport Authority are some of the government agencies partnering with Volvo in the Drive Me project
2016	Volvo Cars and Uber, a leading ride-hailing firm, entered a joint engineering agreement. The XC 90 base vehicle is equipped with key safety features that allow Uber to install its own self-driving system. This will enable Uber to develop self-driving cars for its autonomous ridesharing service
2017	Volvo Cars and Autoliv autonomous driving joint venture Zenuity starts operations. The joint venture, Zenuity, is a new entrant in the growing global market for autonomous driving software systems. The JV marks the first time a premium car maker has joined forces with a tier one supplier to develop advanced driver assist systems (ADAS) and autonomous driving (AD) technologies.
2018	Volvo Cars Tech fund is launched. The fund aims to invest in high potential technology start-ups around the globe. The investments are to be made in areas such as electrification, autonomous driving, artificial intelligence and digital mobility services
2018	Volvo Cars makes a strategic investment in Luminar, a leading start-up in the development of advanced sensor technology for use in autonomous vehicles. The investment made via its newly founded investment fund deepens Volvo's existing collaboration with Luminar.
2018	Volvo Cars signs agreement with NVIDIA to use its DRIVE AGX Xavier technology and will allow Volvo Cars to implement an advanced computer platform for its new cars. The new computing platform using NVIDIA's technology will allow Volvo to develop advanced driver support systems, energy management technologies and in-car personalization options
2018	Volvo Cars signs agreement with Baidu, a leading Chinese internet search provider, to jointly develop electric and fully autonomous drive-compatible cars. According to the agreement, Baidu and Volvo will pool resources to develop electric and fully autonomous cars.
2018	Autoliv completed the spin-off of its electronic segment. The new company Veoneer Inc designs, compiles and sells software, hardware and systems for occupant protection, advanced driving assistance system, collaborative and automated driving
2020	Volvo Cars and Veoneer (formerly Autoliv) split the joint venture firm Zenuity. The JV focused on the development of assisted and autonomous driving software.
2020	Volvo launched a new company Zenseact. The new company will build upon and further develop the strong software platform for advanced driver assistance and autonomous driving systems developed by Zenuity in recent years

This table was compiled from various sources (Autoliv, 2021; Drive Sweden, 2020; Nvidia n.d., 2018; Volvo, 2014, 2016a, 2016b, 2017, 2018a, 2018b, 2018c, 2019a, 2019b, 2020a, 2020b).

of the first author at the case firm allowed familiarization with various activities and identification of aspects not revealed by the interviews, surveys, or other ex-post investigative techniques. Observation data were useful for identifying nonverbal activities such as who interacted with whom, how actors communicated with each other, and to catalogue events as they unfolded (Kawulich, 2005). The literature was reviewed regularly to allow interpretation of the data. This approach positions the study as abductive research (Dubois and Gadde, 2002; Gioia et al., 2013). The second author has conducted several studies at Volvo and Zenuity, and thus has strong contextual knowledge. The authors had regular discussions throughout the study to identify and interpret important events and activities in the case setting.

The data include some 650 pages of field and archival data on the AD program. These meetings involved senior managers and subject experts. In addition, observations allowed collection of data during program increment (PI) planning events (this scaled agile development method was adopted in 2018). PI planning events are two-day events involving teams and senior management in developing sprint plans (each sprint lasts two weeks) for the succeeding ten weeks. The field data also included information gathered during workshops and other events organized by Volvo, involving representatives of other firms and government agencies. The main author also shadowed two senior managers (a technical expert and a business expert) for one week each. The

purpose of shadowing was to understand the case context, observe the meetings amongst various stakeholders and see how these events fed into the AD program. Throughout the study period, regular meetings were held with three senior managers to discuss important events, and obtain clarifications related to technical items, company-specific language, etc. The managers also helped identifying personnel to interview. The meetings with the three managers involved whiteboarding sessions that facilitated the understanding of system designs, organizational structures, and organizational routines. The whiteboard sketches were captured as photos that allowed revisiting the sketches during the analysis of data.

We also conducted 53 semi-structured interviews to confirm our interpretation of the field observations and clarify inconsistencies. Interviewees included employees at Volvo and other ecosystem actors (such as Zenuity, Drive Sweden and Mobility Xlabs) which provided additional perspectives and validated the emerging results. The researchers had access to Volvo's internal network which provided rich information regarding meetings, events and activities and allowed a better understanding of the organizational structure. Detailed information on data sources is provided in Table 2. Information from secondary sources such as developments in regulations for AD technology (national and international), important announcements by Volvo's partner firms (e.g., Luminar, Nvidia, Uber, etc.) and developments in other technologies (such as 5G, Lidar, etc.) was used to complement the field data.

3.4. Data analysis

The case study involved the incorporation of evidence from multiple sources and allowed us to examine whether the data sources converged (Eisenhardt, 1989; Flynn et al., 1990; Yin, 2009). Alongside the fieldwork, both authors held regular discussions on the case to validate interpretations and identify particularly striking elements. Process phenomena are difficult to analyze due to their fluid nature and the multiple levels of analysis involved (Langley, 1999). The rich data collected over the four-year period required a structured data analysis process. To begin with, the entire study period was categorized in three phases to highlight the evolution of the phenomenon over time (see

Table 2
Overview of data collected.

	2016	2017	2018	2019	2020	Total
Number of interviews at Volvo	2	20	6	16	9	53
<i>Senior managers, solution architects, engineers etc.</i>						
Number of Meetings at AD program	11	17	61	25	3 (6)	117
<i>Field notes were taken systematically (No. of Pages^a)</i>	(67)	(113)	(125)	(95)		(406)
Number of Workshops	-	1	2	-	-	3
<i>Participants: Ericsson, SOS alarm, Volvo Car Group, Trafikverket etc.</i>						
Number of interviews with external informants	-	4	-	4	3	11
<i>Other actors working with Volvo and/or commenting on the AD technology in general</i>						
Shadowing senior managers (For about a week)	-	-	2	-	-	2
Archival data						200
<i>Approx. number of pages</i>						

^a This is an approximate number – field notes were taken both in a diary (hand-written) and on a computer (digital). This results in differences such as the page size, font size etc.

Table 3
Overview of data collection activities.

Phase	Time period	Actors	Key findings	Data analysis
A	November 2016–December 2017	Volvo	Competence and resource need. JV to develop AD software	Mind map
B	January 2018–June 2019	Volvo, Zenuity, Ericsson, Trafikverket, SOS Alarm	The Zenuity's role in Volvo's AD program	NVivo coding
C	June 2019–December 2020	Volvo, Drive Sweden, Mobility Xlabs, Zenuity	Collaboration with actors such as Uber, Nvidia, Luminar.	NVivo coding

Table 3). The three phases highlight the systematic combining approach (Dubois and Gadde, 2002). As new constructs and linkages emerged from the field observations and interviews, the literature was revisited in order to revise and sharpen the study (Dubois and Gadde, 2002).

In phase A, data were analyzed using XMind software⁷ (Lee and Fink, 2013). The observational data were mapped in chronological order to identify constructs and visualize important linkages. The most important finding from this phase was the resources and competences needed for the AD program which were identified as the main reason for the JV between Autoliv (now Veoneer) and Volvo. After analyzing phase A, it was decided that digital notes would deepen the analysis and facilitate coding and categorization of the data. For phases B and C, the field notes were analyzed using the NVivo software. The analysis of phase B revealed Zenuity's role in Volvo's AD platform and the analysis of Phase C revealed the increasing number of collaborations in Volvo's AD program.

To structure the data, we applied the Gioia method (Gioia et al. (2013) method that helped cluster the data and identify key aspects of the AD program. Table 4 depicts the data clustering sequence. The Nvivo coding was used to filter statements identifying key aspects of the AD program in all three data collection phases. Comments made by personnel at Volvo were categorized as first order statements which were clustered under second order categories. Patterns in the second order categories were identified, and aligned to three aggregate dimensions:

- i) Resources and competences
- ii) Commercialization
- iii) Modularization

See example of the analysis in Table 4 below.

The structured data analysis helped identify the evolution of the AD program from being an internal project to a program with alliances spanning multiple countries. The ethnographic approach to data collection yielded qualitative process data that explained why and how the various collaborations unfolded at Volvo's AD program. To better illustrate the process of ecosystem emergence, the entire study was mapped using Ann Langley's visual flowchart approach (Langley, 1999), including the various events, activities and decisions identified during the case study (see Fig. 3). Mapping the process data allows "presentation of large quantities of information in relatively little space, and they can be useful tools for the development and verification of theoretical ideas" (Langley, 1999, p. 700).

⁷ XMind is a mind mapping tool (<http://www.xmind.net>) providing different types of mapping charts to visualize information and manage complex information (Lee and Fink, 2013; Buran and Filyukov, 2015).

Table 4
Excerpt from data analysis, as example of coding.

1st order statements	2nd order categories	Aggregate dimension
You need to secure business [...] that means you need a lot of revenue strategy and making external collaboration	Desire to collaborate	ii
(On Zenuity) First thing, be quicker [...] find faster way to develop software [...]. So it's better to try to do it in a separate company. Second, cost of resources [...] we need to find a partner to do that	Establish leadership in technology development	i
We see that we need to work together with society ... need to find test beds ... and Drive Sweden is a good example to build up these projects	Collaborations outside the industry	i & ii
We need to be modular because someone like Firm A would not want to be involved with Firm B. So, we need to think about this as well	Modularity to facilitate collaborations	iii
HAD program is part of AD ART Starting today, AD ART and had unit program are more or less the same	Shift from unit program structure to Agile Release Train (ART)	i
On having multiple supplier: The solution we have is in the cloud [...] We can have multiple supplier [but] we don't need to change in the car but in the cloud	Accommodate multiple suppliers or partners	iii
We have something in flow (an information sharing platform) to work with Zenuity. Whether it works or not is another thing.	Need for coordination	i & iii
We need to understand ... and communicate with other interfaces.	Integration challenges	iii
If we are going to be part in this game, we need to double up or triple up our resources.	Resource needs	i
On Drive Sweden: you need a business in it ... you cannot always have test beds all the time, to make it happen, you need the business side of it ... to get the economy together	Business needs	ii

3.5. Detecting the emergence of an ecosystem through systematic combining

The case study was initiated with a pilot study, intended at understanding the case context. The data from the pilot study revealed complexities involved in developing AD technology. Developing the technology required resources and competence beyond the means of a single actor, and be carried out in multiple stages, in line with the complex product systems (CoPS) literature (Dedehayir et al., 2014; Gann and Salter, 2000). Initially, in phase A, literature on New Product Development (NPD), Complex Product Systems (CoPS) were used to analyze the data. In phase B, several collaborations were set up by Volvo. The data collection then centered on understanding the various alliances and its impact on Volvo's internal activities. The data consisted of both firm and system level activities, for which, we delved into literature on value networks and innovation ecosystems. This facilitated the study of both Volvo's internal activities and its collaboration with the network of actors that supported Volvo's AD technology development.

The firm level observations and interviews highlighted the complexity of the AD technology and the need for Volvo to establish collaborations with external actors. However, the system level analysis also revealed the complex relationships between Volvo and the other

actors in the AD program. The fact that Volvo and Veoneer (formerly Autoliv) are co-located in Sweden and that both firms have a legacy on safety related innovations in the automotive industry may suggest the application of a more region or sector-based innovation concept such as "innovation system". However, it should be noted that our study focused primarily on actors, activities, and the technology platform (i.e., the artifact). Although Volvo and Veoneer are based in Sweden, most of the other actors linked to the Volvo's AD platform development activities and providers of complementary technologies belong to multiple industries and geographies (e.g., Uber, Nvidia, Baidu, Luminar, and Google). Using the innovation ecosystem concept enabled us to address the co-evolution process where actors joined and left the network, and existing actors morphed their roles and routines over time. Further, we identified actors who are diametrically opposed to each other (in their own industries) but were willing participants in Volvo's AD program. This focus motivated the use of the concept of innovation ecosystem in this case study.

Value networks and innovation ecosystem theories helped us to categorize the data at both the firm and system levels. In phase C, the CoPS and NPD literatures were less helpful for capturing the complex process phenomenon. Instead, we used the value networks and innovation ecosystem literature as our frame of reference. Fig. 1 provides a detailed schema of the three phases and the systematic combining approach used as part of the analysis. Thus, the longitudinal case helped identify a nascent innovation ecosystem developing in Volvo's AD program. The AD program and the alliances between Volvo and other actors are described in more detail in section 4.1.

3.6. Research quality

In our longitudinal case study, data were collected from multiple sources to allow triangulation (Goffin et al., 2019; Golafshani, 2003). The results were also validated through informal discussions with Volvo personnel. It is somewhat difficult to generalize the findings from a single case study beyond the powerful example of the case studied (Siggelkow, 2007). However, a case study allows an in-depth understanding of a complex phenomenon (see Goffin et al., 2019), such as the emergence of a new ecosystem. Perks and Roberts (2013) suggest that a

longitudinal case design provides an understanding of the interrelationships among various activities and how they evolve over time. Due to the uniqueness and evolving character of the case setting, the study in this paper is not replicable but the findings should still be useful to inform future studies of ecosystems and also contribute to the growing academic knowledge in the field.

4. Empirical findings and analysis

4.1. The AD program setup

The AD program involved various collaborations, each with a distinct purpose and contribution towards the overall goal. The interviews and field observations showed that the AD program activities focused on three aspects:

- *Competences* - in the areas of sensor fusion, machine learning, and active safety.
- *Resources* - in the form of investments, knowledge, etc.
- *Commercialization* - appropriating value from AD vehicles.

During the fieldwork, people confirmed that automotive firms are being increasingly challenged by technology firms with critical competences in software development and artificial intelligence (AI). Employees at Volvo and Zenuity stated that in order to remain competitive it was necessary to acquire new resources and competences, especially in the area of software development. The collaborative initiatives in the AD program were motivated by resources or competence requirements. One employee told us that:

"It is about resources [...] if we are going to be part in the game, we need to double up, or triple up our resources."

Volvo's decision to develop AD software through a JV was largely driven by the complexity of the technology. AD software development involves collection and processing of data from a suite of sensors (such as radar, lidar, etc.) and requires competences in AI and machine learning. These competences were beyond the traditional automotive industry value chain. While alliances are useful to acquire new

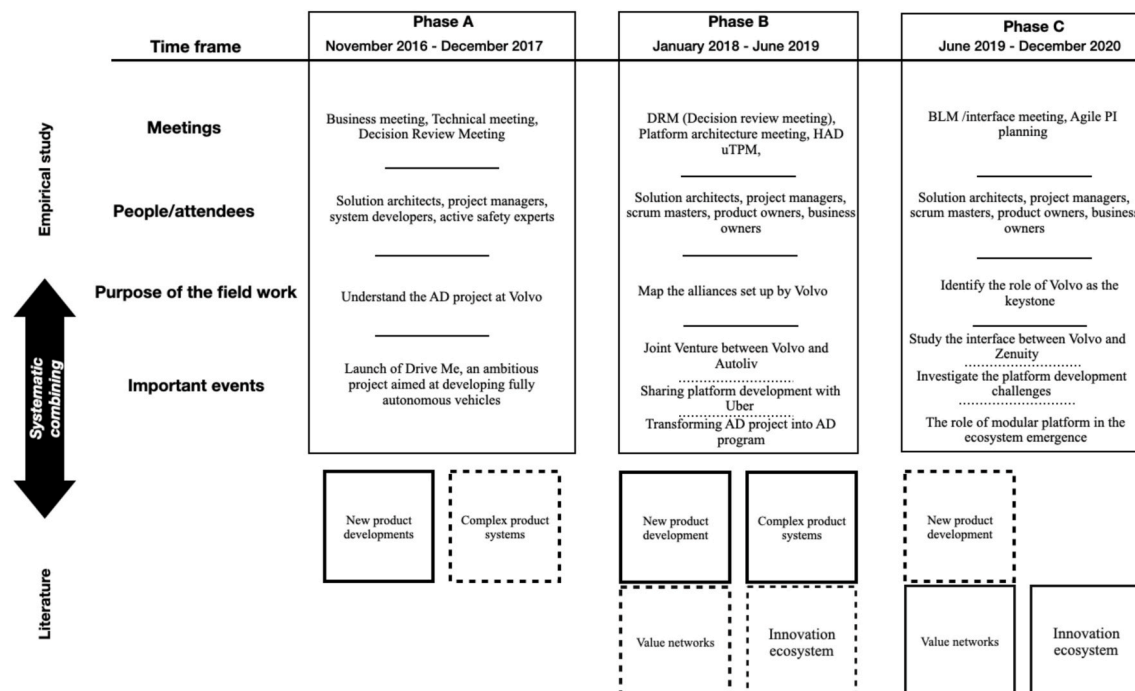


Fig. 1. An overview of the data collection and the systematic combining approach used.

competences and resources, they are seldom used to commercialize technology (Brem et al., 2016). On its own, a superior technology neither creates new standards nor yields economic benefits for the actor that developed the technology (Brem et al., 2016), and platforms seldom emerge without the contribution of complementary innovations (Brem et al., 2016; Gawer and Cusumano, 2014). Further, AD technology still lacks industry-wide standards, regulation, and transport infrastructure, which hampers the commercialization of AD vehicles.

In addition to finding ways to access the additional resources and competences required to build the AD technology, Volvo engaged with several government agencies, such as traffic and road transport authorities, emergency services, etc., to participate in policy making and discussions related to framing the regulations for autonomous vehicles. An employee involved in the business side of the autonomous cars program said that technology development, on its own, was not enough to commercialize autonomous vehicles. He underscored that initiatives such as Drive Sweden were needed to participate in discussions about autonomous mobility regulation. Further, collaborations with firms such as Nvidia, Uber and Baidu, enhanced Volvo's prospects of commercializing its autonomous cars.

The field observations also showed that most collaborations were interconnected. For instance, the Drive Me project provided an interface with government agencies, academia and other technology firms. The collaboration with Uber, enabled Volvo to share the development of the base car. Uber is using Volvo's base car to develop its own self-driving system and the collaboration enabled Volvo and Uber to jointly develop the base car with redundancy (Volvo, 2018c). A senior manager explained that the collaboration with Uber also gave Volvo access to commercialization opportunities in the ride sharing market. This is in line with literature on standardization, which highlights the importance of firms cooperating over the development of new innovations in the context of technology platforms (Brem et al., 2016). Over time, Volvo increased the number of collaborative initiatives (see Table 1). These collaborations, which extend beyond Volvo's traditional value chain, were seen by many employees as a sign of a changing innovation trajectory in the industry, as illustrated in a quote from a senior manager at Volvo:

"If you look at the car industry today, we do not own our value chain [...] what we see for the future, the value chain management will change. Locked together with AD but also with electrification and fleet."

4.2. The interdependence between Volvo and Zenuity

The inherent complexity of the AD technology makes inter-firm alliances essential. However, the decision to delegate the entire software development to Zenuity created an interdependence between the parent firm and the JV. Although Zenuity was part-owned by Volvo, the coordination of tasks between the two firms became problematic and employees at Volvo considered that this resulted in bottlenecks. For example, a manager said:

"It's hard now [...] it's a different company and sitting at different location [...] harder when you are away from each other than to just walk by and discuss [...] we are separated in different areas in Gothenburg [...] we (might) build our misunderstanding on the lack of communication."

Volvo relied on Zenuity to supply the software stack for the AD technology while Zenuity depended on Volvo to provide the development vehicle to collect the data, test its AD software and carry out other machine learning tasks. Many employees felt that this mutual dependence slowed the pace of innovation. However, some managers saw externalizing software development as advantageous since it increased

the rate of software development and allowed the software to be sold to other OEMs in the industry. Our observations revealed that there was concern (amongst employees at Volvo) about the poor flow of information between Volvo and Zenuity. In the weekly meetings, employees expressed their experiences, as the following extracts show:

"It is a different kind of project compared to anything we have done before [On the AD technology development]."

"We do not know what is going on [...] a lot going on at the top level [...] but what is happening with Zenuity?"

Further, it was observed during team meetings that Volvo employees expressed frustration that Zenuity's development plans were not always aligned with Volvo's development activities. The field observations and interviews highlighted an internal challenge that Zenuity had been set up as an independent firm with the purpose of developing AD software for multiple OEMs. This frustration affected other alliances related to the AD program. To ensure compatibility with Zenuity's AD software, important decisions related to the selection of suppliers, technologies, systems, etc. had to be coordinated with Zenuity. As a parent firm Volvo had decided that developing software for multiple OEMs would increase Zenuity's competitiveness and result in the best AD software solution in the industry. This was emphasized by both parents, in various press releases, as the prime motivation for establishing the JV, but this also created uncertainty at the interface:

"Zenuity is not a supplier but a partner ... but ... we ... sometimes don't know how to exactly work with them and how to handle them ... how should we treat them if they are not a supplier then we cannot define exactly what they should do"

JVs are often hierarchically controlled by the parent firms, but observations during team meetings confirmed that Zenuity operated as an independent firm. This information was triangulated with information from interviews held at Volvo and with a Zenuity executive. For example, when Volvo wanted to use a certain firm as its map supplier, it was challenged by Zenuity's preference for a different firm. Volvo had to adapt its platform development by using technologies and systems that would interface with Zenuity's software. In essence, each supplier (for Volvo's technology platform) needed to build in interoperability to allow interfacing of different systems. The following quote from a senior manager is illustrative:

"We need to be modular because someone like Firm A would not want to be involved with Firm B. So, we need to think about this as well."

Volvo and Zenuity also had different ways of working. Volvo's development activities were based on the traditional waterfall method, while Zenuity, like most software firms, used agile development methods. This was seen as a barrier to the coordination of activities. In early 2018, in order to align its operations to those of its partner firms, especially Zenuity, Volvo's AD program adopted agile working methods to facilitate cross-functionality and flexibility in the development process.

4.3. The modular AD technology platform

Establishing Zenuity in partnership with Veoneer to pool resources was in line with the literature on alliances (Adner and Kapoor, 2010b; Ahuja, 2000; Gawer and Cusumano, 2014; Hagedoorn, 2002; Lambe and Spekman, 1997; Rothaermel and Boeker, 2008; Teece, 1986). The decision to transfer Volvo's active safety units to Zenuity including intellectual property and personnel made Volvo, as a parent firm, dependent on Zenuity. Volvo relied on Zenuity for the supply of software for the AD platform while Zenuity's ambition was to supply AD software also to

other OEMs. However, the independent Zenuity relied on Volvo's hardware platform for its development work, and therefore, the technologies and systems used by Volvo for its hardware development needed to interface with Zenuity's software.

Not all firms collaborating with Volvo in the AD program were willing to allow programming interfaces with Zenuity software. Further, the actors included both automotive suppliers and technology firms providing critical components and complementary solutions for the AD technology platform (see Table 1). Beyond firm-level alliances, chiefly aimed at developing platform sub-systems or technology interfaces, it should be noted that Volvo forged alliances beyond the core technology development, primarily to consolidate complementary innovations for its AD technology. To elucidate this, we have highlighted Volvo's participation in Drive Sweden, a public-private partnership, and co-founding MobilityXlabs with other actors such as CEVT, Ericsson and Lindholmen Science Park.

This complex network of alliances and partnerships required Volvo to carefully orchestrate the activities. For instance, firms with competences in areas such as cloud computing, semi-conductor technologies and sensor systems were unwilling to share data or allow Zenuity to interface with their systems. Some of the leading technology firms that intended to develop AD software in-house considered Zenuity a potential competitor and therefore wanted to limit the interfacing with Zenuity software. These complexities demanded careful management of Volvo's alliances to facilitate Zenuity's software development work. This is reminiscent of the challenges faced by Intel and Microsoft in the early PC platform developments (Cusumano and Gawer, 2002). Thus, the AD program faced significant challenges; the hardware (developed by Volvo) and the software (developed by Zenuity) needed to be integrated on the vehicle platform (see Fig. 1). These types of system integration problems are common in the development of complex systems (Madni and Sievers, 2014).

The interdependence between the parent firm Volvo and the JV Zenuity resembles a symbiotic relationship as described by (Davis and Eisenhardt, 2011), who highlighted that the main problem in a symbiotic relationship is the unselfish alignment of R&D efforts towards a common goal. Extant research on JVs (Anderson, 1990; Davis and Eisenhardt, 2011; Garcia-Pont and Nohria, 2002; Hill and Hellriegel, 1994; Kamien et al., 1992; Kogut, 1988; Kumar and Seth, 1998; Williamson and De Meyer, 2012) does not refer to relationships between the parent firm and a JV in which the parent firm's core product depends on the success of the JV. This symbiotic relationship combined with the JV firm's decision to be hardware agnostic implicitly pushed Volvo to develop a modular platform albeit with technologies and systems that enabled interfacing with Zenuity's software architecture. This was important for Zenuity to be competitive and provide state of the art AD software solutions. This development is analogous to Google allowing third-party OEMs to use the Android software platform, in addition to their own Pixel hardware business. The success of Android can be attributed to its large community of developers, manufacturers and users who can interface and integrate their products and services with the Android software platform (see Remneland-Wikham et al., 2011).

The case study shows that Volvo originally established the JV with Veoneer to acquire the resources and competences needed to develop the technology platform. However, the resulting symbiotic relationship between the JV (Zenuity) and the parent (Volvo), resulted in the development of a modular platform that could be used by other actors to develop complementarities, as illustrated in Fig. 2.

In 2021, Volvo also announced an Innovation Portal that allows developers to access the "dashboard and status data" from their vehicles through an "Extended Vehicle API" (Innovation Portal, n.d.). The launch of APIs and open datasets to the research and development community further resembles what happened in the PC and smartphone ecosystems. In those ecosystems, innovation flourished due to the platform owners' willingness to allow other actors to co-create and develop complementarities. Thus, we find compelling evidence highlighting the modularization of Volvo's AD platform and thereby the emergence of an innovation ecosystem where they took the role as the keystone firm. Volvo's engagement in a broad range of alliances, beyond the core AD technology platform, are persuasive examples of interdependence between a multitude of actors from multiple industries and public institutions, a facet that is uncharacteristic for automotive OEMs. Importantly, Volvo did not exert hierarchical control in these collaborations, even the JV firm (Zenuity) was given the freedom to operate as an independent firm and seek its own business opportunities for its AD software solutions.

4.4. The emerging AD innovation ecosystem

In order to illustrate the process of ecosystem emergence, a process map (Langley, 1999) was developed. The mapping in Fig. 3 presents the event chronology in multiple ways: The round-cornered rectangles represent events, decisions are indicated as sharp-cornered rectangles and the ovals represent activities taking place outside Volvo. The location of each rectangle or oval in one of the six horizontal band indicates the location of the event. Some events cross several bands as they represent the interlinking of the event in multiple levels. The triangles, in the lower-most band, represents three trigger points that influenced the evolutionary trajectory of our case.

- Trigger 1: Resource and competence needs of the AD project
- Trigger 2: Interdependence between Volvo and Zenuity.
- Trigger 3: Need to orchestrate and maintain the balance of the network

The need for resources and competence was the first trigger that rationalized Volvo's decision to form the JV. Volvo managers expressed that the alliances were key to staying competitive, motivating the unusually high number of collaborations. Following the establishment of the JV and other alliances, Volvo was faced with a second trigger: the need to synchronize its activities with the JV. This interdependence between Volvo and Zenuity was the second trigger, that led to Volvo's decision to shift to an agile way of working (see section 4.2). The complexity of the technology led to several alliances, organized around

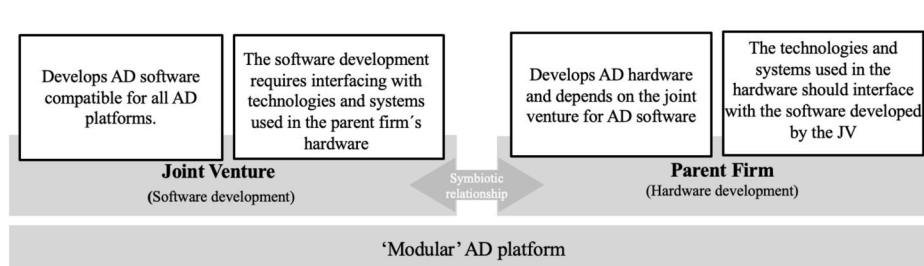


Fig. 2. The symbiotic relationship between the parent firm and the joint venture instigated a modular platform.

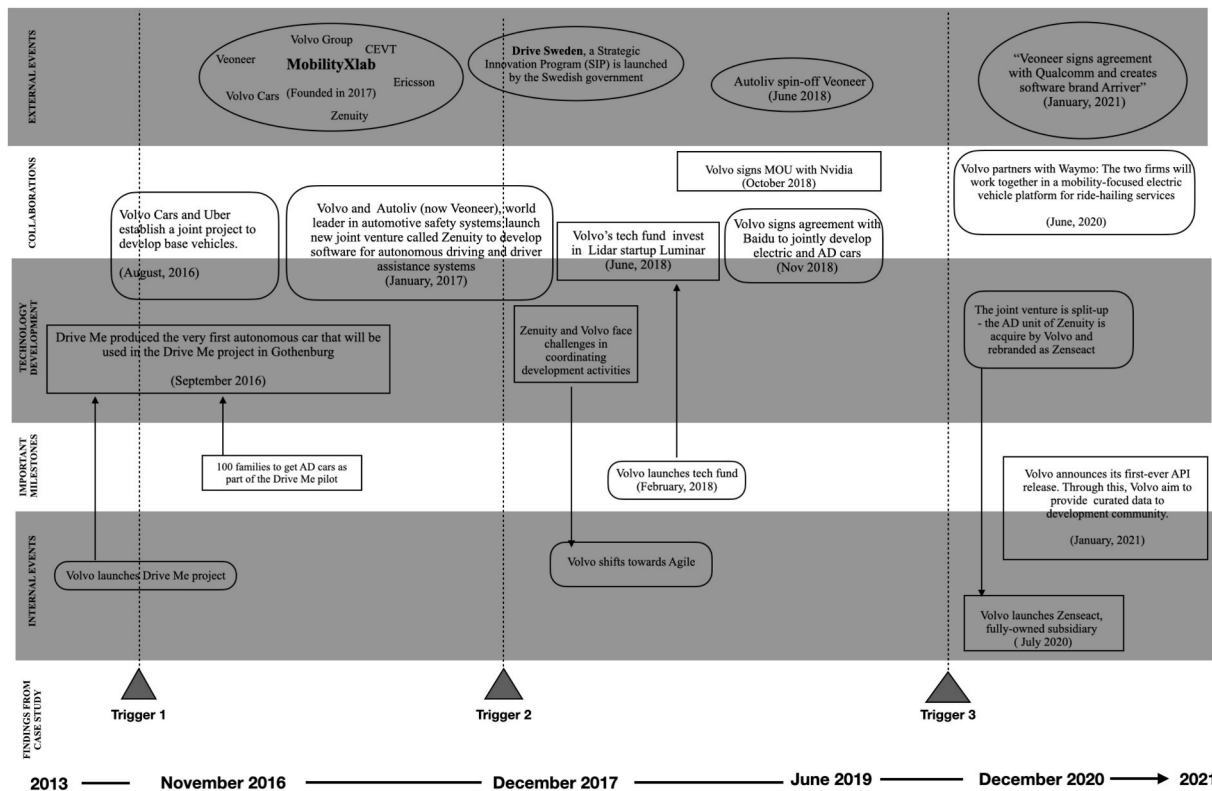


Fig. 3. Timeline showing the emergence of Volvo's innovation ecosystem. (Source: Autoliv, 2021; Drive Sweden, 2020; Nvidia n.d., 2018a; Volvo, 2014, 2016a, 2016b, 2016c, 2017, 2018, 2019a, 2019b, 2020a, 2020b).

Volvo AD platform, in line with literature on innovation ecosystem (Dattée et al., 2018; Gawer et al., 2008, 2014; McIntyre and Srinivasan, 2017). The need to orchestrate and maintain the balance of the network was the third trigger for Volvo, and represents the cause for the emergence of Volvo's AD ecosystems. Interestingly, many of the actors were direct competitors, and some competed with Volvo in other business segments. Volvo's decision to allow Zenuity to commercialize its software to other platforms made Zenuity a direct competitor to many of the technology firms. The recent partnership between Volvo and Google's Waymo (potential competitor to Zenuity) highlights the cooperative and competitive characteristics of Volvo's emerging AD ecosystem (Volvo Cars, 2020b). Volvo, as the platform owner needed to coordinate the activities and ensure that all actors agreed on developing interfaces with the other products or technologies. This also meant that Volvo had to limit its strategic partnership to firms who would interface with Zenuity's software and coordinate with Zenuity in the development process.

The process mapping (see Fig. 3) illustrates the alliances emerging over time, with actors entering and leaving the network, highlighting the evolutionary characteristics of the network. For instance, the JV alliance with Veoneer was retracted in 2020. Additionally, Uber sold its autonomous car unit to start-up Aurora Technologies. Recently, Volvo released a dashboard API to facilitate the development of services by third-party developers. Several new alliances were continuously set up over time (see Table 1 and Fig. 3), and the roles and activities of the alliance partners were being orchestrated by Volvo. All these highlight that Volvo's platform for AD technology is emerging into an innovation ecosystem. Extant literature recognizes that the innovation ecosystem is characterized by the evolution of actors, activities, and the artifact,⁸ along with institutions and complementary relations (see Granstrand

and Holgersson, 2020a). Thus, the evolving network of actors, at both bilateral and multilateral levels, in developing the AD technology platform characterizes an emerging innovation ecosystem.

5. Discussion

5.1. The emergence of an innovation ecosystem

The case study revealed several triggers that instigated the emergence of the innovation ecosystem. The first one was the need for resources and competence that motivated the firm to engage in several alliances. Amongst the several alliances, the JV set up by the case firm was particularly interesting. Our study showed that the incumbent firm formed a JV to develop software for the new technology. This is in line with DTC literature which states that incumbent firms engage in various forms of alliances during a period of DTC since they do not possess the resources and competences required (Lambe and Spekman, 1997).

Moreover, the study identified the delicate interdependence between the JV and one of its parent firms, with both firms relying on each other. This distinct set up had a dual impact on the technology development program. The JV supplied resources and competences, which allowed the parent firm to develop the new technology (Gong et al., 2007; Hagedoorn, 2002; Kumar and Seth, 1998), but it also instigated the development of a modular technology platform which is important for the development of complementarities (Cusumano and Gawer, 2002; Gawer and Cusumano, 2014; Jacobides et al., 2018). The modular technology platform was thus the result of the parent firm's dependence on the JV for its technology development, and the JV's ambition to be a software supplier to other firms. The resulting modularity subsequently

⁸ In our study, Volvo's technology platform, that transitioned from being a firm-specific to modular (or external) platform, is considered the artifact that allowed multiple actors to co-create value.

contributed to the emergence of an innovation ecosystem.⁹ The resulting modularity then contributed to the emergence of an innovation ecosystem with Volvo at the core taking the position as the keystone firm.

The ecosystem literature acknowledges the importance of a keystone firm to coordinate activities and ensure the overall health of the ecosystem (Iansiti and Levien, 2004; Jacobides et al., 2018). Promoting the JV as the dedicated AD software supplier was vital for the AD ecosystem's sustained competitive advantage which is in line with previous work on platforms and ecosystems. This action also highlights the importance of certain actors for the overall ecosystem, and the need (for a keystone firm) to promote these key actors (Rietveld et al., 2018; Rietveld et al., 2019).

The use of product platforms in the automotive industry has been extensively studied. For instance, Philips et al. (1999) studied the increasing use of product platforms, instead of stand-alone products. Jacobides et al. (2016) explored the use of platforms in the automotive industry in the late 1990s and Jovanovic et al., 2021 expanded the investigation to the broader manufacturing industry. Despite the widespread use of product platforms in the automotive industry, ecosystems for co-creating value, especially around digital technologies and services have remained at the fringes of new product development activities. In recent years, however, the advent of new technologies such as BEV and AD, and threat from new entrants such as Tesla and Waymo has drawn attention to the topic. Automotive firms are increasingly extending their collaborations beyond their traditional value chain and embracing value creation in ecosystems.

Innovation ecosystems surrounding a platform with a central actor (usually the platform owner) are ubiquitous in other industries such as personal computers, gaming consoles and smartphones. However, the knowledge gained from technological changes in other industries provide limited help in the management of future technology transitions (Eggers and Park, 2018). The case of AD technology is both similar and different to previous technological changes. For instance, regulation for AD technology is very complex when compared to most other technologies, except for perhaps aerospace or life sciences. Zenuity's ambition to be hardware agnostic, i.e., develop software compatible to other OEM's hardware, is comparable to Amazon's decision to set up Amazon Web Services (AWS) as an independent cloud service provider. Amazon's decision to allow AWS to seek external customers, resulted in the creation of an industry leading cloud platform alongside its e-commerce business.

It can be argued that a network of actors collaborating around a focal value proposition, where participants freely enter and leave, may indicate an open innovation network. However, there is a distinction between an innovation ecosystem and open innovation network (c.f. Shiplov and Gawer, 2020). In an innovation ecosystem, the entry and exit of actors and changes in activities is 'semipermeable', and a keystone decides what actors can enter the network. Further, the selective promotion of actors and designing the roles and activities highlights Volvo's position as the keystone in the emerging innovation ecosystem. We therefore conclude that Volvo's ability to orchestrate the network of actors, is indicative of an emerging innovation ecosystem.

5.2. The role of modularity in innovation ecosystem emergence

Research on product platforms primarily focus on reducing production costs and reaching economies of scale (Autio et al., 2016; Yoo et al., 2010; Argyres and Bigelow, 2010). In the automotive industry, modularization of product platforms is primarily motivated by the desire to offer a wide range of products, with different configurations and pricing,

⁹ The AD innovation ecosystem analyzed in this paper was built around Volvo's AD platform and should not be confused with other developing AD ecosystems (cf. Adner 2006, p. 8–9).

by sharing the same components and systems (Jacobides et al., 2016). Also, modularization of a physical product tends to be closed; it is defined by standardized interfaces and a one-to-one mapping between the different modules (Autio et al., 2016; Yoo et al., 2010). We argue that modularization of a technology platform, with digital characteristics, is much more permeable and facilitates integration of sub-systems beyond the boundaries of a single actor (Autio et al., 2016, p.7). Google Maps is as an example for modularity in a digital platform where Google Maps can be bundled in multiple ways, even beyond ways Google could foresee (see Yoo et al., 2010).

Volvo's connected vehicle API, released as a part of its Innovation Portal, allowing third-party applications to access vehicle data is indicative of a modular architecture that is open and more permeable compared to yesteryear modular products developed in the automotive industry. Further, Uber using Volvo's hardware platform but developing its own AD software (while Volvo relying on Zenuity's AD software) characterizes a layered modular architecture (see Autio et al., 2016). This can be better understood by looking at the ecosystem for hand-held devices. Apple's iPad and Amazon's Kindle are two competing hardware platforms that host a digital layer to distribute e-books, namely: iBook and Kindle stores. However, Amazon also offers its application (digital layer) for the iPad. Additionally, Apple's hardware (iPhone and iPad) is also an important platform for Google's digital layer (Google search, Maps, YouTube etc.). Needless to mention that Apple also offers its own Map service as an alternative to Google Maps (see Yoo et al., 2010, p. 730).

Developing modular technologies and systems has clear benefits beyond outsourcing and vertical disintegration described in literature on product platform. To this point, Baldwin and Clark (1997, p.6) adds, "If modularity brings so many advantages, why aren't all products (and processes) fully modular? It turns out that modular systems are much more difficult to design than comparable interconnected systems." This perhaps explains why not all modular platforms lead to the development of an ecosystem. Furthermore, Adner (2006, p. 6) states, "If you lead an ecosystem, you'll have a chance to tailor its development to your own [...] However, attempting to take the leadership role carries its own risks: It often requires massive resource investments over long periods of time before you find out whether the opportunity is real and whether you have managed to secure the orchestrator role strengths."

Considering this, a firm that endeavors to modularize its platform to reduce cost and manufacturing complexity will hesitate to invest resources in orchestrating the ecosystem. Thus, the modularization that leads to the emergence of an ecosystem is different from the one used for outsourcing or reaching economies of scale. From our case study, we found that the development of the modular platform was an unintended consequence of Volvo's need to source alliances during a period of DTC. The alliance partners worked together with Volvo but also competed with each other, confirming the cooperative and competitive traits that are unique to an innovation ecosystem (Hannah and Eisenhardt, 2018). In this context, Volvo's role was not confined to the traditional OEM's role of outsourcing manufacturing and reducing cost. Instead, in developing the AD technology platform, Volvo had to maintain balance between cooperation and competition, especially between Zenuity and other actors. Thus, we argue that there is subtle, but important distinction between "modularization for outsourcing" and "modularization for developing a platform" during a DTC.

5.3. Summary of key contributions

Previous research on ecosystem often assumes that the platform on which it is built already exists (cf. Gawer et al., 2014, p. 429). There is little discussion of whether or how internal (i.e., firm specific) platforms can be altered into external (i.e., modular) platforms. Seminal works on ecosystem emergence have been predominantly conceptual and recently several scholars have echoed the need for more empirical studies that shed light on the emergence of an ecosystem (Dedeheyir et al., 2018;

Jacobides et al., 2018). This scarcity is somewhat due to the conceptualization of ecosystem being ‘after the fact’ and the long-drawn nature of ecosystem emergence.

Scholars such as Jacobides, Cennamo and Gawer argue that modularity, removal of transaction costs and the presence of non-generic complementarities lead to ecosystem-based transactions (see Jacobides et al., 2018, p. 2270). While modular platforms are considered necessary for the emergence of an ecosystem (cf. Jacobides et al., 2018), few empirical studies discuss the evolution of internal (or firm-specific) platforms into modular (or external) platforms. This longitudinal case study adopted an innovation ecosystem perspective in the context of a DTC and makes the following contributions.

First, the study highlights how the lack of resources and competences during a DTC compelled the case firm to collaborate and establish alliances with actors from multiple industries. Due to the complexity of the new technology, there was an urgency to seek alliances which consequently pushed the case firm to open up its innovation process and co-create value in a broader network, beyond its own industry and even with potential competitors.

Second, we find that the nature of the alliances, established by the case firm, had important implications on the modularization of the platform. In this respect, it is identified that the JV alliance (established by the case firm) implicitly nudged the development of a technology platform with a modular architecture. In the case firm’s perspective, the JV was an important channel to commercialize the software to other actors, generate new revenue and establish leadership in the software business. However, only a modular platform would allow seamless interfacing between the JV firm’s hardware agnostic software and other partners’ technologies and systems.

Finally, the study depicts the co-evolutionary and interdependent nature of collaboration amongst the different actors, with new alliances formed over time, sometimes replacing, or altering the structure of previous alliances. This evolutionary and interdependent nature of value creation resemble what scholars attribute as an innovation ecosystem. Innovation ecosystems usually require a keystone firm (or ecosystem leader) who can design roles and activities for all actors in the network. Accordingly, the study explicates the evolution of both the technology platform and its impact on the emergence of an innovation ecosystem. And highlights the transformation of the case firm into a keystone firm that orchestrated the emergence of the ecosystem. Thus, this paper contributes to literature on innovation ecosystems by exploring the alliances established by an incumbent firm during a DTC and the subsequent emergence of an innovation ecosystem.

6. Conclusion

This paper contributes to the understanding of ecosystem emergence by identifying triggers that can lead an incumbent firm to develop a modular platform and eventually take on the role of keystone firm in the innovation ecosystem. The longitudinal case study of an incumbent’s efforts to innovate in collaboration with a network of actors illustrates the process of innovation ecosystem emergence. It provides new insights on how modular technology platforms come into being and then lead to the emergence of an innovation ecosystem. In the automotive industry, there are vast implications for incumbent firms as new technologies such as AD and BEVs require inter-firm collaborations beyond traditional value chains. This paper puts forward some insights for firms developing new technology platforms and managers involved with ecosystem governance. Not only is it critical to develop the technology per se, but it is also important to also reflect on how the ecosystem develops and how a firm may choose to actively orchestrate its development through its platform strategies.

6.1. Limitations and recommendations for future directions

In our study, we focused on the development of a technology

platform, by an incumbent firm, during a period of DTC. This paper provides insights into the emergence of an innovation ecosystem from one case study and does not provide generalizable results. There is a need to carry out cross-industry and cross-technology studies to further expand the understanding of how ecosystems emerge.

Also, to further our understanding of ecosystem emergence, more research is needed on its evolution over time. As suggested by Dedehayir et al. (2018), the role assumed by the actors may not stay consistent over the various phases of the ecosystem. Thus, further research on the evolution of an innovation ecosystem is warranted. This would provide useful insights for actors to make strategic choices and diligently invest resources in an ecosystem.

As we have primarily focused on firm-level activities where the value co-creation transpires, our findings are limited to the concept of an innovation ecosystem. Literature suggests that actors such as governments, non-profits, and industry consortiums also play an important role in orchestrating the development of new ecosystems. Using the concept of entrepreneurial ecosystem or knowledge ecosystem may provide additional lenses to explore the role of institutions or public sector agencies in supporting an ecosystem.

Additionally, our study does not address if or whether a firm should opt for developing modular technology platforms. Ample historical evidence (such as the failure of Nokia’s Symbian OS, the early Macintosh PC) suggest that many firms fail to embed modularity while developing new technologies. Rather, we explore the factors that resulted in the modularization of a firm’s internal platform and how it serendipitously led to the emergence of an innovation ecosystem.

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