Hardware-layer Dynamics in Mobile Platform Ecosystems: The Case of Apple's iPhone Aftermarket

Short Paper

Roman Zeiss
University of Cologne
Cologne, Germany
zeiss@wiso.uni-koeln.de

Jan Recker
University of Cologne
Cologne, Germany
jan.recker@wiso.uni-koeln.de

Mario Müller
University of Cologne
Cologne, Germany
mario.mueller@wiso.uni-koeln.de

Abstract

The IS literature on mobile platform ecosystems has so far discussed platform dynamics from a software perspective. But recent regulatory and competitive developments have impacted the hardware layer of mobile platform ecosystems: an increasing number of third-party repair providers have started to modify physical components outside the platform owners' direct sphere of influence while platform owners attempt to maintain control over the ecosystem. We report on our ongoing case research to develop an account of what we call hardware-layer dynamics in mobile platform ecosystems. Based on an inductive case study of third-party repair complementors operating in Apple's iPhone aftermarket, we explain how these dynamics are shaped through interactions between complementors and platform owners over time. We expect our contributions to extend our field's attention to the entire modular architecture of digital platforms—and the ecosystem they support.

Keywords: Mobile platform, ecosystems, governance, case study, digital technology, hardware

Introduction

Mobile digital technologies, such as Apple's iPhone or Google's Android phones are at the core of important mobile platform ecosystems, i.e., combinations of mobile hardware and software that provides standards, interfaces, and rules that enable and allow providers of complements to add value and interact with each other and/or users (Teece 2018). Recent regulatory and competitive developments have had an important impact on these mobile platform ecosystems: Jurisdictions, such as the US copyright law exemption to electronics repairs (U.S. Copyright Office 2018), are pushing platform owners to relax legal measures that in the past helped to protect the hardware layer of their platform, i.e., the technical core centered around a mobile operating system, its software complements, and involved actors (Basole and Karla 2011; Reuver et al. 2018). Simultaneously, a growing number of third-party actors specialized on physical hardware modifications have emerged and provide end user repair services outside the platform owners' direct sphere of influence (Riisgaard et al. 2016). Together, these developments bring 'hardware'—the material bearers of transport or machinery in the devices that compose the physical mobile platform core—into focus.

IS research on mobile platform ecosystems has so far been discussing platform dynamics largely from a software perspective (Eaton et al. 2015; Ghazawneh and Henfridsson 2013; Qiu et al. 2017; Sørensen et al. 2015; Ye and Kankanhalli 2018), with some exceptions (Michell and Gupta 1997; Wolf 1994). The physical, material components of mobile platform ecosystems have so far been treated almost entirely as stable 'containers' or 'vessels.' Given the developments in current mobile platform ecosystems, this unidimensional view carries two assumptions:

1. Physical hardware-layer components form a stable core of the mobile platform ecosystem and remain untouched by third-party actors during the evolution of the ecosystem.
2. Mobile platform ecosystem success is sustained by complementary software assets developed by third-party actors, which are governed by software tools and regulations designed by the platform owner.

Our ongoing research sets out to challenge both assumptions: Through an inductive case study of independent consumer electronics spare parts and repair service providers operating in Apple's iPhone mobile platform ecosystem we observe how physical hardware components of the mobile platform devices change over time through actions induced by third-party actors. We also observe how proprietary platform owners actively engage in governance acts attempting to control the physical hardware layer through different instruments and mechanisms designed to "fight off" such third-party actions.

In writing this research-in-progress paper, we report on our ongoing effort to develop an account of what we call **hardware-layer dynamics** in mobile platform ecosystems by explaining how these dynamics are shaped through the interactions between platform owners and third-party complementors over time. The research question guiding our work is: *How do platform owners and third-party complementors shape hardware-layer dynamics in mobile platform ecosystems?*

We consider our expected contributions relevant for three reasons: First, digital platforms have technological interdependencies between components on different layers (Yoo et al. 2010) but these interdependencies have been largely neglected so far. We develop new conceptual tools to "widen [the] scope of digital platform research" (Reuver et al. 2018, p. 129). In doing so, we extend our field's attention from the software layer to the entire modular architecture of digital platforms and the ecosystem surrounding them by explicitly bringing the hardware layer of their architecture into focus.

Second, this extended focus raises new questions about mobile platform ecosystem governance (Eaton et al. 2015; Ghazawneh and Henfridsson 2013). The regulatory and competitive developments in the mobile platform markets have already begun to expand the range of governance requirements beyond the software layer: platform owners must strategically position themselves towards third-party induced changes on the hardware layer. Our work offers a first account of the governance acts that mobile platform owners perform to protect themselves against third-party hardware changes. Thus, our work offers a new conceptual basis for future research on the "strategic interplay between platform owners and ecosystem actors over time" (Constantinides et al. 2018, p. 390).

Third, we take a so-far overlooked complementor perspective and context (McIntyre and Srinivasan 2017), that of independent hardware repair service providers. Complementors differ from platform owners in terms of motivation and abilities, and do not always align with the platform owner's strategic goals and values (Huber et al. 2017). The hardware context is also in so far unique that hardware complementors cannot be as strictly controlled as software complementors, for the types and processes of value co-creation and capture differ remarkably. How mobile platform owners deal with these unique conditions is part of our expected research contribution.

Background

Technological advances have fueled an increasing infusion of digital capabilities into products stimulating new functionalities, products, and use cases (Yoo et al. 2010), allowing companies to use digital products as the core of platform ecosystems. For example, Apple created a well-known ecosystem around its iPhone and the App Store. These digital platforms have two important characteristics, (1) their technological architecture and (2) the social processes constituting their governance (Saadatmand et al. 2019).

From the architectural perspective, mobile platforms are enabled by an underlying modular architecture dividing the platform into a set of stable components with low variety (i.e., the core) and a set of peripheral components with high variety (i.e., complements), which are connected via standardized interfaces (Baldwin and Woodard 2009). This architecture allows third-party actors to provide software (e.g., apps) and hardware complements (e.g., batteries) to the platform core, thereby increasing the value of the platform for its users (Boudreau 2010). The platform core, its complements, and the actors providing and modifying them (i.e., platform owner, third-party software and hardware providers, and users) constitute what we define as *mobile platform ecosystem* (Basole and Karla 2011; Qiu et al. 2017).

Research on the core and peripheral components of digital platform architectures are skewed in that most literature has focused on software elements, neglecting hardware; exceptions can be found in the engineering-oriented literature on embedded systems (Michell and Gupta 1997; Wolf 1994) and hardware product design (Cabigiosu et al. 2013). While this literature provides relevant knowledge on the modularity and layered interrelatedness of technological systems, it does not thoroughly cover the socio-technical and dynamic evolution of ecosystems around platforms that couple hardware and software layers.

The second key characteristic of mobile platform ecosystems concerns the governance, i.e., the question "who makes what decisions about a platform" (Tiwana et al. 2010, p. 679). This aspect gained importance when platform owners adopted a strategy to attract heterogenous third-party actors to design and produce novel complements to the platform's ecosystem (Boudreau 2012). Opening the platform to third-party complementors, the platform owner must carefully govern the platform's ecosystem balancing the equilibrium of stability and innovation-driven evolvability (Tiwana et al. 2010; Wareham et al. 2014).

Like research on the architectural characteristics, governance mechanisms have predominantly been discussed within the scope of software platforms, investigating the arm's length relationship between the platform owner and third-party software developers (Reuver et al. 2018). For example, platform owners provide technological (e.g., SDKs, APIs) and social resources (e.g., documentations, guidelines)—overall conceptualized as *boundary resources* by Ghazawneh and Henfridsson (2013)—to third-party developers enabling and controlling the development of software complements (Eaton et al. 2015).

Our key departure lies in the observation that platform owners such as Apple also exercise governance on the hardware layer of mobile platforms, for instance via the design of technological interfaces between hardware and software layer. Yet, the literature has not yet accounted for this type of governance on the hardware layer, nor examined how the governance acts on the software and hardware layer might interact. Instead, the hardware layer is tacitly assumed to be a 'stable core', which—under the centralized control of the platform owner—remains untouched by third parties. We report on our ongoing empirical study of a case setting where this assumption is being challenged.

Method

Design

We chose a holistic multiple-case design (Yin 2018), focusing on the operations of several third-party actors in the hardware repair aftermarket of Apple's mobile platform ecosystem. We chose case research because even though we have a proper understanding of software-layer dynamics of mobile platforms (Eaton et al. 2015; Ghazawneh and Henfridsson 2013), hardware-layer dynamics remain novel and complex phenomena whose boundaries and contexts are not immediately apparent (Yin 2018).

Our case study research is primarily inductive. However, while we ground our theorizing in empirical evidence collected from primary and secondary data sources (Eisenhardt 1989), our theoretical departure is not entirely from scratch. Instead, our research is sensitized by the concepts of *mobile platform ecosystems*, *platform dynamics*, and *platform governance* (see 'Data Analysis' for more details).

Case Setting

Our case study is set in the repair aftermarket of Apple's iPhone devices, the physical core of the iOS mobile platform ecosystem. We selected this setting for three reasons: First, Apple's mobile platform ecosystem is highly governed and uncontrolled dynamics on the hardware layer (i.e., iPhone device) are by design not intended (Boudreau 2010). Thus, it provides an *extreme* case setting to observe third-party induced hardware-layer dynamics. Second, we want our theoretical contributions to extend existing knowledge on software-layer dynamics (Eaton et al. 2015; Ghazawneh and Henfridsson 2013). Therefore, we chose a case setting that is part of the same mobile platform ecosystem. Third, Apple's mobile platform ecosystem offers a wide and rich range of data sources allowing for insightful in-depth analysis (Eaton et al. 2015).

Since the introduction of the iPhone in 2007, three types of aftermarket services have been established as part of the mobile platform ecosystem: Apple-proprietary, Apple-authorized, and unauthorized services. In addition to Apple-organized repair services, third-party spare parts and repair service providers have organized an unauthorized aftermarket support to end users directly. Third-party spare parts providers specialize on certain components, such as LCD screens, and distribute them via online marketplaces (e.g., *Alibaba*) or specialized importers to third-party repair service providers or end users directly.

Data Collection

We started collecting empirical data from primary and secondary sources in late 2018. Our goal was to establish a rich picture of the history and specificities of the repair aftermarket in Apple's mobile platform ecosystem. Our sampling strategy focused on organizations that operate as third-party spare parts or repair service providers in Apple's iPhone repair aftermarket. We defined two sampling criteria: (1) the organization's central business model operates at the hardware layer of Apple's iPhone mobile platform ecosystem and (2) the organization is still operative. To date, we have selected three case organizations. Table 1 provides details and summarizes our primary data collection completed to date (interviews and observations).

Table 1. Sample Demographics and Summary of Data Sources at the Time of Writing

Organization	*Parts&Repair-1* A German emergent venture that publishes self-recorded repair manuals in form of how-to-videos, matches end users with a deficient device to repair professionals, and resells non-branded spare parts from China to repair professionals and end users.	*Parts&Repair-2* A Dutch e-commerce platform providing high-quality spare parts for a variety of smartphone models of different OEMs at competitive market prices.	*Parts&Repair-3* A US repair platform specializing in curating community-created repair manuals, creating new repair knowledge by disassembling recently released smartphone models, and reselling imported unbranded spare parts.
Year founded	2014	2003	2003
Primary data sources	*Interviews:* • CEO (2x) • CTO • Project Manager Sales • Head of Online Marketing • Head of Operations • Head of Purchase *Observations:* • 3 onsite visits • 1 workshop	*Interviews:* • Head of Marketing & Business Development • Product Category Manager • Repair Professional *Observations:* • 2 onsite visits	• none at the time of writing
Secondary data sources	• Aggregator blog (Techmeme) and tech blogs (Vice Motherboard, MacRumors, Wired) • YouTube videos from online repair community (REWA Technology, JC Programmer) • Press releases (Apple Inc., The Repair Association, Federal Trade Commission) • Public policies (Apple Inc., US Copyright Office)		

We also collected secondary data from tech bloggers and vloggers (Davidson and Vaast 2009). We identified more than 190 relevant blog entries from the blog aggregator *Techmeme* (Vaast et al. 2013) by querying their curated database with the search string '("Apple" OR "iphone") AND "repair".' Snowballing references and blog authors, we further collated more than 25 vlog entries from YouTube. Where possible, we drilled down to the origin of the blog and vlog entries to verify their credibility and evaluated their temporal occurrence. The material includes press releases and public policies announced by the ecosystem's actors, legal documents published by the US Federal Trade Commission, and leaked files.

Data Analysis

Three different perspectives on platforms (Reuver et al. 2018; Sørensen et al. 2015) presently inform our coding process: *Mobile platform ecosystems* research (Basole and Karla 2011; Jacobides et al. 2018; Qiu et al. 2017) provides us with concepts to identify and relate actors involved in Apple's iPhone repair aftermarket; research on *platform dynamics* (Foerderer et al. 2019; Tiwana et al. 2010) offers us a set of concepts to describe the platform's structural development over time; and research on *platform governance* (Eaton et al. 2015; Ghazawneh and Henfridsson 2013; Wareham et al. 2014) provide concepts to explain how platform owners balance the platform-specific equilibrium of stability and evolvability.

We embedded these seed concepts into the typical process of open, axial, and selective coding. Because both data collection and analysis remain ongoing, we omit most details here. So far, we have been performing our data analysis in two iterative steps: First, we analyze primary data prior to examining secondary data, to minimize bias. Second, we probe the secondary data to corroborate the interview statements, performing follow-up interviews in case of noted contradictions, inconsistencies, or incomplete information.

Preliminary Findings

To understand how *hardware-layer dynamics* are shaped through the interactions between platform owner and third-party repair actors, we took two steps.

First, from the data we inductively developed **theoretical concepts** to describe hardware-layer (1) changes, (2) governance acts, and (3) governance responses in mobile platform ecosystems. Table 2 summarizes and illustrates the main concepts of this conceptualization.

Table 2. Key Concepts of Hardware-layer Changes, Governance Acts, and Governance Responses

Concept	Definition	Empirical Illustration
***(1) Hardware-layer changes**: Repair changes to physical components of mobile devices that are enabled or performed by repair actors to recover the components' original technological functionality.*		
Physical component	A physical object in a mobile device, which bears technological functionality.	A camera sensor component provides visual sensing functionality to the motherboard.
Repair actor	A social actor of varying relationship to the platform owner that enables (e.g., spare parts provider) or performs (e.g., repair service provider) repair changes on physical components of a mobile device.	• Proprietary: Apple Store • Authorized: Apple Authorized Service Provider (e.g., *Best Buy*) • Unauthorized: Independent repair shop or spare parts provider (e.g., *iFixit*)
Repair change	An act of modification to a physical component in the architecture of a mobile phone: (a) Restoring: returning a broken physical component to its original state (b) Replacing: exchanging a broken with a new physical component	• Restoring: Recovering the charging functionality by restoring a detached flex cable between charging connector and battery. • Replacing: Recovering the touch functionality by replacing a broken touch sensor component with a new one.
***(2) Hardware-layer governance acts**: Physical, digital, and legal acts performed by the platform owner with the purpose to control hardware-layer changes.*		
Physical act	An act of control that changes the physical modifiability of the hardware layer.	Apple introduces a special screw that can only be operated with a special screwdriver unavailable to unauthorized repair actors *(see first vignette)*.
Digital act	An act of control that changes the technological dependencies between the hardware and the software layer.	Apple releases iOS 8 disabling unauthorized aftermarket home buttons *(see second vignette)*.
Legal act	An act of control that changes the legal conditions for repair actors or end users.	Apple declares to void the consumer warranty of their mobile devices in any case of unauthorized repair.

***(3) Hardware-layer governance responses**: Physical, digital, and legal acts performed by repair actors in response to hardware-layer governance acts.*		
Physical response	A reactive act with the purpose to lift restrictions on the physical modifiability.	*iFixit* introduces a special screwdriver that can operate the special screw introduced by Apple.
Digital response	A reactive act with the purpose to bypass restrictions on the technological dependencies between the hardware and the software layer.	*JC Programmer* introduces a chip re-programmer device enabling repair actors to edit integrated chips that cause the disabling of physical components.
Legal response	A reactive act with the purpose to amend legal restrictions for repair actors or end users.	*Repair.org* creates media coverage and jurisdictional awareness forcing Apple to revise its policy of voiding warranties in any case of unauthorized repair.

Second, we developed a **narrative account** (Pentland 1999) of hardware-layer dynamics that are shaped through repair changes, platform governance acts, and corresponding responses over time. To date, we have focused our data analysis on dynamics emerging from physical and digital governance acts (see Table 2). Figure 1 provides a visual summary of key events since the release of the first iPhone in June 2007. For reasons of brevity, in this paper we only provide two representative vignettes of hardware-layer dynamics.

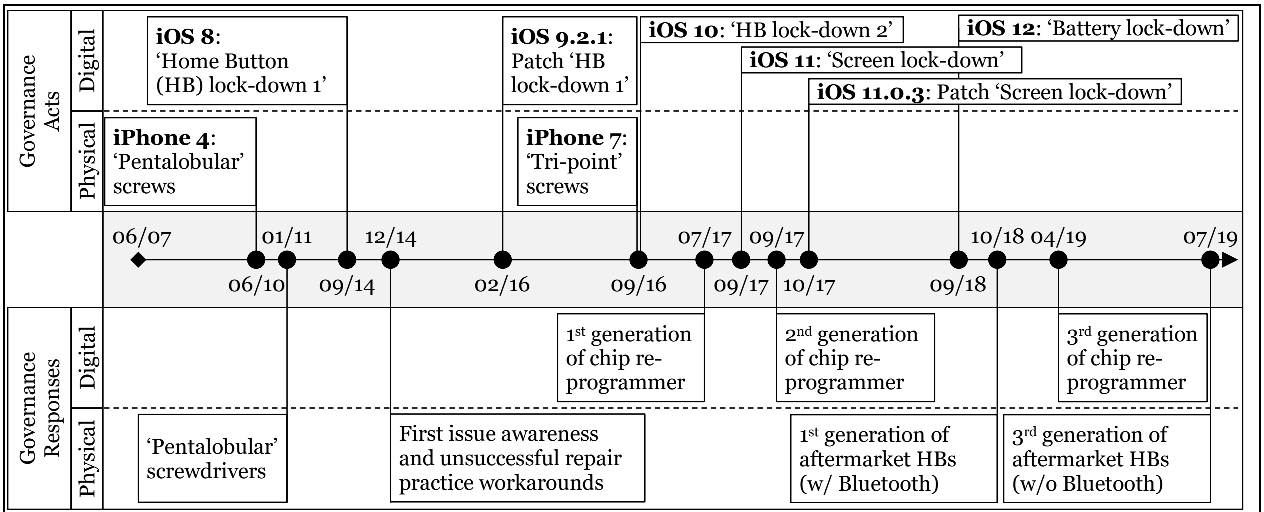

Figure 1. Selected Governance Acts and Responses in Apple's iPhone Repair Aftermarket

The first vignette concerns Apple performing a physical governance act to control the **modifiability** of its ecosystem's hardware layer when it introduced the iPhone 4 with a special—so-called 'Pentalobular'—screw that could not be operated with typical available screwdrivers (see Figure 1). The founder of *iFixit*, a leading online repair community and provider of repair spare parts, released a blog post, shortly after, stating:

> *"This screw head is new to us. In fact, there isn't a single reputable supplier that sells exactly the same screwdrivers Apple's technicians use—which is Apple's point. They picked an obscure head that no one would have."* *(Founder, iFixit Blog, 2011)*

These screws hampered independent repair of iPhones 4 (i.e., hardware-layer changes) as repair actors were not able to open the device without damaging its screws. However, since Apple first released devices with these screws to the Japanese market in mid-2010, *iFixit* was aware of this issue ahead of time and had actively sourced appropriate screwdrivers when the special screws hit the US market in January 2011:

> *"Fortunately, our always-creative hardware acquisition team has been on this problem for a while. It's our responsibility to provide [independent repair service providers] with all the tools [they] need to work on electronics, and we have a solution [...]! [...] We have found a driver that works for the 5-point "Pentalobe" fasteners on the iPhone 4 case."* *(Founder, iFixit Blog, 2011)*

While the issue of impaired modifiability seemed to be settled for a while, Apple introduced another special screw (the so-called 'Tri-point' screw) with the iPhone 7 in September 2016. Again, the suppliers responded quickly with a corresponding screwdriver. For many tool resellers, however, the hassle remains to date:

> *"Apple has two screw types that no other [mobile phone] manufacturer uses. For one of them [i.e., the 'Pentalobular' screw], the screwdriver is available, but expensive. For the other one [i.e., the 'Tri-point' screw], we have a screwdriver, which does not fit perfectly and damages the screws."*
> *(Head of Purchase, P&R-1, 2019)*

Our second vignette describes Apple's repeated exercise of digital governance acts to control the **dependencies** between software and hardware layer, when rolling out updates of its iOS (i.e., software layer) that rendered non-genuine spare parts (i.e., hardware layer) incompatible with the device:

> *"Apple has some iOS updates that disable, for example, the [aftermarket] home buttons and some functions of these home buttons."* *(Head of Purchase, P&R-1, 2019)*

These 'software lock-downs' of aftermarket components first occurred with the introduction of the Touch ID sensor in the home button of the iPhone 5s, whose aftermarket counterparts were locked by iOS 8 released in September 2014 (see Figure 1). As a result of this lock-down, affected end users experienced the so-called 'Error 53', which left them with disabled—'bricked'—iPhones. While the independent repair community became aware of this error—and that it was somehow related to third-party home button or screen repairs—by the end of 2014, an explanation for 'Error 53' remained hidden for a long time. Eventually, reliable news spread clarifying that:

> *"[...] repairs made by third-party services using components not sourced from the original device cause the iPhone to fail a Touch ID validation check because the mismatched parts are unable to properly sync."* *(Juli Clover, MacRumors Blog, 2016)*

Various workarounds for repair practices on hardware layer then emerged, including technically demanding circuit board-level micro-soldering. However, a viable cure to successfully replace a broken iPhone 6 home button was not found. As the iOS 9 update in September 2015 did not bring the desired 'un-bricking' resolution, negative media coverage about increasing numbers of disabled iPhones and class action lawsuits forced Apple to publicly defend its governance. They released a patch to iOS 9.2.1 shortly after. The patch unbricked the phones, yet left the aftermarket home button's Touch ID functionality disabled:

> *"We protect fingerprint data using a secure enclave, which is uniquely paired to the Touch ID sensor. When an iPhone is serviced [...] for changes that affect the Touch ID sensor, the pairing is re-validated. This check ensures the device and the iOS features related to Touch ID remain secure. [...] When iOS detects that the pairing fails, Touch ID [...] is disabled [...]. When an iPhone is serviced by an unauthorized repair provider, [...] invalid components that affect the Touch ID sensor could cause the check to fail if the pairing cannot be validated."(Apple, Press Release, 2016)*

Essentially, Apple actively managed the iPhone's repair aftermarket in this case: while proprietary and authorized repair actors were technically enabled to re-validate replaced home button components, unauthorized repair actors could not and were, therefore, left uncompetitive. It is important to note the complex interplay between physical components and the software functionalities they bear:

> *"It's multiple [issues]: One is that the Touch ID [functionality] does not work anymore and the other [one] is that the home button [component] is completely not registered by the device."*
> *(Head of Purchase, P&R-1, 2019)*

Since the iPhone 5s model, a home button component carries both functionalities, Touch ID and return-to-home. In the 'Error 53' incidence, Apple has performed two levels of digital governance acts in response to hardware-layer changes (i.e., replaced home buttons): Initially, they disabled the entire phone via a software update; eventually, they only disabled the security-relevant Touch ID functionality. This gave third-party repair actors the freedom to recover at least the return-to-home functionality with an aftermarket home button component without disabling the entire phone. Yet, Apple locked both functionalities (i.e., Touch ID and return-to-home) again with the release of iOS 10 in September 2016. This act caused so much of an uproar in the repair community that a Chinese spare parts service provider decided to build its own home button component that enabled third-party repair actors to bypass Apple's new digital governance act:

> *There is a workaround [...]: We now buy a universal home button. That's for four different models [...] connecting via Bluetooth. And the Bluetooth enables the functions that were disabled by Apple."* *(Head of Purchase, P&R-1, 2019)*

Expected Contributions, Limitations, and Research Outlook

With our ongoing inductive case research, our aim is to expand the literature on mobile platform ecosystems by bringing hardware-layer dynamics into the conversation. With the case data explained in this paper, we are currently probing the development of a process theory that explains these dynamics and how they are shaped through change, governance, and response acts made by platform owners and complementors. We are further exploring the possibilities to expand our research towards a comparative case study, to contrast our emergent findings from a highly controlled mobile platform ecosystem (i.e., Apple's iOS-based) to a more loosely controlled mobile platform ecosystem (e.g., Google's Android-based). While Apple tightly integrates and controls software and hardware layers, Google allows its software layer to be married to various hardware layers (e.g., Samsung, Xiaomi). A different motivation might lead to different governance acts.

We expect our findings to be of primary interest to two IS research streams. First, our extended view on the architecture of mobile platforms sheds light on so far neglected hardware-layer dynamics adding to the IS literature on *platform research*. Our research raises new questions on the relationship between hardware and software layers, e.g., how and when do hardware-layer dynamics occur? How do hardware-layer dynamics influence software-layer dynamics and vice versa? What is the role of middleware in platform governance? Second, the concepts we develop from our study of mobile platform ecosystems may also inform other *platform ecosystems* research where hardware components are present. Nowadays, digital product platforms with software and hardware layers are ubiquitously available, ranging from smart home devices (e.g., Amazon's Alexa) to smart production machines (e.g., Industry 4.0). The ecosystems surrounding these digital products differ and understanding how these differences generate diverse hardware-layer dynamics should be central to future research.

For practitioners, our research stresses that hardware-layer dynamics of supposedly software-driven platform ecosystems should not be disregarded. Representing a business opportunity to one (e.g., unauthorized repair service providers) and a threat to the other stakeholder (i.e., platform owner), this issue is an ostensibly clear affair. Acknowledging the regulatory and competitive movements, however, platform owners should reconsider their position. Even alternatives, such as converting unauthorized third-party actors into authorized ones by officially embedding them into the mobile platform ecosystem via sensitively designed hardware-layer governance acts, might be worthwhile to explore.

Several limitations provide boundaries to our research. First, our selected case setting is exclusive to Apple's mobile platform ecosystem limiting the generalizability of our findings. As noted above, we are currently attempting to obtain access to a comparative case setting. Second, while we try buffering potential biases in our tech blog data (Eaton et al. 2015) by triangulating it with interview data from third-party actors, perspectives from the platform owner or authorized service providers are not sufficiently represented in our sample. We will deal with this limitation by actively sampling authorized repair service providers. Third, we chose established concepts from platform governance research as our main theoretical point of departure. We noted already how not all explanatory mechanisms tightly fit our setting. For example, because Apple is not actively trying to attract independent third-party repair complementors it also does not provide relevant boundary resources (Eaton et al. 2015). Finally, other ways of framing our data analysis also exist, e.g., by focusing on modularity (Cabigiosu et al. 2013). We plan to deal with this limitation by constantly probing different theoretical lenses examining their fit to our data.

References

Baldwin, C. Y., and Woodard, C. J. 2009. "The architecture of platforms: A unified view," in *Platforms, markets and innovation*, A. Gawer (ed.), Cheltenham, UK: Edward Elgar Publishing, pp. 19–44.

Basole, R. C., and Karla, J. 2011. "On the evolution of mobile platform ecosystem structure and strategy," *Business & Information Systems Engineering* (3:5), p. 313.

Boudreau, K. J. 2010. "Open platform strategies and innovation: Granting access vs. devolving control," *Management Science* (56:10), pp. 1849–1872.

Boudreau, K. J. 2012. "Let a thousand flowers bloom? An early look at large numbers of software app developers and patterns of innovation," *Organization Science* (23:5), pp. 1409–1427.

Cabigiosu, A., Zirpoli, F., and Camuffo, A. 2013. "Modularity, interfaces definition and the integration of external sources of innovation in the automotive industry," *Research Policy* (42:3), pp. 662–675.

Constantinides, P., Henfridsson, O., and Parker, G. G. 2018. "Introduction—Platforms and infrastructures in the digital age," *Information Systems Research* (29:2), pp. 381–400.

Davidson, E., and Vaast, E. 2009. "Tech talk: An investigation of blogging in technology innovation discourse," *IEEE Transactions on Professional Communication* (52:1), pp. 40–60.

Eaton, B., Elaluf-Calderwood, S., and Sørensen, C. 2015. "Distributed tuning of boundary resources: The case of Apple's iOS service system," *MIS Quarterly* (39:1), 217-243.

Eisenhardt, K. M. 1989. "Building theories from case study research," *Academy of Management Review* (14:4), pp. 532–550.

Foerderer, J., Kude, T., Schuetz, S. W., and Heinzl, A. 2019. "Knowledge boundaries in enterprise software platform development: Antecedents and consequences for platform governance," *Information Systems Journal* (29:1), pp. 119–144.

Ghazawneh, A., and Henfridsson, O. 2013. "Balancing platform control and external contribution in third-party development: the boundary resources model," *Information Systems Journal* (23:2), pp. 173–192.

Huber, T. L., Kude, T., and Dibbern, J. 2017. "Governance practices in platform ecosystems: Navigating tensions between cocreated value and governance costs," *Information Systems Research* (28:3), pp. 563–584.

Jacobides, M. G., Cennamo, C., and Gawer, A. 2018. "Towards a theory of ecosystems," *Strategic Management Journal* (39:8), pp. 2255–2276.

McIntyre, D. P., and Srinivasan, A. 2017. "Networks, platforms, and strategy: Emerging views and next steps," *Strategic Management Journal* (38:1), pp. 141–160.

Michell, G. de, and Gupta, R. K. 1997. "Hardware/software co-design," *Proceedings of the IEEE* (85:3), pp. 349–365.

Pentland, B. T. 1999. "Building process theory with narrative: from description to explanation," *Academy of Management Review* (24:4), pp. 711–724.

Qiu, Y., Gopal, A., and Hann, I.-H. 2017. "Logic pluralism in mobile platform ecosystems: A study of indie app developers on the iOS app store," *Information Systems Research* (28:2), pp. 225–249.

Reuver, M. de, Sørensen, C., and Basole, R. C. 2018. "The digital platform: A research agenda," *Journal of Information Technology* (33:2), pp. 124–135.

Riisgaard, H., Mosgaard, M., and Zacho, K. O. 2016. "Local circles in a circular economy –The case of smartphone repair in denmark," *European Journal of Sustainable Development* (5:1), pp. 109–124.

Saadatmand, F., Lindgren, R., and Schultze, U. 2019. "Configurations of platform organizations: Implications for complementor engagement," *Research Policy* (48:8), p. 103770.

Sørensen, C., Reuver, M. de, and Basole, R. C. 2015. "Mobile platforms and ecosystems," *Journal of Information Technology* (30:3), pp. 195–197.

Teece, D. J. 2018. "Profiting from innovation in the digital economy: Enabling technologies, standards, and licensing models in the wireless world," *Research Policy* (47:8), pp. 1367–1387.

Tiwana, A., Konsynski, B., and Bush, A. A. 2010. "Research commentary — Platform evolution: Coevolution of platform architecture, governance, and environmental dynamics," *Information Systems Research* (21:4), pp. 675–687.

U.S. Copyright Office 2018. *Exemption to prohibition on circumvention of copyright protection systems for access control technologies*: *83 FR 54010*.

Vaast, E., Davidson, E. J., and Mattson, T. 2013. "Talking about technology: The emergence of a new actor category through new media," *MIS Quarterly* (37:4), pp. 1069–1092.

Wareham, J., Fox, P. B., and Giner, J. L. C. 2014. "Technology ecosystem governance," *Organization Science* (25:4), pp. 1195–1215.

Wolf, W. H. 1994. "Hardware-software co-design of embedded systems," *Proceedings of the IEEE* (82:7), pp. 967–989.

Ye, H., and Kankanhalli, A. 2018. "User service innovation on mobile phone platforms: Investigating impacts of lead userness, toolkit support, and design autonomy," *MIS Quarterly* (42:1), pp. 165–187.

Yin, R. K. 2018. *Case study research and applications*: *Design and methods*, Los Angeles: SAGE.

Yoo, Y., Henfridsson, O., and Lyytinen, K. 2010. "Research commentary — The new organizing logic of digital innovation: An agenda for information systems research," *Information Systems Research* (21:4), pp. 724–735.