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STRATEGIC INTERACTION IN PLATFORM-BASED MARKETS: AN AGENT-BASED SIMULATION APPROACH

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Abstract

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Largely enabled by information and Internet technologies, we have recently witnessed the rise of the platform-based business model, where multiple types of actors are brought together to interact on a common multi-sided platform. Immensely successful platform firms such as Apple (e.g., with iOS), Microsoft (e.g., with Windows and Xbox) and Amazon.com (with the marketplace) continue to inspire strategic management scholars and economists, who try to uncover the strategies that lead to such abnormal platform performance and competitiveness. While the extensive focus on the platform has offered useful implications for platform strategy, the resultant inattention to the inherent external resource interdependencies between the platform and other platform-based market participants (i.e., complementors and consumers) has hindered theoretical progress. In particular, the analytical models of multi-sided platforms, which constitute the theoretical core of platform literature, tend to assume homogeneity and perfect rationality of the market participants, and further simplify their strategic interactions, limiting the empirical validity and normative implications of the platform theory.

Therefore, I explore how micro-level strategic interactions between the platform-based market participants affect platform performance and competitiveness, and hence platform strategy. To do so, I use agent-based simulation that enables relaxing the unrealistic assumptions of analytical models, and thus better highlight how heterogeneous and bounded rational agents interact in platform-based markets. In addition to the individual studies that offer a variety of models to capture the complex dynamic interactions, I develop a further set of novel propositions that together illustrate the general argument that moderate control over the complex adaptive system (i.e., the platform-based market) improves platform performance and competitiveness. This is because devolving complementary resource control to the third parties does not only enable the platform owner to leverage demand-side economies of scale, as argued in the extant literature, but devolving resource control may also spur opportunistic complementor and consumer behavior that may at worst disrupt the platform (e.g., the classic case of Atari). Although the contribution is largely conceptual, it also builds on empirical evidence in the literature and that I provide. Finally, I make a minor methodological contribution to the study of platforms, by illustrating the utility of agent-based simulation in studying these complex adaptive systems, an endeavor that is the first of its kind.

Keywords: multi-sided platform; platform-based market; strategy; inter-organizational relationships; agent-based simulation

Acknowledgements

Because few people have the time, or motivation, to read this book any further, let me make this short section at least a bit entertaining and worth reading. It is my quick recap of the actual process of writing the thesis—I should not probably reveal it here as it may (not really) contradict the intended philosophical orientation I formally state in the following. However, I like honesty, and I want to memorialize the process for when I'm old.

This book did not turn out as planned. Actually, there was no plan after all. I ditched the first one somewhere in the middle of the process, as I was "standing on a burning platform" (feat. Stephen Elop), or so I thought. By that time, I had this overly idealistic view of science where one keeps digging deeper and deeper into one specific problem, until it is resolved. Fortunately, though, the one and only article that I came up with as a result was accepted by a (half-)decent journal as indicated below. But the fact that coming to work was truly fun at that time must have inevitably added to the mental discomfort that was about to come during the last two years of the process—I had to start writing more, instead of programming. Despite the effort, I quickly realized that my new plan of writing 11 papers or so for my dissertation eventually was doomed to fail. I barely made it to five, of which one was accepted by AOM just a few days before I had to submit the first version of the book for evaluation. In the end, at least the word "platform" appears in each paper's title… I think I managed to fight the fire pretty well.

The whole dissertation process more generally reflects the idea that learning is circular. When I went to high school, I thought that I was great in mathematics, writing, et cetera. When I went to university, I thought that I was great in mathematics, writing, et cetera. When I went to doctoral school, I thought that I was great in mathematics, writing, et cetera. However, in each stage I had to relearn everything, and it was only in the end when I realized how great I am. Knowing myself, when I learn more in the future, I yet again go around the circle, and thus, I probably won't dare read this book anymore.

Thanks, bandmates, Carmelo, colleagues, Elina and her family, friends, Into, Jukka, Kati, Mikko, Paavo, relatives, Robin, Samuli, SBLUT, Scribendi (EM123), Spotify, Tekes, and Ville.

Irrespective of the content, I bet my mom would be proud.

Pontus Huotari
June 2017
Lappeenranta, Finland

If we knew what it was we were doing,
it would not be called research, would it?

Albert Einstein

Contents

List of publications

This thesis is based on the following papers. The rights have been granted by the publishers to include the papers in the printed version of this dissertation.

I. Huotari, P., Järvi, K., Kortelainen, S., and Huhtamäki, J. (2017). Winner does not take all: Selective attention and local bias in platform-based markets. *Technological Forecasting and Social Change*, 114, pp. 313-326.

II. Huotari, P. (2017). Too big to fail? Overcrowding a multi-sided platform and sustained competitive advantage. *In Proceedings of the 50th Hawaii International Conference on System Sciences*, pp. 5275-5284.

III. Huotari, P., and Ritala, P. (2017). Complementor strategy and platform performance. *In Proceedings of the 77th Academy of Management Annual Meeting*.

IV. Huotari, P., and Järvi, K. (2017). Distributed innovation in platform-based markets: The rationale, scope, and implications of complementor specialization. *Unpublished working paper, under review for a journal*.

V. Huotari, P., and Ritala, P. (2016). Does becoming a platform pay off? Reconfiguring the business model for two-sided markets. *In Proceedings of the 76th Academy of Management Annual Meeting.*

Author's contribution

I am the principal author and investigator in all of the papers. In co-authored papers I, III, IV, and V, while I was primarily responsible for all research stages, the co-authors helped me in data gathering, in designing the methodology, and/or in the writing processes.

1 Introduction

1.1 Background and the research gap

Some of the most valuable firms on Earth—such as Apple, Microsoft, Amazon.com, Alphabet, and Facebook—are pursuing platform-based business models. Motivated by these and many more success stories, management scholars have joined the economist bandwagon (Armstrong, 2006; Caillaud and Jullien, 2003; Evans, 2003b; Rochet and Tirole, 2003, 2006; Rysman, 2004) in recent years to study multi-sided platforms, especially the determinants of platform performance and competitiveness (Cennamo, 2016; Cennamo and Santalo, 2013; Dube, Hitsch, and Chintagunta, 2010; Eisenmann, Parker, and Van Alstyne, 2011; Hagiu and Wright, 2015a, 2015b; Hossain, Minor, and Morgan, 2011; Parker and Van Alstyne, 2005; Shankar and Bayus, 2003; Zhu and Iansiti, 2012). Some scholars now refer to the emergence and success of the platform-based business model as the “platform revolution” (Parker, Van Alstyne, and Choudary, 2016), and they even claim, “Firms that fail to create platforms and don’t learn the new rules of strategy will be unable to compete for long” (Van Alstyne, Parker, and Choudary, 2016). The increasing number of scientific articles on multi-sided platforms (see Figure 3, p. 29) further confirms the relevance of the research topic but also that there is still much to learn about multi-sided platforms. For example, in their recent literature review on platforms in *Strategic Management Journal*, McIntyre and Srinivasan (2017) argue that relationships between complementor attributes and platform performance, and how to leverage complementor dynamics for better platform competitiveness remain unexplained, to name a few of the identified research gaps.

More specifically, management literature on multi-sided platforms has focused—while building on the economics side of the literature on network effects (Farrell and Saloner, 1985; Katz and Shapiro, 1985)—on seeking ways to leverage network effects for better performance and competitiveness (Cennamo and Santalo, 2013; Shankar and Bayus, 2003). Similarly, the persistence of installed base advantages has been under scrutiny (Dube *et al.*, 2010; Eisenmann *et al.*, 2011; Hossain *et al.*, 2011). Furthermore, management scholars have examined the performance impacts of, say, pricing (Clements and Ohashi, 2005; Park, 2004), entry timing (Schilling, 2002; Zhu and Iansiti, 2012), quality (Cennamo, 2016; Liebowitz and Margolis, 1994; Zhu and Iansiti, 2012), and other platform features, such as distinctiveness (Cennamo and Santalo, 2013; Landsman and Stremersch, 2011; Lee, 2013), and openness (Boudreau, 2010; Wareham, Fox, and Giner, 2014). One could infer that the theory is well established. What is intriguing is that platform strategy might even be considered antithetical to traditional strategy because platform strategy is fundamentally about leveraging *demand*-side economies of scale (Katz and Shapiro, 1985; Parker *et al.*, 2016; Schilling, 1999), whereas traditional strategy focuses on managing supply-side factors such as resources (Barney, 1991; Ye, Priem, and Alshwer, 2012).

Despite the burgeoning research, however, the blind spot is the complementor: Few studies have explicitly investigated the ways in which to manage heterogeneous and strategic complementors for performance and competitive advantage (McIntyre and Srinivasan, 2017). For example, the widely held belief that once a critical mass of consumers or end users is on board a platform, most complementors will also support the platform (Armstrong, 2006; Armstrong and Wright, 2007; Hossain *et al.*, 2011; Rochet and Tirole, 2006), is based on an overly simplistic view that positive indirect network effects alone determine the complementor support (Cottrell and Koput, 1998; Dranove and Gandal, 2003; Nair *et al.*, 2004; Ohashi, 2003). However, the number of consumers on the platform makes it only more likely that the complementor can make a *profit* on the platform (Tucker and Zhang, 2010). Furthermore, complementors are actually highly heterogeneous in their attributes (Boudreau, 2012), which may translate into different abilities to support and compete against other complementors on the platform. Indeed, complementors do not perform uniformly (Binken and Stremersch, 2009; Corts and Lederman, 2009; Kapoor and Agarwal, 2017; Lee, 2013). They may also act to deter platform performance (Wareham *et al.*, 2014)—take the classic case of Atari in the 1980s when it was disrupted as opportunistic game producers flooded the platform with poor quality games (Boudreau and Hagiu, 2009). Finally, the interactions between complementors and the platform constitute a bargaining game, in which the platform is not necessarily at a superior market position to command favorable prices (Gawer and Cusumano, 2002), as evidenced by examples such as Microsoft that had to pay a few *hundred million* dollars to Take Two for an exclusive Grand Theft Auto IV deal (see also Li and Agarwal, 2016). Yet the implications of complementor strategizing on platform performance and competitiveness remain underexplored in strategic management and economics literatures. The few models that have aimed to shed light on the issue (e.g., Almirall and Casadesus-Masanell, 2010; Economides and Katsamakas, 2006; Lee, 2014; Mantovani and Ruiz-Aliseda, 2015) still assumed the agents are relatively simplistic, limiting the usefulness of these models.

Furthermore, consumers are heterogeneous and strategic as well. For example, they may delay platform adoption if they expect to benefit more from adoption in the future than today (e.g., wait until there are plenty of platform users), or they can wait for better alternatives in platform competition (Dube *et al.*, 2010; Farrell and Saloner, 1986; Shapiro and Varian, 1999; Zhu and Iansiti, 2012). Although it is widely recognized that consumer expectations matter for platform demand, much less attention has been paid to the fact that *complement* demand is also affected by consumer expectations. For example, consumers may delay complement adoption as strategic complementors intertemporally price discriminate between heterogeneous consumers (Nair, 2007). This also matters for platforms since they often charge for interactions by taking complement sales commissions. Further, heterogeneous consumer preferences for complement variety, diversity, and quality matter for complement demand and thus, platform performance (Cennamo, 2016; Steiner *et al.*, 2016; Sun, Rajiv, and Chu, 2015; Ye *et al.*, 2012). The performance and competitive implications of these micro-level interactions between heterogeneous and strategic complementors and consumers for platforms have received little attention in the extant literature, in which the interactions are a definitive feature of multi-sided platforms (Hagiu and Wright, 2015a, 2015b).

Moreover, I conjecture that none of the platform-based market participants are perfectly rational either (Cennamo and Santalo, 2013). In contrast, and in addition to the homogeneity and other simplifying assumptions, analytical models of multi-sided platforms typically assume perfect rationality (Armstrong, 2006; Caillaud and Jullien, 2003; Van Alstyne and Parker, 2005; Rochet and Tirole, 2006; Weyl, 2010). Note that these analytical models constitute the theoretical core of platform theory (see section 2). However, given the inherent dynamic complexity of and limited information about the market system (Davis, Eisenhardt, and Bingham, 2009; Sterman, 1994), I assume the market participants are *bounded rational* (Arthur, 1994; Simon, 1991). This assumption naturally leads to treating platform-based markets as complex adaptive systems where mutually interdependent agents approximate optimal strategies through learning and adaptation, and over time (Anderson, 1999; Holland, 1995; Katz and Shapiro, 1994; Kauffman, 1993). This evolutionary perspective has only recently been brought up in the strategic management literature on platforms (Kapoor and Agarwal, 2017), and therefore it is relatively unknown how the evolutionary dynamics affect market outcomes. This perspective, of course, poses methodological challenges as analytical models cannot capture the out-of-equilibrium, evolutionary dynamics of the complex adaptive system (Arthur, 1989, 1999; Nelson and Winter, 1982). Moreover, empirical analysis is challenging because of endogeneity due to network effects. However, the methodological challenge can and will be resolved here mainly by utilizing agent-based simulation that excels in capturing systemic phenomena emerging from micro-level interactions between heterogeneous and bounded rational agents (Arthur, 2006; Fioretti, 2013; Grimm *et al.*, 2005). In addition to enabling me to more realistically capture the evolutionary dynamics of the market system, the agent-based simulation approach is, to the best of my knowledge, the first of its kind when it comes to exploring the topic at hand.

Therefore, in the spirit of problematization (Alvesson and Sandberg, 2011), I question the unrealistic assumptions of extant platform research, mainly that of the market participants being homogeneous, perfectly rational agents. In similar vein, I question the utility of analytical models that also assume the market participants are simplistic, such that important factors are omitted in modeling the strategies of the market participants (e.g., the assumption that complementors do not factor in within-platform competition). I argue that relaxing these assumptions would significantly add to the empirical validity of models of multi-sided platforms, hence also improving their normative implications for platform strategy. Moreover, relaxing the assumptions will imply out-of-equilibrium dynamics of the market system matter for market outcomes—uncovering and explaining how the dynamics matter enables making the platform theory more general as platform-based markets are more likely to remain under constant change than reach a stable equilibrium (Arthur, 1999; Nelson and Winter, 1982).

1.2 Objective

The fundamental goal in strategic management research is to explain variation (i.e., heterogeneity) in firm performance (Guo, 2016; Madsen and Walker, 2017). The present dissertation follows this general convention, while applied to the platform-based market context. In other words, I examine factors that contribute to platform performance, both in absolute and relative (i.e., relative to competitors) terms. Specifically, I examine how not only the interactions between the platform and platform participants, but also the interactions between the latter, that is complementors and consumers (Binken and Stremersch, 2009; Boudreau, 2012; Gupta, Jain, and Sawhney, 1999; Hagiu and Wright, 2015a), affect platform strategy as a whole. On the most general level, the thesis is that the strategic *behavior* of platform-based market participants significantly adds to systemic complexity that ought to be reduced through increased platform control over the market system (Davis *et al.*, 2009). This perspective—which is generally rooted in systems and complexity theory (Anderson, 1999; Holland, 1995; Kauffman, 1993; Sterman, 2000), and more specifically in the behavioral theory of the firm (Cyert and March, 1963) and evolutionary economics (Nelson and Winter, 1982)—better acknowledges the systemic nature of platform-based markets and the bounded rational behavior of the participants (Arthur, 1994; Simon, 1991), adding to our understanding of the market's structural and performance/competitive dynamics.

Even more specifically, in addition to the individual studies that provide the core of the thesis, I develop a set of novel propositions that together highlight several implications of strategic interaction in platform-based markets for platform strategy. At the heart of these propositions is the idea that platform strategy is not that antithetical to traditional strategy (Parker *et al.*, 2016; Schilling, 1999). The inherent external resource interdependencies between the bounded rational and strategic platform-based market participants (Barney, 1991; Dyer and Singh, 1998; Pfeffer and Salancik, 1978) pose management challenges that are arguably best resolved through increased platform control over the complex adaptive system (Davis *et al.*, 2009; Sterman *et al.*, 2007). These control mechanisms include, say, vertical integration into complement production (Cennamo, 2016) and effective governance (Boudreau and Hagiu, 2009). This is not to say that the platform-based business model is "doomed to fail"; however, important strategic trade-offs result from completely devolving complementary resource control to third parties (Boudreau, 2010, 2012; Cennamo and Santalo, 2013; Kapoor and Lee, 2013). For example, autonomous complementors can hinder platform performance and competitiveness through the production of poor quality complements (Boudreau and Hagiu, 2009; Wareham *et al.*, 2014).

Overall, I argue that the extant literature has not truly treated platform-based markets as *complex adaptive systems* (Anderson, 1999; Arthur, 1994, 1999), despite the anecdotal recognition that they are "systems markets" (Katz and Shapiro, 1994). I embrace the complexity (see also Tsoukas, 2017) by going beyond simplistic assumptions about market participants (Alvesson and Sandberg, 2011)—which have enabled scholars to rely too much on analytical modeling in building the platform theory (Armstrong, 2006;

Caillaud and Jullien, 2003; Parker and Van Alstyne, 2005; Rochet and Tirole, 2003, 2006; Weyl, 2010)—and utilize agent-based simulation models to uncover the determinants of platform performance and competitiveness. To put this goal into the research question format, I ask the following:

> *How do micro-level strategic interactions between the platform-based market participants affect platform performance and competitiveness (and thus, platform strategy)?*

Answering the research question requires (1) characterizing the strategic interactions between the platform-based market participants, and (2) exploring how these ought to be managed by the platform. Accordingly, problematizing the critical assumptions of extant research (e.g., perfect rationality of market participants) leads me to adopt more realistic assumptions (e.g., bounded rationality) that better characterize the market participants and hence their interactions. Agent-based simulation then enables me to capture the complex micro-level interactions, and evaluate the effectiveness of various strategies in boosting platform performance and competitiveness in the complex adaptive system.

However, because (simulation) models are always highly simplified versions of reality, they will necessarily omit factors that contribute to a phenomenon under study (Nelson, 2016; Sterman, 2000). Yet models can still be useful in informing about phenomena (Box, 1976). Simulation models are especially useful in theory development when the phenomena are complex and hence challenging to study with other research methods (Davis, Eisenhardt, and Bingham 2007; Harrison, Carroll, and Carley, 2007). Moreover, even if one could hypothetically come up with a perfect replica of reality, the model would be useless in that one cannot understand it any better than the complex reality (i.e., one is better off studying the reality itself; Grimm *et al.*, 2005). Therefore, I emphasize that the models of mine, or the individual publications on which I build the thesis, tackle the research question from five, not all-inclusive perspectives. In the first two and the last one, I focus on the consumer market side and examine how some consumer attributes affect platform performance and competitiveness. In the remaining two publications, I turn to examining some aspects of complementor strategy and attributes, and their effects on platform performance. To expand on these individual studies, I finally develop a set of novel propositions that aim to offer synthesis of the largely conceptual study and guidance for future research on platforms.

1.3 Definitions and research scope

Before going deeper into the extant literature and the findings of the dissertation, I define the most important concepts used in this study. The definitions not only help make the thesis easier to understand but also provide the boundary conditions of the study.

1.3.1 Multi-sided platform and platform-based market

When the existing definition of a "multi-sided platform" *is* well-established and explicit, I see little reason for coming up with a new definition. Therefore, following Hagiu and Wright (2015a), I see that the two fundamental features of a multi-sided platform are *direct interactions* and *affiliation*. The former means "that the two or more distinct [market] sides retain control over the key terms of the interaction, as opposed to the intermediary [i.e., platform] taking control of those terms" (p. 163). More practically, interactions involve trading (e.g., on Amazon.com), exchange of information (e.g., on Facebook), and so on, depending on the type of a platform, and instead of the platform regulating these interactions, the market sides can freely negotiate prices, delivery, and other terms of the interactions. Then, affiliation means "that users on each side [of the platform] consciously make platform-specific investments that are necessary in order for them to be able to directly interact with each other" (p. 163). In practice, affiliation often means paying access fees upon entry (e.g., buying video game console hardware) or commission fees to the platform based on the volume of interactions (e.g., Amazon.com).

However, the definition of a multi-sided platform has been discussed in the past and there are multiple definitions in the literature. Perhaps the most widely used definition was put out by Rochet and Tirole (2003, 2006), who emphasize indirect network effects and non-neutrality of platform fees as necessary conditions for multi-sidedness, both of which are *in*sufficient according to Hagiu and Wright (2015a).[1] I use the more up-to-date definition because it usefully narrows the set of platforms to which the developed propositions are meant to apply. For example, they do not necessarily apply to supermarkets, although supermarkets exhibit indirect network effects and thus have been considered multi-sided platforms by some scholars (Rysman, 2009). Not that I would not also emphasize the major role of indirect network effects and (non-neutrality of) platform fees in shaping performance and competitive outcomes in platform-based markets (Armstrong, 2006; Clements and Ohashi, 2005; Dube *et al.*, 2010). However, other than that, supermarkets or other types of resellers do not follow the rules of multi-sided platforms, and thus, reselling is a distinctive and arguably a substitute business model for the multi-sided platform (Hagiu and Wright, 2015b). The key differentiator is that in the case of multi-sided platforms, the ownership of residual control rights remains with the complementors or sellers, unlike when a reseller buys products from the third parties and sells the products on its own further downstream (Hagiu, 2007; Hagiu and Wright, 2015a). In general, I study the strategic implications of this devolvement of control to third parties.[2]

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[1] Note that Rochet and Tirole (2003, 2006) talk about *two*-sided platforms explicitly—multi-sided platforms can have either two or more distinctive sides. Although two-sided platforms are perhaps the most common, three-sided platforms are not that uncommon either—take Facebook, which connects end users with complementary service providers and advertisers.

[2] To emphasize, from market structural perspective, enabling third parties to remain residual claimants of their demand is a key definitive indicator of multi-sidedness (Hagiu and Wright, 2015a). However, this is *not* to say that the platform could not also devolve control of the platform itself to third parties (e.g., Google enables Android phone makers to modify the platform). Although I do not explicitly investigate the latter

Moreover, and even more clearly, the thesis does not necessarily apply to, say, product platforms (Sköld and Karlsson, 2013). This is because product platforms are used to organize internal development (Gawer, 2014; Gawer and Cusumano, 2014), whereas multi-sided platforms enable third parties to innovate on the platforms (Baldwin and Woodard, 2009; Boudreau, 2012). More generally, along the continuum of platforms, I am strictly interested in platforms that facilitate innovation and interactions in a multi-sided market (Gawer, 2014; Thomas, Autio, and Gann, 2014). Without the prefix "multi-sided," the term platform is used in various fields with a variety of meanings (at the time of writing in January, a simple topic search on the Web of Science retrieved more than 300 000 entries for "platform"), similar to "ecosystem" (Autio and Thomas, 2014; Oh *et al.*, 2016). Some scholars talk about platform ecosystems (Tiwana, 2015), a term I wish to avoid because of its ambiguity (Adner, 2017). Instead, I use the term "platform-based market" (Zhu and Iansiti, 2012) when I refer to the system of actors comprising platform(s), complementors, and consumers or end users as a whole. Other scholars have also used terms such as platform markets (Cennamo and Santalo, 2013), system markets (Binken and Stremersch, 2009; Katz and Shapiro, 1994), or platform-mediated systems (Gupta *et al.*, 1999) with essentially the same meaning. Note also that I occasionally use the loose term "platform-based business model" as a substitute for multi-sided platform (some scholars also talk about the marketplace business model; e.g., Hagiu and Wright, 2015b). Apart from the fifth publication that has some implications for the business model literature, I am not engaging in the discussion of business models in this dissertation. However, note that the use of the term is consistent with the view of business models as activity systems, transcending firm boundaries to include partners or sponsors (Casadesus-Masanell and Zhu, 2013; Zott and Amit, 2010; Zott, Amit, and Massa, 2011).

Finally, although the thesis may apply to multi-sided platforms with businesses as end users (i.e., business-to-business platforms, such as marketplaces for technology; e.g., Dushnitsky and Klueter, 2017), I emphasize that the study findings are largely based on consumer-oriented platforms, especially video gaming consoles that are a "canonical example" of a multi-sided platform (Corts and Lederman, 2009, p. 121). This focus may obviously limit the generalizability of the results, but I am not alone in this regard—video gaming console platforms are perhaps the most widely studied platforms in the literature (e.g., Binken and Stremersch, 2009; Cennamo, 2016; Cennamo and Santalo, 2013; Clements and Ohashi, 2005; Landsman and Stremersch, 2011; Lee, 2013; Shankar and Bayus, 2003; Venkatraman and Lee, 2004; Zhu and Iansiti, 2012). Thus, from this point onward, I refer to end users as consumers.[3] More specifically, I mostly focus on platforms that facilitate trade between the market sides, which include simple trading platforms,

platform strategy, the general arguments of this thesis are in line with Boudreau (2010). He shows evidence that while "granting access" (i.e., equivalent to what I mean by devolving control) can greatly boost third-party innovation, devolving platform control is unlikely to do so, because of additional coordination problems. That is, in the absence of coordination, devolving platform control leads to greater variation in the core components of a technology platform, which is detrimental to third-party innovation (Boudreau, 2010) and thus platform performance in the long run (Baldwin and Woodard, 2009).

[3] In the publications, I use consumer, end user, or buyer terms, although in all of the publications (especially in the first one) the platforms under study are best thought of as consumer-oriented platforms.

such as Amazon.com (in publication II, I refer to the market sides as buyers and sellers), and technology platforms, such as video gaming consoles where complementors utilize the platform as a foundation for innovation in addition to trading with consumers (Boudreau, 2012; Venkatraman and Lee, 2004). However, in the fifth publication, I also study content application providers who can monetize their applications/platforms through sponsoring advertisers (Casadesus-Masanell and Zhu, 2013). In the end, all of these arguably diverse platforms are multi-sided, about which the platform theory aims to comprehensively inform (Hagiu and Wright, 2015a).[4] In sum, Figure 1 clarifies the concepts of a multi-sided platform and platform-based market used in this study.

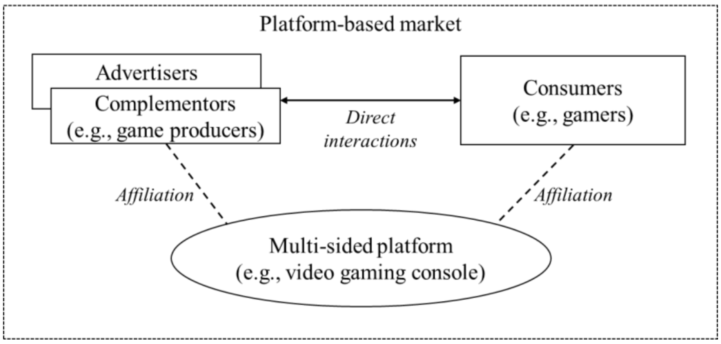

Figure 1. Multi-sided platform and platform-based market (adapted from Hagiu and Wright, 2015a).

1.3.2 Strategy, performance, and competitiveness

Given the focus on platform strategy, this thesis does not go too deep into related issues in strategic management. However, this thesis characterizes resource interdependencies in platform-based markets, and the resultant implications for platform strategy. Thus, I briefly describe relations to the resource-based (Barney, 1991) and relational views of the

[4] If I were to adopt the definition of Rochet and Tirole (2006), then according to Rysman (2009, p. 127) "virtually all markets might be two-sided [multi-sided] to some extent." Although this would have been relieving, as I could have studied "virtually any market", having no scope limitations in theory development is unlikely to result in anything practically useful. On the other hand, while the adopted definition is significantly more exclusive as it necessitates the third parties own residual control rights, the variety of platforms that I studied (e.g., video gaming consoles, online marketplaces, and ad-sponsored content applications) satisfy this and the other definitive features of a multi-sided platform (see Hagiu and Wright, 2015a, p. 163-171). Although one could still have the opinion that the definitive features are overly inclusive, I argue that the general implications of this thesis apply for the diverse platforms. For example, just as if opportunistic game producers disrupted Atari, because the platform let game producers to operate too autonomously (see also Boudreau and Hagiu, 2009; Wareham et al., 2014), one could easily imagine how nobody would play Clash of Clans if advertisers were let completely free to decide on how to display the ads in the game (i.e., ads are a nuisance). As another less obvious example, the results from the first and fifth publications of mine imply that both complementor-supported and ad-sponsored platforms could effectively discriminate between heterogeneous consumers by employing price skimming (i.e., intertemporal price discrimination; Stokey, 1979).

firm (Dyer and Singh, 1998), which are two major schools of thought in this subject and are relevant here (Shankar and Bayus, 2003; Sun and Tse, 2009). Then, I also discuss relations to resource dependence theory (Pfeffer and Salancik, 1978), which is an influential theory of firm boundaries and performance (Santos and Eisenhardt, 2005; Drees and Heugens, 2013). In general, I see strategy in platform-based markets is about the control of *external* resources, a view that I explicate further in the following sections. Nevertheless, in the following I give functional definitions for the concepts used in the subheading.

Strategy research explains variation in firm performance (Guo, 2016; Madsen and Walker, 2017). There are essentially two types of variation: within- and between-firm variation (Certo, Withers, and Semadeni, 2016), of which the latter is typically of most interest to strategy scholars. That is, we often want to explain competitive advantage, which means above-average firm performance in competition. Consequently, competitiveness simply means a firm's ability to compete, which is examined in the first two publications. However, firms tend to have individual characteristics that further impose performance heterogeneity. For example, in platform-based markets, the growth trajectory of a platform influences its further growth because of network effects (Farrell and Klemperer, 2007); in other words, the growth process is path dependent (Arthur, 1989). In the last three publications, I explain within-firm variance in performance, that is, the factors that influence platform performance relative to itself. Practically speaking, and related to measurement, I equate performance with revenue, profit, or number of transactions, depending on the publication—and competitiveness is a derivative measure of the former (e.g., market share measured through the number of transactions). These measures are often used in platform research when explaining performance and competitiveness (Cennamo and Santalo, 2013; Parker and Van Alstyne, 2005; Sun and Zhu, 2013).

Therefore, for analyzing competitive and business strategy in general, I follow Van den Steen's (2016) general definition of strategy: "the smallest set of (core) choices to optimally guide the other choices." This definition is the current functional definition of strategy, and it usefully distinguishes mere plans of action from the essential actions that achieve a specific goal (Van den Steen, 2016). Thus, I study the actions that aim to maximize performance and competitiveness as defined above. Given these presumed goals of strategy, I pay less attention to important decisions (important decisions are not necessarily strategic; Van den Steen, 2016) that do not aim to fulfill these specific goals. For example, in terms of platform strategy, I do not go too deeply into the discussion of how to best design a platform technology architecture, even if design choices are important (Baldwin and Woodard, 2009; Tiwana, Konsynski, and Bush, 2010). However, I discuss high-level technological choices, such as the degree of openness (Boudreau, 2010) and hardware quality (Zhu and Iansiti, 2012), that are shown to be strategically relevant. Similarly, pay attention to the "smallest set of choices" part of the definition: It implies that strategies are simple, consisting of a few high-level decisions (see also Davis *et al.*, 2009). Again, this is useful in narrowing the research scope, and the developed propositions embrace this simplicity approach.

Finally, because a multitude of actors are strategically interdependent in platform-based markets, it is worth emphasizing that I am explicitly interested in examining how the *platform owner* (e.g., video game console provider) can strategically maximize its performance and competitiveness. However, I advance the extant literature by more comprehensively accounting for the strategic actions of complementors (e.g., game producers) and consumers, on which platform strategy depends. Therefore, I will also characterize complementor and consumer strategies, which aim to maximize profitability or utility of the focal complementor and consumer, respectively. Thus, when I talk about platform competition, I mean that two or more platforms compete against each other (e.g., PlayStation vs. Xbox). When I talk about complementor competition, I mean that two or more complementors compete against each other (e.g., a game producer vs. a game producer). Relatedly, when I talk about within-platform competition, I mean complementor competition on a platform (e.g., a game producer vs. a game producer on PlayStation). Complementors compete for consumers to make a greater profit. However, complementors and platforms also compete against each other in the sense that they must negotiate the terms by which revenue from the interactions with consumers is shared (e.g., the case of Mircosoft vs. Take Two)—in other words, complementors do not just cooperate with the platform. Moreover, while consumers do not necessarily compete against each other,[5] their demands for the platform and complementors (e.g., heterogeneous preferences for quality) obviously affect the strategies of the latter parties. All in all, these strategic interactions between the platform owner, complementors, and consumers constitute a complex trilateral bargaining game, at multiple levels of analysis (i.e., market and individual). The specific interest of mine is to aggregate the market-level phenomena (i.e., platform performance and competitiveness) from individual-level interactions between the market participants.

1.4 Outline

The remainder of this dissertation is structured as follows. In the next section, I review the existing literature on multi-sided platforms. Then, I discuss the methodological approach of this dissertation and related philosophical issues. Third, I summarize the main findings of the five publications. Figure 2 shows the findings from each publication and their contribution to answering the research question. Fourth, I explicate further implications of strategic interaction for platform performance and competitiveness. Last, I discuss the overall implications for research and practice and present conclusions.

[5] On content-generation platforms where consumers are involved in content production (e.g., Instagram), they are “switching platform sides” (i.e., from an economic standpoint) and may thus be thought of as complementors to the platform. In this case, content producing consumers compete for attention (Boudreau and Jeppesen, 2015; Sun and Zhu, 2013).

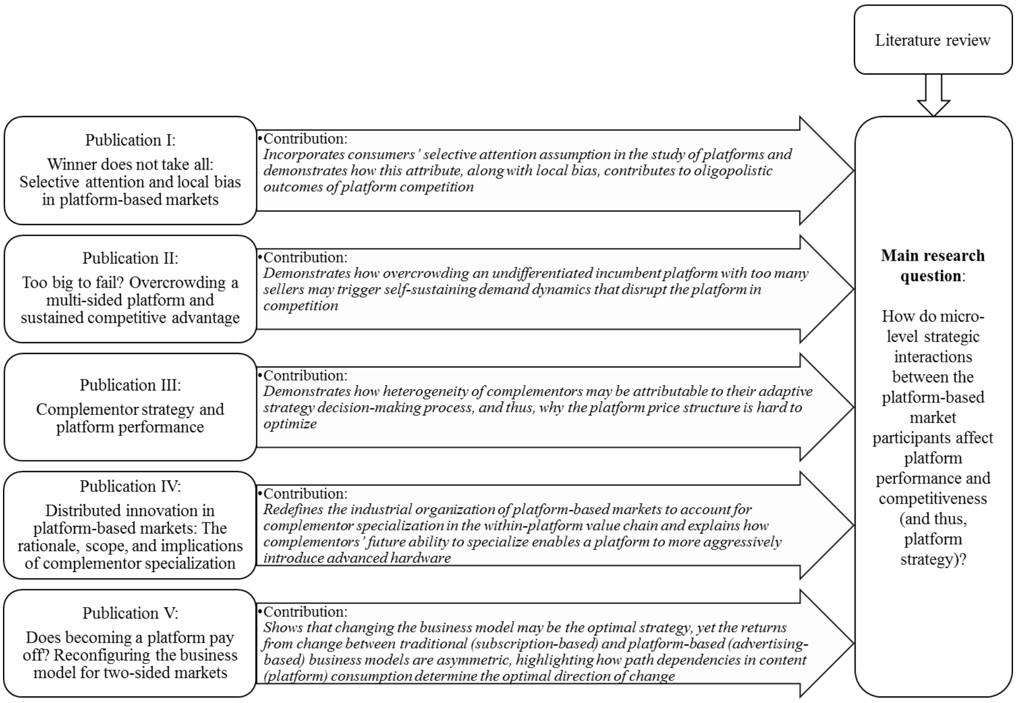

Figure 2. Findings of the studies and their contributions to answering the research question.

2 Present understanding

The rise of the platform-based business model largely coincides with the rise of the Internet, which can be thought of as a multi-sided platform in itself (or more specifically, Internet service providers that control Internet access): multiple types of actors are affiliated with the technology to interact together (Hagiu and Wright, 2015a; Viard and Economides, 2015). However, medieval markets, where buyers and sellers gathered to transact with each other physically, the latter taxed by the city government or some other facilitator (i.e., the platform), are multi-sided as well. People still trade similarly at, say, sports card conventions, and these markets are studied by platform researchers today (Jin and Rysman, 2015). In this sense, there is little new in the business model—except that today's information and Internet technologies impose fewer if any restrictions on platform growth because of low marginal costs of servicing additional users (Noe and Parker, 2005). In addition to low marginal costs, network effects imply demand-side economies of scale, boosting user participation to platforms (Katz and Shapiro, 1985). It is thus no wonder why firms such as Uber, Airbnb, and PayPal are transforming or even disrupting their respective industries with the platform-based business model,[6] as traditional players cannot arguably match the efficiency with which platforms create value through network effects (for more examples, see Parker *et al.*, 2016).

The long list of these success stories and the uniqueness of the platform-based business model (Hagiu and Wright, 2015a; Parker *et al.*, 2016; Schilling, 1999) have motivated economists (e.g., Nobel laurate Jean Tirole; see Rochet and Tirole, 2006) and more recently, strategic management scholars (for a review, see McIntyre and Srinivasan, 2017) to increasingly investigate multi-sided platforms during this century (see Figure 3, p. 29). To make sense of this development, in this section of the dissertation, I aim to review the relevant scholarly literature on multi-sided platforms (sections 2.2 and 2.3) and reflect on this literature (section 2.4) to facilitate my own theory development. First, in the following section I describe my literature search approach.

2.1 Literature search

To facilitate the literature review, I adopted a semi-systematic approach. That is, I systematically selected original scholarly literature on multi-sided platforms to review. What follows is a subjectively constructed view of the present understanding of platforms (largely coinciding with the story in McIntyre and Srinivasan, 2017), based on the

[6] Uber connects drivers and riders. Airbnb connects hosts and guests. PayPal connects buyers and sellers. In each case, the platform enables the third parties to freely interact with each other (i.e., the platform does not own residual control rights), while the platform participants need to affiliate with the platform in order to directly interact (for example, the given platforms take X percent of the revenue generated from transactions between the platform participants). Therefore, all of the given platforms are pursuing essentially the same platform-based business model (Hagiu and Wright, 2015a).

selected articles.[7] Furthermore and importantly, in the following two sections I simply review the literature without reflecting on it so much. More elaborate reflections will follow in section 2.4.

Specifically, I used the following literature inclusion criteria. First, Table 1 contains the list of keywords searched from the titles, abstracts, and keywords of scholarly articles (and all other literature selection criteria). To the best of my understanding, the list of keywords includes all of the most widely used and basically equivalent terms denoting multi-sided platforms or platform-based markets. I used the ISI Web of Science as a search engine, because it covers a wide range of journal sources and it usefully narrows the search to scholarly articles with the "article" refinement functionality. On February 3, the keyword search retrieved 577 entries in total.

Table 1. Literature selection criteria and number of articles in each stage.

Criteria	***Number of articles***
Keyword search from ISI Web of Science, February 3, 2017: *TS=("two-sided market" OR "two-sided markets" OR "twosided market" OR "twosided markets" OR "multi-sided market" OR "multi-sided markets" OR "multisided market" OR "multisided markets" OR "two-sided platform" OR "two-sided platforms" OR "twosided platform" OR "twosided platforms" OR "multi-sided platform" OR "multi-sided platforms" OR "multisided platform" OR "multisided platforms" OR "platform-based market" OR "platform-based markets" OR "platform market" OR "platform markets" OR "system market" OR "system markets" OR "systems market" OR "systems markets")*	577
Published in the following top-tier journals: • Strategic management: *Journal of Management, Management Science, Academy of Management Journal, Journal of Business Research, Strategic Management Journal, Organization Science, Journal of Marketing, Journal of Business Venturing, Journal of Management Studies, Academy of Management Review*. • Economics: *NBER Working Papers, (The) American Economic Review, (The) Journal of Finance, Review of Financial Studies, (The) Quarterly Journal of Economics, Econometrica, (The) Journal of Economic Perspectives, Review of Economics and Statistics, (The) Review of Economic Studies, Journal of Development Economics.*	33
Relevant articles based on the literature search	21
Including articles the former ones had cited at least two times and that were relevant topic-wise	82 *(final review sample)*

[7] To explicate the point in-between the lines, I see little reason in making a fully systematic literature review here, given that McIntyre and Srinivasan's (2017) article is recent, and the fact that it is published in *Strategic Management Journal*.

Second, to narrow the overly inclusive literature selection in the first stage and to ensure that the articles are high quality (i.e., rigorously conducted studies), I followed the management research convention in excluding articles published in lower-tier journals (e.g., Gans and Ryall, 2017; Grant and Verona, 2015; Hillman, Withers, and Collins, 2009; McIntyre and Srinivasan, 2017; Zott *et al.*, 2011). What is a top-tier journal, then? For example, in order "to assess the conceptual development, empirical research, application, and future direction of RDT [i.e., resource dependence theory]," Hillman *et al.* (2009, p. 1405) reviewed articles in 18 journals (and other sources, such as books) judging from their reference list (i.e., they do not report literature selection criteria). When reviewing business models, Zott *et al.* (2011) looked for articles "published in leading academic and practitioner-oriented management journals" (p. 1020), which totaled nine and three, respectively (although they expanded the search scope to include more practitioner sources). Grant and Verona's (2015) review of the literature on organizational capabilities included articles published in eight "leading strategy and general management journals" (p. 72). And to give some recent examples from the special issue "Reviews of Strategic Management Research" in *Strategic Management Journal*, Gans and Ryal (2017) reviewed value capture theory based on articles published in 27 journals (and in some additional sources), whereas McIntyre and Srinivasan (2017) reviewed articles on platforms published in 36 journals (and in some additional sources). Neither of the latter papers described their journal selection processes in depth.

Given the ambiguity associated with the journal selection criteria in these review papers, which were published in top-tier management journals, I took it as a license to approach my journal selection criteria loosely. That is, from the initial 577 articles, I included only articles published in the top 10 strategic management or economics journals, ranked according to the h5 index, and as listed by Google Scholar (i.e., subfields "Strategic Management" and "Economics," respectively, in the overall category "Business, Economics & Management"). The reason why I focus on strategic management journals is obviously that this is a dissertation about platform strategy, but the literature stream is greatly influenced by the economics literature on platforms as well. Some economic models of platforms, such as Armstrong (2006), Caillaud and Jullien (2003), and Rochet and Tirole (2003, 2006), are among the most widely cited papers in the whole literature on platforms, constituting its theoretical core. For example, one can easily verify that many if not the most of strategic management articles that I review cite at least one of these specific articles. Therefore, ignoring the economics literature stream would have greatly weakened the theoretical grounds of this dissertation. On the other hand, I acknowledge that platforms have been studied in other fields as well (e.g., information systems research; Tiwana, 2015)—to limit the scope of the review, I focus on the two fields that are largely complementary to each other (McIntyre and Srinivasan, 2017).[8]

[8] McIntyre and Srinivasan (2017) review three streams of research on platforms: strategic management, economics, and technology management. I actually review many of the articles that they put into the last category (e.g., Baldwin and Woodard, 2009; Boudreau, 2010; Venkatraman and Lee, 2004), demonstrating how the boundaries are malleable. Besides, because the most of reviewed articles were obtained based on the citation criteria (as I describe below), I would have expected to get more articles from other fields than

The list of included journals is in Table 1. After I selected these journal criteria, the initial sample was reduced to 33 journal articles. Furthermore, I skimmed the 33 articles to determine their relevance to the review. In this stage, I excluded articles such as Adner (2017)—note that I refer to this specific article elsewhere in this dissertation as the article is loosely related to the present discussion (i.e., Adner discusses the ecosystem construct)—that did not discuss implications for the theory of multi-sided platforms *primarily*. This means that I also excluded purely empirical articles, that is, those that did not discuss theoretical implications for the topic at hand (e.g., Gandal, 1995; Hendel, Nevo, and Ortalo-Magne, 2009; Viard and Economides, 2015). Furthermore, the term "two-sided market" is used in economics to mean multiple things. Thus, I excluded Ostrosky's (2008) and Hoppe, Moldovanu, and Sela's (2009) studies of two-sided matching, as they are only loosely related to multi-sided platforms.[9] I excluded 12 articles, which left 21 relevant articles.

Finally, given the low number of relevant articles in the sample, I included articles the former ones had cited at least two times—the number two was somewhat arbitrary but higher than the median of one and the average of 1.29 in the sample—and that were relevant topic-wise. This should ensure that my selection of articles corresponds to the "core" of the platform literature. Specifically, I first went through the reference lists of the 21 articles in the remaining sample and counted the number of citations for the articles in the reference lists. Second, I went through the 138 articles that had been cited at least two times out of all 995 citations.[10] After I had evaluated their relevance topic-wise,[11] the final sample of scholarly articles and other sources to be reviewed increased to 82. All papers that I cite in the following two sections were included in this sample.

strategic management and economics, if the other fields had offered important complementary insights to strategic management and/or economics perspectives on platforms.

[9] To emphasize, matching is important in platform-based markets (Damiano and Li, 2008), but there is a wholly separate literature stream on matching that is not closely related to the present discussion.

[10] I wrote a simple Python program to go through the reference list produced by ISI Web of Science and to count the citations. Given the high overall number of citations, the programmatic approach should be useful in mitigating errors in data collection. However, note that the search engine's output may contain spelling errors that will translate to counting errors (e.g., two strings do not match even if they refer to the same article). Given that my literature review is not systematic, I simply moved forward without correcting for the errors in citations (and this ought not to reduce the representativeness of the sample if the errors were randomly distributed).

[11] I followed the same approach I adopted after the preceding journal selection, except that in addition to scholarly journal sources, I included articles published in scholarly book chapters (e.g., Baldwin and Woodard, 2009) and in practitioner journals (e.g., Eisenmann *et al.*, 2006), as they were often cited in the sample. Because the focus is on reviewing articles, I excluded whole books (Evans, Hagiu, and Schmalensee, 2006; Evans and Schmalensee, 2007b; Gawer and Cusumano, 2002).

Judging from the data shown in Figure 3, there has been increasing attention toward multi-sided platforms.[12] The figure also plots the balance between theoretical and empirical work on platforms over time.[13] I will assess this development later in section 2.4.

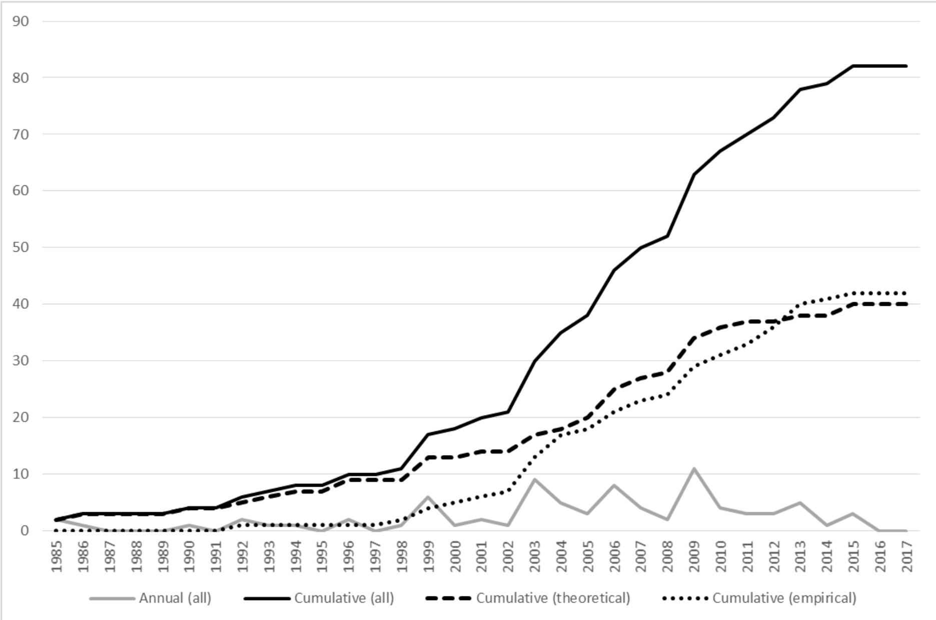

Figure 3. Number of selected scholarly articles on multi-sided platforms over time.

2.2 Market structural properties and platform demand

2.2.1 Indirect network effects

The early seed of interest in platforms arose after acknowledging the importance of *network effects*—the utility of technology usage depending on usage within a user's network of users. Katz and Shapiro (1985) and Farrell and Saloner (1985) were the first

[12] The downward trend in the later years is likely because I am missing recently published articles that did not appear in the selected top-tier journals and that have not had the time to accumulate enough citations (i.e., as it appears, lower-tier journals, such as *RAND Journal of Economics*, have published many influential articles on multi-sided platforms). As examples of the most recent developments in platform theory, see Cennamo (2016), Kapoor and Agarwal (2017), and Li and Agarwal (2016).

[13] I considered an article empirical (theoretical) if it did (not) have a dedicated empirical analysis. There were some borderline cases in which I used subjective judgment. For example, Hagiu and Wright (2015b) lean heavily on the theoretical side, although they present some empirical evidence as well (i.e., I considered the article theoretical). However, although Chao and Derdenger (2013) have a strong theory development section, they also present an in-depth empirical analysis (i.e., I considered the article empirical).

to demonstrate how network effects may explain technological incompatibility and thus, lock-in.[14]

In platform-based markets, *indirect* network effects tend to be particularly prevalent: That is, consumer demand for a platform tends to depend on the availability of complementary products for the platform, and vice versa. For example, consumer demand for PC hardware depends on the availability of software, and the availability of software depends on hardware demand. Thus, agents will typically support the dominant technology (e.g., PCs equipped with Microsoft Windows), as long as it is incompatible with competing and even better technologies as then users cannot utilize complementary products across competing technologies (Corts and Lederman, 2009; Frels, Shervani, and Srivastava, 2003; Schilling, 2002, 2003; Zhu and Iansiti, 2012). In a follow-up article, Farrell and Saloner (1986) were the first to demonstrate the strategic implications. An early mover can exploit its installed base of users through predatory pricing, thus increasing barriers to entry. However, the authors further demonstrated how a product preannouncement can be used to overcome installed base advantages (see also Dranove and Gandal, 2003; Nagard-Assayag and Manceau, 2001), but again with the potential social cost of excessive standardization.[15] A classic example of this latter type of market outcome is the victory of the late entrant VHS (JVC) over the technologically superior early entrant Betamax (Sony), although there might have been various reasons for the latter's demise (Cusumano, Mylonadis, and Rosenbloom, 1992; Ohashi, 2003; Park, 2004).

Over the years, many more researchers have empirically documented the existence and importance of indirect network effects in explaining the performance and competitiveness of multi-sided platforms in a variety of settings (Basu, Mazumdar, and Raj, 2003; Binken and Stremersch, 2009; Clements and Ohashi, 2005; Corts and Lederman, 2009; Cottrell and Koput, 1998; Dranove and Gandal, 2003; Frels *et al.*, 2003; Gandal, Kende, and Rob, 2000; Gupta *et al.*, 1999; Kaiser and Wright, 2006; Landsman and Stremersch, 2011; Nair *et al.*, 2004; Ohashi, 2003; Park, 2004; Rysman, 2004; Schilling, 2002; Stremersch *et al.*, 2007; Tucker and Zhang, 2010; Venkatraman and Lee, 2004). The notion of indirect network effects helps to acknowledge the important market structural properties of multi-sided platforms: They consist of multiple distinctive market sides, such as complementors and consumers, interacting with each other through intermediaries (Rochet and Tirole, 2006). In other words, platforms are vertically *disintegrated* from the production of complementary products, and platforms do not buy from third parties and sell the products

[14] Katz and Shapiro (1985) and Farrell and Saloner (1985) refer to increasing utility to network usage as network *externality*. However, Liebowitz and Margolis (1994, p. 135) were right to note that network externalities are "*unexploited* [emphasis added] gains from trade regarding network participation." Thus, network externalities are thought of as market failures: The associated parties cannot internalize the benefits from trade, and thus, external parties can enjoy the externalities for free (Liebowitz and Margolis, 1994). Weyl (2010) "proves" the conjecture put out by Liebowitz and Margolis (1994) that platforms can at least imperfectly internalize the externalities (i.e., there are no externalities). Thus, I tend to talk about network effects.

[15] In another follow-up by Katz and Shapiro (1986), which was not included in the review sample because it is cited once here, "sponsorship" (i.e., exclusive supply of technology) was also demonstrated to lead to excessive standardization (or "excess inertia").

to consumers directly (Economides and Katsamakas, 2006; Hagiu and Wright, 2015b). Nevertheless, platforms play a facilitating role in connecting the market sides, resulting in a market-mediated interdependence between them in addition to the direct interdependence between complementors and consumers (Gupta *et al.*, 1999).

Information and Internet technologies have largely enabled firms to monetize the business model, because of low marginal costs of servicing additional users (Noe and Parker, 2005). Bresnahan and Greenstein (1999) were among the first to document how the personal computer industry, initially controlled by vertically integrated giants, such as IBM, was disrupted by Microsoft that distributed innovation (or “divided technical leadership,” as they called it) to many third-party firms that were free to contribute to the Windows platform while Microsoft monetized primarily by selling the operating system. The essence of the business model is thus to leverage demand-side economies of scale (Katz and Shapiro, 1985) through the devolvement of complementary resource control (Boudreau, 2010, 2012).[16]

2.2.2 Price structure design

Given the prevalence of indirect network effects in platform-based markets, economists have emphasized the role of price structure design in leveraging the effects. Rochet and Tirole’s (2003, 2006) definition of a multi-sided (or two-sided, as they say) platform even necessitates that the structure of prices is non-neutral; that is, the allocation of prices to the market sides matters for platform demand (i.e., demand is not solely determined by the total prices). Non-neutrality of prices is arguably important when it enables cross-subsidization, that is, increasing the attractiveness of affiliation for one side “at the expense” of another (Caillaud and Jullien, 2001), and thus increasing the total number of transactions (Rochet and Tirole, 2003). Especially when there is no installed base (Clements and Ohashi, 2005; Ohashi, 2003; Park, 2004), price structure design is arguably important in getting all market sides “on board” (Rochet and Tirole, 2003, 2006).

One of the main findings is that the market side that values the other side less (i.e., indirect network effects are asymmetric) will be subsidized. As an example, dating clubs charge men for access to “women’s nights,” as men value access to women more than the latter value access to men (Armstrong, 2006; Caillaud and Jullien, 2003; Kaiser and Wright, 2006). To explicate the logic, women care about men just enough so that they will jump on board if it is cheap (or free), and thus, men agree to pay the higher price. In contrast, even if there were a lot of men due to subsidization, women might not care enough to pay the higher price. Even monopoly platforms can rationally give away products for free or below marginal cost when it effectively leverages indirect network effects. Moreover, this may be socially beneficial (Economides and Katsamakas, 2006; Evans, 2003a; Parker and

[16] Arthur’s (1989) discussion of how supply-side economies of scale may lead to increasing returns and thus technological lock-in is closely related to the present discussion. However, the crucial difference is that network effects imply *demand*-side economies of scale (Katz and Shapiro, 1985).

Van Alstyne, 2005), in contrast with the predatory pricing arguments (Evans, 2003a; Farrell and Saloner, 1986). However, whether monopolization or platform competition enhances social welfare depends on the context (Armstrong and Wright, 2007; Damiano and Li, 2008; Rysman, 2004).

Furthermore, charging for platform access or affiliation is not the only way to monetize a platform. Interaction- or transaction-based pricing schemes may make it easier to get the market sides on board (i.e., getting them on board is not as critical, by definition) and thus make a profit (Armstrong, 2006). In some situations, differentiation in terms of the pricing scheme or structure (e.g., proprietary vs. open source platforms) may enable multiple competing platforms to coexist in the market and enhance social welfare (Ambrus and Argenziano, 2009; Caillaud and Jullien, 2003; Casadesus-Masanell and Ghemawat, 2006; Economides and Katsamakas, 2006).

Overall, economists have highlighted many nuances to the platform pricing decisions. Pricing is affected by, say, the level of multihoming, substitutability of complements (competition among complementors), and heterogeneous preferences (Armstrong, 2006; Armstrong and Wright, 2007; Belleflamme and Toulemonde, 2009; Damiano and Li, 2008; Economides and Katsamakas, 2006; Hagiu, 2009; Hagiu and Spulber, 2013; Weyl, 2010), dynamics of platform adoption and demand expectations (Hagiu, 2006, 2009; Hagiu and Spulber, 2013; Hagiu and Wright, 2015b; Seamans and Zhu, 2014), and perhaps more. For brevity, I do not go through all the nuances of price structure design.[17]

2.2.3 **Multi-sidedness and technology architecture**

At this point, it might seem as if the study of platforms is about the study of indirect network effects and price structure design (Rysman, 2009). However, network effects are pervasive in the economy in general (Economides, 1996; Liebowitz and Margolis, 1994); therefore, if network effects were the definitive feature of a multi-sided platform, the theory would be too broad in scope (Rochet and Tirole, 2006). Hagiu (2007, p. 118), for example, argues that "even the pricing structure chosen by a pure merchant [i.e., a reseller] (that is, its bid and ask prices) affects the total volume of transactions conducted."

Therefore, in a more recent elaboration, Hagiu and Wright (2015b, p. 185) posit that "a fundamental distinction between marketplaces [i.e., multi-sided platforms] and resellers is the allocation of control rights between independent suppliers and the intermediary over noncontractible decisions… In the case of a pure marketplace, all of these residual control rights rest with independent suppliers." That is, the presence of network effects is *not* a necessary condition for multi-sidedness (Hagiu and Wright, 2015b).[18] Multi-sided

[17] Besides, as I will generally criticize the analytical modeling approach to platform theory development, I would not put too much faith in the validity of all the nuanced platform pricing strategy implications of the analytical models (see for example the third publication of mine).

[18] In a "sister" article, which was not included in the review sample because it is cited once here, Hagiu and Wright (2015a) further explicate the definition of a multi-sided platform (see section 1.3 in this

platforms may not exhibit indirect network effects, or they could be weak (Stremersch *et al.*, 2007). For example, Chou and Shy (1990) argue that supply-side economies of scale in complement (software) production could explain consumer adoption of hardware in the computer industry. Furthermore, Noe and Parker (2005) argue that high fixed and low marginal costs, which are typical for platforms (or Web-based firms), may account for the phenomena typically attributed to network effects, such as the winner-take-all (i.e., one platform dominates) outcome (see also Mantovani and Ruiz-Aliseda, 2015).

Moreover, a further distinctive feature of a multi-sided *technology* platform that does not imply network effects is the technology architecture, meaning the system is composed of low-variety core components (i.e., the platform) and high-variety peripheral components or complements (Baldwin and Woodard, 2009). Platform architectural choices affect complementary innovation: a relatively stable platform core is arguably needed so that the production costs of various peripheral components (i.e., complements) are lowered (Boudreau, 2010). Similarly, and generally speaking, there is a variety of regulatory instruments beyond pricing (e.g., technology rules, contracting choices) that platforms owners use to manage network externalities (Boudreau and Hagiu, 2009). This is relevant, say, in mitigating the explosion of complement variety and diversity that tends to happen in completely autonomous platform systems (Boudreau, 2012).

2.2.4 Direct network effects

In addition to indirect network effects, there may be *direct* network effects within one side of a platform. These effects have received much less attention in the literature relative to indirect network effects. Nevertheless, Shankar and Bayus (2003), for example, show that network size and strength, the latter referring to "the marginal impact of a unit increase in network size on demand" (p. 376), on the consumer side explain platform demand.

dissertation). They (Hagiu, 2007; Hagiu and Wright, 2015a, 2015b) argue that the platform model is preferred when (1) suppliers have an information advantage over the focal firm (i.e., a platform ensures complementors adapt their decisions to their private information whereas a reseller may face the moral hazard problem); (2) marketing spillover effects across products are insignificant (i.e., a reseller can more effectively internalize the spillovers that complementors cannot do on the platform); (3) the platform does not have a significant marginal cost disadvantage relative to the reseller (i.e., near-zero marginal costs are a significant enabler of demand-side economies of scale that the platform model builds on); (4) when suppliers have non-pessimistic expectations for the platform (i.e., the reseller overcomes pessimistic expectations by taking the market risk of not getting the goods or services sold that the platform, by definition, cannot do); (5) consumers prefer complementary product variety and are familiar with the available complements (i.e., if they are uninformed, the reseller can better inform them about product features through marketing); and (6) complementors are regularly in direct contact with consumers (which the reseller would restrict). Finally, they speculated about (7) the role of asymmetric information (i.e., it is possibly harder for the platform to verify the quality of the products sold through the marketplace than it is for the reseller) and (8) suppliers' bargaining power (i.e., it is harder for the platform to aggregate its users' bargaining power than it is for the reseller).

Furthermore, competition among complementary product providers can actually be thought of as a *negative* direct network effect, possibly leading to "congestion" (Liebowitz and Margolis, 1994). Even if there are many buyers on a platform, competitive concerns may restrict complementors from joining the platform (Tucker and Zhang, 2010). Church and Gandal (1992) account for the competitive effect and find that an industry may be insufficiently standardized (i.e., standardization would increase social welfare) when assuming consumers place a high value on complement variety. In a follow-up article (Church and Gandal, 1993), they argue that lower complement development costs may explain excessive standardization of a platform technology. Venkatraman and Lee (2004) illustrate further how high "density overlap" (i.e., essentially competitive intensity, reflecting on the similarity of competing platforms' portfolio of complementary products) contributes negatively to complementor support for a platform. In other words, the need for differentiation may explain why competitors do not converge on a common standard even in the presence of indirect network effects (Augereau, Greenstein, and Rysman, 2006), or why they differentiate horizontally ex ante in the consumer preference space (it appears the product scope of individual complementors tends to remain unchanged over time; Boudreau, 2012). Furthermore, leveraging supply-side economies of scope through platform diversification (or multihoming) in conjunction with horizontal diversification (i.e., producing various types of complements) may improve complementor performance, because of complementarities between the strategies (Tanriverdi and Lee, 2008).

However, platforms with low complementor support may also be unattractive as such high embeddedness may indicate market concentration and thus lower monetization options for complementors (Venkatraman and Lee, 2004). Similarly, aggressively expanding complement variety *in conjunction with* exclusive contracting (i.e., singlehoming of complementors is enforced) may backfire because the latter strategy puts the alliance partners of the platform in a favorable market position, thus reducing innovation incentives for non-exclusive complementors (Cennamo and Santalo, 2013).

Finally, even if there were *ex ante* positive direct network effects on one side of a platform, that side may become congested as well, creating an ex post negative direct network effect (Eisenmann, Parker, and Van Alstyne, 2006). For example, crowding out of niches reduces innovation incentives in commercial platforms (Boudreau, 2012), or for non-commercial content generation platforms, increasing competition for attention may cancel out the network effect (Boudreau and Jeppesen, 2015).

2.2.5 Quality of network effects

Moreover, mere network size may not fully capture the value of the network to users. Importantly, the marginal value of an additional network user typically decreases in network size (Shankar and Bayus, 2003). In addition, the value of network effects has been shown to change during the technology life cycle. Although they tend to become more critical as the network grows over time (Clements and Ohashi, 2005), platform aging may ultimately render the network less valuable at least in the case of technology platforms (Venkatraman and Lee, 2004). In other words, the technological quality of a platform also plays a role in shaping platform demand (Zhu and Iansiti, 2012).

Complementary product diversity on a platform has also been shown to be an important factor in fulfilling various customer needs (Cottrell and Koput, 1998). To clarify, diversity of complements increases as complementors produce various *types* of complements. One would expect that the heterogeneous type preferences of consumers imply multiple platforms can coexist and serve different consumer segments (Hossain *et al.*, 2011). But sometimes horizontal differentiation among complementors to meet the various needs (Boudreau, 2012) arguably leads to monopolistic platform competition (Hagiu, 2009), especially if exclusive contracting with complementors is allowed as it enables to make a platform distinctive and thus gain a competitive edge (Armstrong and Wright, 2007; Corts and Lederman, 2009; Damiano and Li, 2008).

Moreover, high-quality complementary products outsell their rivals, and having these "superstars" (Binken and Stremersch, 2009) on board on a platform is critical to its success (Corts and Lederman, 2009; Lee, 2013; Stremersch *et al.*, 2007; Tellis, Yin, and Niraj, 2009).[19] Binken and Stremersch (2009) explain how it is not exclusivity per se that explains abnormal platform sales but the subsequent inability of competing platforms to contract with exclusive superstars. Furthermore, certain demand dynamics associated with indirect network effects, such as the chicken-and-egg problem, may prove to be more complex in reality. For example, against conventional wisdom, Stremersch *et al*. (2007) show evidence that consumer demand for technology platforms tends to *precede* complementor demand (e.g., snob users just adopt advanced hardware, even if there were no or few complementary products for it).[20] Moreover, Tellis *et al.* (2009) argue that network effects may make it *more* likely that the best-quality platforms diffuse, if quality-conscious consumers drive early adoption. In line with this view, Hossain *et al.* (2011) argue that vertical differentiation in terms of quality predicts strong market concentration (around the highest-quality platform), whereas multiple horizontally differentiated platforms can coexist in the market.

[19] In a recent article in press, which was not included in the review sample, Cennamo (2016) explicates the difference between variety ("the number *and* diversity of complements available for it [i.e., platform]") and quality ("the average level of consumption benefits [i.e., at the platform level]"). I depart from these definitions only slightly: when I talk about complement variety, I mean the number of complements on a platform, whereas complement diversity increases in the type of complements.

[20] The typical argument is that consumers have little reason to adopt a platform, unless there are complementary products to buy. Thus, platform owners should arguably get complementors to jump on board first—the chicken-*and*-egg problem being that complementors may be pessimistic about the platform's ability to expand the installed base when there are few platform users.

2.3 Strategic management in platform-based markets

2.3.1 Network effects and expectations management

Unsurprisingly, a great deal of strategic management literature on platforms has focused on network effects. Schilling (1999, p. 273) argues that because of network effects, "the dynamics of [platform] technology selection yield strategic implications that are different—if not *antithetical* [emphasis added]—to traditional strategic management imperatives." For example, technology protection is rarely feasible in platform-based markets, as such protection discourages or disables platform participation by third parties and thus mitigates network effects (Schilling, 1999; Shapiro and Varian, 1999). As touched upon in the preceding section, the network effect advantage may be sustainable, even resulting in one platform gaining full dominance of the market, which is referred to as "tipping" (Evans, 2003a) or "winner-take-all" (Schilling, 2002). Some authors (Shankar and Bayus, 2003; Sun and Tse, 2009) have thus characterized network effects as resources for platforms that explain their competitive advantage, in line with the resource-based view. Conversely, the lack of an installed base may seriously weaken competitiveness, even if platform switching costs were negligible (Evans and Schmalensee, 2010). However, given the discussion in the preceding discussion, there are obviously significant nuances in these demand relationships that affect strategy as discussed below.

Management of network effects is crucially about managing demand expectations; that is, platform users form and act on the future expectations of platform network size (Frels *et al.*, 2003; Park, 2004). One way to manage them at the early stage of the platform life cycle are preannouncements (Farrell and Saloner, 1986). Nagard-Assayag and Manceau (2001) argued that product preannouncements are vital for generating permanent interest in a platform and thus accelerating its market penetration (see also Farrell and Saloner, 1986), although lower complementor expectations (relative to consumers) may also slow it down (thus, consumers should be targeted first). In contrast, Dranove and Gandal (2003) show that the preannouncements can only *temporarily* slow down incumbent technology adoption, so they have limited but some use for entrant platforms in overcoming incumbency advantages. Furthermore, commitment in terms of, say, legitimate investments in technology (Schilling, 2003; Suarez, 2004) or pricing (Hagiu, 2006) may serve as signals of credibility and thus promote platform adoption. On the other hand, in the latter case, not committing to price on one side may be effective in overcoming negative expectations on the other market side (e.g., announcing a lower initial price for buyers ensures sellers will jump on board; see Hagiu, 2006).

2.3.2 Entry timing and pricing

A natural follow-up decision to preannouncements is platform entry timing, and the decisions related to pricing (Ohashi, 2003), hardware quality (Zhu and Iansiti, 2012) and openness (Boudreau, 2010). I call these together platform technology strategy.[21] Schilling (2002) argues that being too early or late in the market increases the likelihood of technological lock-out, the latter argument indicating the problems of overcoming the installed base advantages of incumbents. However, a too early entrant may also have an underdeveloped technology (Zhu and Iansiti, 2012), making the entrant unable to satisfy consumer needs, and developing complements for it may also be costly (see also Church and Gandal, 1993), thus locking the entrant out. However, it may be easier to overcome the incumbency advantages of mature technology platforms (i.e., entering late might be beneficial), as complementors arguably prefer to support newer ones (Venkatraman and Lee, 2004).

Furthermore, first-mover and technology advantages may simply be lost when platform firms price the technology too high, as high prices discourage early adoption and thus slow down installed base growth (Ohashi, 2003; Park, 2004). Having a variety of complements becomes arguably more critical over the platform life cycle, whereas pricing is then less critical than initially (Clements and Ohashi, 2005). However, completely free platforms (i.e., open source) may not effectively compete with proprietary platforms even in terms of market share (Economides and Katsamakas, 2006). Thus, price structural design is key not only in terms of generating interest but also ultimately in making a profit (Eisenmann *et al.*, 2006). Dynamic pricing strategies may prove to be the most effective (Hagiu, 2006), especially in competition where, say, unresponsiveness to platform entry may be futile (Seamans and Zhu, 2014).

2.3.3 Technological quality and openness

In many cases, such as video gaming consoles, platform hardware remains basically the same during the platform life cycle. Thus, hardware quality decisions are typically inseparable from entry timing decisions. In addition to the main effect that hardware quality positively affects consumer demand, the indirect effects on complementary product provision and thus, installed base growth add to the simple demand relationship (Nair *et al.*, 2004). Furthermore, Basu *et al.* (2003) show that specific hardware attributes may be more susceptible to increases in complementary product variety, thus enabling a platform provider to sustain higher prices, other things being equal.

Moreover, having a strong installed base of users may enable a platform owner to successfully implement technological change: Backward compatibility with the preceding technology reduces switching costs, thus helping users to change to the new technology (Shapiro and Varian, 1999). From a late entrant platform’s perspective, however, producing significantly higher technological quality than the competition may be necessary to compensate for the lack of installed base (Schilling, 2003). On the other hand, in some situations—particularly when indirect network effects are not too strong and consumers do not value the future availability of complements that much—even a

[21] For non-technological platforms, such as Amazon.com, pricing and openness decisions are still relevant, obviously.

minor hardware quality advantage may be enough to overcome incumbents' installed base advantages (Zhu and Iansiti, 2012). Anyway, investing in continuous learning processes to implement the technological change is arguably required (Schilling, 2002).

A third subcategory of platform technology strategy decisions relate to openness—that is, decisions about the degree to which to rely on third parties (Baldwin and Woodard, 2009; Boudreau, 2010).[22] The definitive feature of the platform-based business model is outsourcing complement production; however, in-house production (Gawer and Henderson, 2007; Hagiu and Spulber, 2013) can be used effectively to improve performance and competitiveness in some situations. For example, vertical integration into complement production may help to overcome pessimistic expectations early in the platform life cycle (substitute third-party production), increase market power relative to complementors and consumers (complement third-party production), and differentiate from competitors when producing distinctive types of complements (Hagiu and Spulber, 2013). Moreover, because variation in the peripheral complementary components of a technology platform (Baldwin and Woodard, 2009) may naturally imply low quality (Boudreau and Hagiu, 2009), engaging in complement production may also serve as a way to perform quality control.[23] In-house complement production also allows for better price coordination in the complement market, thus arguably raising platform performance and competitiveness (Economides and Katsamakas, 2006). Finally, for largely similar reasons as discussed above, the platform may be better off vertically integrating into reselling, as evidenced by Amazon.com that resells some products while still enabling third-party sellers to directly interact with consumers (Hagiu and Wright, 2015b).

However, when vertically integrating into the complement market, it might also be critical to signal that the complementors are not "squeezed out" as it would hurt complementor innovation (Gawer and Henderson, 2007).[24] One way to do so is to devolve control of the platform itself, as the resulting loss of platform market power should credibly signal trust to third parties. However, such devolvement of control may not be as effective in fostering third-party innovation as opening up complementor access, possibly because of coordination problems (i.e., third parties may not have common objectives; Boudreau, 2010). Furthermore, opening up the platform may expose it to the threat of cloning (Baldwin and Woodard, 2009), as exemplified by Amazon.com's extensive use of Android application program interfaces in its Fire OS (although it is unclear whether this hurts Google's Android).

[22] In Rysman's (2009) terminology, openness is about decisions on 1) how many market sides to pursue and 2) compatibility with competing platforms.
[23] In an article not included in the review, Wareham *et al.* (2014) explicate the platform governance mechanism for controlling complement quality.
[24] Furthermore, Cennamo (2016) finds that in the later stages of the platform life cycle, vertical integration increases competition among complementors to the degree that the third parties innovate less, which also hurts platform competitiveness (see also Cennamo and Santalo, 2013).

2.3.4 Exclusivity deals

Furthermore, alliance strategies such as exclusive contracting—that is, deals that do not allow selected complementors to support more than the one platform—could make it easier for platforms to undermine competition (Armstrong and Wright, 2007). Exclusivity deals have thus resulted in antitrust concerns (Evans, 2003a; Shapiro, 1999). Corts and Lederman (2009) argue that multihoming of complementors (i.e., that they support multiple platforms) makes consumers more indifferent to choosing between competing platforms, thus possibly explaining why multiple platforms can compete head to head. Other things being equal, late entrant platforms might then prefer compatibility with early entrant platforms (Eisenmann *et al.*, 2006; Schilling, 2003).

On the other hand, and controversially, as shown by Landsman and Stremersch (2011) and Lee (2013), *incumbents* would actually favor compatibility (see also Armstrong, 2006; Caillaud and Jullien, 2003; Hagiu, 2006), as then the new entrants would not be able differentiate. In other words, securing exclusive contractors would be vital for entrant platforms (see also Venkatraman and Lee, 2004).[25] Exclusive contracting is also not only vital for ensuring distinctiveness of a platform (Cennamo and Santalo, 2013), but it is also a way to ensure a quality advantage relative to competitors (Binken and Stremersch, 2009)—such vertical differentiation may be more critical for competitiveness than horizontal differentiation (Hossain *et al.*, 2011).

However, exclusive contracting comes at a cost. Apart from obviously requiring investments from platform owners (e.g., the multimillion dollar deal between Microsoft and Take Two), it also induces price competition among complementors, favoring the strategic allies of the platform. Exclusive contracting is essentially about price discrimination between complementors. Thus, securing exclusive contractors is beneficial only if the innovation incentives for non-exclusive complementors can be preserved (Cennamo and Santalo, 2013).

2.3.5 Other collaboration strategies

In addition to exclusive contracting, other collaboration or alliance strategies (e.g., joint ventures) may involve joint investments in innovation. For example, in the video gaming console market, platform owners co-develop and publish games with third-party complementors. However, Mantovani and Ruiz-Aliseda (2015) argue that without exclusiveness (differentiation), competition between platforms in a saturated market may trap the owners into a prisoner's dilemma in which they invest more and more in collaboration with complementors in order to vertically differentiate, but no platform is

[25] To explicate the seemingly contradictory logic, even if consumers are more indifferent to choosing between platforms with multihoming complementors, and thus, two similar platforms share the market equally other things being equal, consumer indifference makes consumers continue supporting an entrant platform with an installed base advantage as long as the late entrant has no additional benefits (i.e., exclusive content) to offer. In other words, entry timing matters.

able to appropriate the increased value that has been created (i.e., society benefits at a cost to firms).

Similarly to partnering with complementors and engaging in complement production, some authors have examined product bundling as a platform strategy. Choi (1996) was the first to formally illustrate how a monopoly in platform-based markets (or "systems markets," as he called it) can effectively leverage its dominant market position across industry boundaries through tying (e.g., Microsoft tying TCP/IP stack with its Windows 95 back in the days), effectively mitigating competition/innovation in the secondary market. More practically, the platform then enforces incompatibility through making buyers adopt a whole system from the same firm (Choi, 1996). Similarly, Bakos and Brynjolfsson (1999) suggest that even platform firms that sell information goods could benefit from the bundling of some complementary products to the platform offering (e.g., video game consoles and specific game titles are often sold as a bundle), because then it is easier to predict consumer valuations for the bundle than for the goods in the bundle individually (and when consumer valuations for goods differ systematically, offering various bundles aimed at different consumer segments enables price discrimination). More recently, Chao and Derdenger (2013) discuss "mixed bundling" (i.e., offering individual products and a bundle concurrently) as an effective price discrimination tool and rationalize the strategy of lowering the standalone platform prices for consumers and complementors (i.e., relative to the case that there was no bundle in the first place) when the bundle is offered.[26]

Of course, platforms still want to unbundle most complementary products as the benefits of increased demand predictability due to bundling may not outweigh the decreased ability to grow transaction volume (Parker and Van Alstyne, 2005). Yet a platform can also "envelop," as described by Eisenmann *et al.* (2011, 2006), by entering a related market through leveraging the platform's installed base in another market, which may be effective in disrupting incumbent platforms in the target market. As an example, Google envelops when it bundles its new products (e.g., Android) with its search engine. In general, these type of seemingly unrelated interindustry diversification strategies work despite the lack of supply-side synergies, because of demand-side synergies caused by simultaneous consumer utilities and indirect network effects (Ye *et al.*, 2012). Specifically, envelopment is effective especially when the old and new user bases overlap significantly (less need for aggressive price discounts) and when there are significant economies of scope in the delivery of bundles as it enables to offer aggressive discounts, if necessary (Eisenmann *et al.*, 2011).

[26] The basic rationale for the price cutting of standalone products when also offering them as a bundle is that the effectiveness of this mixed bundling as a price discrimination tool enables better profit extraction, so then the platform is not so reliant on cross-subsidization in making a profit. In other words, mixed bundling may also serve as a way to overcome the chicken-and-egg problem.

2.3.6 Governance

Finally, platforms should also self-regulate to solve for market failures (e.g., network externalities; Boudreau and Hagiu, 2009). This is particularly relevant for platforms where motivations to produce content go beyond profit seeking (Boudreau and Lakhani, 2009). For example, Boudreau and Jeppesen (2015) find that although content production may respond to network effects even if complementors gained no monetary benefits from production, competition for attention may cancel out the network effects, and thus platform owners should perhaps design better reputation systems or such to allow content producers to get noticed. A further implication is that attracting unpaid complementors early on in the platform life cycle may be a viable strategy for overcoming the chicken-and-egg problem, because of the insignificance of network effects (Boudreau and Jeppesen, 2015).

Moreover, Sun and Zhu (2013) find that content producers may trade off content diversity for popularity (i.e., less niche content) when incentivized by ad revenue, although they also demonstrate a resultant content quality improvement. In other words, depending on the importance of content diversity, platform owners should carefully design their monetization model for content contributors (e.g., a platform may lose its distinctiveness if it imposes strong competition for ad revenue).

2.4 Reflections

In this section, I reflect on the literature reviewed in the preceding two sections. This facilitates the construction of my theoretical framework that, to reveal the main blind spot already here, better acknowledges the strategic *behavior* of the platform-based market participants. Before I take the more critical approach, however, I offer some synthesis of the extant literature.

2.4.1 Synthesis

The economics stream of research has established that multi-sided platforms facilitate direct interactions between distinctive market sides that are affiliated with the platform. Indirect network effects are likely to be present in many platform-based markets, but they are an insufficient condition for multi-sidedness, unlike direct interactions and affiliation. In addition, direct network effects, and especially the negative ones among complementors (i.e., within-platform competition), are likely to be prevalent in platform-based markets. Finally, when network effects are present, not the mere installed base size or complement variety but also network features, such as the diversity and quality of complementary products (i.e., the market participants are heterogeneous), affect platform demand, as well as platform features, such as technological quality (hardware quality, the quality of matching algorithms, etc.).

In turn, the strategic management literature on platforms has devoted great attention to studying how platforms can leverage network effects for competitive advantage. In other words, platform strategy appears to be crucially about managing demand-side economies, rather than supply-side factors as is typically the case in strategic management. Specifically, strategic decisions by platforms are related to generating early interest (e.g., preannouncements) and solving for chicken-and-egg problems or unfavorable expectations (e.g., through penetration pricing, proper entry timing, and investing in hardware quality), partnering (e.g., exclusive contracting, bundling), and competing with complementors (e.g., substituting production) in order to differentiate from competing platforms, compatibility and openness (e.g., sharing intellectual property), and self-regulation and governance (e.g., designing effective reputation systems and making rules).

Overall, it seems that the economics and management streams of the platform literature align relatively well with each other. While economists have emphasized studying platform price structures, and management scholars have been interested in various ways to leverage network effects, exclusivity deals, for example, have received mutual interest (Armstrong and Wright, 2007; Cennamo and Santalo, 2013; Landsman and Stremersch, 2011; Lee, 2013). Furthermore, and unexpectedly, the focal point in both literature streams is the platform. Only selected authors examined complementors (Boudreau, 2010, 2012; Boudreau and Jeppesen, 2015; Tanriverdi and Lee, 2008; Venkatraman and Lee, 2004) or consumers (Ye *et al.*, 2012) in greater depth, as confirmed by McIntyre and Srinivasan (2017). The extensive focus on the platform, while giving the impression of a well-established theory, turns out to be the biggest problem in the literature, as I explicate in the following sections.

From methodological point of view, it appears that practically all theoretical work on the subject is based on *analytical* modeling (Armstrong, 2006; Caillaud and Jullien, 2003; Hagiu, 2006; Hagiu and Wright, 2015b; Parker and Van Alstyne, 2005; Rochet and Tirole, 2003, 2006), that is, the pen-and-paper approach to solving for equations—which follows the conventional economic paradigm that clearly assumes profit or utility maximization, perfect rationality of actors, and so on (Friedman and Savage, 1948; Neumann and Morgenstern, 1947). Apart from the few theoretical papers that were more conversational (Liebowitz and Margolis, 1994; Rysman, 2009), the only truly qualitative approaches (i.e., case studies) to theory development were adopted by Cusumano et al. (1992), Bresnahan and Greenstein (1999), Gawer and Henderson (2007), and Boudreau and Hagiu (2009). To the best of my knowledge, examples of qualitative approaches appearing out of the sample are scarce as well.

Therefore, practically all empirical work on platforms appears to be based on *statistical* modeling. Take the many papers that empirically tested for the significance of indirect network effects (see section 2.2). Finally, judging from the pattern of publications over time (Figure 3, p. 29), which clearly shows that theoretical work preceded the empirical work, I conclude that the study of platforms follows the positivistic research paradigm or the hypothetico-deductive approach (Popper, 1959) where theory is first developed “in isolation” and then tested empirically (Nelson, 2016; Van Maanen, Sorensen, and

Mitchell, 2007).[27] The theoretical integrity that this approach provides at best is also apparent from the fact that scholars have been able to consistently build on similar data sets, from the video gaming console industry in particular (e.g., Binken and Stremersch, 2009; Cennamo, 2016; Cennamo and Santalo, 2013; Clements and Ohashi, 2005; Corts and Lederman, 2009; Landsman and Stremersch, 2011; Lee, 2013; Shankar and Bayus, 2003; Venkatraman and Lee, 2004; Zhu and Iansiti, 2012).[28] While I will mostly criticize the analytical modeling approach to platform theory development, note that the thesis builds heavily on the rich empirical literature on platforms.

2.4.2 Additional issues

I acknowledge that some of the omitted issues in the reviewed sample of articles have been discussed elsewhere. To highlight a few, for example, Nair (2007) examines the role of (complementary) product durability and forward-looking behavior and heterogeneity of consumers in the video gaming console industry and thus rationalizes the strategy of intertemporal price discrimination when consumers strategically wait for adoption (i.e., wait for lower price). Furthermore, Broekhuizen, Lampel, and Rietveld (2013) demonstrate that artist-led distribution, where powerful publishers and distributors are bypassed through online platforms, may reduce focal firm (complementor) performance as opposed to using publishers to market products *through* the platform. This is because the complementary marketing resources and capabilities of third-party publishers more than compensate for the share of increased sales that producers pay to publishers. Thus, platforms cannot substitute for third-party publishers due to the lack of sufficient marketing resources or capabilities. Moreover, Claussen, Essling, and Kretschmer (2015) find that the complementary producer's performance suffers when it is too close to technological frontier (i.e., when supporting too advanced platforms with no to little number of users), because the products may then become obsolete before sales take off due to the installed base growth.

As a final example, after the first version of this dissertation was already under evaluation, a new study by Kapoor and Agarwal (2017) turned out to provide empirical evidence on the relationships between platform complexity and complementor competitiveness.

[27] There is hardly a true in-isolation approach to theory development. However, clearly, after the unavoidable empirical intervention in the theoretical definition of the market structural features of platforms (i.e., early theoretical papers were motivated by various empirical examples), it was possible to move forward by following the axiomatic assumptions of economics (e.g., profit/utility maximization and perfect rationality) without having to care for complex empirical realities (e.g., bounded rationality).

[28] As a side note, but interestingly, these patterns are in stark contrast to those observed in the study of business and innovation ecosystems, which are a highly related topic (Gawer and Cusumano, 2014; Tiwana, 2015), and where most work is, to the best of my knowledge, qualitative. I suspect the main reason for these differences is that the structural properties of multi-sided platforms or platform-based markets are clearly defined in contrast to those of ecosystems, partly because the ecosystem construct is still relatively new (Adner, 2017). Therefore, if we were to generate more useful ecosystem theory, which might also benefit the study of platforms (e.g., Kapoor and Agarwal, 2017), we would better agree on the definition of ecosystem (Oh *et al.*, 2016; Ritala and Almpanopoulou, 2017). For example, as long as the structural properties of ecosystems were not clearly defined, it is hard to model them.

Specifically, they found that increasing platform complexity improves the ability of a complementor to sustain its competitive *advantage*, especially when the complementor's platform experience is high, because experience facilitates effective exploration and competitive imitation that are necessary conditions for survival in complex environments (Nelson and Winter, 1982).[29] However, they also found that platform generational transitions tend to erode complementor's competitive advantage, because the transitions necessitate adaptation, which is harder to implement when platform complexity is high (see also Schilling, 2003; Cennamo, 2016).

2.4.3 Challenges with analytical modeling of platforms

These aforementioned examples demonstrate unequivocally that, in addition to platforms, complementors and consumers act strategically. This implies conflicting interests between the market participants. For example, complementors may price too high from the platform's perspective (Casadesus-Masanell and Yoffie, 2007), or they can undermine platform quality, when it is costly to develop complementary products (Claussen *et al.*, 2015; Wareham *et al.*, 2014). Consumers, on the other hand, can force a decrease in prices by strategically waiting for platform or complementary product adoption (Dube *et al.*, 2010; Nair, 2007).

However, with few exceptions, the platform participants have typically been modeled as homogeneous (e.g., that complementors would be all the same, implying within-actor homogeneity),[30] and relatively non-strategic agents (Lee, 2014). The notion relatively means here that even though game theoretical, analytical models assume agents are strategic, many important strategic decisions have been omitted in these models to simplify them. Economides and Katsamakas (2006, p. 1070) for example argue that "it is important to evaluate competition not just in the platform market or just in the applications [i.e., complement] markets, but additionally in the combined interaction across these markets." Therefore, they find that platform price structure and competitive outcomes (e.g., a proprietary platform is likely to dominate an open source one in terms of profit and market share) are critically affected when accounting for bilateral contracting between platforms and complementors. In a similar vein, Lee (2014) accounts for the bilateral bargaining game between platforms and complementors, and finds that multiple platforms can coexist in the market *due to exclusivity*. In other words, banning exclusive contracts would arguably lead to standardization (see also Lee, 2013). Then, Almirall and Casadesus-Masanell (2010) demonstrate that although opening up innovation (e.g., relying on complementors in production) enables a firm to more effectively discover new valuable combinations of product features, the benefits may be mitigated due to the costs of managing the divergent goals of third parties. As a final

[29] In other words, average complementor competitiveness is reduced due to increasing platform complexity, as apparently only the highly experienced complementors can effectively adapt and hence sustain an advantage.

[30] Fortunately, though, everyone acknowledges platforms, complementors, and consumers differ from *each other* (i.e., cross-actor heterogeneity).

example, Mantovani and Ruiz-Alizeda (2015) demonstrate that competing platform firms may commit too many resources to collaboration with complementors. More value is created, but competitive positions may not be not improved, and thus, the excess value flows to consumers.

However, even in those few papers that assume complementors and consumers are relatively more strategic, the standard assumption of the perfect rationality of market participants (Friedman and Savage, 1948; Neumann and Morgenstern, 1947) is widespread among modelers and is particularly problematic here. In general, it is well-established that especially in dynamic environments, humans are very poor decision makers because our brains are bad at comprehending non-linear behavior inherent to dynamic systems, the actors have limited information about the systems, many confounding explanatory variables contribute to system dynamics and ambiguous relationships, and so on (Sterman, 1994). Take platform owners who can undermine platform performance and competitiveness *accidently* by pursuing multiple seemingly beneficial strategies in conjunction (Cennamo and Santalo, 2013), despite their bird's-eye view of the market (i.e., if anybody, platform owners should have access to relevant information to make rational decisions).

Therefore, there is little reason to believe that the platform participants, that is, complementors and consumers, can make perfectly rational decisions, either. One manifestation of this that complementors can crowd out their own innovation incentives (Boudreau and Hagiu, 2009). For example, the mere lack of information on the number of buyers on a platform may make new sellers support the platform when there were many *sellers* already (i.e., sellers substitute the information on competitive intensity with platform popularity; see Tucker and Zhang, 2010). This example also helps clarify that bounded rationality does *not* imply irrationality in the sense that bounded rational decisions are optimal from a decision maker's viewpoint (i.e., given the limited information)—but the viewpoint is only a part of the bigger picture in which the decisions tend to be suboptimal (and thus, in a way, irrational).

Moreover, especially when it comes to consumers, there is little reason to believe that the tenets of rational utility maximization hold in reality (Kahneman and Tversky, 1979; Thaler, 2016). For example, do they really evaluate all interaction possibilities and their value when there are thousands of complementors to interact with (Boudreau, 2012)? Evidence suggests that consumers tend not to register all relevant information in evaluating complementary offerings on platforms, even if the information is provided at arm's length (Englmaier, Schmöller and Stowasser, 2017). Similarly, Zhu and Iansiti (2012) attribute oligopolistic outcomes of platform competition in part to consumer myopia (i.e., they mostly care about existing complements, and not that much about their expected future availability).

I thus contend that the platform-based market participants are heterogeneous, bounded rational, and strategic, making the market a *complex adaptive system* (Anderson, 1999; Holland, 1995; Kauffman, 1993) where the participants learn and approximate optimal behavior over time in a trilateral bargaining game (Arthur, 1994; Nelson and Winter, 1982; Kapoor and Agarwal, 2017). The existing economic models, despite taking into account the various interaction effects, do not conform to this reality so well. In addition to the preceding simplifying assumptions, most analytical models are essentially static (Armstrong, 2006; Caillaud and Jullien, 2003; Rochet and Tirole, 2003, 2006; Weyl, 2010), not dealing with dynamic issues, such as incumbent platform responses to competitive entry (Seamans and Zhu, 2014). Nevertheless, as is evident in the economic models of multi-sided platforms, for example, the pricing decisions of platforms have not only direct effects on platform usage decisions, but also indirect network effects result in a reinforcing feedback effect over time where the increasing number of users fosters further adoption, other things being equal. Add in competition among complementors, which is due to the increasing number of complementors on a platform, and you have complex interaction effects taking place. Platform usage depends on prices, and on the relative strength of positive indirect to the negative direct network effects.

Despite the acknowledgement of these dynamic effects, however, most analytical modelers focus on analyzing equilibrium outcomes in a static world, although understanding disequilibrium dynamics is vital to policy formulation (Sterman *et al.*, 2007). Furthermore, the model where the installed base of a platform increases complementors' incentives to support the platform (and vice versa) simplifies the fact that complementors care truly about profits rather than the number of consumer users (which positively affects the profit potential of the complementors on the platform). Ideally, one should thus account for competitive dynamics among complementors to understand system behavior. Moreover, complementors may have heterogeneous resources that contribute to their differing ability to cope with competition (McIntyre and Srinivasan, 2017), as is evident when recognizing the possibility of highly skewed performance outcomes for complementors (Binken and Stremersch, 2009; Corts and Lederman, 2009; Lee, 2013; Kapoor and Agarwal, 2017). Apart from complementors, consumers are not merely price takers, either: For example, they have heterogeneous preferences (Steiner *et al.*, 2016; Sun *et al.*, 2015), and they can be forward-looking to a degree (Dube *et al.*, 2010; Zhu and Iansiti, 2012). To be fair, these attributes have been selectively accounted for by some economists/analytical modelers (Armstrong and Wright, 2007; Damiano and Li, 2008; Weyl, 2010). However, dealing with all this complexity (realism) in one model is beyond the ability of analytical modelers.

2.4.4 Empirical challenges

Turning to the empirical research on platforms, there are potential challenges as well. Above all, statistical identification of relationships is highly challenging due to endogeneity arising from network effects. To explicate, the standard assumptions of regression analysis, such as the independence of regressors, do not apply here because of simultaneity and auto-correlation (e.g., usage on one platform side depends past usage on the other side, and vice versa). Moreover, if, for example, consumer usage depended not only on positive indirect network effects but also on positive direct network effects, disentangling between the two effects is even harder—without mentioning the identification problems arising from competition effects among complementors.

Admitted, platform researchers use sophisticated methodologies, such as instrumental (Cennamo and Santalo, 2013; Li and Agarwal, 2016) and difference-in-differences regression (Seamans and Zhu, 2014; Zhang and Zhu, 2011), to correctly deal with the endogeneity inherent into demand relationships in platform-based markets. Therefore, the challenge in empirical research on platforms is not as much that there would not be a statistical method to deal with endogeneity, as it is about *not having the data*. For example, the lack of strong instruments or exogenous shocks renders instrumental or difference-in-differences regression unusable, respectively.

For all these reasons, and given the problems with analytical modeling, I find the utility of (agent-based) simulation particularly high in studying platform-based markets (Davis *et al.*, 2009; Harrison *et al.*, 2007). First, it fits well with the prevalent analytical modeling approach (i.e., both are formal modeling approaches). Second, and most importantly, I can relax some simplifying assumptions, particularly the ones related to the homogeneity, and perfect rationality and non-strategic behavior of platform participants, and effectively study complex dynamics with few data and methodological restrictions (see section 3 for a more elaborate justification).

2.4.5 **Platform strategy versus traditional strategy**

Finally, I briefly talk about relations to strategic management research in general. The notion of platform strategy being antithetical to traditional strategy (Parker *et al.*, 2016; Schilling, 1999) definitely has some merit, but I argue here that there are significant commonalities as well. To clarify, the typical argument is that platform strategy is fundamentally about leveraging demand-side economies of scale, because of network effects (Katz and Shapiro, 1985), while traditional strategy is fundamentally about managing supply-side economies, such as resources and capabilities (Barney, 1991). The distinction is clear when it comes to the acknowledgement that managing consumer utilities is critical for platform success (Ye *et al.*, 2012) but somewhat semantic when it comes to managing complementors. That is, complementors can clearly be thought of as *external* supply-side resources for platforms, consistent with the resource-based view (Shankar and Bayus, 2003; Sun and Tse, 2009) or more specifically with the relational view that acknowledges critical resources may span firm boundaries (Dyer and Singh, 1998). In particular, the term “complementor” embodies the message that third parties provide complementary resources and capabilities for platforms to improve mutual performance and competitiveness (Brandenburger and Nalebuff, 2011; Yoffie and Kwak, 2006). Yet this cooperation also constitutes a bilateral bargaining game in which platforms and complementors compete against each other to appropriate the increased value created (Gans and Ryall, 2017). Issues such as resource dependence (a)symmetry (Casciaro and Piskorski, 2005) and trust (Das and Bing-Sheng, 2001) affect how many resources each party devote to mutual value creation versus individual value appropriation, affecting the overall benefits of cooperation (Panico, 2016).

Therefore, acknowledging the multi-actor resource interdependencies within the platform-based market system, it is quite evident that resource dependence theory (Pfeffer and Salancik, 1978) may well explain the market structural properties and power relationships between the actors. To recap, resource dependence theory states that firms need to procure resources from their environment in order to preserve their autonomy (Boudreau, 2012; Wareham *et al.*, 2014), which results in the firms engaging in various types of interorganizational relationships in the procurement of resources (Drees and Heugens, 2013; Hillman *et al.*, 2009). The possession of resources then becomes a power issue (Casciaro and Piskorski, 2005; Santos and Eisenhardt, 2005). Thus, I find the theory well-equipped to explain why platforms devolve complementary resource control. Instead of merely minimizing the transaction costs that would otherwise prohibit the different market sides from interacting with each other (Evans and Schmalensee, 2007a), platforms outsource innovation to complementors when they can better meet consumer needs than the platforms could do alone (Baldwin and Woodard, 2009). As an example, I bet hardly anybody would believe that Apple and Google could produce the hundreds of thousands of applications to their iOS and Android platforms, respectively, had they not relied on third parties. Therefore, platform owners (and complementors) appear to have limited resources.

Regarding power, becoming a platform leader may not automatically imply superior performance relative to the other market participants (Gawer and Cusumano, 2002). There are several examples from the video gaming industry where key *complementors* (or superstars; e.g., Binken and Stremersch, 2009) used their strong market position to negotiate better contracts with platform owners (e.g., Microsoft had to pay a few *hundred million dollars* to Take Two for an exclusive Grand Theft Auto IV deal). Or take Facebook that integrated Instagram with a $1 *billion* deal (Li and Agarwal, 2016). Finally, take Taylor Swift, who forced Apple to pay royalties to *all* artists at Apple Music by threatening to withdraw from the platform. Despite these examples, few scholars have tried to understand how resource interdependencies affect platform boundaries and market power between platforms and complementors. Yet these are clearly fundamental questions in the strategy and industrial organization literatures (Jacobides and Winter, 2005).

2.4.6 **Summary**

In summary, while the platform theory has been actively developed in the last decades, providing useful implications for platform strategy, the extensive focus on the platform has hindered theoretical progress (see also McIntyre and Srinivasan, 2017). In particular, the research gap, or rather the problem (Alvesson and Sandberg, 2011), in the extant literature is that the analytical models of multi-sided platforms, constituting the theoretical core of the literature, tend to assume the platform-based market participants are homogeneous and perfectly rational, which are clearly unrealistic assumptions. In reality, the market participants differ in their attributes and strategies, and they are bounded rational. Furthermore, the analytical models tend to simplify strategic interactions between the market participants to the degree that important strategic decisions, for example those of complementors in managing their competitiveness on platforms, are omitted. This is problematic, because platforms, complementors, and consumers are all strategically interdependent on each other, and thus simplifying the strategic interactions is likely to generate behavior that is inconsistent with reality where the agents, at least bounded rationally, account for the strategies of one another.

In other words, the descriptive power of analytical models of multi-sided platforms conforming to the assumptions, as well as their normative implications for platform strategy, are limited. However, relaxing all the problematic assumptions makes analytical modeling infeasible. Furthermore, statistical modeling of platforms is challenging due to endogeneity arising from network effects. Therefore, to study platform-based markets as complex adaptive systems, I advocate the use of simulation modeling, and agent-based simulation, in particular, as it excels in this task, as I will explain in the following section.

3 Methodology

This section describes the methodological approach of the dissertation at a high level (for detailed model and experimental design descriptions, see the publications). I start off with a general discussion of the role of modeling, or simulation modeling in particular, in management research (I also abstract from management research a bit to give some perspective). Along the way, I elaborate the utility of and the philosophical issues related to simulation. This facilitates the in-depth methodological discussion of agent-based simulation, model/theory development, and analyses in this dissertation.

3.1 Simulation modeling in management research

Simulation means numerical analysis of formal models that have a well-defined structure so that they are amenable to rigorous analysis. They include, say, pure equation-based models (e.g., system dynamics), and agent-based models (Davis *et al.*, 2007; Harrison *et al.*, 2007).[31] Simulation is thus *not* about using computers per se, as numerical analysis has been exercised with pen-and-paper since the birth of math, but computers are definitely useful in analyzing complex models. From the learning perspective, however, using a computer is necessary for simulation as a computer enables experimenting with a model fast, thus quickening the learning feedback (Sterman, 1994). Acknowledging that the scientific process is about learning how the world operates, computers are an invaluable tool in simulation modeling. However, to be precise, the *only* scientific reasons to use simulation, or to analyze a formal model numerically instead of analytically, are these: There is either no closed-form solutions to the model, or the "out-of-equilibrium-solutions" (Arthur, 1999; Fioretti, 2013) are of interest. In other words, a simulation is needed when analytical approaches are infeasible, which loosely equates to when formal models are semi- or highly complex (i.e., the degree to which analytical approaches can deal with complexity is highly context-specific).

Therefore, in the end, the value of simulation in research boils down to the value of semi- or highly complex formal models in describing the world. They appear to be appreciated more in other disciplines than in management (Harrison *et al.*, 2007). For example, Einstein's field equations for general relativity, which are non-linear differential equations, do *not* have closed-form solutions without making simplifications to the model (Kramer, 1980)—yet hardly anybody in the field of physics denies the profound scientific impact of this model as it has descriptive power. Moreover, I include the whole opening paragraph from Rapaport *et al*. (1996, p. 9) here as it well illustrates the value of simulation in molecular physics (see also Allen and Tildesley, 1989), and because simulating molecular dynamics is so highly related to the adopted agent-based simulation approach used here (see the following section): "Molecular dynamics simulation provides the methodology for detailed microscopic modeling on the molecular scale. After all, the nature of matter is to be found in the structure and motion of its constituent building

[31] I explicate in the following that agent-based models can utilize equation-based logic, so they *can* be purely equation-based, although programmatic logic is often used in conjunction.

blocks, and the dynamics is contained in the solution to the N-body problem. Given that the classical N-body problem *lacks a general analytical solution, the only path open is the numerical one* [emphasis added]. Scientists engaged in studying matter at this level require computational tools to allow them to follow the movement of individual molecules and it is this need that the molecular dynamics approach aims to fulfill." Similarly, and beyond physics, ("molecular") simulation is used extensively in other natural sciences. Grimm *et al*. (2005, p. 987) state, "Ecology, in the past 30 years, has produced as many individual-based models as all other disciplines together have produced agent-based models, and has focused more on bottom-up models that address real systems and problems."

The fact that in management research, or social sciences in general, a significant minority of all papers utilize simulation (Harrison *et al.*, 2007)—as an example, recall that almost all models of multi-sided platforms and platform-based markets were analytical (see the preceding section)—is remarkable, since economic and social systems, in general, are complex (Arthur, 1999; Nelson, 2016). To explicate, complexity in itself does not warrant using simulation or formal modeling in general (Davis *et al.*, 2007), but given that especially economists think that formal modeling is the de facto way to study business phenomena, it is remarkable that the inherent complexity of business phenomena leads economists to choose a method (i.e., analytical modeling) that enforces simplicity. Arthur (1999, p. 107-108) puts it this way: "Conventional economic theory chooses not to study the unfolding of the patterns its agents create but rather to simplify its questions in order to seek analytical solutions… Conventional economics thus studies consistent patterns: patterns in behavioral equilibrium that would induce no further reaction." Certainly, modeling (theorizing) always necessitates abstraction from the real world, but ignoring reality for the sake of simplicity (e.g., the perfect rationality assumption in economics) is *not* logical (Tsoukas, 2017, p. 3): "from realizing that the world that is complex, it does not necessarily follow that our theories must simplify it; the complexity of the world may well spur researchers to seek to develop ever more complex theories to cope with it." Ironically, this approach may have been more prevalent in the early days of management research when simulation was embraced (Cohen, March, and Olsen, 1972; Harrison *et al.*, 2007; Lomi and Larsen, 1996). Similarly, in economics, two prevalent theoretical approaches, behavioral theory of the firm (Cyert and March, 1963) and evolutionary economics (Nelson and Winter, 1982), advocated the use of simulation—but had limited practical impact on the field.

In the platform-based market context, where increasing returns due to network effects are prevalent (Arthur, 1989; Farrell and Saloner, 1985; Katz and Shapiro, 1985), simulation may be the only way to go when it comes to formal modeling, if we care about descriptive power (Arthur, 1999, p. 108): "In economics, positive feedbacks arise from increasing returns. To ensure that a unique, predictable equilibrium is reached, *standard economics usually assumes diminishing returns* [emphasis added]." Multiplicity of equilibria is well-documented in the platform literature (Farrell and Klemperer, 2007; Katz and Shapiro, 1994). Increasing returns are also hard for people to comprehend, adding to complexity (Arthur, 1994; Sterman, 1994).

Overall, the utility of simulation in this research, and in management and economics research in general, lies in its enablement of relaxing problematic assumptions about reality and thus, in making our theories more descriptive (Harrison *et al.*, 2007). In other words, simulation aids in developing simple theory further to account for previously omitted factors and in elaborating the consequences beyond the atomistic relationships that define a model (Davis *et al.*, 2007). Moreover, simulation may at times be the only viable method for empirical testing, as conducting controlled experiments in the business world is highly challenging (Sterman, 2000).

However, to emphasize, simulation modeling is *not* a perfect substitute but instead is a complement for analytical, and especially for statistical, modeling. Analytical models may work for analyzing simple problems, or parts of a more complex model in isolation. For example, when designing an engine, understanding the underlying physical processes of how individual engine parts work is, of course, critical (to come up with a valid simulation model of the whole engine). However, the problem in isolating social phenomena in particular from their larger context (which is common among analytical modelers) is that one more readily omits important explanatory variables (Nelson, 2016). For example, analyzing firm strategy without accounting for competition (Weyl, 2010) may lead to erroneous conclusions about effects on focal firm performance, as competitor responses are ignored.[32] Then, however, the purpose of simulation modeling is slightly different from that of statistical modeling. Whereas simulation modeling lies at the intersection of theory development and testing (Davis *et al.*, 2007), statistics is solely about the latter (apart from explorative statistics). Thus, at best, the relationships between individual variables of a (simulation) model are empirically validated using statistical modeling, demonstrating the complementarity between the methods. However, simulation models also explain relationships between variables, or can be used to test them, but the relationships of interest are *distant*. Whereas the atomistic relationships of a simulation model are given (i.e., they define the model structure), their mutual interactions may produce new insight into higher-order relationships (Harrison *et al.*, 2007). For example, and related to agent-based simulation, individual-level interactions may produce system-level phenomena that are non-apparent from the model structure (Lomi and Larsen, 1996). These individual-to-system-level effects may be further validated with statistical modeling.

Finally, simulation models can go only so far, especially in the social sciences. As Nelson (2016, p. 9) puts it: "while some aspects of these phenomena and the factors influencing them can be described by numbers, those numbers only make sense when they are part of a broader verbal description, and in many cases the numbers are uncertain indicators of what they purport to count or measure." Simulation models thus are always highly stylized versions of social reality that can help us understand the world and make better decisions (for a more detailed discussion on philosophical issues, see the model

[32] As a disclaimer, I am also a victim of this approach (i.e., publications III, IV, and V), but my main focus in these publications was to understand the interdependence between the platform and its participants' strategies.

development section). Moreover, one of the main problems in simulation is related to the lack of computing power. It is very easy to come up with simple models that take too much time to run (e.g., I simulated some of the developed models for *days*). This lack of computing power may, at worst, constrain our ability to learn from a model, as proper experimentation cannot be performed (i.e., we have to oversimplify the model).

3.2 Agent-based simulation (and why it is needed here)

Agent-based modeling is fundamentally just about disaggregating system-level phenomena to its atomistic components. That is, it is about modeling the behavior of *individuals* who interact together and thus contribute to system-level phenomena as a whole (Fioretti, 2013; Macal and North, 2010). Importantly, note that the individuals are not necessarily people; they can also be firms/organizations, or any other meaningful decision-making units, that interact with each other, say, in a competitive market (Lomi and Larsen, 1996). Important implications can follow from this bottom-up representation, such as that then system-level phenomena exhibit emergent properties, meaning that the agent-level interactions produce aggregate behaviors that the individuals themselves do not exhibit (Macy and Willer, 2002). For example, stock market crashes can emerge out of interactions in which individual agents “press the panic button” (i.e., ignore their private information) and just start following each other’s lead in selling off stocks (Tesfatsion, 2002). In general, the implicit (and realistic) assumptions include that individuals are autonomous and have different attributes, they behave nonlinearly (e.g., according to if-then rules), they learn and adapt, their behavior affects the behavior of other agents, and so on (Bonabeau, 2002)—all of which contribute to the system-level dynamic complexity that characterizes social systems (Holland, 1995; Kauffman, 1993). It is not an overstatement that agent-based simulation can *easily* account for this complexity, unlike top-down modeling and simulation methods, such as system dynamics (Rahmandad and Sterman, 2008).[33]

However, I strongly emphasize that in agent-based modeling there is *no* predetermined way to account for individual-level behavior. The method is highly flexible in how behavior is modeled, and enables, say, exploring how differing behavioral assumptions of individuals affect collective behavior (Bonabeau, 2002). Again, I contend that agent-based modeling is fundamentally just about taking the individual-level perspective to modeling. It could thus be understood as a broader set of approaches, including game theoretical models that also explain social outcomes as a consequence of strategic interaction between individual players. However, when employing computational methods, one can go beyond and relax some fundamental assumptions made to simplify game theoretical models (e.g., the use of representative agents when there are more than two players) so that they are analytically solvable (Epstein, 1999). Moreover, the game

[33] Note that the terms agent-based *modeling* and agent-based *simulation* are used interchangeably by simulation modelers. In this dissertation, I mostly use the latter term because it clearly emphasizes the role of simulation (in the present section, I use the former term when generalizing beyond *simulation*-aided agent-based modeling).

structure need not be fixed. A primary benefit of doing so is the ability to examine out-of-equilibrium economics (Arthur, 2006; Fioretti, 2013). To put it bluntly (Arthur, 1999, p. 109), this "complexity economics is not a temporary adjunct to static economic theory but theory at a more *general* [emphasis added], out-of-equilibrium level." In other words, real social and economic systems may be more likely to remain non-stationary than to reach an equilibrium (Gersick, 1991).

Agent-based simulation is not the only computational method for studying out-of-equilibrium economics, though. Perhaps the most prevalent method is still system dynamics (Sterman *et al.*, 2007). To compare, system dynamics (Forrester, 1961; Sterman, 2000) is fundamentally just about solving for differential equations numerically. Nevertheless, the effort of numerically solving for differential equations, which has been exercised quite a lot in economics and management, has been labeled system dynamics. Not all authors make a great deal out of their method—they just solve for differential equations (Hagiu, 2006). However, sometimes putting a label on a method that is fundamentally just about something ordinary is useful in communicating about the method. The label system dynamics emphasizes the role of simulation in solving for differential equations, when they are too complex to solve for analytically. Dynamic complexity arises from feedback loops and delays. In other words, explicit focus is given to temporal issues (Luoma *et al.*, 2017). However, system dynamics is a top-down simulation method (Macy and Willer, 2002) as the collective behavior of individuals is imposed by aggregate equations. For example, the famous Bass (1969) model of new product diffusion, like all system dynamics models, assumes perfect mixing (i.e., consumers are fully connected with each other) and homogeneity of individuals. Thus, one cannot assess with system dynamics how, say, consumer networks affect diffusion dynamics, which, however, is straightforward with agent-based simulation (Lee, Lee, and Lee, 2006; Parunak, Savit, and Riolo, 1998; Rahmandad and Sterman, 2008).

Moreover, agent-based simulation compares closely to cellular automata and NK modeling, which originate from biology and have been used in management research to study, say, product diffusion (Goldenberg, Libai, and Muller, 2002) and innovation strategy (Almirall and Casadesus-Masanell, 2010). Cellular automata and NK modeling are special types of agent-based models: *simple*. Following Fioretti (2013, p. 230), "Automata are agents entertaining relations with their *neighbors only* [emphasis added]. In their turn, the organisms and species of the NK model are agents that *limit themselves to compute fitness* [emphasis added]." Therefore, why to use these special type of agent-based models in management research, as they may *impose* unrealistic assumptions about agents? I see little reason to do so when agent-based simulation, in general, does *not* impose any structural constraints on a model (apart from the obvious disaggregation of phenomena to agent-level). Thus, at best, agent-based simulation enables highly flexible model creation, based on equations, such as in analytical or system dynamics modeling, and on program code; the latter enables neatly simulated patterns of behavior (Grimm *et al.*, 2005).

Modeling flexibility does *not* mean agent-based models need be more structurally complex than top-down models (e.g., system dynamics). In some situations, the latter would be much more complex if they were to describe a phenomenon as accurately as a simpler agent-based model. Thus, whether one needs to go agent-based or not depends on the phenomenon of interest. To abstract away from strategic management research, consider the flow of water. There is little reason to model the flow of water as an outcome of particle-level interactions between water molecules, as aggregate-level differential equations describe the flow highly accurately. The main reason differential equations work in this case is that the water molecules are practically homogeneous, and they interact in highly predictable and uniform ways. Even if one molecule changed its direction, the rest would likely continue flowing to their original directions because of the weak interactions between that molecule and all the other molecules.

However, when agents have heterogeneous attributes, and especially when structural constraints or properties affect the interactions (e.g., social networks between consumers), system-level phenomena may exhibit emergent properties that *cannot* be reproduced with aggregate models (Macy and Willer, 2002; Rahmandad and Sterman, 2008). Consider a swarming flock of starlings, also called a murmuration. Even thousands of these birds in the flock may simultaneously and abruptly twist and turn in the air such that the whole thing looks like an ever-changing sludge. How is it possible that this chaotic-looking system does not fall apart (or from the sky), as it is obvious that the birds are simplistic creatures and no central bird coordinates the flock's movement? It turns out that the aggregate behavior of this system (i.e., flock movement) can be replicated well with a few assumptions about individual bird movement. In essence, each bird starts with a distinct location in the air (i.e., birds are heterogeneous in their location), they avoid colliding with nearby birds, and they try to match their speed with and stay close to neighboring birds (Reynolds, 1987). Although such interactions produce highly complex aggregate behavior, thus necessitating the use of simulation in analyzing the model, the structural properties are very simple.[34]

A few facts about platform-based markets warrant the use of agent-based simulation in studying these systems. First, platforms, complementors, and consumers are different from each other (i.e., cross-actor heterogeneity) in terms of their strategic goals and attributes—and further, the individual types of actors also differ (i.e., within-actor heterogeneity). For example, complementors have heterogeneous resources, and consumers have heterogeneous preferences for complement variety and diversity. Now, because it is evident that the market participants differ, analytical modelers *have* accounted especially for cross-actor heterogeneity—and sometimes also for within-actor heterogeneity (e.g., consumer preferences; Damiano and Li, 2008; Weyl, 2010). Thus, the presence of cross-actor and/or within-actor heterogeneity alone is not a sufficient condition for the use of agent-based simulation, although cross-actor and within-actor heterogeneity complicates analytical modeling and thus could also promote the use of

[34] In this case, a video is worth a thousand words. See https://www.youtube.com/watch?v=cFU5_pVkoZM (accessed February 27, 2017).

agent-based simulation if heterogeneity is significant (Garcia, 2005). Moreover, strategic interaction itself does not obviously imply analytical modeling is infeasible (Lee, 2014; Panico, 2016).

However, when heterogeneity is *structural*, which means that the outcomes of individual-level interactions between the market participants are intricate, constrained by their location in the system (e.g., consumer adoption of a platform depends on the use of it within the consumer's network), and significantly affect other agents through time, agent-based simulation is *the only* method for uncovering the dynamics of the system (Fioretti, 2013). Abstracting, and reconsidering the bird example again, the birds are actually *homogeneous* in their decision-making logic. However, the fact that they must not collide with each other gives rise to structural heterogeneity, in which a bird's location at one point in time will affect their and neighboring birds' locations, and thus the whole system movement, the next time, and so on through complex interactions. Similarly, one can easily see that, for example, if a complementor's past performance affected its future performance, which is a reasonable assumption given their performance heterogeneity (Binken and Stremersch, 2009),[35] one *must* account for this structural and dynamic heterogeneity by aggregating system-level phenomena (e.g., platform performance) from the bottom up (i.e., by modeling the behavior of individual complementors and how consumers interact with the complementors over time). Moreover, given the agents learned and adapted through time due to their bounded rationality (Arthur, 1994; Kapoor and Agarwal, 2017), this further creates individual-level path dependencies that must affect system-level phenomena.

In summary, strategic interactions between the platform-based market participants may easily produce path-dependent structural heterogeneity (e.g., because of network effects) that significantly affects platform performance and competitiveness in the long run. This is more likely when acknowledging that the market participants are bounded rational and that they exhibit cross- and within-actor heterogeneity; even the platform may not be able to effectively coordinate this autonomous and self-evolving system (Cennamo and Santalo, 2013; Wareham *et al.*, 2014). I contend that if and when examining the dynamics of platform performance and competitiveness were of interest, then agent-based simulation should be the default modeling method of choice.[36]

[35] To explicate, the increasing returns and therefore, performance heterogeneity (Arthur, 1989) of complementors may be due to supply-side economies of scale in complement production (Chou and Shy, 1990), or increasing consumer utility to complement usage (Brynjolfsson and Kemerer, 1996) as with platforms.

[36] One minor issue that also supports the use of agent-based simulation, and in the study of business systems in general, is that we can assess how the *number* of agents matters for the phenomena of interest. Further, we need not unrealistically assume that "there is a unit mass of consumers" (Casadesus-Masanell and Zhu, 2013; Mantovani and Ruiz-Aliseda, 2015), a very typical assumption in analytical modeling. In reality, consumers, and all the other market participants are *discrete* decision-making units! However, I agree that the continuity assumption may sometimes be acceptable when the number of agents is not of particular interest and/or when there are many real agents in the market of interest (i.e., the discrete behavior of individuals is less likely to have an effect on the system's response).

3.3 Model (theory) development

Philosophically speaking, I appear to be a critical realist. Critical realism is a form of post-positivism—which, in turn, is obviously a derivative of positivism—that asserts there is a reality out there, but because of the limitations of humans, we are unable to comprehend it perfectly. In contrast, the pure positivistic view, which was prevalent until Popper (1959) wrote about falsification, is that it is possible to measure the reality out there as it is and thus get a perfect picture of it. However, be it natural sciences, or social sciences in particular, the real phenomena of interest are typically so complex that it is practically impossible to observe and model them perfectly (Nelson, 2016). All we can hope for is to study the reality as objectively as we can, while accepting the inherent distortions imposed by our subjectivity. Simulationists must accept that "all models are wrong" (Box, 1976), yet there may still be some *utility* in simplifying the real world to a computer program. And I would argue that the utility of simulation in management research is at least as high as, if not greater than that of, in natural sciences. The inherent complexity of business phenomena not only necessitates going beyond simple analytical models, but simulation may sometimes also be the only effective method to do controlled experiments and thus learn about reality (Davis *et al.*, 2007; Harrison *et al.*, 2007).

One might find it controversial that given the thesis follows a post-positivistic or critical realist philosophical paradigm, I proceed from empirical analysis to conceptual agent-based modeling, and finally even to purely conceptual modeling (i.e., no simulation). That is, if I were to adopt a purely hypothetico-deductive approach as a whole, I should have started with conceptual development and ended up with empirical testing, right (Van Maanen *et al.*, 2007)? However, especially when it comes to (simulation) modeling, it is practically never a linear but an iterative process, where initial assumptions and relationships between variables may be revisited at the analysis stage to gain a better understanding of the complex systemic phenomenon under study (Sterman, 1994, 2000). As an example, it was natural to dig deeper into consumer and complementor behavior, given the empirical findings from the first publication, which clearly have not yet received enough attention from scholars. Theoretical advancements are often motivated by empirical observations that existing theory cannot explain (Alvesson and Sandberg, 2011; Smith and Hitt, 2007). Besides, the given ordering of publications is truthful to the actual process of the research (except for when it comes to the last publication that was written somewhere in the middle of the process)—reordering the publications to make it look as if I started with a hypothesis and then tested it would have been pretending that the thesis actually turned out that idealistically. As Van Maanen *et al.* (2007, 1146) put it: "Reflexivity need not go deep to question this overly simplified and idealized version of the interplay between theory and data. Practicing organizational researchers know both from experience and readily available collegial critique that any narrative suggesting an orderly, standard model of the research process is rather misleading… method can generate and shape theory, just as theory can generate and shape method."

Thus, modeling is *explorative* in the sense that a model, which is a theory of how multiple explanatory constructs explain a certain phenomenon (Sutton and Staw, 1995), is refined until the phenomenon is explained (well enough).[37] Therefore, reasoning based on (simulation) models is fundamentally *abductive*: One tries to come up with a model that produces behavior consistent with empirical observations ("inference to the best explanation"). Importantly, alternative models may also be consistent with the data. Thus, one needs to solve for the trade-off between analytical tractability and descriptive accuracy. Typically, a simple model that explains the phenomenon well enough is favored over a complex model that does not significantly add to the descriptive power of the simpler model. This is also called the "keep it simple stupid" principle (Axelrod, 2006), which economists have taken too literally, however.

Therefore, if modeling was fundamentally abductive, why would this dissertation follow post-positivistic paradigm? Because *all* science is fundamentally abductive. As put by Mantere and Ketokivi (2012, p. 72), we "predict, confirm, and disconfirm through deduction, generalize through induction, and *theorize through abduction* [emphasis added]." Because developing theory is at the heart of science, all science thus is clearly based on abduction (Mathieu, 2016).[38] And it follows that our models (theories) are necessarily wrong in the exact sense, as reality cannot be replicated in a model, and we can come up with only good enough models that potentially have some utility. In light of new evidence, old models (theories) can be refined or completely replaced by better ones (Kuhn, 1962). Think of the history of astrophysics. Once, we had a model of the solar system (or rather, the geocentric system), where the Sun and other planets circled around the Earth, the center of the universe, and this model predicted stuff like seasonal changes and planetary movements pretty well. The fact a more descriptive model was to come (i.e., the heliocentric model) implies coming up with the earlier one (and the latter) was about abduction. It was consistent with empirical observations, but there was (and is) no way to prove that it was the correct model.

However, and importantly, once we have a model, inferring conclusions from it *is* deductive. In other words, one (i.e., a rigorous researcher) cannot interpret the implications of a (simulation) model in alternative ways. Thus, testing for the validity of a simulation model should optimally follow the exact same procedures as that of statistical models (Kelton and Law, 2000). By the way, statistical models are just that, *models* (estimated from data)—although often simulation models in management research are used to describe stylized facts, in which case statistical validation is infeasible. Nevertheless, whether one attempts to replicate stylized facts or numerical data with a model, one deductively rejects a model in favor of another one if the former lacks descriptive power (Popper, 1959). Consider the previous example once more. For a long time, scientists deduced how planets moved based on the geocentric model. However, it failed to account for all data, and thus, it was rejected. Importantly, falsifying the theory did not lead to support for the alternative (i.e., the heliocentric model); therefore,

[37] Models are more than diagrams, which are not theory, as they do not explain why and when things happen unlike models (Sutton and Staw, 1995).
[38] Science is about explaining real-world phenomena. Therefore, mathematics, as an example of a purely human invention that does not exist in the real world per se, is not a science. However, physics, as an example of a field that utilizes mathematical models to explain real-world phenomena, is a science.

abduction was needed to come up with a better alternative. Because by definition a model cannot replicate reality, the null hypothesis that the model's output corresponds to empirical data is *necessarily* false. Therefore, a more productive approach to theory testing is to ask whether the model's output corresponds to data *reasonably well* (Kelton and Law, 2000).

In summary, modeling is theory development (Davis *et al.*, 2007). I have tried to explain numerical observations and stylized facts about platforms through the development of agent-based simulation models (and a purely conceptual model). In other words, I have come up with a new theory that should better acknowledge some realities of the world that previous analytical models have ignored. Thus, instead of filling a research gap and accumulating existing knowledge per se, modeling followed the logic of problematization in which core assumptions were reevaluated (Alvesson and Sandberg, 2011). This can, in a way, be interpreted as replication that is undervalued in management research (Bettis, Helfat, and Shaver, 2016). An unsuccessful attempt to replicate existing theory (e.g., see my first publication) may warrant refining it or developing a new one (Kuhn, 1962). The refinements of the existing theory were about changing its underlying assumptions and demonstrating some of the implications. Thus, I have not debunked existing theory. I strongly build on the empirical literature on platforms (Boudreau, 2012; Cennamo, 2016; Cennamo and Santalo, 2013). In this way, I hope to have advanced the descriptive power of the platform model, or theory.

3.4 Analyses

Practically, I used AnyLogic 7 (www.anylogic.com) to come up with and simulate the agent-based simulation models. It is an integrated development environment for Java applications, and thus, I could use all Java methods available, including some third-party packages not included in the software (see the third publication for more details). Most importantly, AnyLogic provides a built-in architecture for constructing agent-based models and running appropriate simulation experiments (e.g., parameter variation). Nevertheless, the developed models are software independent. One could replicate them with any capable programming language. AnyLogic makes the whole model development and simulation process simple. Model verification (Davis *et al.*, 2007; Harrison *et al.*, 2007), which is about ensuring that the model works as intended, is also straightforward with AnyLogic because of the built-in debugging and analysis tools (e.g., time plots and histograms) that enable observation of model behavior on the go (rather than outputting the data to an external program, which is typically more time-consuming).

In terms of experimental design, I simply used brute force: One simulates all possible parameter combinations. Because of the limited numerical precision in simulation, all means *feasibly many*—to evaluate their effects on system response. This approach is definitely not efficient when it comes to computation but is the most accurate from the analytical perspective and was feasible because my models are still simplistic (not too many exogenous parameters). One can then evaluate the individual and interaction effects of input parameters on system response simply by looking at the response surfaces (three-dimensional visualizations of how the output depends on two input parameters at a time, and other things being equal). In more complex models, more clever experimental designs, such as factorial designs and thus response estimation methods (e.g., regression analysis), need to be used (Kelton and Law, 2000).[39]

For analysis, I mostly relied on Python (https://www.python.org/) and related data analysis and visualization libraries, such as Pandas (http://pandas.pydata.org/) and Matplotlib (http://matplotlib.org/), respectively.[40] In other words, the simulation output data were exported from AnyLogic to a textual format (i.e., csv and related file formats), from which the data can be analyzed in external software. For example, when calculating confidence intervals for output statistics (e.g., the median market shares in the second publication), I implemented a custom function for non-parametric bootstrapping (Efron and Tibshirani, 1994) in Python (e.g., publications II and IV). Bootstrapping is basically a panacea in simulation modeling, as simulation models can easily produce non-normally distributed output data, and therefore, traditional confidence interval estimation methods (e.g., *t*-test) do not necessarily work. However, bootstrapped confidence internals tend to be asymptotically consistent and unbiased regardless of the underlying distribution of the data (Efron and Tibshirani, 1994; Kelton and Law, 2000).

To further explicate the statistical analysis of simulation models, it is a must when the models are stochastic—systematic variation in the output variables cannot be distinguished from random variation based on a single simulation run (unlike when the models are purely deterministic). In here, all of my models contain stochastic elements, either embedded in the structures and/or in the input parameters. Now, while acknowledging that the statistical analysis of simulated time series data is as challenging as that of real time series data (e.g., because of auto-correlation), if one was interested in analyzing it as such (Kelton and Law, 2000), I have relied on the neat property of simulation that makes statistical analysis easy: replications of a stochastic model *are* independent and identically distributed (i.e., i.i.d., unless one intentionally uses the same random numbers across replications). Thus, a fundamental assumption of basic statistical methods, such as non-parametric bootstrap, is satisfied. Therefore, even for a dynamic variable, estimating its mean value (i.e., confidence intervals) at certain point in time can be done by replicating a model many times, observing the values at the same time in the simulation, and bootstrapping over the replication sample. In fact, sampling error becomes miniscule when replicating a model sufficiently many times, and thus all differences in the mean output (i.e., due to changes in input parameters) will be statistically significant (Sterman and Rahmandad, 2008). Thus, at times, simply plotting the mean (or other statistic) of an output variable with respect to input parameters suffices

[39] To explicate, in complex models, one typically needs to estimate a *meta*-model, which is a regression model of the simulation model, to efficiently evaluate the effects of input parameters on the system's response. This approach should not be confused with statistical validation of simulation models (e.g., I used regression analysis in the first publication to evaluate the predictive validity of the simulation model).

[40] A custom web-scraper was also developed with Python for gathering the data from Metacritic (done by a co-author).

to assess their relationships—there will be uncertainty about the validity of a model anyway, so one should not take statistical significance too seriously when it comes to simulation models.

Moreover, I used R for ordinary least squares (OLS) regression analysis in the first publication. Because statistical validation of agent-based models seems to be uncommon (Fagiolo, Moneta, and Windrum, 2007), it is worth discussing this specific validation approach. Simply put, a way to establish the predictive validity of an agent-based (or any simulation) model is to compare its output to real observations of interest one to one and test whether they correlate significantly. For example, I established that the given model's predictions for the monthly number of adopters for PlayStation 3 and Xbox 360 correlate significantly (i.e., $p < 0.001$) with real data and that they are relatively unbiased. The comparison was based on monthly observations because of the significant auto-correlation inherent in observations of a cumulative number of adopters over time (with which the model parameters were estimated). Furthermore, a methodological innovation was to use real data as the input for the model. Specifically, complementor actions (i.e., game launch times and qualities) and adoption times of consumers (i.e., when they were in the market for adopting a console) were parameterized from data. This arguably reduced the output variance of the model significantly (Kelton and Law, 2000) and enabled us to focus on simulating consumer choices between competing platforms, and thus, platform competitive dynamics. However, I must note that there may be endogeneity concerns when using data as input for simulation models, especially here due to the positive indirect network effects (i.e., I cannot rule out the possibility the results were overdetermined by the data). Dealing with them completely requires coming up with a purely conceptual simulation model (i.e., no data used to parameterize the model), but then statistical empirical validation is challenging because there is significant uncertainty about the exact ways in which all actors in the system behave in reality (i.e., model predictions have little one-to-one correspondence with real observations). This is why agent-based simulation models are typically used to explain stylized facts about reality (Rand and Rust, 2011).

4 Publications

This section of the dissertation summarizes the objectives and contributions of the five publications on which I have built the thesis. The discussion remains at a high level—for detailed discussions, one should refer to the original publications.

4.1 I: "Winner does not take all: Selective attention and local bias in platform-based markets"

4.1.1 Background and objective

A central argument in the extant literature on platforms is that, other things being equal, the platform with the biggest installed base of complementors should attract most of the new consumers, and vice versa, and thus take over the entire market eventually, because of the positive indirect network effects (Schilling, 2002). To explicate, (positive indirect) network effects imply increasing utility to network usage (Katz and Shapiro, 1985). For example, then, a video gaming console with increasing availability of games should make the platform more attractive to consumers, and increasing installed base of consumers should in turn make the platform more attractive to game producers (Schilling, 2003). As Hossain *et al.* (2011, p. 1913) put it, "this is a virtuous circle with increasingly many buyers [e.g., consumers] and sellers [e.g., game producers] being attracted. This intuition, which is easily formalized, suggests that tipping (i.e., all players selecting the same platform) is an equilibrium in these markets."

However, several empirical examples demonstrate that multiple competing platforms can share platform-based markets (Corts and Lederman, 2009; Zhu and Iansiti, 2012). Another example was studied in the present paper: the competition between the video gaming consoles PlayStation 3 and Xbox 360. This case was particularly interesting in that the early entrant platform Xbox not only had the arguable first-mover advantage (Lieberman and Montgomery, 1988), as it was launched a year before PlayStation and thus had the greater initial installed base. But Xbox was also priced lower initially than the competitor and had a greater pool of complementary products throughout the life cycles of the two platforms—despite all this, PlayStation won the competition in terms of global consumer adoption eventually, with a small margin. We empirically examined the drivers of this seemingly unexpected "winner does not take all" outcome, which could at best improve our understanding of competitive dynamics in platform-based markets (see also Lee *et al.*, 2006; Noe and Parker, 2005; Schilling, 2002).

For simplicity, we focused on modeling consumer adoption of the platforms. To allow for that, we used the empirical data (Figure 4) to parameterize the agent-based models such that complementor and platform decisions, and aggregate consumer demand were assumed from data (i.e., while the adoption times of consumers were determined from the data, we modeled/predicted consumer choices between the alternative platforms).[41] The data was primarily gathered from www.metacritic.com, consisting of quality and launch time information for more than 2000 games published on the consoles. Importantly, note that the game quality information is console-specific—in other words, games published on both Xbox and PlayStation may have had different Metascores (i.e., quality values), partly attributing to the observed quality advantage of the latter console (better first-party exclusives also explain the difference in favor of PlayStation). In other words, in addition to enabling us to assess the effects of complement quality on platform adoption, the data account for complementor multihoming (i.e., multi-platform game releases).

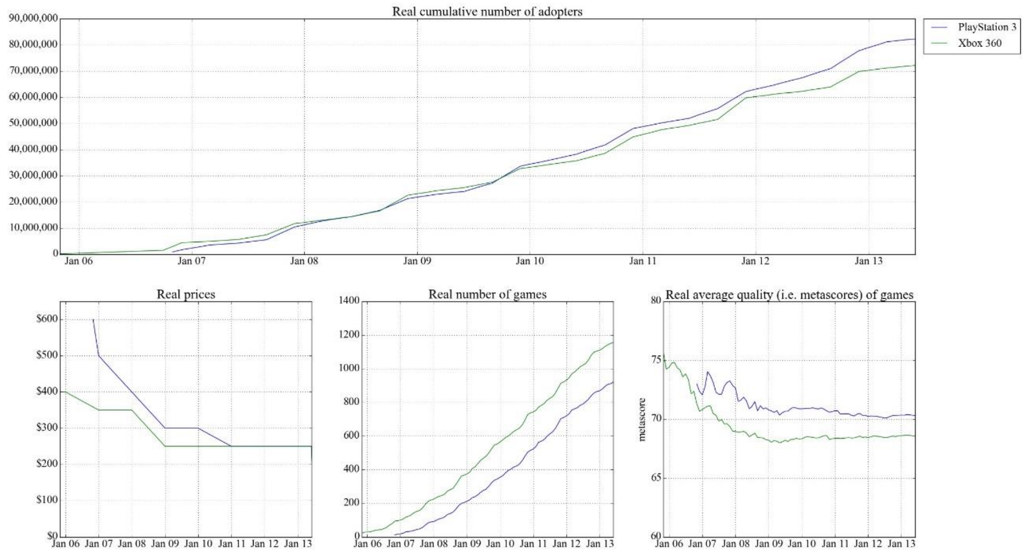

Figure 4. The empirical data used in the study.

4.1.2 Results and contributions

The main result was that the oligopolistic outcome of competition between PlayStation 3 and Xbox 360 could be explained only if we assumed the consumers of the platforms were selectively attentive *and* locally biased. First, selective attention, which generally refers to the cognitive inability of humans to comprehend other than salient information at a time (Kahneman, 1973; Ocasio, 1997), here means that consumers pay differential attention to complementary product quality, depending on market dynamics (see also Englmaier *et al*., 2017). Specifically, we argued that they pay more (less) attention to newer complementary products and their quality when additional (less) good-quality complementary products are introduced to the competing platforms. Then actively managing the pool of complementary products would be vital for platform

41 An alternative statistical approach would be to estimate a discrete choice model (e.g., Corts and Lederman, 2009).

competitiveness, as the dynamics of complement introduction matter for consumer utility. Second, local bias generally means that the market share of a product in a *portion* of the whole network of adopters may not equal the global market share of the product, and thus, the network structure between consumers matters for product diffusion (Lee *et al.*, 2006). Here, following the extant literature (Afuah, 2013; Suarez, 2005), the specific argument is that not the installed base as a whole but the platform adoption decisions of consumers' connections, or friends, partly determine the consumers' adoption decisions. Hence, targeting promotional efforts, if possible, would be vital in order to accelerate platform diffusion in the consumer network (Tucker, 2008). We formalized the consumer network such that it exhibited small-world properties, that is, high clustering and yet small characteristic path length, as is typical of real social networks (Watts and Strogatz, 1998).

The methodological strategy was to contrast the proposed agent-based model, assuming selective attention and local bias, to alternative models that have more conservative assumptions about consumers (i.e., consumers value either complementary product quality as is and/or the general connectivity of the consumer network). The finding that the proposed model fit the empirical data best, and that the alternative models did not actually fit the data at all, led us to conclude that platform adoption decisions and thus competitive outcomes were likely shaped by consumers' selective attention and local bias. Therefore, we attributed the success of PlayStation 3 to its ability to actively renew its pool of complementary products and their quality. Because of selective attention, actively introducing new good-quality complements to the market matters more for adoption than expanding the size of the pool of complementary products and its overall quality. Importantly, however, we also showed that if it was only about actively renewing the complement pool, PlayStation 3 should have won with a clearer margin. In other words, the installed base of Xbox 360 protected it from the entry, but only to a degree given the locally biased consumers who adopted the late entrant if the cosumers' friends had not adopted Xbox yet (if consumers had valued the installed base as a whole, Xbox should have arguably won despite PlayStation's quality advantage). Finally, it appears Xbox's pricing advantage was unsustainable as well. To put it in another way, the study demonstrated that a late entrant platform may *rationally* price higher than an early entrant platform because of sustained vertical differentiation (i.e., sustained quality advantage). For an illustration of the predictive ability of the model, see Figure 5 (for detailed analyses of model parameterization, see the original publication).

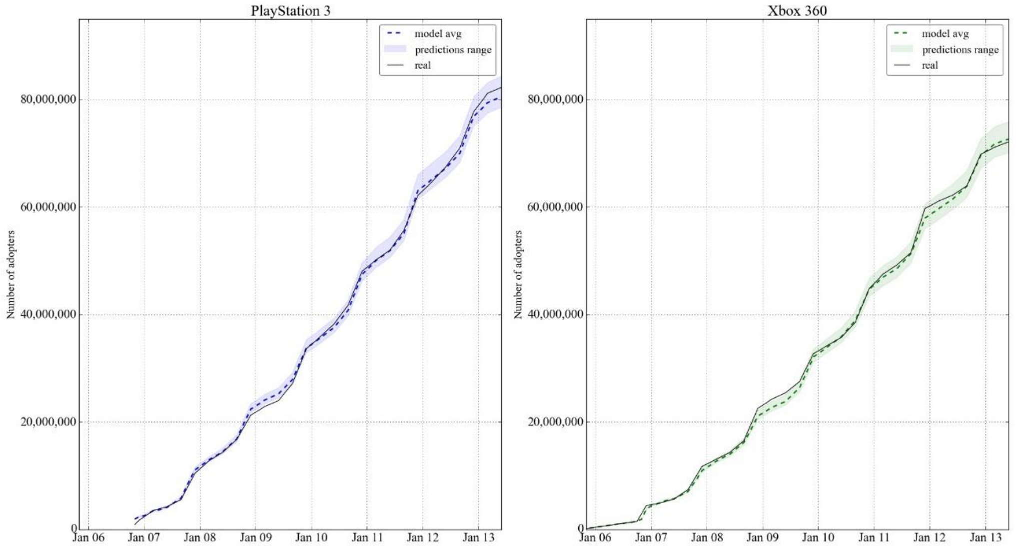

Figure 5. The most accurate predictions of the agent-based model vs. real number of adopters for the competing platforms PlayStation 3 and Xbox 360.

All in all, the main contribution of the paper was to introduce the new selective attention assumption of consumers to the study of platforms, and also to provide empirical evidence for the local bias assumption. Albeit the latter assumption is not new, the two assumptions together (i.e., neither alone) help explain why a late entrant platform with an ability to actively renew the pool of complements may also sustain higher prices in platform competition, and win.[42] Apart from problematizing the winner-take-all argument (Alvesson and Sandberg, 2011), the study was also among the few that used agent-based simulation for *predicting* empirical phenomena directly. Thus, although the study did not develop new methodology per se (Fagiolo *et al.*, 2007; Kelton and Law, 2000), the study arguably provided a minor illustrative methodological contribution to the literature that has not fully realized the potential of agent-based simulation in studying (platform) strategy and competitive dynamics.

[42] To emphasize, because of our focus on modeling consumer adoption, we did not examine why PlayStation was able to sustain its complement quality advantage despite Xbox lead the competition in terms of the installed base, availability of complements, and pricing, as the data show. Uncovering the rationales behind such as an unexpected finding would obviously be an interesting direction for further research.

4.2 II: "Too big to fail? Overcrowding a multi-sided platform and sustained competitive advantage"

4.2.1 Background and objective

The second paper also challenged the winner-take-all argument, providing additional explanations for the oligopolistic market outcomes of platform competition. Unlike in the first publication, where quality differentiation was of primary interest (see also Hossain *et al.*, 2011), in the present paper I studied competition between *identical* platforms. Specifically, I investigated with a conceptual agent-based model whether it was still possible for an undifferentiated late entrant platform to challenge an incumbent platform with full initial support from buyers and sellers (who singlehome). If so, and as happened to be the case, the study would highlight that the lack of platform differentiation may explain the non-persistence of installed base advantages.

4.2.2 Results and contributions

The simulation results demonstrated that overcrowding a platform with too many sellers—that is, a situation in which the platform is unable to sustain a sufficient performance for all sellers—can trigger *disruptive demand dynamics* in which the incumbent platform with full initial support from buyers and sellers loses that support and will thus share the market with an entrant although its attributes are identical to those of the incumbent (e.g., pricing, types of sellers). Specifically, I showed that the relative number of sellers to buyers on a platform increases the likelihood that the platform will lose its installed base advantage.

The result is simply driven by negative direct (i.e., within-platform competition among sellers) and positive indirect network effects (i.e., buyers value more sellers, and vice versa). When even a small number of lonely buyers (e.g., "snob" users; Stremersch *et al.*, 2007) affiliate with an entrant platform with no seller support, and even if the sellers switching to the entrant platform have to regain their reputation (i.e., I assumed that a seller's preceding sales on a platform will positively affect the seller's future sales on the platform, which is why agent-based simulation needed to be used here),[43] the sellers switch when the platform has enough buyers to compensate for the loss in seller reputation.[44] In other words, extreme competition drives the "excess" sellers to the entrant

[43] For example, on Amazon.com, a buyer can observe the other buyers' reviews of a seller before making the decision to interact. One would expect that the highly prominent sellers are more reputable, and that reputation fosters further seller sales. In other words, if a seller has not made a sale on a platform, the seller has no reputation on the platform and therefore the seller has to build the reputation "from scratch". In the agent-based model, the variety seeking behaviour of buyers (that I describe below) makes it possible that they can "accidently" interact (against the expected probability of the interaction) with sellers with no reputation.

[44] Along with enforcing buyers and sellers to singlehome, the assumption that seller reputation is non-transferable across platforms makes it more likely, other things being equal, that the sellers do not disrupt their own sales by leaving the incumbent/affiliating with the entrant platform. In other words, had I assumed

where the sellers still have a chance of making a sale because of low competition. This in turn triggers more buyer support for the entrant, in which case more sellers jump in, and so on (i.e., because of positive indirect network effects), eventually disrupting the incumbent. The identical competing platforms will then share the markets for buyers and sellers equally.

However, and to emphasize, the incumbent platform can apparently sustain its installed base advantage if the incumbent had sufficiently few sellers relative to the number of buyers, and even if some of the latter chose to unexpectedly affiliate with the entrant. To clarify, buyers were assumed to affiliate with platforms (and interact with sellers) probabilistically based on the number of sellers (preceding seller sales), and the buyers were also assumed to be variety seeking (e.g., McAlister and Pessemier, 1976), but only to the slightest degree. That is, I allowed for a small probability of buyers affiliating with the (entrant) platform that has no/a lower number of sellers (and interacting with a seller with no reputation), such that it was still expected (i.e., if we naively calculate the expected number of buyers/sellers at time $t + 1$ based on platform usage at time t) that the platform with an installed base advantage would win (see the equations in the paper). It turned out that the chance events were not likely enough to trigger the self-sustaining demand dynamics that disrupt the incumbent platform if it was not overcrowded. In this case, the lonely buyers/excess sellers leaving the incumbent are too few to trigger positive indirect network effects in favor of the entrant platform.[45] To illustrate these findings, Figure 6 plots the market shares of the incumbent platform with respect to the number of buyers and sellers, and time.

seller reputation was transferable (which it might be in reality), it would not have been too surprising to observe that the sellers can switch to the entrant platform. Moreover, if sellers were allowed to multihome as well, one might have presumed, on the one hand, that multiple platforms will more likely share the market because the sellers may just as well support multiple platforms (if not too costly), and then the buyers would be indifferent to choosing on which platform they interact with sellers (Corts and Lederman, 2009). However, I acknowledge that the analyses could be expanded in the future such that the assumptions are relaxed, and their criticality is assessed, because it is not evident that the results will hold (given the limited space in the original publication, I kept the model as simple as possible). For example, non-transferability of seller reputation also implies that the disruptive demand dynamics are more likely to become self-sustaining, because the sellers who already support the entrant platform are thus also less likely to switch back to the incumbent platform, other things being equal.

[45] Because the stochastic model of mine can produce results consistent with the winner-take-all argument (i.e., when the incumbent platform has sufficiently few sellers relative to buyers), the results are not clearly random and merely due to the probabilistically behaving buyers.

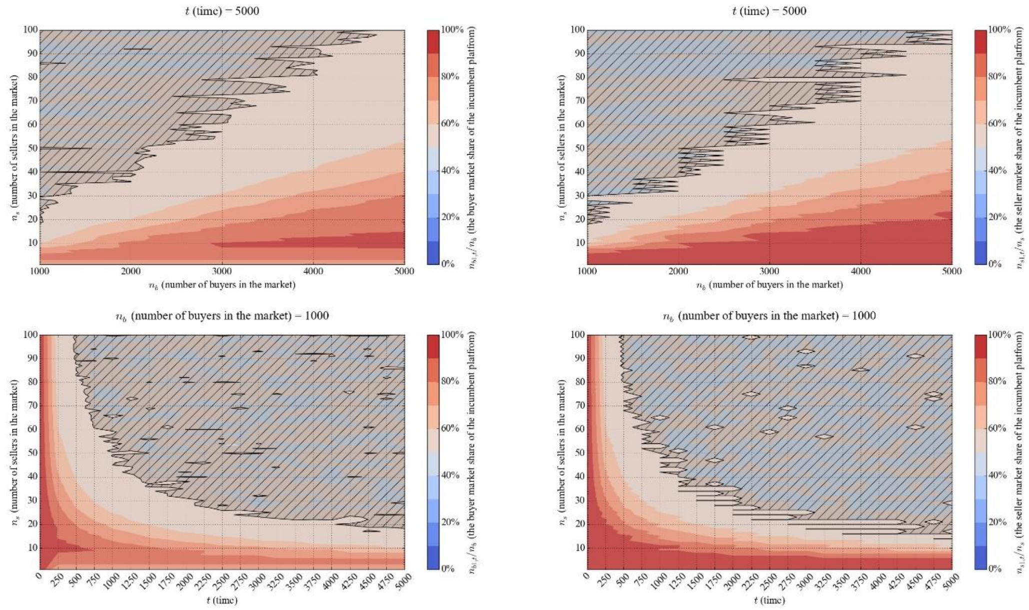

Figure 6. Median buyer (left) and seller (right) market shares of the incumbent platform with respect to the number of buyers and sellers in the market (upper), and with respect to time (lower). The hatched areas indicate the range of parameters where disruption of the incumbent platform is observed.

To the best of my knowledge, although within-platform competition has been accounted for in some economic models of platforms (Belleflamme and Toulemonde, 2009) and the resulting negative effect of congestion on platform performance has been discussed (Liebowitz and Margolis, 1994; Tucker and Zhang, 2010), researchers have not shown that extreme seller competition may trigger disruptive demand dynamics from the incumbent platform's perspective. This finding is highly relevant since complementors can rarely sustain their competitiveness in hypercompetitive platform environments (Kapoor and Agarwal, 2017), so one would expect that overcrowding is a common determinant of platform disruption, other things being equal. The study thus adds to the literature by highlighting the important role of negative direct network effects (i.e., competition among sellers) in shaping inter-platform competitive outcomes. Specifically, the study explains how a lack of differentiation may explain platform disruption in case of overcrowding (Cennamo and Santalo, 2013; Hossain *et al.*, 2011).

4.3 III: “Complementor strategy and platform performance”

4.3.1 Background and objective

As is evident by now, the platform literature has examined platform strategies and their performance implications in great depth, while giving little attention to examining what drives complementor performance, and how the interdependence between complementor and platform strategy affects the latter (McIntyre and Srinivasan, 2017). However, understanding this interdependence is crucial since strategic complementors do not simply cooperate in favor of the platform, but complementors compete against other complementors and the platform in order to make a profit. At worst, strategic complementors may act to hinder platform performance, for example by decreasing complement and hence platform quality (Wareham *et al.*, 2014). Therefore, this paper was (and is) among the few attempting to formalize complementor strategy (or at least some parts of it) and examine the performance effects of complementor strategizing on platform performance.

The paper focused specifically on formalizing complementors’ within-platform competitive moves related to quality, pricing, and horizontal differentiation in the consumer genre preference space (Cennamo, 2016) and examined the effects of platform commission fees on platform performance with agent-based simulation under the assumption of strategic complementors (see also Lee, 2014). A further implicit motivation behind the study was to explore the reasons for the skewed performance outcomes of complementors that are apparent in platform-based markets (Binken and Stremersch, 2009; Kapoor and Agarwal, 2017).

4.3.2 Results and contributions

Because of the lack of research on complementor strategy (for exceptions, see Boudreau, 2010, 2012; Kapoor and Agarwal, 2017; Venkatraman and Lee, 2004), the present formalization was a contribution. However, it accounted for only a small fraction of relevant decisions—that is, the setting of quality levels, prices, and locating in the consumer genre preference space, decision variables that also affect platform performance and competitiveness (Cennamo, 2016)—while omitting decisions on entry timing and diversification across platforms (i.e., single- vs. multihoming). Despite the limited scope, we assessed complementors’ equilibrium strategies (emerging over time) on a monopoly platform that sets commission fees exogenously. Figure 7 illustrates the formalization, in which the strategy (i.e., quality, price, and genre) of a complementor depends on the expected strategy of the closest rival within the platform.

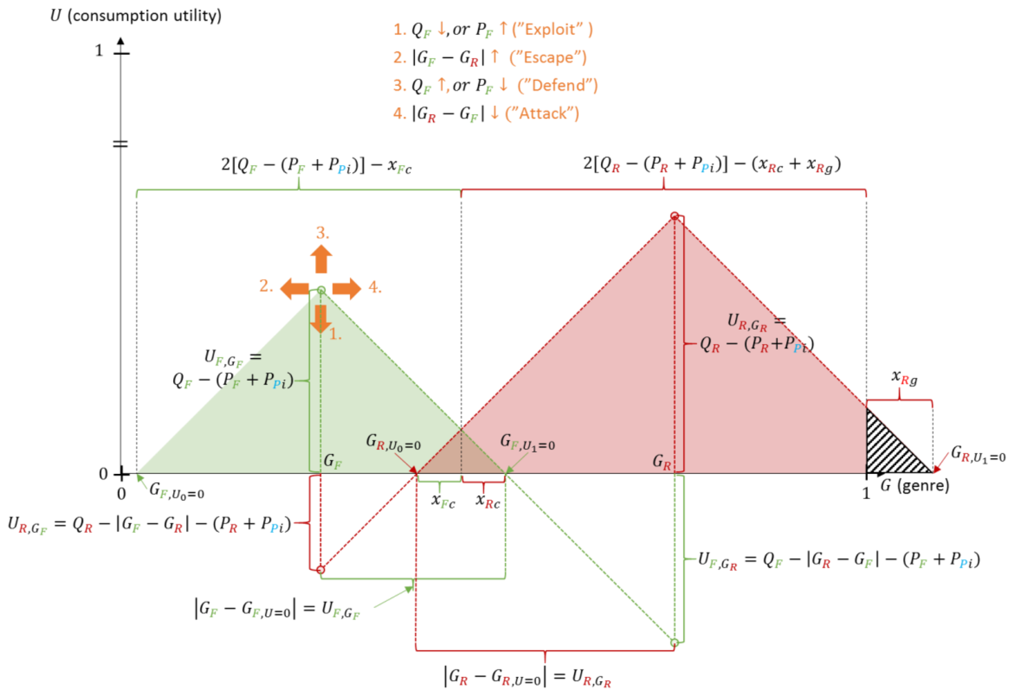

Figure 7. Consumption utilities of the focal complementor F and its closest rival complementor R with respect to their present genres and F's strategic options.

The implicit assumptions behind this framework (Figure 7) are that, first, consumers favor transacting with better-quality complementors with low prices (note that they account for platform commission fees as well) and that can satisfy the consumers' uniformly distributed (between 0 and 1) type or genre preferences. Thus, it is possible to picture a zone in the consumer preference space where the complementor is possibly competitive (i.e., the region where the utility triangles lie above zero on the y-axis). Second, due to limited attentional capabilities, complementors cannot account for the strategies of *all* rival complementors within (and outside) the platform as they are typically too many (Boudreau, 2012). Thus, we assumed that complementors focus on competing with their closest rival (in reality, they may compete with a small number of closest rivals). Third, a complementor adjusts its strategy adaptively (Kapoor and Agarwal, 2017) through incremental changes in the strategic parameters (one at a time, for simplicity) over time, and at a time the tactical choices involve four possible moves as pictured in the figure. The tactic of choice at the time is the Nash equilibrium of the subgame between the focal complementor and its closest rival complementor.[46] In summary, complementors'

[46] Why would a complementor decrease quality, as pictured in the framework? Because decreasing quality lowers complement production costs, and thus may outweigh the negative effects on revenue, if rival complementors are not to outcompete the focal complementor either. In other words, we posit that

equilibrium strategies emerge over time as a result of dynamic adaptation in the complementors' changing competitive landscape.

It follows that, as the simulation results confirmed, complementor heterogeneity in strategies and performance may simply be attributable to their adaptive decision-making process. We assumed the strategic attributes of all complementors initially were homogenous. Therefore, the effects of platform commission fees on the platform's revenue performance were found to be highly non-linear (see Figure 8). The optimal price structure of the platform is practically unpredictable given the complementors acted as described (the upper two rows in the figure). Should the platform owner be able to optimize the price structure, increasing the number of complementors and consumers on the platform does not automatically increase platform profit either (the lower left subplot in the figure). Strategic complementors may apparently crowd out the market and thus, as a whole, act against the optimally priced platform (take also the increasing variance in platform performance outcomes when more complementors are added to the market, as pictured in the lower right subplot in the figure).

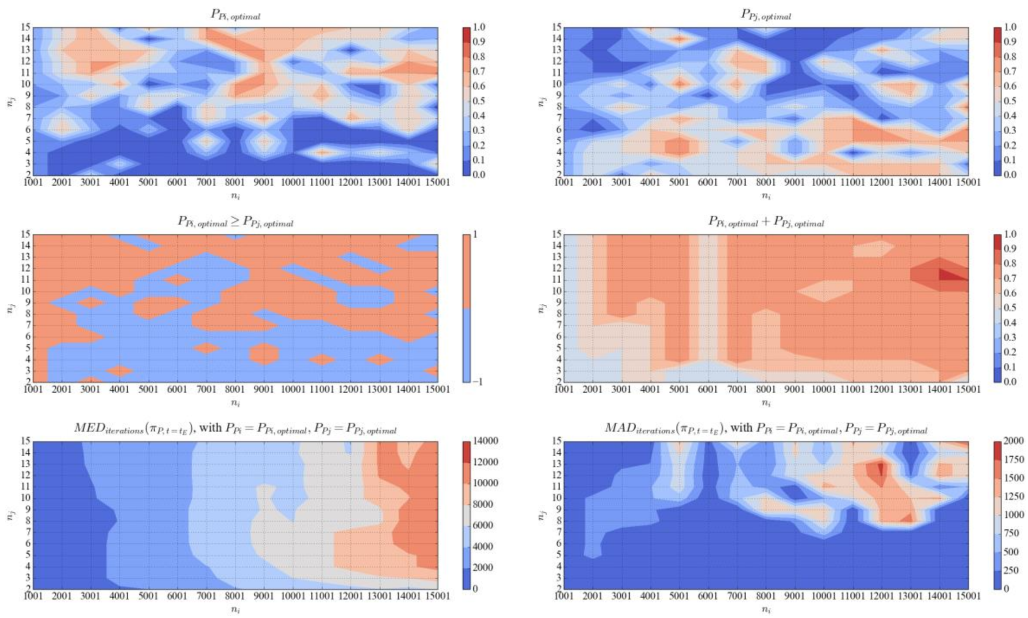

Figure 8. Optimal commission fees to consumers $P_{Pi,optimal}$ and complementors $P_{Pj,optimal}$ and the resultant median platform profits in equilibrium of simulation iterations $MED_{iterations}(\pi_{P,t=t_E})$, and their median absolute deviations $MAD_{iterations}(\pi_{P,t=t_E})$—with respect to the number of consumers n_i (x-axes) and complementors n_j (y-axes) in the market.

insufficient competition among complementors may make them exploit their market power (i.e., they lower quality), thus hurting the platform.

In summary, the paper contributes to the extant literature by formalizing complementor strategy and examining its effects on platform performance and (pricing) strategy. Although the results give a somewhat chaotic picture of the market dynamics, in contrast to the literature that presents more stylized facts, we argue that the bounded rationality of complementors that drive the results is a representative assumption, and thus, there is some validity in the unpleasant results (i.e., managing complementors through pricing is hard if not impossible). Note that, however, the model omits important strategic choices made by complementors and platforms, and platform competition, which may affect performance outcomes. The results might imply that effective governance is required for managing autonomous complementors (Boudreau and Hagiu, 2009; Wareham *et al.*, 2014). Furthermore, there are still some *small* technical issues (see the publication for more information) regarding obtaining Nash equilibria in the subgames that need to be solved in future research.

4.4 IV: "Distributed innovation in platform-based markets: The rationale, scope, and implications of complementor specialization"

4.4.1 Background and objective

The essence of the platform-based business model is to distribute innovation to third-party complementors and thus leverage demand-side economies of scale (Baldwin and Woodard, 2009; Boudreau, 2012; Dougherty and Dunne, 2011; Wareham *et al.*, 2014). Given this apparent division of labor between platforms and complementors, the present study was motivated by the empirical fact that complementors can and do *further* distribute innovation in the within-platform value chain and that this is highly prevalent. See Figure 9, which illustrates how most game producers outsource marketing to external third-party publishers (resellers) in the advanced video gaming console markets (www.metacritic.com).[47] Despite this, to the best of our knowledge, this vertical scope specialization of complementors, which is bound to affect complementor innovation and thus, platform performance, has received little attention from scholars (for an exception, see Broekhuizen *et al.*, 2013). To emphasize, this constitutes a significant research gap, because as far as we wanted to understand the determinants of platform performance (i.e., the ultimate goal of platform strategy research), it is important to understand "how complementors' attributes and *structural positions in the platform-complementor ecosystem* [emphasis added] influence their likelihood of support to a platform" (McIntyre and Srinivasan, 2017, p. 155). Thus, the present paper attempted to conceptually explain the rationale, scope, and implications of this complementor specialization in the within-platform value chain and proposed revenue performance effects on platforms.

[47] I greatly appreciate the help from Jukka Huhtamäki in obtaining the data.

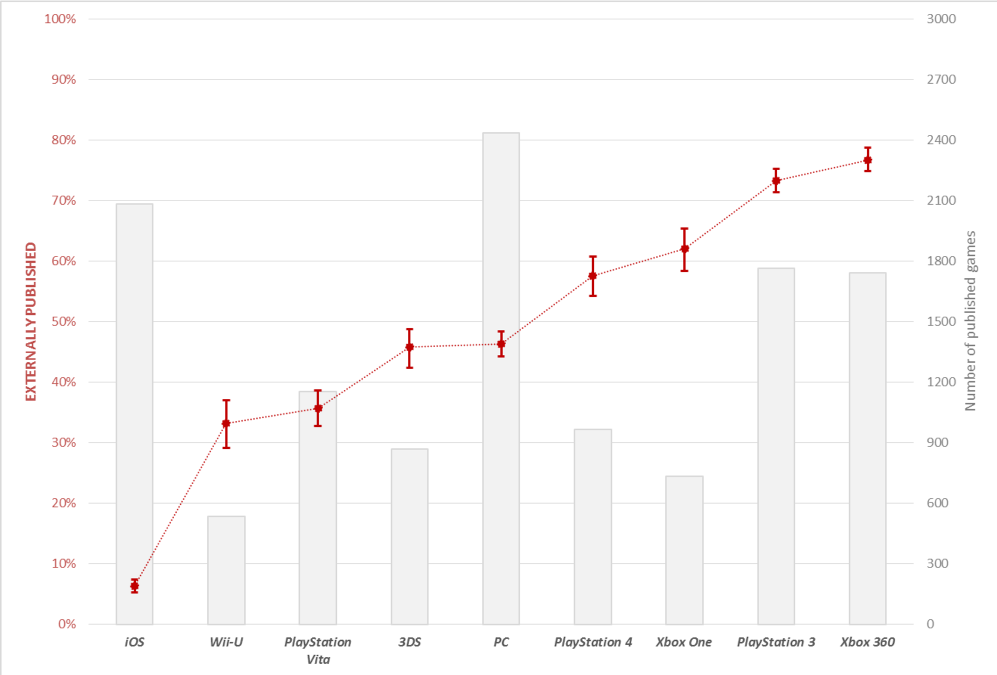

Figure 9. Proportion of externally published games and the number of published games for the nine major gaming platforms, according to Metacritic (on June 11, 2016). The bootstrapped confidence intervals (at the $\gamma = 0.95$ confidence level) for the proportions were calculated with nonparametric bootstrapping with 1000 bootstrap samples (Efron and Tibshirani, 1994).

4.4.2 Results and contributions

The main result of the paper is the following multi-level theoretical framework (Figure 10) that explains why complementors specialize in the within-platform value chain and how that affects the platform's revenue performance. In brief, complementor specialization is arguably driven by the scarcity of resources in innovation, as their resources are limited, and because innovation is the primary role of complementors in platform-based markets (by definition, multi-sided platforms outsource innovation to the third parties). To clarify, innovation is defined here as the production and marketing of complementary products and services—production then refers to coming up with the complementary products, while marketing is understood broadly as the commercialization stage of the innovation process. Specialization in production relieves internal marketing resources to be used in production, while marketing is outsourced to third-party resellers.[48] Thus, complementors preserve their autonomy (profitability)

[48] While a multi-sided platform facilitates interactions between complementors and consumers, the platform does *not* commercialize the complementary products, by definition (Hagiu and Wright, 2015a). Due to

through specialization when resource demands in innovation increase (Broekhuizen *et al.*, 2013; Drees and Heugens, 2013). The premise behind the argument is that platforms distribute innovation to complementors in the first place, because platforms would not have the resources to innovate in such a scale that the complementors do as a whole (Baldwin and Woodard; 2009; Boudreau, 2010, 2012). Therefore, the more general argument is that external resource dependencies in innovation explain firm boundaries in platform-based markets, consistent with resource dependence theory (Pfeffer and Salancik, 1978).

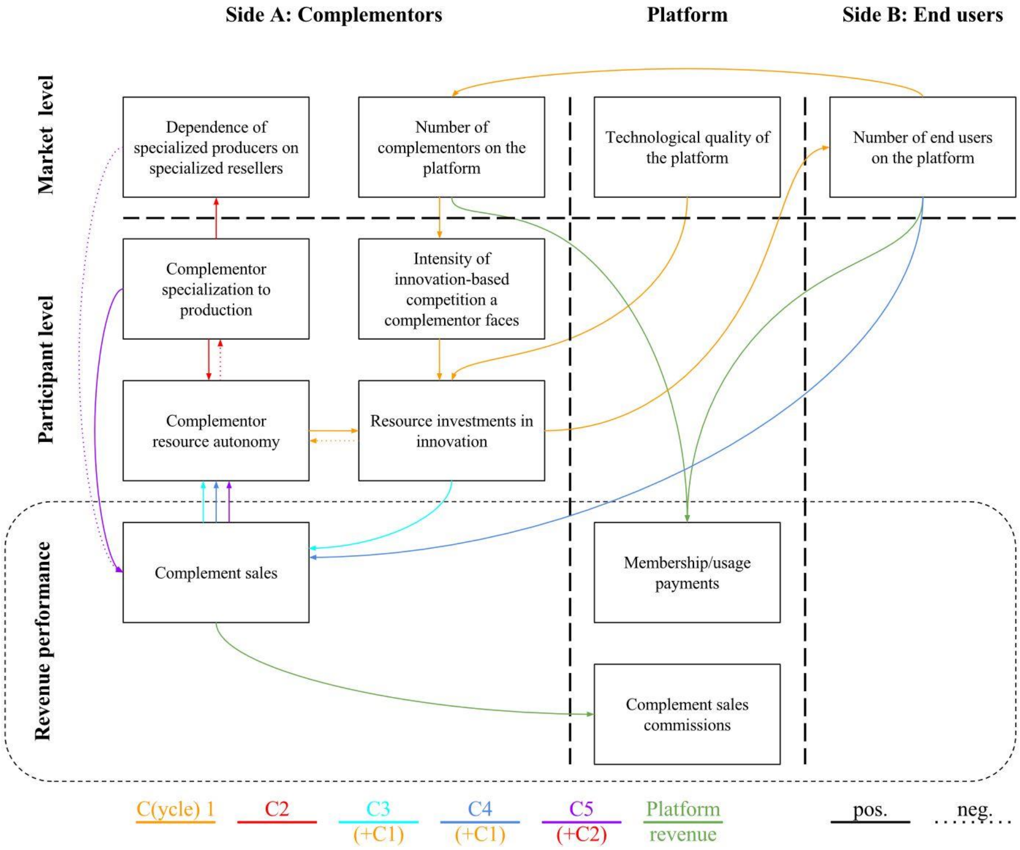

Figure 10. The effects of platform-based market structural characteristics on platform revenue performance.

Furthermore, we argued that there are two primary drivers of increasing resource investments in complementor innovation, and thus their vertical scope heterogeneity. First, and quite clearly, staying behind competing complementors is not an option when

complementor specialization in production, marketing is then outsourced to third-party resellers (e.g., game publishers), which are distinct from the platform (Hagiu and Wright, 2015b).

they all try to gain an edge through innovation (i.e., the escape competition effect; Aghion *et al.*, 2005). That is why platform owners wish to stimulate within-platform competition (Armstrong, 2006; Cennamo and Santalo, 2013). Second, and more interestingly, we argued that the quality of platform technology, in terms of features that contribute to complementary product quality (e.g., storage capacity of a gaming console enables making more content to a game), increases complementor innovation resource investments as the making of high-quality complements necessitates utilizing advanced technology (Claussen *et al.*, 2015). Looking back at the empirical data (Figure 9) once more, it shows *pretty*[49] clearly that specialization is directly and strongly proportional to the hardware quality of a gaming console.[50] To emphasize, although the data are limited, the variance in external publishing across the platforms is huge enough (e.g., more than a ten-fold difference between iOS and PlayStation 3/Xbox 360 in terms of percentage points) that the proposition platform quality plays a role in complementor specialization is warranted.

Finally, because complementor specialization is arguably affected by resource demands in innovation, and vice versa (i.e., specialization ensures that there is a sufficient amount of resources to innovate), it is quite clear that the platform benefits from complementor specialization in terms of increased revenue performance, other things being equal. The multi-level framework was devised, based on extant literature, to illustrate this effect (see the various demand dynamics in the figure). For example, complement sales and thus commission fees are preserved when complementors can retain their ability to innovate through specialization. However, to complicate things, specialization may not be possible if there are few if any internal marketing resources yet to be outsourced (that is, the producer is already fully dependent on external resellers in marketing). It follows that complementor specialization serves the platform in a way that the platform can boost its performance through increasing its technological quality (Gretz, 2010; Zhu and Iansiti, 2012), *as long as complementor specialization is possible*. Thus, as an example, the performance of platform owners in the advanced video gaming console markets was hurt after the owners intensified the within-platform competition too much (Cennamo, 2016; Cennamo and Santalo, 2013) perhaps in part because most complementors in these markets were already specialized as indicated in our data (i.e., the average complementor may not withstand too much competitive pressure as the complementor cannot specialize any further). Moreover, increasing overall dependence on external resellers may increase their bargaining power to the degree that the producers and thus the platforms will be worse off in revenue performance.

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[49] Note that we use the data only as *anecdotal* evidence, because there are only nine observations of hardware of which only PCs would have had enough temporal variation in hardware quality, if we were to have the panel data, to estimate its effect on specialization.

[50] While we do not have exact technological specification data of the consoles, it is clear that PlayStation 3/4, and Xbox 360/One are of higher quality (e.g., in terms of processor speed, storage capacity, etc.) than the handhelds (i.e., 3DS, PlayStation Vita, Wii-U, and iOS-devices). PCs are a more problematic category to compare because of the vast heterogeneity in PC hardware.

In summary, the paper adds to our understanding of industrial organization of platform-based markets (Evans and Schmalensee, 2007a; Tee and Gawer, 2009) by explaining how external resource dependencies affect firm boundaries, and distribution of innovation (Baldwin and Woodard, 2009; Boudreau, 2012; Broekhuizen *et al.*, 2013; Hillman *et al.*, 2009; Santos and Eisenhardt, 2005). Integrating resource dependence theory (Pfeffer and Salancik, 1978) in the study of multi-sided platform structure has enabled us to open up the black box of the complementors market side (Hagiu and Wright, 2015b; McIntyre and Srinivasan, 2017), and opened up new avenues for future research especially in terms of understanding power (im)balances (Casciaro and Piskorski, 2005) between the platform-based market participants. For example, the distribution of value between third-party producers and resellers, and platforms remains to be explicated. Note that agent-based simulation was not used here, because the theoretical grounds were so underdeveloped (Davis *et al.*, 2007).

4.5 V: "Does becoming a platform pay off? Reconfiguring the business model for two-sided markets"

4.5.1 Background and objective

Enabled by Internet technologies that make business model change and development highly flexible (Amit and Zott, 2001; Wirtz, Schilke, and Ullrich, 2010), digital content industries such as software, entertainment, or media are increasingly experimenting with hybrid business models. One prominent model is *freemium* (e.g., LinkedIn, Spotify), which "has become the dominant business model among Internet start-ups and smartphone app developers" (Kumar, 2014, p. 27). The "free" component of the freemium model is often advertising-based where the platform is monetized indirectly through sponsoring advertisers (Casadesus-Masanell and Zhu, 2013). However, Kumar (2014, p. 28) noted that "despite its popularity and clear benefits, freemium is still poorly understood." Further, business model innovation or change remains an unsubstantiated topic (Achtenhagen, Melin and Naldi, 2013; Chatterjee, 2013; Demil and Lecocq, 2010). According to Casadesus-Masanell and Zhu (2013), they were *first* (p. 464) to formally model business model innovation or change, and especially sponsor-based models. Other than that, there are to date no known studies of intertemporal dynamics—that is, whether changing between free and premium over time pays off—and we contend that this is a significant research gap. Changing between the two business models is commonplace, especially in the digital content industries; for example, many gaming firms have changed during the game life cycle from subscription-based to "free-to-play" (e.g., Bethesda's "The Elder Scrolls Online" and Carbine with "Wildstar"). These examples also demonstrate how the staged solution to building up a platform may be the optimal strategy, instead of immediately going platform-based (Hagiu and Eisenmann, 2007). To formalize these arguments, in this paper we came up with an agent-based simulation model with which to study the dynamic performance effects of changing between subscription-based and platform-based (advertising-based) business models, the "components" of freemium.

4.5.2 Results and contributions

The present study contributes to the emerging body of research on business model change as well as platform-based business models (Hagiu and Wright, 2015b; Rochet and Tirole, 2006) by investigating the dynamic performance effects of switching between subscription-based and advertising-based models (as instances of non-platform and platform-based approaches). Our main argument is that the potential for *intertemporal price discrimination* (Nair, 2007; Papanastasiou and Savva, 2016; Stokey, 1979) may explain the benefits of business model change for the focal firm. For instance, in switching between subscription-based and advertising-based models, consumer pricing is among the many things that change. Over time, this switching in itself constitutes a business model that we call *dynamic freemium*, in which a product or service is sequentially offered both free of charge and at a premium price. Just as the rationale of pure freemium is static price discrimination (Demil and Lecocq, 2010, p. 231; McGrath, 2010; Teece, 2010), switching between business models may enable a firm to exploit differences in consumers' reservation prices or utilities over time by means of abrupt price changes. To the best of our knowledge, existing studies have not explained when freemium models work, especially in dynamic settings despite the ubiquity of such models, especially in the software industry (Kumar, 2014). If dynamic freemium performs well, setting up a platform in stages is about more than overcoming the chicken-and-egg problem or pessimistic expectations (Caillaud and Jullien, 2003; Hagiu and Wright, 2015a, 2015b). The potential for price discrimination means that digital content providers may find it inherently beneficial to switch between non-platform-based and platform-based models.

We built an agent-based simulation model to understand the effects of dynamic freemium on revenue performance in the digital content industry. The simulation results (see the publication for numbers) indicate that changing from the subscription-based to the advertising-based business model can yield better overall revenue performance over time than adherence to either business model alone. In other words, reducing the price of usage from subscription price to zero when changing the business model can effectively discriminate between consumers who are willing to pay the price premium and those who are not but will come on board when the app (platform) is free to use, despite the nuisance of ads. This result seems robust to modest variations in consumer and advertiser characteristics (distribution of reservation utilities), although the relative performance of business models pre- and post-change is affected. Effective price discrimination is likely to require price setting and content/platform design that is suboptimal pre- and/or post-change, given that short-term (pre- and/or post-change) revenue performance tended to be lower for business model switching than overall revenue performance for either model alone. Reflecting on the "static" freemium, this seems intuitively plausible; clearly, the optimal subscription price will be lower when not discriminating between consumers, as this is the only way of driving more reserved consumers to pay. The same logic applies in the dynamic setting; less reserved consumers would come on board even if the subscription price was higher than in the optimal "static" scenario (subscription-based model alone). As a result, more reserved consumers would wait for a price decrease, which can be delivered by changing the business model.

We also found that switching from an advertising-based to a subscription-based business model is less beneficial than switching in the opposite direction—that is, the returns from switching are likely to be asymmetric, other things being equal. This is explained by content consumption dynamics; if consumption is not limited pre-change when the content is free-to-use, most if not all consumers will find that the disutility due to a price increase (as a result of business model change) is greater than the utility of "remaining" usage, and the content will no longer be used. In the simulations, business model change was set to occur after all consumers had stopped using the content, regardless of the direction of change. Restricting usage pre-change might therefore increase the benefit of switching from an advertising-based to a subscription-based model, as there would necessarily be "premium content" for consumption following the change. This is indeed the rationale for static freemium, as free versions often lack the premium features available through subscription (Kumar, 2014; McGrath, 2010; Teece, 2010). Our findings explicate how free content is detrimental to the performance of dynamic freemium if these features are *not* limited. Further, we found that this effect is asymmetric—that is, when changing from subscription-based to advertising-based, it is *not* necessary to limit the features of free content to realize positive returns because subscription pricing prevents less reserved consumers from acting opportunistically by consuming all content while it is free. Our simulation results also suggest that if changing from advertising-based to subscription-based is to be worthwhile, limiting consumption pre-change *is* necessary (other things being equal) because less reserved consumers will exploit the free content. However, we found that the benefits of limiting consumption were insufficient to make it a better strategy than business model change in the other direction, regardless of distribution of reservation utilities. In some user settings, the change strategy performed even worse than either standalone business model.

The individual-level path dependencies in consumption account for both the successes and failures of dynamic freemium (and are the reason why agent-based simulation needed to be used here). Assuming no diminishing returns on content usage, a firm has no incentive to switch between business models because any hypothetical short-term benefits of switching are mitigated by the long-term benefits of a single optimal business model.[51] In contrast, diminishing returns on usage limit the potential value that can be captured over time, and the short-term benefits of switching between free and premium may therefore be substantial. However, as discussed, path dependencies in consumption also dictate that switching from free to premium is not beneficial unless pre-change consumption is limited (e.g., by offering limited content per se, or by changing the business model before users can take full advantage of free content). This may further explain why going from free to premium can be problematic, beyond consumers' dislike of price increases (see Pauwels and Weiss, 2008). For practitioners, the main significance

[51] Disregarding the path dependencies arising from network effects that may warrant staged setup of the platform (Hagiu and Spulber, 2013; Hagiu and Wright, 2015a, 2015b).

of our research is that any freemium business model must be carefully designed, especially in dynamic settings, where it may be necessary to limit free content consumption. At best, business model switching may extract more value from consumers through intertemporal price discrimination.

4.6 Summary

Overall, the five publications contribute to our understanding of platform-based market structural properties and the determinants of platform performance and competitiveness, from a variety of angles. The first publication was an empirical study, while the rest were largely conceptual. Further, the first three and the fifth utilized agent-based simulation as a methodology, while the fourth was purely conceptual (with anecdotal data to support the arguments). For a summary of the papers' contributions, see Table 2.

Table 2. Summary of the five publications in the dissertation.

Publication	Objective	Contribution
I: *Winner does not take all: Selective attention and local bias in platform-based markets*	Explore reasons why a late entrant platform may win the platform competition	Incorporates consumers’ selective attention assumption in the study of platforms and demonstrates how this attribute, along with local bias, contributes to oligopolistic outcomes of platform competition
II: *Too big to fail? Overcrowding a multi-sided platform and sustained competitive advantage*	Explore reasons why a late entrant platform may win the platform competition	Demonstrates how overcrowding an undifferentiated incumbent platform with too many sellers may trigger self-sustaining demand dynamics that disrupt the platform in competition
III: *Complementor strategy and platform performance*	Formalize the complementor strategy and explore the effects of complementor strategizing and heterogeneity on platform performance	Demonstrates how heterogeneity of complementors may be attributable to their adaptive strategy decision-making process, and thus, why the platform price structure is hard to optimize
IV: *Distributed innovation in platform-based markets: The rationale, scope, and implications of complementor specialization*	Explain the drivers of complementors’ vertical scope heterogeneity and its effects on platform performance	Redefines the industrial organization of platform-based markets to account for complementor specialization in the within-platform value chain and explains how complementors’ future ability to specialize enables a platform to more aggressively introduce advanced hardware
V: *Does becoming a platform pay off? Reconfiguring the business model for two-sided markets*	Explore the dynamic performance effects of changing between traditional and platform-based business models	Shows that changing the business model may be the optimal strategy, yet the returns from change between traditional (subscription-based) and platform-based (advertising-based) business models are asymmetric, highlighting how path dependencies in content (platform) consumption determine the optimal direction of change

5 Strategic interaction and platform strategy: propositions for future research

In this section, I further characterize the strategic interaction between platforms, complementors, and consumers. Then, I discuss potential implications for platform strategy. Overall, this section of the thesis builds on the extant literature and the author's publications. Note that the subsections do not follow a particular order, except that I first present the baseline of strategic interaction and then discuss its implications in more depth. The result is a set of novel propositions for the performance and competitive effects of platform strategies.

I acknowledge that any individual proposition that I develop is worth a more in-depth investigation. For example, the propositions are likely to omit external factors that further affect (e.g., moderate) the proposed relationships between constructs. However, fully developing and validating the individual propositions (six in total) is clearly beyond the scope of this dissertation, because such a task is likely to necessitate coming up with multiple, if not six full papers. Rather, my primary goal is to expand on the issues arising from my research and the extant literature, providing useful suggestions for future research, at the least. The propositions are developed to make the suggested future research directions more evident.

5.1 The baseline

When acknowledging complementors and consumers act strategically, implying that they have aligned and misaligned strategic objectives from the perspective of a platform, the platform should help complementors and consumers reach their goals (i.e., cooperate) *and* act against those goals (i.e., compete with complementors and not maximize consumer utility) simultaneously. In general, this idea refers to the strategy of "coopetition" (Brandenburger and Nalebuff, 2011). Platforms compete with complementors either literally through engaging in competition within the platform (i.e., vertical integration) or indirectly through strategies (e.g., pricing) that are not in the best of interest of the complementors. Simultaneously acting for and against complementors ensures that complementor innovation is encouraged, but the complementors are also "kept on their toes" so that they align with the platform's strategic goals. To explicate, platforms and complementors may not jointly maximize their own profits if they were purely cooperative (Economides and Katsamakas, 2006; Mantovani and Ruiz-Aliseda, 2015). Similarly, maximizing consumer utility may not always be beneficial for the platform. For example, restricting complementor access to a platform and thus, reducing complement variety and diversity (Boudreau, 2012) decreases consumer utility. However, as I argue, it may be vital for controlling competition among complementors so that it does not escalate on the platform (recall the case of Atari).

Therefore, platform strategy is inherently about dealing with cooperative and competitive tensions, or strategic trade-offs (Cennamo and Santalo, 2013). Conversely, complementor strategy is about managing the trade-off between maximizing focal profitability and helping the platform achieve that goal as well. In the end, complementors could not make a profit at all if the platform did not provide the resources to reach consumers. Finally, consumers cannot just benefit from interacting with complementors but must also bear the prices of platform affiliation and complementary products and count on the platform's ability to provide more value in aggregating network effects. Overall, this constitutes a *trilateral* bargaining game.

Additionally, one major component in the characterization of strategic interaction in platform-based markets is bounded rationality, or even irrationality, of the actors (Arthur, 1994; Simon, 1991). That is, I conjecture that *none* of the involved actors can make perfectly rational decisions. For example, the fact that some authors have identified strategic trade-offs in platform-based markets (Cennamo and Santalo, 2013) implies some platform owners made bounded rational decisions. That is, identifying the negative effect of *simultaneously* pursuing multiple seemingly beneficial strategies (i.e., securing exclusivity deals and expanding the variety of complements) necessitated observing the negative performance outcomes in reality (which would not have happened if the platform owners were perfectly rational). In all my publications, I have accounted for bounded rationality in one way or another. In the first publication, I assumed consumers were selectively attentive; in the second, I assumed they made probabilistic choices; in the third, I posited that complementors adapt their strategy with respect to their key rivals only; in the fourth publication, I highlighted how the lack of resources drives the vertical scope specialization of complementors;[52] and in the fifth publication, the consumers and advertisers were assumed to be myopic. The assumptions of bounded rationality are consistent with strategic management research in general, especially when it comes to the resource-based view in which causal ambiguity (Lippman and Rumelt, 1982) is a fundamental assumption in the theoretical logic (Amit and Schoemaker, 1993; Dierickx and Cool, 1989). Causal ambiguity means that a firm cannot perfectly anticipate the value of resources. In addition, lack of information is likely to generate behavior that is bounded rational, especially in complex dynamic systems where firms may not easily "escape" suboptimal performance trajectories due to path-dependence (Arthur, 1994; Sterman, 1994). Most generally, my research acknowledges the cognitive limits of human decision-making in economic problems (Kahneman and Tversky, 1979; Thaler, 2016), as also presumed in the behavioral theory of the firm (Cyert and March, 1963), and evolutionary economics (Nelson and Winter, 1982).

However, it is hard to pinpoint all the exact ways in which the actors in platform-based markets are bounded rational. On the contrary, perfect rationality is easy and explains in part why economic models of platforms rely on it (e.g., from mathematical perspective, it is convenient to assume that actors have perfect information to make rational decisions).

[52] The fourth publication implicitly assumes that a complementor continues to specialize as long as specialization preserves resource autonomy (which is rational from the individual complementor's viewpoint), without accounting for the possibility that, at the market level, producers become increasingly dependent on third-party resellers (which may enable the latter to exploit market power over the individual producer eventually).

Nevertheless, important cues in the literature drive the story. Above all, one of the most evident manifestations of the bounded rationality of complementors (and platforms) is that platforms may get overcrowded. If complementors were rational, the platforms could sustain above zero profits for all complementors in equilibrium (i.e., a complementor would not enter if it knew it could not do it profitably). In other words, complementors cannot seemingly predict their demand, at least not too far into the future. The same goes for platforms owners. They also contribute to the excess capacity problem (i.e., too many complementors relative to consumers), for example, by subsidizing complementor adoption heavily (Clements and Ohashi, 2005) and by not giving complementors enough information on platform usage (Tucker and Zhang, 2010). Take the downturn in the U.S. videogame market in the early 1980s due to Atari not being able stop opportunistic game producers from flooding the market with poor-quality games (Boudreau and Hagiu, 2009). This story is remarkably consistent with Sterman *et al*. (2007), who show that even if aggressive "get-big-fast" strategies were optimal in climbing the "learning curve" (i.e., implying supply-side increasing returns; see also Arthur, 1989), other things being equal, delays in capacity adjustments and bounded rational demand forecasts prove fatal when demand growth slows down. The firm will find itself with more excess capacity the more aggressive the firm is, and thus, the firm's performance suffers eventually. The additional problem here is that the bounded rational third-party complementors, which can trade off long-term performance for short-term performance (Rahmandad, Henderson, and Repenning, 2016), cannot obviously be managed directly by platform owners. Finally, if complementors and platform owners cannot predict their demand, with their dedicated organizational resources, I would not put too much confidence in the predictive abilities of individual consumers either—they may as well be myopic (Zhu and Iansiti, 2012) or form bounded rational demand expectations at best (Englmaier *et al.*, 2017).

Therefore, bounded rational expectations on the future outcomes of platform-based markets, or even myopia, play an arguably major role in strategic interaction. A pessimistic economist could comment that learning solves for bounded rationality eventually (Thaler, 2016). Admitted, the actors learn and adapt, but the inherent dynamic complexity associated with platform-based markets, and limited information about them, may fundamentally limit the ability to learn, predict, and manage the complexity (Arthur, 1994, 1999; Davis *et al.*, 2009; Sterman, 1994). Even if we imagined learning could solve for bounded rationality, temporal deviations from optimal behavior during the learning process matter for the market outcomes because of the feedback effects (e.g., the network effects). Generally, in complex systems, small changes in the initial conditions of a system, and/or temporal deviations from optimality, may imply huge differences in outcomes as the dynamics unfold. The system must not even be highly complex, or even random or adaptive at all, so that it can end up in chaos—take the chaotic motion of a double pendulum. Therefore, the bounded rationality of the platform-based market participants may easily shift the balance toward too little or much cooperation or competition between them, which, in the long run, may not benefit any party. For example, when launching a platform, complementors and consumers may be overly pessimistic about the future ability of the platform owner to expand. Thus, they may be unwilling to commit any resources to the benefit of the platform in the short run, even if in reality they could benefit eventually (Hagiu and Wright, 2015b). However, and related to the excess capacity problem, even if the platform owner stepped in to control the overheating of the complement market (e.g., by limiting platform access), doing so may trigger fears among complementors that the platform owner will now and forever exploit its market power (Gawer and Henderson, 2007)—without mentioning consumers whose perceived consumption utilities may also decrease as a result (e.g., they may *think* that control is bad for platform quality, although it can at best improve it) and decrease their platform support.

Generally, I argue that because of bounded rationality, "letting the thousand flowers bloom" (Boudreau, 2012)—that is, letting complementors and consumers be completely autonomous (Wareham *et al.*, 2014)—is more risky from the platform owner's perspective than in an ideal world where the actors are rational. For example, although platforms and complementors can freeride on each other's efforts in the hypothetical world of perfect rationality, when their strategies are not complementary enough (Casadesus-Masanell and Yoffie, 2007), bounded rational agents may not even realize the potentially significant complementarities. In game-theoretical terms, the Nash equilibria of the latter game with bounded rational players is relatively more unlikely to include the cooperative equilibrium. Thus, I argue that increasing control over the complex adaptive system, or rather, not letting it get out of hand in the first place, is the cornerstone of platform strategy (Davis *et al.*, 2009). In relation to the preceding example, if overheating the complement market was avoided in the first place due to stricter control, complementors may not feel that they were being squeezed out ex post (Gawer and Henderson, 2007). Overall, these arguments are in line with traditional management strategy in which internal control of resources is a mandatory condition for competitive advantage (Barney, 1991). However, they are also consistent with the idea that some reliance on third parties, which is inevitable (Pfeffer and Salancik, 1978), is beneficial for firm performance and competitiveness if managed properly (Dyer and Singh, 1998). While the essence of the platform-based business model is to devolve complementary resource control, some coordination is arguably required to direct the system (Kapoor and Lee, 2013). With these logics in mind, I highlight nuanced issues in the following sections that arise from strategic interaction between bounded rational agents in platform-based markets.

5.2 Distinctiveness versus diversity

A platform is said to be distinctive, if it has distinctive types of complementary products relative to competing platforms (Cennamo and Santalo, 2013). For example, a gaming console may have relatively many first-person shooter games, making it distinct from a platform with relatively fewer number of these type of games. In turn, complement diversity increases in the number of distinctive types of complementary products on the platform (Cennamo, 2016). For example, a gaming console's game catalogue is diverse if it has first-person shooter games, sports games, role-playing games, casual games, et cetera.

I argue that there is a potential trade-off between pursuing strategies that increase the distinctiveness of a platform (e.g., exclusivity deals) and its diversity of complementary products (e.g., expanding the variety of complements, as it also leads to greater complement diversity as shown in Boudreau, 2012). I build my argument on two assumptions. First, a consumer does not value complement diversity on a platform per se. However, diversity increases the probability that *a* type of a complementary product matches the consumer's type preferences, and thus increases his or her willingness to affiliate with the platform and transact with the complementor (Steiner *et al.*, 2016). Note that this does *not* mean the consumer may not like multiple types of complements, but instead that he or she is indifferent to the availability of at least *some* types of complements. For example, a gamer who likes all kinds of first-person shooter games *may* be indifferent to the availability of sports games. Thus, from the perspective of the platform, increasing complement diversity is beneficial in making it more likely that different types of consumers (e.g., first-person shooters and sports gamers) find the complementary offerings useful in satisfying their differing needs. However, keeping the platform distinct from competitors is important in coordinating similar types of consumers or complementors on the common platform (Lee, 2013).

Second, there are limited types of complementary products. In other words, consumer type preferences are distributed in limited space. In the third publication, I modeled the genre or type preference space so that it is a continuous line with a certain limited length (1 in this case), where the distinctiveness of a complement depends on its distance from other types of complements on the line. Thus, the distinctiveness of a platform is a distance function that accounts for all types of its complements relative to those of competing platforms. Now, it is unclear how exactly to measure the distance between two distinctive types of complementary products in reality. Nevertheless, to illustrate the point, it is quite clear that first-shooter games are quite different from sports games. The fact that some consumers may like only one type of these games implies some sort of preferential distance, even if the preferences were discrete (i.e., the consumer either likes a type or genre or not). Further, the labels used to describe the game types are limited in reality. Although one could argue that the labels may not reflect the true types of games, with potentially infinitely many variations, that such labels are used to describe content reveals that we like putting products into *familiar* categories. Finally, even if we assumed new categories could be developed, it implies that at one point in time we have a limited number of types or genres.

Thus, it follows that increasing the diversity of complementary products *reduces* the distinctiveness of a platform eventually, because then complementors no longer effectively differentiate (i.e., closed boundaries of type or genre preference space), other things being equal. To explicate, assume two competing platforms each had one complement initially and that the complements were fully differentiated and thus of type 0 and 1, respectively, in the continuous preference space. Now suppose that the type of a platform is measured as the average type of the platform's complements and that its distinctiveness from the competing platform increases in the average type distance. Initially, the absolute type distance between the given competing platforms is $1 - 0 = 1$.

It is then clear that adding new *differentiated* complements (i.e., whose type is distinct from the previously added complements) to the platforms implies their average types approach each other (i.e., the center of consumer preference space, 0.5), and thus, the platforms *must* become less distinctive. Now, even if the platforms started at the center of the consumer preference space, and thus, they could differentiate in the opposite directions first (i.e., the average type of a platform would get closer to 0 or 1), the newly added and differentiated complementors will eventually hit the boundaries of the preference space (i.e., 0 or 1). Thus, there is no room for them and the platforms to go except the center of the consumer preference space (i.e., platform distinctiveness is reduced).

In other words, although horizontal differentiation of complementors, which is what they do anyway (Boudreau, 2012), may help the platform satisfy various types of consumer needs in the short run, the long-term potential for reducing distinctiveness may act against the platform in competition (Cennamo and Santalo, 2013; Corts and Lederman, 2009). Take the smartphone industry for example, where Android phone makers have gradually lost their distinctiveness and ended up in fierce competition (Paik and Zhu, 2016). Thus, provided that there is sufficient diversity, a platform owner should then perhaps restrict complementor access to the platform (e.g., through increasing prices) if and when distinctiveness is important for the platform's competitiveness (e.g., the first and second publications). Or the platform owner could perhaps try to direct innovation through governance mechanisms (see section 5.6). However, distinctiveness is arguably not that important for monopoly platforms, unless excessive complement diversity leads to fragmentation and thus decreases the platform's perceived quality. Therefore, I summarize these arguments in the following proposition:

> *Proposition 1: Other things being equal, balancing complement diversity and platform distinctiveness improves platform performance and competitiveness.*

The dynamic effects of platform strategies that boost complementor innovation (Boudreau, 2010)—affecting complement variety and diversity (and quality) (Boudreau, 2012), platform distinctiveness (Corts and Lederman, 2009; Venkatraman and Lee, 2004), and finally platform performance and competitiveness (Cennamo and Santalo, 2013)—are not comprehensively understood. Therefore, future research could better highlight how specific platform strategies (e.g., vertical integration to complement production) affect the various complement attributes and platform performance and competitiveness (e.g., Cennamo, 2016). Acknowledging the inherent relationship between complement diversity and platform distinctiveness is vital in this regard.

5.3 Technological progress versus complementor value appropriation

Evidence suggests that technologically better platforms may not simply be "locked out" (or lose platform competition; Schilling, 2002), in case they had an installed base disadvantage, after all (Gretz, 2010; Tellis *et al.*, 2009; Zhu and Iansiti, 2012). Staying behind technological progress is also detrimental to platform performance and competitiveness despite an installed base advantage (Schilling, 2002; Venkatraman and Lee, 2004). However, I argue that technological advancement in platform-based markets may be constrained because of supply-side factors. That is, there is a fundamental trade-off in quickening the pace of platform innovation (i.e., introducing new hardware or technology) and enabling complementors to appropriate value from their complementary innovation (Clements and Ohashi, 2005; Kapoor and Agarwal, 2017). Moreover, when introducing advanced hardware, it may not be optimal to leap toward technologically as much as possible, because of the complementors' inability to cope with the increased resource demands. In general, these arguments conform to the traditional Schumpeterian view of innovation, where "monopoly rents" need be allowed to a degree to incentivize innovation (Aghion *et al.*, 2005; Schumpeter, 1934).

To explicate, because complementors have limited resources to innovate and innovation takes time, platform owners must credibly signal that the complementors are not "squeezed out" (Gawer and Henderson, 2007). A primary way to signal that complementors can appropriate value from an innovation is to continue expanding the existing installed base of consumers. However, especially when new incompatible technology is introduced to the market, the installed base must be built up from scratch. Thus, quickening the pace of technological progress signals incredibility to complementors. Even if the new technology is backward compatible, complementors may delay their new platform support although it helps them make better-quality complements (i.e., vertical differentiation), as long as there is no significant installed base, and as developing the platform for advanced hardware requires more resources from complementors in utilizing the platform's technological features (Claussen *et al.*, 2015). Moreover, platform generational change, constituting a technological discontinuity, introduce uncertainty that negatively affects complementors' ability to sustain their competitiveness on the platform (Kapoor and Agarwal, 2017).

Similarly, in the fourth publication, I proposed that introducing moderately advanced platform hardware may be the optimal strategy. Then the direct positive effects on performance or competitiveness may not be negated as the complementors have room for vertical scope specialization. For example, take the division of labor between game producers and publishers (resellers) in the video gaming console markets that mutually benefits the parties (Broekhuizen *et al.*, 2013). That is, when resources are scarce, complementors may specialize in complement production to preserve resources and outsource marketing to resellers, which market the complements through the platform. I showed preliminary evidence (the fourth publication) that this vertical within-platform disintegration is directly and strongly proportional to the hardware quality of a gaming console. Thus, I contend that increasing hardware quality too much may increase producers' resource investments in innovation such that specialization is not enough to preserve the producers' ability to innovate. For example, if more than half of all complementary products on a platform are co-marketed with specialized resellers, it may show that most producers have no more internal marketing resources to be outsourced or reallocated to production. Then specialization no longer serves the platform as it tries to introduce advanced hardware. Moreover, producers and platforms may become overly reliant on third-party resellers (e.g., take the dominant role of Electronic Arts and Activision in the game publishing field) that can then bargain a disproportionate share of the value created.

In summary, although complementors favor technological advancements to a degree (Gretz, 2010; Venkatraman and Lee, 2004), platform innovation may, at worst, decrease complementors' ability to appropriate value from third-party innovation (Kapoor and Agarwal, 2017), when they have limited resources. In sum, I develop the following proposition:

> *Proposition 2: Other things being equal, introducing moderately advanced platform hardware and at a moderate pace improves platform performance and competitiveness.*

Albeit the empirical literature on platforms has studied the dynamics of platform usage over the platform life cycle (e.g., Clements and Ohashi, 2005), the drivers of platform generational transitions and cross-generational platform usage remain underexplored (for exceptions, see Schilling, 2003; Cennamo, 2016; Kapoor and Agarwal, 2017). Yet as the platform providers continue to introduce new hardware, and thus compete across technology generations (e.g., PlayStation 1, 2, 3, and 4 vs. Xbox, Xbox 360, and Xbox One), we should advance the platform theory to account for the effects of technological change on platforms. Investigating the given proposition will be useful in this regard.

5.4 Penetration pricing versus (intertemporal) price discrimination

Platforms have an incentive to subsidize a group of users to leverage network effects (Parker and Van Alstyne, 2005; Rochet and Tirole, 2006), especially when the platform is new (Clements and Ohashi, 2005; Ohashi, 2003), other things being equal. However, complementors have an incentive to intertemporally price discriminate in order to exploit heterogeneous reservation prices and the forward-looking behavior of strategic consumers. This is evidenced in the video gaming console market where game prices fall over time, so that the "snobs" (i.e., who buy games early) are charged more than the more reserved consumers (i.e., who wait for lower prices; Nair, 2007). This "price skimming" strategy arguably results in a pricing conflict when a platform is launched—the platform prefers a low price while complementors prefer a high price—because consumer utility of platform affiliation and engagement in interactions are impacted by platform and complementor prices, and thus, they may delay platform adoption (Casadesus-Masanell and Yoffie, 2007).

However, the results in the first publication suggest that *platforms* can effectively price discriminate over time as well, if they remain sufficiently vertically differentiated (i.e., quality advantage). Stimulating installed base growth through penetration pricing may not be required even if the platform entered late (i.e., it has an installed base disadvantage). This begs the question, is there a pricing conflict after all? It seems that for *technological* platforms, price skimming may be a viable strategy. This is arguably because of technological progress, which renders a platform technology obsolete over time. In the early life cycle stage, technology snobs may just as well adopt a platform, irrespective of its and its complements' price tags (Stremersch *et al.*, 2007). Pricing, thus, may become more of an issue later in the platform life cycle when price-sensitive users consider adoption, even if increasing elasticity to complement variety counteracts the increasing price elasticity (Clements and Ohashi, 2005).

Furthermore, the bundling of platform hardware and selected complements may also solve chicken-and-egg problems effectively early on, as bundling segments consumers and thus price discriminate statically (Bakos and Brynjolfsson, 1999; Chao and Derdenger, 2013; Eisenmann *et al.*, 2011). Moreover, the results in the fifth publication suggest that, under diminishing consumption utilities (e.g., content becomes outdated in usage), the focal firm can intertemporally price discriminate between heterogeneous consumers through changing from subscription to advertising-based (platform-based) business model over time.

Finally, decreasing platform prices may, at best, signal about the technology strategy of a platform to complementors, which can adjust their own strategy accordingly and in advance. To clarify, one can more readily predict the end of platform life cycle from the platform's price history (i.e., the lower the price gets, the more likely the platform owner will advance new hardware with a higher price tag), and thus, complementors can better price discriminate themselves and prepare for the technology generational change (Kapoor and Agarwal, 2017).

In summary, I contend that the effectiveness of penetration pricing may be limited in certain situations, or aggressive pricing may even be unnecessary for platforms to penetrate. However, it is quite obvious that better segmentation enables raising prices (take bundling). Thus, the novelty of the following proposition is that it links technology to the pricing equation. To the best of my understanding, few if any scholars have explicitly noted that the technological progress and obsolescence of platforms matter in the following yet intuitive way:

> *Proposition 3: Other things being equal, technological obsolescence of a platform increases the positive performance impacts of platform intertemporal price discrimination strategies relative to penetration pricing.*

Despite the economists in particular have extensively studied and emphasized the importance of price structure design in getting the market sides on board (Rochet and Tirole, 2006) and making a platform profitable (Parker and Van Alstyne, 2005), it remains unclear how important getting the pricing right is (McIntyre and Srinivasan, 2017). Furthermore, counterintuitive examples such as Sony's ability to sustain a relatively high price for PlayStation 3 question the effectiveness of aggressive pricing strategies in leveraging network effects for better performance and competitiveness (see the first publication). Therefore, I contend that the question of how to optimally structure prices remains open for further elaboration, whereby the given proposition would offer useful direction for future research.

5.5 Cooperating versus competing with complementors

Here, I generalize the argument that pursuing a platform strategy that puts selected complementors in a favorable market position while hurting the rest may at worst (best) decrease (increase) platform performance and competitiveness. This discussion is closely related to Cennamo and Santalo (2013), who studied the trade-off of stimulating competition among complementors (i.e., that should increase innovation, other things being equal) and simultaneously pursuing exclusivity deals with selected complementors. The authors found that doing so hurts complementor innovation and thus, platform performance and competitiveness, when the two strategies are employed with equal intensity, because then the strategic allies of the platform are in a too favorable market position (i.e., pricing advantage) against non-exclusive partners. Thus, the non-exclusive complementors decrease innovation, hurting platform performance and competitiveness (see also Li and Agarwal, 2016). Moreover, and again because of the competitive effect, Cennamo (2016) found that vertical integration into complement production may be beneficial only in the early stage of the platform life cycle when overcoming chicken-and-egg problems is vital for growth (see also Hagiu and Spulber, 2013).

Aside from these findings that highlight the possible negative consequences of individual platform strategies, I develop a more general proposition that says moderately cooperating with selected complementors is beneficial for platform performance and competitiveness, as then the negative effects due to increased competition should remain weak. In addition to the previous strategies, take the bundling of a complement: The non-bundled complements, albeit not directly realizing gains from bundle sales, may benefit indirectly from the resultant ability of the platform to better segment consumers (Chao and Derdenger, 2013; Eisenmann *et al.*, 2011). However, if the consumer segment to which the platform is targeted is too narrow, multiple types of complementors may find the platform unappealing. Similarly, promoting content production through revenue sharing increases the production of popular content and thus the platform's appeal to consumers if not overdone, as content diversity is also reduced (Sun and Zhu, 2013). Moreover, competition for attention may then burst out (Boudreau and Jeppesen, 2015), and thus, only a few superstars can become popular (i.e., the complement market becomes monopolistic; Binken and Stremersch, 2009). Additionally, collaboration in innovation with complementors (e.g., through joint ventures) may at best increase value creation and capture. However, aside from increasing costs (Mantovani and Ruiz-Aliseda, 2015), the platform may also and at worst share too many resources with the joint venture partners that they become too competitive with the other complementors (i.e., the same logic as when it came to exclusivity deals; see Cennamo and Santalo, 2013).

Again, the bounded rationality of complementors plays a role here. Even if a platform was able to compete more effectively and secure a monopolistic market position eventually as a result of cooperating with selected complementors, the immediate negative competitive effects of such cooperation for the other complementors may make them non-cooperative to begin with. In other words, complementors may not be willing to sacrifice their short-term performance for long-term performance, because they might be risk averse, because the market outcomes are uncertain, or because they focus on satisfying stakeholders that demand better short-term results (Rahmandad *et al.*, 2016). In other words, out-of-equilibrium dynamics matter (Sterman *et al.*, 2007). Abstracting a bit, these arguments are loosely consistent with time compression diseconomies (Dierickx and Cool, 1989): It is less efficient to invest in building twice as big a resource stock or capability (e.g., securing two times more exclusive content) in half the time than to spread the investments over a two times longer timeframe. Complementors may also need time for competitive adaptation (Kapoor and Agarwal, 2017). Formally, I develop the following proposition:

> *Proposition 4: Other things being equal, cooperative platform strategies that favor selected complementors moderately and thus increase within-platform competition among complementors moderately lead to increased platform performance and competitiveness.*

It is not widely recognized that platform strategies that are used to boost complementor innovation and/or platform performance and competitiveness may have negative side effects as well (for the exceptions, see Cennamo, 2016; Cennamo and Santalo, 2013; Li and Agarwal, 2016). The given proposition is thus useful in bringing up the general point, whereas future research could highlight the exact mechanisms related to specific platform strategies.

5.6 Opening versus closing (governance)

What I mean by opening or closing a platform here is related to the autonomy of complementors—that is, a platform is said to be more (less) open the more (less) able the complementors are to come and go and decide on their own actions (Wareham *et al.*, 2014). The essence of the platform-based business model is devolving complementary resource control to complementors, while leveraging demand-side economies of scale (Baldwin and Woodard, 2009; Boudreau, 2012; Hagiu and Wright, 2015a).[53] However, giving complementors full freedom may not be highly productive.

Boudreau and Hagiu (2009) set forth hypotheses for the performance effects of platform governance. Their main argument is that the price structure design is not enough to solve market failures caused by network externalities (Liebowitz and Margolis, 1994), and thus, effective governance is needed to ensure efficiency in third-party innovation. More recently, Wareham *et al.* (2014) explicated specific technology platform governance mechanisms to appropriately bound complementors without constraining their actions too

[53] Again, platform access can be opened as well (Boudreau, 2010), but devolving complementary resource control is the definitive feature of a multi-sided platform as described in section 1.3.1.

much. Essentially, these authors are saying that effective platform governance can improve platform performance. The results in the third publication also show that optimizing the price structure design may not be enough to maximize platform performance when complementors are strategic. However, here I go beyond and claim that effective governance can potentially make a platform more *competitive.* For example, strictly open source platforms rarely outcompete proprietary or commercial open source platforms (e.g., Linux vs. Windows), because openness encourages freeriding on others' innovation efforts (Casadesus-Masanell and Ghemawat, 2006; Economides and Katsamakas, 2006; Kumar, Gordon, and Srinivasan, 2011).

To explicate, platform governance is fundamentally about reducing the autonomy of complementors or consumers, in a way or another (Wareham *et al.*, 2014). Therefore, platform governance reduces the platform's ability to leverage the network effects for competitive advantage (Economides and Katsamakas, 2006). However, setting rules for how to access and interact on the platform (take Facebook's privacy settings) can help solve market failures. Specifically, when it comes to platforms where the market sides transact with each other, regulating competition (e.g., by restricting access) among complementors may help ensure that they all can enjoy sufficient performance. Thus, effective platform governance enables complement markets to function relatively freely while also correcting for problems due to monopolization of the complement market. Too much of either thing is non-desirable.

Therefore, in platform competition, a more effectively governed platform may have a more loyal user base, and an installed base disadvantage (i.e., governed platforms may not be as effective in leveraging network effects as open platforms) may not turn out to be a competitive burden. Take Apple's iOS where third-party complements are inspected by Apple before launch, as opposed to Google's Android where complementor access is basically unrestricted. In light of the present discussion, it might not be a coincidence that Apple is making the most of mobile device industry profits with iOS although the vast majority of consumers and complementors are supporting Google Android (see also Kapoor and Agarwal, 2017).[54] Thus, I develop the following proposition:

> *Proposition 5: Other things being equal, in the presence of network externalities, effectively (i.e., moderately) governed platforms enjoy better performance and competitiveness.*

[54] Although the direct comparison between Apple and Google is unfair in the sense that the latter does not obviously rely too much on mobile *device* profits, as it is engaged in the mobile business to make a greater profit on the advertising market, the commercial success of iOS is still remarkable given its relatively low market share. In comparison, just like Android dominates in terms of market share in the mobile industry, Windows has boasted a near monopoly in the PC market for a while, and Microsoft and its hardware partners like Intel have definitely made a profit as a result. Indeed, this may be attributable to the fact that Microsoft does not let complementors modify the operating system too much (in comparison, Google enables complementors to modify Android significantly).

To emphasize, governance clearly matters for making platform markets to function properly, but it is less clear whether effectively governed platforms can also outperform their rivals. Furthermore, we should better highlight the more exact governance mechanisms that can be utilized to improve platform performance, and possibly competitiveness (see for example a recent, unpublished working paper from Rietveld, Schilling, and Bellavitis, 2016).

5.7 Compatibility versus incompatibility (technology architecture)

Compatibility decisions are distinct from those of opening or closing. For example, in my view, an open platform can be incompatible with competitors, while a closed platform can be compatible. Whereas opening or closing is about governance (see the preceding section), compatibility decisions are related to the design of platform technology architecture (Baldwin and Woodard, 2009) that specifically affects the ability of a consumer or complementor to use or convert complements across platforms. From the consumer's perspective, if a platform is completely (in)compatible with another one, a consumer can(not) use all (any) complements across the platforms. Although compatibility is often either-or, it can also be a matter of *degree*. For example, it is technically possible to run Windows software on Linux using emulators (e.g., Wine), but with a cost in software performance due to the additional middle layer (i.e., the emulator) that is absent if the software were run natively. Compatibility can also be assessed from a complementor's perspective: The more similar the technology architectures of two platforms are, the more compatible they are, and the easier it is for complementors to convert their offerings across platforms (e.g., reuse program code).

Technological incompatibility constitutes a switching cost for consumers and/or the complementors supporting a platform (i.e., as they've paid a lump sum for platform access), and thus, incompatibility should arguably be enforced (Farrell and Saloner, 1985; Katz and Shapiro, 1985). However, there are important nuances to compatibility decisions. From an entrant platform's perspective, compatibility may be a good thing if a competitor had a clear installed base advantage, as then the switching costs are lowered (Eisenmann *et al.*, 2011). How can incumbent platforms protect their competitiveness, then? In addition to intellectual property protection (Paik and Zhu, 2016), an interesting yet overlooked strategy is to *complexify* the technology architecture. Then competitors may not readily learn about it and design a similar architecture to which it is easy to convert complements (Schilling, 2002). Moreover, complementors may at best learn new valuable capabilities in developing complements for a complex technology architecture, thus possibly increasing their competitiveness and platform quality (see the first publication, and Kapoor and Agarwal, 2017), or at least Sony believed so as it used this strategy in its design of PlayStation 3.[55]

However, complexifying platform technology architecture too much will obviously raise complement development costs, at least in the short term when the complementors learn

[55] See https://www.cnet.com/news/sony-ps3-is-hard-to-develop-for-on-purpose/ (accessed March 1, 2017).

about the architecture, and may thus contribute negatively to complementor support. Complexity also requires greater adaptation from complementors when introducing new platform generations, contributing negatively to complementor's ability to sustain competitive advantage (Kapoor and Agarwal, 2017). Furthermore, developing, producing, and maintaining a complex technology architecture can raise platform costs such that they outweigh the benefits (Tatikonda and Rosenthal, 2000). Moreover, highly capable complementors (e.g., due to developing for complex architectures) may more easily support multiple platform architectures, as described by one producer (see the link in footnote 55): "Anyone making a game, if you're going to make it for both, just lead on the PS3 because if it works on the PS3, it'll work on [Xbox] 360." However, incumbent platforms arguably suffer less from complementor multihoming than entrants (Landsman and Stremersch, 2011; Lee, 2013). Thus, entrant platforms may as well prefer differentiating and complexifying their technology architecture to a degree, as then they may more easily attract unique or exclusive complementors (i.e., then incumbent complementors cannot easily support multiple platforms, and thus if and when some were to support the entrant, they have to *switch* for it). In summary, I put out the following novel proposition:

> *Proposition 6: Other things being equal, moderately differentiating and complexifying a platform technology architecture improves platform performance and competitiveness.*

Acknowledging the relevance of platform technology architectural choices in affecting complementary innovation is a relatively new thing in the literature (Baldwin and Woodard, 2009; Boudreau, 2010). Given this relationship, more closely examining how to design the technology architecture is an important future research avenue in the strategic management literature on platforms.

6 Discussion and conclusions

6.1 Answering the research question

This dissertation answered the main research question by describing the strategic interaction between platform-based market participants (Zhu and Iansiti, 2012), and the resulting performance and competitive effects on multi-sided platforms (Hagiu and Wright, 2015a, 2015b). In addition to the individual studies, I developed a further set of propositions (see the preceding section), based on my publications and the extant literature, each of which directly explains how certain platform strategies affect platform performance and competitiveness when accounting for strategic interaction.

More specifically, this dissertation has challenged some prevalent assumptions in the extant platform literature (Alvesson and Sandberg, 2011)—namely, the perfect rationality of platform-based market participants and that they are homogeneous and relatively non-strategic (i.e., simplistic) agents. The fact that these assumptions are clearly unrealistic raises external validity concerns (Arthur, 1999), thus also questioning the normative implications of analytical models of multi-sided platforms (e.g., Armstrong, 2006; Caillaud and Jullien, 2003; Rochet and Tirole, 2003, 2006), which constitute the theoretical core of the literature. Relaxing the assumptions lead me to characterize platform-based markets as complex adaptive systems (Anderson, 1999; Holland, 1995), in which heterogeneous and bounded rational platforms, complementors, and consumers approximate optimal behavior over time in the trilateral bargaining game (Arthur, 1989; Cennamo and Santalo, 2013; Kapoor and Agarwal, 2017). To study the complex evolutionary dynamics of the system, and the drivers of platform performance and competitiveness, I used agent-based simulation that excels in analyzing how micro-level dynamic interactions between heterogeneous and bounded rational agents affect system-level phenomena (Fioretti, 2013).

For example, in the first two publications, I challenged the winner-take-all hypothesis (i.e., that one platform dominates; e.g., Hossain *et al.*, 2011), which builds on the assumption that positive indirect effects alone would dictate complementor and consumer support for a platform (Lee *et al.*, 2006; Schilling, 2002). In the process, more realistic behavioral assumptions about consumers were incorporated in the study of platforms, and these assumptions were demonstrated to play a significant role in consumer adoption of platforms and platform competitive dynamics (see also the fifth publication). In the third and fourth publication, complementors were pictured as adaptive agents, and their strategic behavior was also demonstrated to affect platform performance and strategy in significant ways. Finally, building on the individual studies and extant literature, I developed a set of novel propositions that further highlighted performance and competitive effects of increasing complement diversity and platform distinctiveness (Cennamo and Santalo, 2013), improving platform technological quality (Zhu and Iansiti, 2012) and complexifying the technological architecture (Kapoor and Agarwal, 2017), price discrimination (Clements and Ohashi, 2005), substituting complement production (Cennamo, 2016), and effective governance (Boudreau and Hagiu, 2009).

I generally argue that moderate control over the complex adaptive system (i.e., platform-based market), in other words not completely devolving control of the interactions to third-party complementors or consumers (Boudreau, 2010, 2012; Hagiu and Wright, 2015a), is beneficial for the platform. This is because complex adaptive systems, in general, may at worst "go out of hand" as the path-dependent dynamics unfold (Arthur, 1989), thus hindering platform performance and competitiveness (Davis *et al*., 2009; Sterman *et al*., 2007). Take Atari that was disrupted due to autonomous game producers flooding the market with poor quality games (Boudreau and Hagiu, 2009; Wareham *et al*., 2014). On the contrary, more tightly controlled platforms such as Apple's iOS continue to generate abnormal profits despite the platform is highly congested (Kapoor and Agarwal, 2017; Liebowitz and Margolis; 1994).

6.2 Theoretical implications

What good is it that we integrate behavioral assumptions (i.e., bounded rationality) in the study of platforms (Arthur, 1994; Cyert and March, 1963; Nelson and Winter, 1982; Simon, 1991) and acknowledge that market participants have heterogeneous (Barney, 1991; Dyer and Singh, 1998) and limited resources (Pfeffer and Salancik, 1978)? None, if you ask an economist, who prefers parsimonious frameworks that are analytically solvable (Armstrong, 2006; Caillaud and Jullien, 2003; Hagiu and Wright, 2015b; Rochet and Tirole, 2006; Weyl, 2010). However, if one cares about descriptive power, I argue that the behavioral and resource assumptions are vital. They imply that platform-based markets are correctly thought of as complex adaptive systems where bounded rational strategic agents learn and adapt, and cooperate and compete to achieve their individual and not perfectly aligned goals (Anderson, 1999; Holland, 1995; Kapoor and Agarwal, 2017). Thus, to predict systemic phenomena, such as platform performance and competitiveness, one must account for complex strategic interactions between the market participants that emerge over time. In practice, failing to do so may easily undermine platform performance and competitiveness (Cennamo, 2016; Cennamo and Santalo, 2013). Consequently, simulation methods, and agent-based simulation in particular (Bonabeau, 2002; Fioretti, 2013; Macal and North, 2010), come in handy to study and develop theory of these systems, and in predicting market outcomes (Davis *et al.*, 2007; Harrison *et al.*, 2007; Sterman, 2000).

Therefore, it may at first seem antithetical that I have derived a set of stylized propositions for the performance and competitive effects of platform strategies. Is it not so that complexity cannot be managed so easily (or at all)? Indeed, I argue that platforms should try to reduce systemic complexity, that is, not to "let a thousand flowers bloom" (Boudreau, 2012) through more tightly controlling or coordinating complement production, as autonomous complementors can act against the platform (Wareham *et al.*, 2014). This argument is related more generally to the notion that in more dynamic environments entrepreneurial firms should add in structure (e.g., constraints on action) to ensure efficiency, although too much structure reduces flexibility, constituting a strategic trade-off (Davis *et al.*, 2009; Kapoor and Lee, 2013). Furthermore, simple strategies tend to do just fine, or they may even outperform complex strategies in highly dynamic environments (Davis *et al.*, 2009; Van den Steen, 2016). The developed propositions capture both ideas of increasing structure and simple strategies as solutions for complexity.

Thus, in a way, the theoretical contribution of this thesis lies in the recognition that platform strategy is not that different from traditional strategy (Parker *et al.*, 2016; Schilling, 1999). Similarly as the resource-based view builds on, say, the causal ambiguity assumption (Amit and Schoemaker, 1993; Dierickx and Cool, 1989; Lippman and Rumelt, 1982), which limits the ability of firms to recognize the value of resources and thus possibly explains performance heterogeneity, here the baseline assumption is that the market participants are bounded rational, and this may easily undermine the resource value (Shankar and Bayus, 2003; Sun and Tse, 2009). However, platform strategy is definitely harder than traditional strategy in the sense that one needs to manage for *external* resource dependencies that are by definition out of a firm's direct control (Dyer and Singh, 1998; Pfeffer and Salancik, 1978), and that the strategic goals of the system participants differ. Multi-level and three-way resource interdependencies between platforms, complementors, and consumers may further give rise to power imbalances and conflict (Casciaro and Piskorski, 2005; Pfeffer and Salancik, 1978). In summary, I see that platform strategy is fundamentally about *balancing flexibility and control* (Almirall and Casadesus-Masanell, 2010), where the latter can be achieved through vertical integration (Kapoor and Lee, 2013) and other traditional strategic management approaches (e.g., intellectual property protection).

However, I emphasize that despite the critical nature of the study, I have not simply debunked existing theory. Instead, I tried to investigate its boundary conditions and refined it in the process, while relying extensively on empirical research on platforms (Boudreau, 2012; Cennamo, 2016; Cennamo and Santalo, 2013). To be fair, I bet that economists and strategic management scholars are well aware of the problematic assumptions that underlie the platform theory. They just cannot cope with the complexity that arises from relaxing these assumptions. When acknowledging platform-based markets are complex adaptive systems, analytical modeling becomes infeasible (Arthur, 1989, 1994, 1999), and statistical modeling, even if technically feasible, becomes challenging because of data problems. Therefore, and finally, I have demonstrated the utility of agent-based simulation in the study of platforms, an endeavor that is to the best of my knowledge the first of its kind, thus serving as an illustrative methodological contribution. I dare say that agent-based simulation is the *only* modeling/simulation method with which it is possible to realistically account for structural, individual-level heterogeneity inherent in platform-based markets and examine competitive dynamics emerging over time (Arthur, 2006; Fioretti, 2013). Most clearly, my empirical analysis (publication I) hopefully motivates further model creation and empirical validation of agent-based models, an endeavor that is too often neglected (Fagiolo *et al.*, 2007).

6.3 Practical implications

One should be wary of drawing strong normative conclusions from a largely conceptual study. Nevertheless, if we accepted the risk of my propositions proving to be false, one could translate them into direct strategic guidelines to act upon. The overarching theme in the propositions is that 1) platforms should control third-party innovation to a degree and that 2) remaining differentiated is vital. In other words, traditional strategic management guidelines apply to a degree in platform-based markets. Regarding the first theme, devolving complementary resource control is a powerful way of leveraging demand-side economies of scale, but overdoing it may backfire because of the resulting lack of control over the complex adaptive system. Therefore, it may not be surprising that, as an example, none of the most valuable platform firms on the planet are fully dependent on third parties. Apple is widely known for its closed innovation approach, Microsoft delivers core complements such as Word and Excel with Windows OS, Alphabet strictly protects Google search algorithms, Amazon.com was originally fully vertically integrated and still is to a degree, and Facebook has integrated vital services (e.g., Instagram) in the platform.

Second, trusting that merely an installed base advantage is enough to sustain (above average) performance is probably a fool’s game. There are so many more value elements in addition to network size that strategic complementors and consumers care about that extensive focus on leveraging network effects may strike back. In particular, it seems somewhat evident that differentiating a platform is vital. This can be achieved through selectively substituting third-party complement production, securing exclusivity deals, restricting platform access (i.e., limiting diversity), bundling, and governance. Differentiated platforms can more readily sustain their performance and competitiveness, and are less prone to attacks from platforms with a bigger installed base and vertically integrated firms. These guidelines are basically in line with the traditional Porterian view of strategy (Porter, 2008). However, differentiating a platform is not easy, when it depends mostly on third parties. Indirectly affecting the direction of third-party innovation (e.g., which types of products they come up with), for example, through governance, may be required to keep the platform distinctive and non-fragmented. In other words, coordinating external resources is vital for differentiation and competitiveness (Dyer and Singh, 1998; Kapoor and Lee, 2013). Yet again, this constitutes a trade-off, where leaning too much toward coordination will likely reduce complement diversity and quality, and platform performance and competitiveness as well. In summary, platform strategy is about carefully maneuvering between the extremes of control and flexibility (Cusumano *et al.*, 1992; Davis *et al.*, 2009).

6.4 Limitations and future research

From a practical standpoint, the main limitation of the study is its largely conceptual nature. More research is obviously needed to validate the proposed relationships between platform strategy, and performance and competitiveness. However, the focus on theory development was intentional, and thus, from the theoretical standpoint, limited empirical validation is not a problem per se. Instead, the main limitation of the study is that, although correctly treating platform-based markets as complex adaptive systems and employing proper tools to analyze them (i.e., agent-based simulation), a more careful examination of the *internal* validity of the developed propositions is still warranted (Davis *et al.*, 2007). In other words, the implications of the theory of platforms are yet to be understood in full. Turning this into an opportunity, this dissertation provides a leverage point for future research.

To highlight some of the high-level issues remaining to be elaborated (see section 5 for the detailed future research suggestions), we should more closely examine how bounded rationality affects the decisions of platform-based market participants and market outcomes. I contend that the bounded rationality assumption should be the default in models of platforms (Arthur, 1994, 1999; Kahneman and Tversky, 1979; Simon, 1991), or at least its effects should be compared to those of rationality assumptions (Sterman *et al.*, 2007). Even though the platform literature itself may not presumably add much to the literature on the human decision-making (or maybe it can?), the benefits of integration are greatly asymmetric (i.e., we can come up with more descriptive models of platforms) and thus ought not to stop us from drawing from human decision-making literature (Mayer and Sparrowe, 2013). To put it another way, there is not much practical sense to assume the perfect rationality of platform-based market participants, just because the human decision-making literature has established that bounded rationality adds to systemic complexity and decision-making problems in general. This reasoning is line with Thaler (2016) who argues “behavioral economics” in general need not be a distinctive field in the future: All economics ought to be behavioral; therefore, the prefix could just be omitted.

Moreover, this dissertation is only the first step toward an integration of resource-oriented views (i.e., resource-based view, relational view and resource-dependence theory) to the theory of platforms (Santos and Eisenhardt, 2005). Similarly, one of the most fruitful future research prospects is related to power dynamics and balances. How does vertical scope specialization of complementors or platforms affect the value distribution between producers, resellers and platforms? Given the interdependency between actors, resource (im)balances play an arguably important role (Casciaro and Piskorski, 2005; Panico, 2016). As a consequence, more nuanced questions include how does consolidation of market power in, say, resellers (e.g., take the dominant role of Electronic Arts and Activision in video game publishing/reselling) affect value distribution? Put provocatively, is it even desirable to always be a platform leader (e.g., can a complementor become more powerful than a platform; Gawer and Cusumano, 2002)?

Third, we should turn our focus to studying dynamics, instead of static equilibria that the platform-based markets may not ever converge to (Arthur, 1999). Even if they converged, for a moment (Gersick, 1991), the process through which the convergence occurs is as, if not more, important to understand and manage in practice than the outcome itself. For example, in video gaming console markets, getting the most out of an existing generation before introducing a new one is vital to making a profit (Cennamo, 2016; Clements and Ohashi, 2005). Too little is also known about cross-generational platform competition (Schilling, 2003). In summary, we need an evolutionary theory of multi-sided platforms that accounts for the behavior of all platform-based market participants and their interactions (Nelson and Winter, 1982; Tiwana, 2015; Tiwana *et al.*, 2010). This dissertation is only the first step in that direction.

Finally, and in line with the preceding argument, I envision the making of a general model that accounts for *all* relevant explanatory variables at once, so we no longer need to adopt in-isolation approaches that necessarily ignore important feedback or interaction effects. Pay attention to the notion "relevant": It implies that not everything should be taken into account, as then we cannot make sense of the model. However, an analytical modeler will still argue that coming up with a semi-complex model is overkill. On the contrary, are we to learn anything practically valuable from analytically solvable models that are based on unrealistically simple assumptions? Grimm *et al*. (2005, p. 988) describe the value of bottom-up (i.e., agent-based) models in the journal *Science* nicely: "If model design is guided only by the problem to be addressed (which often is the explanation of a single pattern), the model will be too simple. If model design is driven by all the data available, the model will be too complex. But there is a zone of intermediate complexity ['the Medawar zone'] where the payoff is high." I argue that currently in economics and management, model design is almost solely based on problems to be addressed, rather than data (see also Tsoukas, 2017). In general, I hope that the method biologists, as an example, use routinely to understand real ecosystems (Grimm *et al.*, 2005) would be used more in the study of business ecosystems (Adner, 2017), and platform-based markets in particular, which are, without a doubt, much more complex than their natural counterparts (Nelson, 2016). Hopefully, this study demonstrated how going beyond simplicity to the Medawar zone can pay off. Moreover, along the way there, we might develop the methodology especially in terms of empirical validation (Fagiolo *et al.*, 2007; Rand and Rust, 2011).

6.5 Conclusion

Multi-sided platforms are revolutionizing the economy, and thus, strategic management scholars and economists have increasingly investigated these platforms. However, the problem with the existing platform theory is that it builds on analytical models that assume away bounded rationality and heterogeneity of the platform-based market participants (i.e., platforms, complementors, and consumers). That is, the analytical models tend to build on the unrealistic assumptions of perfect rationality and homogeneity of the agents, while also simplifying their strategic interactions, which raise external validity concerns and limit the normative implications of the platform theory.

To address this problem, I examined how micro-level strategic interactions between the platform-based market participants affect platform performance and competitiveness, and hence platform strategy. To do so, I used agent-based simulation, an approach that is the first of its kind in the study of platforms, thus serving as an illustrative methodological contribution on its own. Most importantly, I add to the platform theory by recognizing platform-based markets as complex adaptive systems in which bounded rational agents learn and adapt to approximate their optimal strategies over time. Given the strategic interdependence between the agents, I generally argue that devolving complementary resource control to the third parties does not only enable the platform owner to leverage demand-side economies of scale, as argued in the extant literature. That is, devolving resource control may also more likely spur opportunistic complementor and consumer behavior that may at worst disrupt the platform (e.g., the classic case of Atari). Therefore, the platform owner is arguably better off retaining moderate control of the market system, as achieved through vertical integration, governance, and other strategies, than letting the third parties to freely interact on the market. All in all, this study is the first step in the direction to develop an evolutionary theory of multi-sided platforms.

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