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Disruption in Platform-Based Ecosystems

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Abstract

We study intergenerational platform-technology transitions as instances of potentially disruptive innovation at the ecosystem level. Examining the launch of 12 platform technologies in the U.S. videogame industry covering three console generations from 1993 until 2010, we show that incumbents introducing next-generation platform technologies with advanced capabilities increase the challenges of developing complements for the platform technology, steepening complementors' learning curves and disrupting the very same complementors that platform owners need to thrive in the next-generation competition. We find that, because of these struggles, platforms with advanced capabilities but high complement-development challenges show a pattern of defection of complementors toward rival, less challenging platforms. Our study extends mainstream disruptive-innovation theory to the context of platform-based ecosystems by offering a systemic view that accounts for disaffection on the part of technology complementors—rather than end users—as the main reason for disruption.

Key Words: Disruption; Ecosystem; Innovation; Platform; Technological transition

INTRODUCTION

The theory of disruptive innovation (Christensen, 1997; Christensen and Raynor, 2003) is considered one of the most influential theories of how firms and industries respond to technological change, and is highly popular among practitioners (The Economist, 2011).[1] In recent business journalism, the vocabulary of disruption has been relentlessly applied to highly visible technological firms such as Google, Amazon, Uber, and Airbnb, all deemed “disruptors” of existing industries. These firms all base their business operations upon their core, proprietary technological platforms (Gawer, 2014). They also rely on vibrant ecosystems of independent complementors to supply complementary products and services that enhance the value of their core technological platform (Gawer and Cusumano, 2002; Parker, Van Alstyne, and Choudary, 2016). Because of these so-called “multi-sided platform dynamics” (Rochet and Tirole, 2003; Evans, 2003), fueled by reinforcing network effects (Katz and Shapiro, 1994; Farrell and Klemperer, 2007),[2] platform ecosystems exhibit a specific structure of economic relationships among interdependent firms (Adner, 2017; Jacobides, Cennamo, and Gawer, in press) and depart from the traditional contexts in which disruptive-innovation theory was originally developed. Despite the hype in the business press, we have limited knowledge about how disruption unfolds in such contexts (but see Ansari, Garud, and Kumaraswamy, 2016).

Whether in videogames, smartphones, or enterprise IT systems, platforms are embedded in highly innovative ecosystems and evolve through intergenerational technological transitions, whereby the next generation of platform technology can offer greater benefits to users to the extent that they can enjoy better complements (Claussen, Essling, and Kretschmer, 2015; Cennamo, 2016). For instance, a videogame console transitioning from 2D to 3D graphics capability can offer users a more immersive gaming experience by depicting more realistic game-worlds, and can also benefit complementors by providing them with a new technology for developing better games that are potentially more appealing to users (de Vaan, 2014). However, those benefits (and the value of the next-gen platform) are conditional on the provision of complements that use the new technological capabilities of the next-gen platform (Cennamo, 2016).

Incumbent platform owners face an inherent tension during these generational transitions (Reimer, 2005). They might want to advance their next-gen platform to the technological frontier to stay ahead of the competition and impress users. Yet, since complementors would also need to migrate to the next-gen platform to create significant value for users (Ansari and Garud, 2009), incumbents can fail to create value unless they secure continued support from complementors to produce the next-gen complements that users expect from the technology (Cennamo, 2016). Thus, a successful transition to the next-gen platform is not guaranteed. The introduction of next-gen platform technologies may create technological discontinuity with the previous generation and open a window of opportunity for competitors (e.g., Cennamo, 2016). This can occur because disruptive tensions might emerge on the complementors' (supply) side when they need to migrate to next-gen platform technologies (e.g., Ansari et al., 2016; Ansari and Garud, 2009). This paper aims to shed light on these issues by addressing an important but under-studied set of questions: How do generational technological transitions affect disruption in platform ecosystems? And how do incumbent platforms navigate the process of disruption?

Existing related work in various streams of literature, summarized in Table I, has focused on different aspects to explain why some technologies can disrupt incumbents or fail to be adopted in the market. However, they tend to focus on the technology characteristics and value for end users, and neglect to examine the broader interdependencies in the ecosystem of complement providers. Drawing on the idea advanced in Ansari et al. (2016) that, while disrupting incumbents' technology, next-gen technologies might also disrupt the providers of complementary products that they vitally need for the new technology to succeed in the market, we consider these intergenerational technological transitions as instances of potentially disruptive innovations at the ecosystem level. Though next-gen platforms may well consist of innovations generated along the same technological trajectory as the previous generation, they may not be sustaining innovations for incumbents to the extent that they remove the backward compatibility of the next-generation platform (and can thus destroy the value of the last-gen platform's installed base), and to the extent that they break established linkages with their complementors. Choices that incumbents make in bringing about new technologies may well therefore render a significant portion of incumbents' assets obsolete and loosen their ecosystem linkages, hampering their relationships with end users and complementors.

INSERT TABLE I ABOUT HERE

We explore these issues in the context of intergenerational technological transitions in the videogame industry in the United States. The videogame industry has been often characterized as a multi-sided platform ecosystem (e.g., Cennamo and Santaló, 2013; Zhu and Iansiti, 2012), with the console being the platform, one side consisting of the population of game developers and the other side being the population of console owners. This industry provides a particularly favorable setting to explore how disruptive innovation unfolds in ecosystems, as every few years it undergoes a series of technological intergenerational transitions wherein at each transition multiple console makers launch new generations of their console (platform) technologies that take performance to an entirely new level. We conducted an in-depth qualitative and quantitative descriptive analysis of the launch of 12 next-gen platform technologies, covering three generations from 1993 until 2010.

We observe a consistent path across these intergenerational transitions. First, we identify a trade-off: we find that incumbents' next-gen platforms with greatest technological capabilities increase development difficulty for complementors[3] and, thus, are less likely to obtain timely and high-quality complements in the early phases of the intergenerational transition. We suggest that this is because developers find it more challenging to support these platforms compared to rival, less challenging platforms in the generation. This occurs despite complementors having preferential linkages with incumbent platforms. Second, we show a pattern of developers defecting during these intergenerational transitions from these more advanced platforms to rival, less challenging platforms. Third, we show that platform firms, aware of these risks and drawbacks, use different actions to manage this trade-off, including the internal development of complements and sharing of complement development knowledge with independent developers to ease the development challenges on the platform.

Our study contributes to the systemic view of disruptive innovation (Ansari et al., 2016; Afuah, 2000) by highlighting a paradox: specifically, to survive and grow, incumbent platform firms that cannot deter rivals or new entrants from introducing innovative next-generation technologies that may disrupt their ecosystem can choose to invest in bringing about these innovations themselves. However, because complementors need to renew their learning and other investments to be able to use the new technology capabilities, only a limited number of complements will be made available in a timely manner, ultimately constraining the new platform's commercial appeal. This is particularly the case for advanced, next-generation platforms that end up significantly altering the required knowledge base and imposing significant changes in complementors' development processes.

The study reveals an important variation on the reason why platforms fail in the market. While mainstream disruption theory in the strategy and innovation literature has emphasized demand-based factors such as heterogeneous customer preferences and underserved markets as key drivers affecting the success or failure of next-generation technologies (Christensen, 1997; Adner, 2002), it has generally ignored the role of complementors. Exceptions are recent advances such as Ansari et al. (2016) and the related work by Afuah (2000), which have highlighted the importance of inter-firm linkages in the case of disruption in systemic technologies, focusing on the challenges faced by new entrants aiming to disrupt ecosystems. Our study confirms these challenges in the context of platform ecosystems, focusing more specifically on incumbent platform owners as well as their ecosystem developers. We identify the various trade-offs ensuing from technological transitions in multi-sided platform ecosystems that platform owners and their complementors face during the transition phase.

RESEARCH METHODOLOGY AND CONTEXT

We conducted an explorative inductive multiple case study (Eisenhardt, 1989; Yin, 1994). This method is useful when existing theories fall short of answering the existing question, and when the question relates to a process or evolution over time (Langley, 1999; Hannah and Eisenhardt, 2017). We study videogame consoles, such as Sony's PlayStation or Microsoft's Xbox, that serve as platforms on which game titles are developed by complementors (developers) and consumed by end users (gamers). This setting enables us to answer our research questions by dint of its four main features. First, videogame consoles are an archetypal example of platform-based ecosystems (Cennamo and Santaló, 2013; Gawer and Cusumano, 2014). Second, as technological devices with different hardware characteristics, they allow us to exploit variance on functionalities, as well as development challenges across multiple hardware within and across technological generations. Third, there have been multiple generations of platform releases and several changes in market leadership that allow us to separate platforms that "win" from those that "lose." Fourth, the availability of data on console performance in terms of installed base and game release quality and quantity allows us to track each console's evolution and its success or failure.

Our analysis covers all major consoles released from 1993 until 2010, the final year for our console sales data. During this period, 12 consoles were released. We have treated each console and the games developed for it as a separate platform case and tracked the evolution of its associated ecosystem. Videogame consoles have historically been divided into different generations based on the word instruction length (in bits), CPU speed, and amount of RAM, with each generation representing a competitively and technologically distinct period (de Vaan, 2014; Forster, 2005). Table II lists consoles per their technological generation and their main technological features, and reports their long-term market performance.

INSERT TABLE II ABOUT HERE

Data Sources

We relied on multiple data sources to understand the intergenerational transitions in our context. First, we used the key trade journal for game developers in the industry, Game Developer magazine (published from 1994–2013, a total of 161 issues), and its online counterpart, Gamasutra.com. Second, we used the abstracts and audio and video presentations available from the key conference for videogame developers, the Game Developers' Conference, for the years 1999–2007. Moreover, we consulted books that documented the history of the videogame industry, as well as individual console producers (Kent, 2001; Pettus, 2013; Harris, 2014). We also collected "Retrospective" sections of the various issues of Retro Gamer magazine, where each platform in our sample is explored in depth through interviews with key managers and game developers who have worked for each platform. Finally, we collected[4] publicly available information through videogame industry websites such as arstechnica.com, 1UP.com, Gamespot.com, Gamasutra.com, and IGN.com on key interviews involving the developmental aspects of each console (e.g., how easy was development for console X vs. console Y, or developers' experiences in developing for console X vs. console Y). In addition, we thoroughly read scholarly articles on videogame consoles to cross-check our understandings and findings (Gallagher and Park, 2002; Schilling, 2002; Venkatraman and Lee, 2004; Corts and Lederman, 2009; Clements and Ohashi, 2005). Combinations of these sources allow us to reduce retrospective bias, as many of the articles were written at the time of the events. Moreover, retrospective sources allow us to compare what has been reported in earlier sources and determine whether the ex post stories of key individuals are congruent, which reduces the risk of incorrect deductions from the history of events.

In addition to the above qualitative sources, we used an extensive dataset on the U.S. videogame industry assembled from multiple data sources to build a description of the evolution of each platform. The primary data source comes from the MobyGames website, an online database on videogames. The MobyGames database has been found by previous research to be comprehensive and accurate (Mollick, 2012; de Vaan, 2014).[5] At the time of data collection, MobyGames had information on over 68,000 titles, all voluntarily entered by site users according to a detailed set of data-entry instructions. To ensure accuracy, MobyGames requires that all contributed data is peer reviewed. The data includes title, platform, publisher, developer, credits, release date, release country, and aggregated critical review scores. Using this data allows us to track the evolution of games on a platform in terms of quantity and quality, as well as other key dimensions such as share of games provided by the console owner compared to third-party complementors. We have reliable data on videogame titles for each console for the period January 1995–December 2009. This data is further complemented with monthly platform sales data collected by NPD Research for the years 1995–2010, which allows us to track the installed base of each platform by month and year to assess the performance of each platform in the generation, as shown in Table II.

Data Analysis

We began our analysis by combining our data sources to build a comprehensive historical case of each platform in our sample (Eisenhardt, 1989). Each case tracks a platform from its launch to the market until its eventual discontinuation (either prematurely as a failure, or due to obsolescence as a success). We focused on information that we could corroborate from our multiple data sources. We directed our attention and understanding of the evolution of each platform based on the events that occurred during the technological transition. Next, we identified emergent patterns by analyzing our cases based on our research question (Yin, 1994). Following up our singular cases, we undertook cross-case analysis using replication logic by using each pair of platforms as an experiment to confirm our emergent patterns across cases (Eisenhardt and Graebner, 2007).[6] By using tables and graphs (Miles and Huberman, 1994), we built tentative constructs to compare across our cases, as well as the established literature to refine our theoretical insights. Through this iterative cycle, we refined our insights and relationships and how they relate to the exiting literature with our logic of mechanisms (Eisenhardt, 1989).

Complement Development Challenges

We evaluate each console in terms of its complement development challenges, e.g., how difficult is it for developers to fully use these platform capabilities in their product development, taking into consideration complementors' costs and the difficulties of using these technologies.[7] Capturing complement development challenges requires identifying factors that reflect how difficult it is for developers to develop games for the whole platform system. We use two main development characteristics: (1) Using a specialized (and sometimes also novel) programming language that is required for complementors to be able to use platform capabilities through its interfaces (i.e., low-level programming language use) and (2) parallel processing, i.e., programming for the optimized use of multiple processing units (or multiple cores). These factors are strongly correlated with the difficulty of programming for a console. For instance, a low-level programming language requires co-specialized investments that are only useful for the target console and take time to learn. Moreover, using a low-level language involves a much longer process than using a high-level language (see Afuah, 2000). We also include one additional factor that has been highlighted by developers in determining the difficulty of development: the use of an inferior storage medium—which is exemplified by the Nintendo 64's use of cartridges when developers were having difficulties in fitting games developed for CD-ROMs on to cartridges.[8] Using these three factors for each console, we rank consoles within generation based on their challenge scores (most difficult = 3 to least difficult = 0). Table III presents a summary of consoles in terms of their complement development challenges.

INSERT TABLE III ABOUT HERE

Intergenerational Transitions in Videogames (U.S.)

In our observation period, we observe three different generational transitions with 12 new technologies (consoles). Figure 1 presents a timeline of console releases by each firm and the start of each console generation in the U.S. between 1993 and 2010, also noting new entrants to the market at the time of their first console.[9] Except for Nintendo and Sega, which were already present in the console market, all other firms were new entrants during our observation period. The 3DO and Atari Jaguar essentially started Generation 5 (G5), but both quickly exited the console market. Sega initiated Generation 6 (G6), yet exited the console market within just two years. The final new entrant, Microsoft, also joined the market in this generation with its Xbox console. In

Generation 7 (G7), all firms were incumbents; these also represent the firms still active in the market at the time of writing.

INSERT FIGURE 1 ABOUT HERE

RESULTS

In this section we present the evidence associated with our three claims: (1) evidence of a trade-off between platform capability and platform's complement development challenges—while developers (complementors) can use the new capabilities to create novel and better games, they face steep learning curves and increased development costs, which impair their ability to provide timely complements for the platforms with high complement development challenges; (2) evidence of developers defecting in the face of high complement development challenges—a significant proportion of developers associated with incumbent platforms in one generation tend to defect from it at the next, when the incumbent's new platform becomes too challenging relative to competing platforms (i.e., when the transition exacerbates the development challenges of one platform, developers leave it to start developing games for competing consoles in the new generation that are less challenging—even if they had reasons to stay with the previous platform, such as platform-specific investments that could be shared across the consoles of the same platform owner); and (3) evidence of how platform owners react to and manage these difficult ecosystem transitions—we present evidence on how these platform owners attempt to minimize developer defections by adopting a variety of practices, including first-party games, teaching developers how to develop for the platform, and sharing knowledge and development tools.

Trade-Off between Platform Capabilities and Complement Development Challenges

We find evidence at each transition that, although the technical advances of next-generation technologies offer new possibilities to complementors for game development, taking full advantage of the new console's (platform) capabilities also creates higher development costs for complementors, inasmuch as it requires new development processes and programming and design approaches. When working with the most powerful consoles of the next generation, complementors generally could not directly apply what they had learned from the previous generation, and needed to make new investments and experiment to match consumer expectations in the transition years, as exemplified by the following quote:

> *The next generation of consoles… p*romise to expand the technological boundaries of game development by a quantum leap, exponentially increasing the amount of digital canvas we developers have to work with. With this increase in capability comes a correspondingly higher level of expectation on the part of the consumer, and an increased burden on us as developers to evolve with and take full advantage of the new hardware.
>
> (Guymon, 1999, p. 23)

New knowledge and processes are required for developers to take full advantage of the next-generation consoles and to meet customer expectations, as summarized in an article by the developer Naughty Dog's co-founder (Andy Gavin) and ex-programming director (Stephen White):

> The **learning curve** may be the most obvious of all difficulties, and **is often one of the most disruptive elements** *of a video game's development schedule…* **new console hardware is normally drastically different** *and more powerful than the preceding hardware…* **[a] *developer has to learn many new things.…* A problem that stems from the giant gaps in technology between console generations is that it makes it difficult to reuse code that was written for a previous generation of console hardware**.
>
> (White and Gavin, 1999, emphasis added)

We summarize in Table IV specific changes pertaining to each intergenerational transition, together with what became obsolete and what was the new "paradigm." These changes, however, represent an average change that is driven by all consoles in the next generation. Depending on the specific technical architecture and limitations of each next-generation console, the added difficulty for developers can be more or less acute, with different effects on the intensity of the discontinuity and the need for retooling. If the new console was very challenging to develop for, this was an abrupt transition for developers, and if the console was less challenging, this represented a smoother transition.

INSERT TABLE IV ABOUT HERE

The evidence for our first claim (that there are trade-offs that complementors experience when they face the opportunity to develop games for next-generation platforms) is built from a combination of qualitative evidence of the difficulties of programming for next-gen platforms with increased capabilities. It is summarized in Appendix Table A.I and Tables V and VI, which respectively report the number of games each console received during the transition phase and other potential factors that may influence these patterns, such as the launch price of the console, entry time, backward compatibility, and the installed base of the last-gen console.

INSERT TABLES V and VI ABOUT HERE

Table V presents descriptive evidence on the number of third-party (independent) developer releases, the share of multihoming titles (titles that are released on multiple consoles) that are released first on the focal console and later on the others, and the number of high-quality third-party ("superstar") titles. Each year in the table reflects a calendar year for the focal console. For example, "Year 1" shows the total number of releases in 1993 for the 3DO (released in November 1993) and in 1995 for Sony PlayStation 1 (released in September 1995).[10] Qualitative evidence summarized in Table A.I in the Appendix shows that platforms with high complement development challenges are related to steeper learning curves and more costly development for game developers (especially in their first years). We thus expect a negative correlation between the complement development challenges of a console and the number of third-party titles and the share of multihoming titles first released on the console.[11] This pattern is indeed evident in Table V: overall, especially in the early periods of the transition, more powerful but challenging platforms receive fewer and lower-quality games from independent developers (compared to competing, less challenging platforms).

In G5, the least challenging console, the Sony PlayStation 1, had a superior number of third-party releases compared to all other consoles, and especially compared to its close competitors, the Sega Saturn and the Nintendo 64. In G7, the console with highest complement development challenges, the Sony PlayStation 3 (PS3), had the fewest games in its first year of release, and then briefly caught up with the Microsoft Xbox 360; later it fell behind the Xbox 360, but had more releases than the Nintendo Wii. Clearer evidence can be appreciated by considering the percentage share of multihoming titles (released on console) that were first released on the focal console. In G5, the Sony PlayStation 1 had the highest share of its multihoming titles being released first on the console (and then later released on other consoles), and the 3DO followed it, except in the first and last years, with challenging consoles generally receiving lower shares of their multihoming titles as first releases. For both pieces of evidence, G6 shows a somewhat unique pattern: the Sony PlayStation 2 (PS2) had a higher number of third-party releases and higher percentage share of its multihoming titles as first releases on the console (except in its first year). This might be explained by two key differences with respect to the transitioning of the challenging consoles in the other generations. First, the PS2 was fully backward compatible with the PlayStation 1, the dominant console at the time of its release. Second, it was the sole, uncontested G6 console from early 2001, when Sega (with its Dreamcast) left the console market, until the Nintendo GameCube and Microsoft Xbox appeared in late 2001. By that time, Sony was controlling over 60% of the market with its PlayStation 1 and 2 consoles.

Looking at the number of third-party superstar releases, in G5 we see that consoles with greater complement development challenges had fewer third-party superstar titles, showing the initial difficulties developers faced in making use of the capabilities of these consoles. Even in G6, we see that the Xbox was able to surpass the PlayStation 2 in the number of superstar releases in the early years. This is strong evidence since, despite the strong market foothold of the PlayStation 2 at the time the Xbox entered the market, the latter was able to attract more third-party superstar titles. In G7 we see an interesting pattern: the Wii, though a leader in the number of third-party releases, is last in terms of number of third-party superstar releases. This is due to its inferior capabilities.[12] Also, while the Xbox 360 was leading early on in terms of the number of third-party titles and superstars, the PlayStation 3 was able to attract a large number of high-quality titles later in the evolution of the generation. We will explain in a later section how Sony managed to achieve this in the face of the initial struggles during the transition period.

In Table VI, we look at other key factors that can influence these trends: price at launch, launch date, backward compatibility, and installed base in the previous generation. Each of these factors interacts to influence the outcomes presented earlier. Yet, none of them can explain these results by itself (except the idiosyncratic case of the PlayStation 2, mentioned above). For example, we can see that entering the market earlier than other consoles does not guarantee a higher number of titles, or even a higher share of multihoming titles first released on the platform. In fact, in G5 and G6, consoles released early on show evidence to the contrary. If we consider price, Nintendo's consoles are the cheapest in each generation—yet, again in G5 and G6, we do not see these consoles gaining in number of titles (and user sales). Nor do backward compatibility and last-gen installed base individually have a determining role. This is reflected in the evidence from the PlayStation 3 in G7. Despite Sony having the highest installed base in G6 with the PlayStation 2, and the PlayStation 3 initially being backward compatible, the console had severe difficulties in attracting titles during the transition phase. Backward compatibility and installed base together had a strong influence in G6 only because PlayStation 2 was, de facto, the only platform in the market that developers could use to build and sell their product.

Complementors Defecting to Less Challenging Platforms during Generational Transitions

The evidence for our second claim (that complementors tend to defect to less challenging platforms in generational transitions) is built from the combination of qualitative evidence of the problem (summarized in Table A.II in the Appendix) and Figure 2, which shows, for each generation, the change in the focus of game releases from the top five complementors of each console (as the percentage of releases in a generation). We find a clear pattern across all generations: Developers defect to less challenging consoles if the incumbent's next-generation console increases their development difficulties. In the transition from G4 to G5, both Sega and Nintendo came out with a challenging console, and, as reflected in the figure, the majority of the top five developers of each console in the previous generation reduced their share of releases on the next generation of consoles, as reflected by the downward slopes. Looking at the transition from G5 to G6, both platform owners switched from a challenging console in G5 to an easier one in G6 and attracted a higher share of releases on their next-generation consoles from their top five developers in G5.[13] On the other hand, the PlayStation 2, the most challenging console of G6, shows downward slopes for all its top developers—i.e., top developers embedded in the PlayStation 1 partly defected from the PlayStation 2 to less challenging consoles. This is a striking finding: Despite its market dominance, the console still provoked disaffection among its complementors owing to its high complement development challenges. Figures for G7 show the same consistent pattern: Both Microsoft and Nintendo are overwhelmingly represented by upward slopes, as both transitioned to simple consoles, whereas Sony's PlayStation 3 shows a downward slope, being an even more challenging console than the PlayStation 2.

INSERT FIGURE 2 ABOUT HERE

How Platform Owners Respond to Their Complementors' Disaffection to Manage the Transition

In this section, we provide evidence regarding platform owners' actions to manage the conflicting incentives faced by complement providers during intergenerational transitions. Platform owners are aware of the potential challenges for complementors associated with the technical advances of their next-gen platforms, and take action to limit these hurdles for complementors while aiming to provide the advanced features that may appeal to users. The following quotes provide examples of this point:

> We recognize that our technical architecture has initially made Sega Saturn more difficult to develop for than other next-generation formats, including the PlayStation. **But that is also why we know that Sega Saturn is a superior gaming platform**.... *We absolutely believe* there will continue to be dramatic differences in software as our developers learn to unleash the power of Sega Saturn.[14]
>
> (Tom Kalinske, CEO of Sega of America, 1995, emphasis added)

> *We don't provide the "easy to program for" console that [developers] want, because "easy to program for" means that anybody will be able to take advantage of pretty much what the* hardware can do, so then the question is what do you do for the rest of the nine-and-a-half years? [Commenting on the 10-year lifecycle projection of Sony for PS3] S***o it's a kind of – I wouldn't*** **say a double-edged sword –** ***but it's hard to program for, and a lot of people see the negatives*** **of it, but if you flip that around, it means the hardware has a lot more to offer**.
>
> (Kaz Hirai, CEO of Sony Computer Entertainment, emphasis added; Reisinger, 2009)

We find that platform owners used two basic actions to manage this issue. First, they developed their own complements (first-party development) to compensate for the lack of third-party complements owing to complementors struggling with the new development environment. They used the internal knowledge acquired in developing first-party complements to codify and share it with independent complementors, thus accelerating their learning process while also reducing the related costs for complementors. Second, platform owners tried to smooth out the learning curve by further instructing complementors on how to make best use of the new platform's capabilities, and by developing and sharing tools that help with handling (i.e., abstracting) some of the platform-specific programming tasks. We find that platform owners engaged intensively on both activities, particularly for those next-gen consoles high in complement development challenges.

Direct Investment into Complement Provision (First-Party Games) and Knowledge Sharing with Independent Complementors

Table VII shows the share of first-party games for consoles by generation. We find that platform owners with an advanced but more challenging platform generally have a higher share of first-party games out of total game releases, except for the mixed evidence in G6. As for G6, we observe that the PlayStation 2 sometimes has a higher and sometimes a lower share of first-party titles of its yearly releases.[15] Overall, this evidence supports the idea that platform owners with challenging platforms had to invest heavily in the production of first-party complements to overcome the initial development difficulties of independent complementors.

INSERT TABLE VII ABOUT HERE

This is also so because first-party games set a standards reference (i.e., quality standards) for independent complement providers by showcasing the technical capabilities of the platform. However, unless the platform owner transferred part of the development process knowledge required to master the new technical capabilities of the platform and tap into its potential, matching the quality of first-party complements would prove cumbersome for complementors, who still needed to spend time learning the intricacies of the platform architecture and development.

We see that, during our observation period, Sony deliberately tried to leverage its experience with the production of first-party games to share and disseminate the knowledge required for developers to master the console's development environment and speed up the development process. We collected evidence about these knowledge dissemination efforts by analyzing the Game Developers' Conference (GDC) events held by the platform owners.[16] The GDC is the most prominent event[17] where platform owners make new platform announcements through keynote speeches and share technical and developmental information on platforms.[18] We collected GDC lectures (1999–2007), presentations, and keynotes that are aimed at managing the developmental aspects with each platform. This data shows that Sony delivered more presentations for its PS2 and PS3 consoles on development-related issues than Microsoft, Nintendo, or Sega (presented in Appendix Table A.III). They ranged from high-level keynote speeches on the new platform architecture to specific tutorial sessions on programming, and sessions where first-party development studios shared their best practices. (Details of sessions are presented in Appendix Table A.IV.)

Supporting Complementors with Development Tools

Anticipating the developmental challenges of the PS2, Sony announced the first Tools & Middleware program, first launched in 1999 in Japan and aimed at enlisting independent game-development tool firms to optimize their tools (after a licensing agreement) for PS2 game development. Game development tools allow complementors to ease developmental issues by taking care of hardware-specific programming tasks ("hardware abstraction"), thereby smoothing the initial learning curve. By this virtue, development tools also allowed development of games for different platforms – hence getting more widespread across all game development efforts in the industry. We can see in Figure 3 the sudden rise in the use of development tools around the years 2000–2001 and onwards. The program proved critical for Sony to guarantee developers' support for the PS2 by partly easing early developmental difficulties.

INSERT FIGURE 3 ABOUT HERE

Platform owners also differ in how they use first-party development studios (developers owned by the platform owner) to create and/or share development tools for independent complementors. Having unrestricted access to internal research and development and proprietary information, these studios could build the most effective tools to develop complements, regardless of the platform's complement development challenges. However, these tools were not made immediately available to independent complementors. On the one hand, internal studios take advantage of their insider knowledge of the platform architecture to create high-quality games that could become highly popular with users and create a differentiation point for the platform. On the other hand, it also takes time for internal studios to make sense of the new development process, standardize the process, and codify it into automated development tools. We found that Sony was active in both G6 and G7 in sharing its internally developed tools (created by its first-party development studios). Although these tools were not made available immediately (twenty-ninth month of the PS2 and fifth month of the PS3), their release to third-party developers boosted the performance of these platforms considerably, as Table VIII shows. Both the PS2 and the PS3 initially lag in terms of third-party superstar titles compared to their competition (the Xbox and the Xbox 360, respectively). However, in the period following the release and sharing of these tools to third-party developers, both the PS2 and the PS3 gain the lead in terms of the third-party superstars attracted to the console. By contrast, Sega, Nintendo, and Atari (G5), whose platforms proved challenging for complement development, did not engage in such active effort; the number of superstars they received over time did not increase, and never got close to that of the PlayStation 1 (see Table VIII).

INSERT TABLE VIII ABOUT HERE

Managing Across Generations

We observe that all platform owners who failed with advanced but challenging platforms in previous generations changed their platform architecture design and attempted to reduce transitioning difficulties for complementors with the platforms they developed for the following generation. They did so by taking bold architectural design choices: They made consoles with a simple architecture (even if this meant sacrificing part of the platform's technical capabilities). This was the case, for example, for Sega's Dreamcast (which was much easier to develop for compared to the Saturn), Nintendo's GameCube, and even more so the Wii. Sony, after losing leadership with the PS3 in G7, adopted a simpler, PC-like architecture with its next-gen PS4 console in G8 (not covered in this analysis). As the PS4's head architect, Mark Cerny, explains:

> It looks so obvious in retrospect… We talked to some people who made games about what sort of hardware *they'd* like to make their games on… So, the PS3 comes out and it has a weak launch lineup, of course, due to the hardware being rather difficult to use… I just started thinking there was a better way.
>
> (Seppala, 2013)

DISCUSSION AND CONCLUSION

We have studied intergenerational technological platform transitions as potential instances of disruptive innovation by examining the extent and manner in which disruption unfolds in platform ecosystems, and how incumbent platforms navigate the process of disruption. In these interdependent settings, performance-enhancing technological transitions should reinforce the value of the incumbent dominant platform, since the platform owner can leverage its well-established ecosystem and user base to successfully promote and shift to the next-gen technology. Research on platform market competitive dynamics has indeed stressed how hard it is for challengers to dethrone an incumbent dominant platform, owing to the strength of network effects (Caillaud and Jullien, 2003; Hagiu, 2005; Parker and Van Alstyne, 2005; Rochet and Tirole, 2006) associated with the user installed base and the plentiful supply of complements generated by the complementor ecosystem—also referred to as "application barriers to entry" (Gilbert and Katz, 2001). However, in several cases we have observed changes in platform leadership resulting from intergenerational transitions, with incumbent dominant platforms failing in the next-gen technology.

What, then, can explain the failure of incumbent dominant platforms during intergenerational technological transitions? We advance a disruption logic at the ecosystem level, considering these intergenerational technological transitions as potentially disruptive of the incumbent's established ecosystem. We have identified important trade-offs and document how, in platform-based ecosystems, a technology's significant advance in technical performance can in fact hinder this technology's very ability to gain support from complement providers, ultimately leading the new platform technology to fail. As we have documented, this paradox is particularly acute when the improvements of the next-generation platform technology alter the knowledge base and development process of complement providers, steepening their learning curves and requiring them to make new technology-specific investments. Thus, intergenerational technological transitions can lead to the disruption of incumbent platforms by breaking the established linkages with their complementors, which then limits the production of the timely, high-quality complements that are needed for the next-generation platform to succeed in the market.

Implications for Theory

Our study reveals an important variation to the mainstream disruption theory and a paradox that is specific to disruption in platform ecosystems.

The Incumbent Platform Innovator's Paradox

We uncover an important paradox, which is that the incumbents who introduce innovations might end up disrupting the very actors in the ecosystem whose support they depend on: the developers of complements that are essential to the new platform's success. As a resulting effect, this weakens the platform by limiting the number of complements made available during the transition period. We find that what impairs complementors' incentives, and their ability to develop platform-compatible complements for the advanced next-gen platform, is that innovation ends up significantly altering the required knowledge base, introducing significant changes in the development processes necessary for complementors to develop complements. The introduction of significantly more powerful platform technologies by platform firms therefore creates two kinds of costs for complementors: (1) transitional learning costs associated with learning how to develop next-generation complements; and (2) increased development costs due to extended and new opportunities offered by the superior performance and new functionalities of the next-generation technology.

The paradox is that, in these contexts, the very disruptive innovations these incumbents bring forth tend to create steep learning curves and significantly increase development costs for complementors, dampening incumbents' own platforms' chance of success. This echoes the paradox identified in Ansari et al. (2016) in the general context of ecosystems innovation: that new entrants who are disruptors need to gain the support of the very incumbents that they disrupt. Our paradox, although related, differs in the sense that our disruptors are the incumbents themselves, and they need the support of the complementors who they are disrupting. In the context of platform-based ecosystems subject to network effects, successfully managing this trade-off is critical to platform survival, as complements are essential to the platform's success. Thus, disaffection with incumbents' technologies is driven in these contexts by complementors rather than end users, owing to the "overshooting" of technological capability that creates development challenges for complementors.

This finding also echoes Tushman and Anderson's (1986) classification of technological innovations as competence-destroying vs competence-enhancing, which recognized that for technological innovation to succeed it must not only respond to a demand in terms of use but also, from the supply side, avoid weakening the competences of adopting firms. However, the technologies described in Tushman and Anderson (1986) have a standalone value for consumers, i.e., consumers do not require complements to use the technology, although complements, if available, might extend the range of applications of the technology and hence enhance its value to users. The focus on the supply side is for the various components that are needed from suppliers to create the technology itself, or the use of the technology in the production process of other firms. However, there is no interdependence between the demand for the technology on the one side and the supply of complements on the other—which is, in contrast, a key attribute of platform technologies. For however much additional power and technical functionality the next-gen platform can offer users, it will have no or very limited value without complements that take advantage of these improvements. The focus in our analysis on the impact of next-gen technologies on a platform's complementor ecosystem would rather contrast "ecosystem-destroying" platforms with "ecosystem-enhancing" ones. When the next-gen platform significantly shifts the development opportunities for complementors, but also alters complementors' development process and requires new learning investments, disruption of the incumbent's established ecosystem is more likely to occur. However, disruption does not result automatically from the technical characteristics—i.e., the "types" of technologies. In order for challengers to disrupt the incumbent's ecosystem with the introduction of such technologies, they have to address their own ecosystem challenges. Our analysis reveals that, in our setting, first Sony, with its PlayStation in Generation 5, and then Microsoft, with the Xbox in Generation 6 (and to a greater extent in Generation 7), managed to successfully enter the market and gain support from complementors by achieving a good balance between the technical advances offered in their next-gen platforms and the costs for complementors to learn about and develop for the platform. Meanwhile, dominant incumbents failed to block disruption and, in fact, helped to accelerate the process by introducing next-gen platforms that were technically more advanced but also more challenging and costly to develop for by complementors, as we have documented.

A Variation on Disruption Theory: Bringing (Systemic Interdependency and) Network Effects into Disruption Leads to Incumbents Disrupting Themselves

The paradox highlighted above implies an important variation to disruption theory: To survive and grow, incumbent platform firms choose to invest in bringing about next-generation technology innovations themselves, which may ultimately end up disrupting their existing ecosystem. They do so because of the pressing need to anticipate or respond to the competitive threat of rivals introducing next-generation platforms. In contrast to mainstream theory, where incumbents do have the capabilities to respond to new entrants but fail to do so in a timely way, in platform-based ecosystems incumbents may actually anticipate rivals' competitive moves because of the dynamics of indirect network effects. Platform-based ecosystems subject to network effects create significant unique conditions because of the dual role that complementors play in, on the one hand, hampering new entry and, on the other hand, fueling a more intense kind of competition by new entrants.

While studies of platform market dynamics (Caillaud and Jullien, 2003; Hagiu, 2005; Parker and Van Alstyne, 2005; Rochet and Tirole, 2006) have stressed the role of network effects as barriers to entry, network effects fundamentally change new entrants' incentives, which has a knock-on effect on incumbents' incentives and behavior. In the presence of network effects, entrants' only chance to displace incumbents might be to generate new technologies that render the incumbent platform's complementary products (i.e., the games) obsolete, and thus destroy an incumbent's installed base advantage (e.g., Schilling, 2003; Sheremata, 2004). In the presence of intense competition from rivals and new entrants, incumbents cannot block entry, and they tend to choose to introduce advanced, radically new platforms themselves, at the risk of disrupting the established linkages to their own complementors' ecosystems (e.g., Garud and Kumaraswamy, 1993).

This departs from the prediction of the mainstream theory of disruptive technologies that disruption will come from new entrants introducing technologies that target the low end of the market. In fact, to be able to disrupt incumbents' ecosystems, challengers (incumbents and new entrants) need to introduce next-generation technologies with significant advances and new functionalities that have the potential to break the established linkages of dominant incumbents' complementor ecosystems. Our logic integrates the early intuitions of Schilling (2003) and Sheremata (2004) that, in contexts where network effects are present, entrants' only chance to challenge incumbents is technology leapfrogging. As we have articulated and documented in our analysis, this only happens when platform owners manage to balance the trade-off between platform capabilities and complement development challenges for complementors: technically, by achieving the right balance in their architectural design, and organizationally, by instilling routines for knowledge sharing and the creation of tools that facilitate the development process, saving time and cost for complementors. Considering the interdependence between technological advances and their impact on the complementor side is an important conceptual step for a nuanced understanding of disruption (and failure) of intergenerational technological transitions in platform-based ecosystems. Our study has therefore shed light on and extended a literature that was ambiguous as to whether, in the context of platform-based ecosystems, the existence of complementors would hamper new entrants or instead make them even keener to compete strongly and dislodge incumbent platforms.

Limitations and Avenues for Future Research

While the evidence provided in this article points to the potential trade-offs that incumbents face when introducing disruptive platform technologies, we do not mean to suggest that incumbents are better off not pursuing technological innovation on platforms. On the contrary: We have shown that the paradox of technological superiority within platform-based ecosystems can be managed.

In our context, some platform owners did recognize these drawbacks and invested in the production of first-party complements as a way to showcase the technical potential of their platforms and generate direct knowledge about the complement development process that could be passed on to complementors in the form of best practices and/or development tools. Other platform owners failed to recognize and address the issue in a timely way. This further impeded the learning required by complementors to harness the power of the new technology, as in the case of Sega in the fourth generation, for which "the software development kits (SDKs) for Sega CD were late in arriving from Japan, which was one of the major contributing factors towards the lack of a good software base" (Pettus, 2013, p. 282). This was largely due to Sega's contradictory incentives to produce strong complements internally and obtain large profits from their sales, partly at the expense of third-party games. However, we did not assess how platform owners manage this tension between internal (i.e., organization units') and external (i.e., complementors') incentives. We anticipate that platform providers can vary greatly in their organizational structures and mechanisms for maintaining the coherence of incentive schemes. Exploring this variation can provide fertile ground for a more nuanced understanding of disruption in platform ecosystems, and more generally for understanding innovation dynamics in ecosystems.

Also, managing the paradoxical properties of next-generation platforms is critical because the superior performance of the technology is a prerequisite for platforms to remain competitive over the longer term. Although we have found that advanced technology can generate liabilities during the intergenerational transition phase, so does having an underpowered technology in the long run, as illustrated most notably in the case of the Wii: Despite its strong initial momentum, overall it obtained only a few high-quality ("superstar") complements compared to its main rivals, losing market share over the evolution of the technological generation. Similarly, those consoles pioneering the new generation that offered superior performance but also additional development difficulties (such as the Atari Jaguar) simply could not attract enough developers. While we focused our analysis on the intergenerational transition phase, it might also be useful to systematically analyze the later conditions, during the next-generation technological evolution, which might enable or hinder providers of advanced next-gen technologies to properly address complementor challenges and gain their development support.

In conclusion, we see much promise in further studying the interaction between competitive and innovation dynamics within platform-based ecosystems. This is a rich area of study that has the potential to advance theory in management research on disruption and competition, as well as provide managerially relevant knowledge.

NOTES

1. The Economist has defined it as "one of the most influential modern business ideas." "Aiming High," June 30, 2011, www.economist.com.

2. Network effects can be direct (i.e., within-side) or indirect (i.e., cross-side). For multi-sided platforms, it is the indirect, or cross-side, network effects that are particularly relevant: When they are positive, the more complements are available for a platform, the more the value of the platform increases for users; and the more users the platform has, the more complementors are incentivized to develop complements for it. Such positive cross-side network effects have important consequences for the growth and stability of platform-based ecosystems (Armstrong, 2006; Hagiu and Wright, 2015).

3. We define a platform's complement development challenges as how difficult it is for third-party complementors to develop complements for the given platform technology. We study the overall difficulty that complementors face when developing complements for a focal platform, including the consequences of the next-gen platform technology for the development routines and technological environment of complementors. Thus, this construct differs from related constructs such as platform complexity (e.g., Cennamo, Ozalp, and Kretschmer, 2018), which capture the number of dimensions to be considered and their interdependence, but focus only on the characteristics of the platform technology. A platform can be technologically complex and yet require no changes in the development routines and technological environment of complementors, and thus impose limited development challenges for complementors. By contrast, a next-gen platform may have limited technological complexity but introduce novel features that require new knowledge and/or alter the development process of complementors to make use of the platform's new capabilities, thus increasing development challenges for complementors.

4. In the event that an online source was no longer accessible, we accessed it with the Internet Wayback Machine (http://archive.org/web).

5. MobyGames lists its goal as: "To meticulously catalog all relevant information – credits, screenshots, formats, and release info – about electronic games (computer, console, and arcade) on a game-by-game basis, and then offer up that information through flexible queries and data mining… In layman's terms, it's a huge game database." Available at http://www.mobygames.com/info/faq1#a1 (April 2 2016).

6. "Central to building theory from case studies is replication logic (Eisenhardt, 1989b). That is, each case serves as a distinct experiment that stands on its own as an analytic unit. Like a series of related laboratory experiments, multiple cases are discrete experiments that serve as replications, contrasts, and extensions to the emerging theory (Yin, 1994)" (Eisenhardt and Graebner, 2007, p. 25).

7. Although our reconceptualization could also be extended to include challenges that users face in using a technology (see Claussen et al., 2015, for an example), we focus only on complementors' challenges for their critical impact on the technology's value, and also because in our setting technologies are similar in that respect (i.e., vis-à-vis users).

8. It may be argued that development challenges could be lessened with the provision of the right development kits and tools. However, whereas it could be less challenging developing for a platform that offers development tools, the absence of such tools does not in itself make a platform more difficult to develop for. Moreover, none of our difficult-to-develop-for platforms had timely and adequate tools provided early in their lifecycle.

9. The Atari Jaguar is considered a new entrant since it left the console market after the Atari 7800 (released in 1986) and instead focused on personal computers until the release of the Jaguar in 1993.

10. We chose to follow calendar year by console for Table V, since consumers make the majority of console and game purchases in the Christmas period, and industry professionals determine performance outlook of each platform based on their available games and installed base at the end of each year.

11. Obviously, other factors may play a role in the console selection as well, such as the market share of the target console, which is well reflected in the descriptive data regarding the PlayStation 2. However, everything being equal, the reason that one console gets a multihoming title earlier than other consoles is related to the ease of development, since otherwise we would have observed a simultaneous release, which doesn't count as a "first release" in calculating our measure.

12. The Wii's technical inferiority became a problem after its first couple of years, as developers required higher hardware capabilities. For example, when asked if Call of Duty 2 would also be released on the Wii, the developer of the series, Infinity Ward, commented that: "If we felt like we could deliver the cinematic experience we were going for on other platforms, then we would gladly move to that platform. Right now, we don't think the Wii can deliver the exact experience that we're doing. We like to be very equal across all platforms, and if it's not equal then we won't do it" (Dring, 2009).

13. In fact, the only downward slope in the Dreamcast, with Electronic Arts reducing its releases to 0, is due to a firm decision: Electronic Arts decided not to support Sega anymore as it was disappointed in the previous generations.

14. Accessed from Google Usenet group archives, rec.games.video.sega. Available at http://groups.google.com/forum/#!topic/rec.games.video.sega/VuUmORr-bw8; accessed February 24 2014.

15. Contrary to our expectation, the Dreamcast had a much higher share of first-party games. The Sega Dreamcast was an "irregularity," since Sega had announced in January 2001 that it would

exit the console market. Independent developers accordingly discontinued their support for the console, canceled the titles they had in development, and stopped releasing any further ones. Despite discontinuing investments into the console, Sega did invest in the production of games, which became its main business focus—hence the unusually high share of first-party titles on the console.

16. Direct information was not accessible because console game development and console hardware-specific knowledge are heavily protected by nondisclosure agreements imposed by platform owners.

17. Before the Dreamcast announcement at GDC 1998, new platform announcements were usually made at the Electronic Entertainment Expo (E3). After 1998, the majority of platform announcements were made at the GDC for North America, except for Nintendo, which for the observation period made announcements at E3 but usually leaned more on its press conferences in Japan. The GDC is much more like academic conferences, with roundtables, presentations and lectures, whereas E3 has more of a marketing and consumer orientation.

18. For example, as briefly discussed earlier, Sony's keynote at the GDC 2000 ("The Future of the PlayStation") explained how the PlayStation 2 required a steeper than usual learning curve owing to its hardware, and the live on-stage talk with the developer Naughty Dog (acquired by Sony in 2001) further detailed how specific coding was required (in assembly language for the VU0 and VU1 chips) to design games effectively for the platform. However, while sharing this knowledge, Sony itself did not provide libraries to code for the PS2—complementors were expected to develop their own libraries by learning the intricacies of these chips. By contrast, Microsoft's keynote at GDC 2000 ("Opening Keynote: Bill Gates"), announcing the Xbox, detailed how developers could easily use the already-familiar (to them) Windows and X86 (Intel Pentium) CPU programming to customize games for the Xbox.

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Table I. Research Streams on Intergenerational Shifts and Disruptive Potential

Dimensions	Outcome	Innovation Impact On
Focus: Technological Change		
Competitive effects of innovation	Innovations can be categorized based on their differential impacts on systems of production and marketing	Incumbents, users, and suppliers
Dramatic increases in technological performance through generational shifts	Technology shifts with S-curves of performance/cost, where new technologies quickly surpass the existing generation technologies in performance and/or efficiency.	Incumbents vs entrants
Competence-enhancing vs. competence-destroying technological change	Radical innovations make incumbents' capabilities obsolete, therefore causing them to fail.	Incumbents vs entrants
Dimensions of innovation: incremental vs. radical; architectural; disruptive	Radical innovations are not the only explanation in incumbent vs. entrant dynamics. Architectural innovations suggest seemingly incremental innovations that change the architectural linkages may cause incumbents to fail, whereas disruptive innovations may cause incumbents fail by locking in their customer value network and defeated by seemingly inferior innovations.	Incumbents vs entrants
Complementary assets	Incumbent vs. entrant dynamics also depend on the need and availability of complementary assets. Radical technological changes, even if competence-destroying, may still not threaten incumbents if existing complementary assets are still valued.	Incumbents vs entrants
Value network of the innovator	It is critical to think firms are not sole entities, but they have their value networks, which are the context they are in based on their customers, suppliers and complementors.	Incumbents vs entrants, suppliers, complementors, and users
Illustrative studies: Abernathy and Clark, 1985, Foster, 1986, Tushman and Anderson, 1986, Teece, 1986, Anderson and Tushman, 1990, Henderson and Clark, 1990, Afuah and Bahram, 1995, Christensen, 1997, Tripsas, 1997, Adner, 2002, Ansari and Garud, 2009		
Focus: Network Effects and Technological Standards		
Path-dependence	Small gains early on (either by moving first or by chance) can create disproportional differences between technologies on the longer run due to externalities.	Competing technologies
Excess inertia	Technologies with superior performance may still end up not being adopted due to users of the existing technology benefitting through a large installed base.	Competing technologies, users
Increasing returns to adoption	New adopters (or possible switchers) enjoy higher utility by using technologies that have a higher installed base	Competing technologies, users

Compatibility and standardization	Interoperability may decrease competition among competitors by combining network externalities of competing technologies. It may also cause a "trap" by lowering the chance of entrants to challenge the standard.	Competing technologies, users
Technological leapfrogging	For a new technology to compete with an entrenched standard, it must provide a significant technological improvement.	Incumbents vs. entrants, competing technologies, users
Complementor overlap/apps market competition	Having too many complementary products on your platform/ecosystem may create negative incentives for complementors due to competition.	Competing technologies, complementors
Illustrative studies: David, 1985, Katz and Shapiro, 1994, Arthur, 1989, Garud and Kumaraswamy, 1993, Schilling, 1998, Garud, Jain, and Kumaraswamy, 2002; Gallagher and Park, 2002, Schilling, 2003, Suarez, 2004, Venkatraman and Lee, 2004		
Focus: (Platform-Based) Ecosystems		
Complementor overlap/apps market competition	Having too many complementary products on your platform/ecosystem may create negative incentives for complementors due to competition	Platform owner, complementors
Increasing returns to adoption by multiple-sides of the market (e.g., users and complementors)	Positive feedback effect between having more users and complementors.	Platform owner, complementors, users
Importance of platform quality (technological performance)	Platform quality may make up for the initial lack of installed base and complements by attracting initial users through superior quality/performance.	Platform owner, users
Interdependence in innovation within ecosystems	Focal firm outcomes determined by challenges of suppliers and complementors. Suppliers and complementor challenges also have differential effect on the focal firm outcome.	Platform owner/focal firm, complementors, suppliers
Platform architecture: modularization and complexity	Platforms are technological architectures formed by a core and periphery. Core is represented by the core platform technology, whereas the periphery is formed by complements. Connection between the two is formed via modular interfaces. Platform architecture (together with interfaces) determines the incentives for complementors to support a technology.	Platform owner, complementors
Ecosystem complexity and development challenges	Ecosystem complexity (the number of unique components or subsystems that interact with the complementor's product) and development bottlenecks of next-gen platform technologies may both provide a context for complementors to sustain their performance, but also may magnify challenges they are facing with technological transitions.	Platform owner, complementors
Ecosystem/platform governance	Platform architecture is closely connected with platform governance decisions: vertically integrating to complement production depends on the relationship between platform architecture and complementors.	Platform owner, complementors
Illustrative studies: Gawer and Cusumano, 2002, Garud, Jain, and Kumaraswamy, 2002; Baldwin and Woodard, 2009, Adner and Kapoor, 2010, Tiwana et al., 2010, Zhu and Iansiti, 2012, Cennamo and Santaló, 2013, Anderson et al., 2014, Gawer, 2014, Claussen et al., 2015, Kapoor and Furr, 2015, Adner and Kapoor, 2015, Ansari et al., 2016, Kapoor and Agarwal, 2017		

Table II. Sample Consoles in the U.S. Videogame Industry (1993–2010)[a,b,c]

Console	U.S. Launch Date	Platform Parent	CPU Bits	MHz	RAM	Media	Launch Price	Market Share	Titles (Superstars)
				Generation 5					
3DO	Oct. 1993	3DO	32-bit	12.5	2	CD	$699	1.4%	126 (10)
Jaguar	Nov. 1993	Atari	32-/64-bit	26.6 × 2	2	Cartridge	$249	0.4%	126 (10)
Saturn	May 1995	Sega	32-bit	28 × 2	2	CD	$399	4.4%	150 (9)
PlayStation	Sept. 1995	Sony	32-bit	33.87	2	CD	$299	55.2%	526 (51)
Nintendo 64	Sept. 1996	Nintendo	64-bit	93.75	4	Cartridge	$199	38.7%	142 (12)
				Generation 6					
Dreamcast	Sept. 1999	Sega	128-bit	200	16	GD	$199	6.9%	181 (18)
PlayStation 2	Oct. 2000	Sony	128-bit	294.9	32	DVD	$299	52.6%	971(108)
Xbox	Nov. 2001	Microsoft	Pentium II	733	64	DVD	$299	23.2%	653 (93)
GameCube	Nov. 2001	Nintendo	128-bit	485	40	MiniDVD	$199	17.3%	416 (45)
				Generation 7					
Xbox 360	Nov. 2005	Microsoft	Power PC	3200 × 3	512	DVD	$299	37.6%	451 (47)
PlayStation 3	Nov. 2006	Sony	Power PC	3200 × 7	256	Blu-ray	$499	22.2%	312 (39)
Wii	Nov. 2006	Nintendo	Power PC	729	88	WiiDVD	$249	40.2%	386 (10)

Notes: [a] Market share shows the long-run sales share of the platform within its generation. Following Corts and Lederman (2009), it is defined as the total installed base share (number of consoles sold) of the console in the month in which the first platform of the next generation is released.

[b] To calculate the long-run market share for Generation 7 consoles, we combined our data from NPD Research console sales (until June 2010) with data coming from vgchartz.com (July 2010–November 2012).

[c] Titles (Superstars) shows the number of third-party game titles (third-party superstars titles) for the same period considered in the market share, except for the Generation 7 consoles. Owing to our data availability on titles, Generation 7 covers the period November 2005–December 2009.

Table III. Summary of Consoles by Their Complement Development Challenges Factors

Console	Low-Level Language Use	Parallel Processing	Inferior Storage Media Use	Relative Degree of Development Challenges
		Generation 5		
3DO	NO	NO	NO	LOWEST
Jaguar	YES	YES	YES	HIGHEST
Saturn	YES	YES	NO	HIGH
PlayStation	NO	NO	NO	LOWEST
Nintendo 64	YES	NO	YES	HIGH
		Generation 6		
Dreamcast	NO	NO	NO	LOWEST
PlayStation 2	YES	NO	NO	HIGHEST
Xbox	NO	NO	NO	LOWEST
GameCube	NO	NO	NO	LOWEST
		Generation 7		
Xbox 360	NO	YES	NO	LOW
PlayStation 3	YES	YES	NO	HIGHEST
Wii	NO	NO	NO	LOWEST

Table IV. Changes Required for Complementors during Intergenerational Transitions: Knowledge, Tools and Language of Game Development

Intergenerational Transition / Changes required	Generation 4 → Generation 5	Generation 5 → Generation 6	Generation 6 → Generation 7
Knowledge	2D game programming and design → 3D game programming and design.	Single-platform programming → Cross-platform programming.	Single-thread programming → Multi-thread programming.
	Development optimized for cartridge memory → CD-Rom.	General programming and design tasks → Specialized programming and design tasks and project management (exponentially increasing project sizes).	Specialized programming and design tasks and project management → Highly specialized programming and design tasks, and coordination/collaboration through multiple outsourced tasks (extremely large projects, very specialized roles such as facial animation, and outsourced animation tasks, quality assurance).
Tools	Custom 2D/Pixel development tools → 3D animation tools (e.g., SoftImage, Lightwave 3D, PowerAnimator, 3D Studio) and Video Codec Tools. Major change in proprietary in-house tools.	Existing 3D animation tools → New 3D/Graphics Tools (e.g., Higher resolution/handling higher-number polygons), Middleware Tools, Early Physics and AI Tools; (e.g., Renderware, CRI, 3DS Max, Incredibuild,Maya, tcsh, Exceed, CVS). Major change in proprietary in-house tools.	Existing 3D/graphics tools → New 3D/graphics tools (e.g., high-definition resolution/higher polygon count, lighting and occlusion) and advanced physics, AI, networking tools and game engines (e.g., Umbra,Yebis, SpeedTree, Enlighten, Pixologic ZBrush, Softimage XSI, Nvidia Physx, Havok Physics, Demonware, Autodesk Kynapse, Havok AI, OC3 FaceFX, Unreal Engine, CryEngine). Major change in proprietary in-house tools.
Programming Languages	Console-specific/Assembly programming → C and/or Assembly (console-dependent).	C and/or Assembly (console-dependent) → C, C++ and/or Assembly (console-dependent).	C, C++ and/or Assembly (console-dependent) → Predominantly C++ with assembly for optimizing PS3.

Table V. Platform Title Release Descriptives[a]

Generation	Console	Number of Third-Party Game Releases					First Releases as % of Multihoming Titles					Number of Third-Party Superstar Releases				
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 1	Year 2	Year 3	Year 4	Year 5	Year 1	Year 2	Year 3	Year 4	Year 5
5	3DO	10	64	39	11	[b]	0%	44%	53%	32%	[b]	2	10	4	0	[b]
5	**Atari Jaguar**	**0**	**1**	**15**	**3**	[b]	**0%**	**6%**	**0%**	**0%**	[b]	**0**	**0**	**4**	**0**	[b]
5	**Sega Saturn**	**29**	**78**	**41**	**2**	[b]	**24%**	**31%**	**12%**	**0%**	[b]	**4**	**8**	**4**	**0**	[b]
5	Sony PlayStation	34	136	127	144	162	31%	39%	50%	69%	52%	11	21	26	38	39
5	**Nintendo 64**	**2**	**26**	**64**	**83**	**54**	**0%**	**13%**	**35%**	**43%**	**15%**	**0**	**8**	**15**	**12**	**12**
6	Sega Dreamcast	37	116	28	[b]	[b]	27%	15%	43%	[b]	[b]	3	13	2	[b]	[b]
6	**Sony PlayStation 2**	**40**	**140**	**204**	**196**	**200**	**19%**	**54%**	**42%**	**24%**	**13%**	**3**	**17**	**24**	**25**	**19**
6	Microsoft Xbox	28	138	166	153	168	24%	7%	8%	5%	4%	4	23	24	23	20
6	Nintendo GameCube	16	130	121	78	72	20%	6%	8%	12%	13%	3	13	15	9	6
7	Microsoft Xbox 360	15	67	103	121	110	10%	13%	5%	1%	2%	1	6	7	15	14
7	**Sony PlayStation 3**	**10**	**68**	**105**	**102**	**103**	**0%**	**2%**	**0%**	**0%**	**0%**	**0**	**7**	**15**	**15**	**11**
7	Nintendo Wii	26	109	121	125	78	11%	6%	12%	4%	8%	0	3	4	3	1

Notes: [a] Platforms in bold are those with high degree of complement development challenges in each generation.

[b] Platform had left the market.

Table VI. Potential Key Factors Influencing Platform Attractiveness for Developers[a]

Generation	Console	Price	Launch Date	Backward Compatibility	Previous-Generation Base
5	3DO	$699	Nov. 1993	New Entrant	New Entrant
5	**Atari Jaguar**	**$249**	**Nov. 1993**	**New Entrant**	**New Entrant**
5	**Sega Saturn**	**$399**	**May 1995**	**No**	**11.7 million**
5	Sony PlayStation	$299	Sep. 1995	New Entrant	New Entrant
5	**Nintendo 64**	**$199**	**Sep. 1996**	**No**	**8 million**
6	Sega Dreamcast	$199	Sep. 1999	No	1.4 million
6	**Sony PlayStation 2**	**$299**	**Oct. 2000**	**Yes**	**17.4 million**
6	Microsoft Xbox	$299	Nov. 2001	New Entrant	New Entrant
6	Nintendo GameCube	$199	Nov. 2001	No	12.2 million
7	Microsoft Xbox 360	$299/$399	Nov. 2005	Yes	13.5 million
7	**Sony PlayStation 3**	**$499**	**Nov. 2006**	**Yes**	**30.6 million**
7	Nintendo Wii	$249	Nov. 2006	Yes	10.1 million

Notes: [a] Platforms in bold are those with high degree of complement development challenges in each generation.

Table VII. First-Party Title Release Shares by Platform[a]

Generation	Console	First-Party Titles as % of All Titles				
		Year 1	Year 2	Year 3	Year 4	Year 5
5	3DO	0%	4%	13%	15%	[b]
5	**Atari Jaguar**	**100%**	**93%**	**55%**	**63%**	[b]
5	**Sega Saturn**	**41%**	**24%**	**32%**	**71%**	[b]
5	Sony PlayStation	21%	13%	15%	15%	15%
5	**Nintendo 64**	**75%**	**26%**	**14%**	**11%**	**19%**
6	Sega Dreamcast	27%	15%	43%	[b]	[b]
6	**Sony PlayStation 2**	**9%**	**11%**	**7%**	**8%**	**7%**
6	Microsoft Xbox	24%	7%	8%	5%	4%
6	Nintendo GameCube	20%	6%	8%	12%	13%
7	Microsoft Xbox 360	17%	4%	10%	7%	4%
7	**Sony PlayStation 3**	**29%**	**15%**	**13%**	**11%**	**10%**
7	Nintendo Wii	10%	11%	5%	6%	10%

Notes: [a] Platforms in bold are those with high degree of complement development challenges in each generation.
[b] Platform had left the market.

Table VIII. Distribution of Third-Party Superstar Titles by Platform Age Periods[a,b]

Generation 5					
	PlayStation 1	**Nintendo 64**	**Saturn**	3DO	**Jaguar**
1–12 months	9	**1**	**4**	2	**0**
13–24 months	6	**2**	**3**	7	**1**
25–36 months	13	**9**	**2**	1	**0**
37–48 months	19	**4**	**0**	0	**0**
49–60 months	15	**5**	**0**	0	**0**
Generation 6					
	PlayStation 2	Xbox	GameCube	Dreamcast	
1–12 months	**12**	21	13	11	
13–24 months	**21**	24	15	6	
25–36 months	**27**[b]	27	12	1	
37–48 months	**23**	20	5	0	
49–60 months	**15**	4	1	0	
Generation 7					
	PlayStation 3	Xbox360	Wii		
1–12 months	**5**[b]	6	2		
13–24 months	**15**	9	3		
25–36 months	**17**	15	4		

Notes: [a] Bold columns show platforms with high degree of complement development challenges (high or moderately high) in each generation. Bold and underlined columns show platforms with high degree of complement development challenges that had released its first-party developers' development tools for third-party developers.

[b] shows the period within which these tools were made available (PS2, March 2003, twenty-ninth month of platform, also see Appendix Table A.IV GDC 2002 session "Introduction to the Performance Analyzer for Playstation 2"; PS3, March 2007, fifth month of platform, also see Appendix Table A.IV GDC 2007 session "Presenting PLAYSTATION® Edge: Advanced Graphics Tools and Technologies for PlayStation 3 Development").

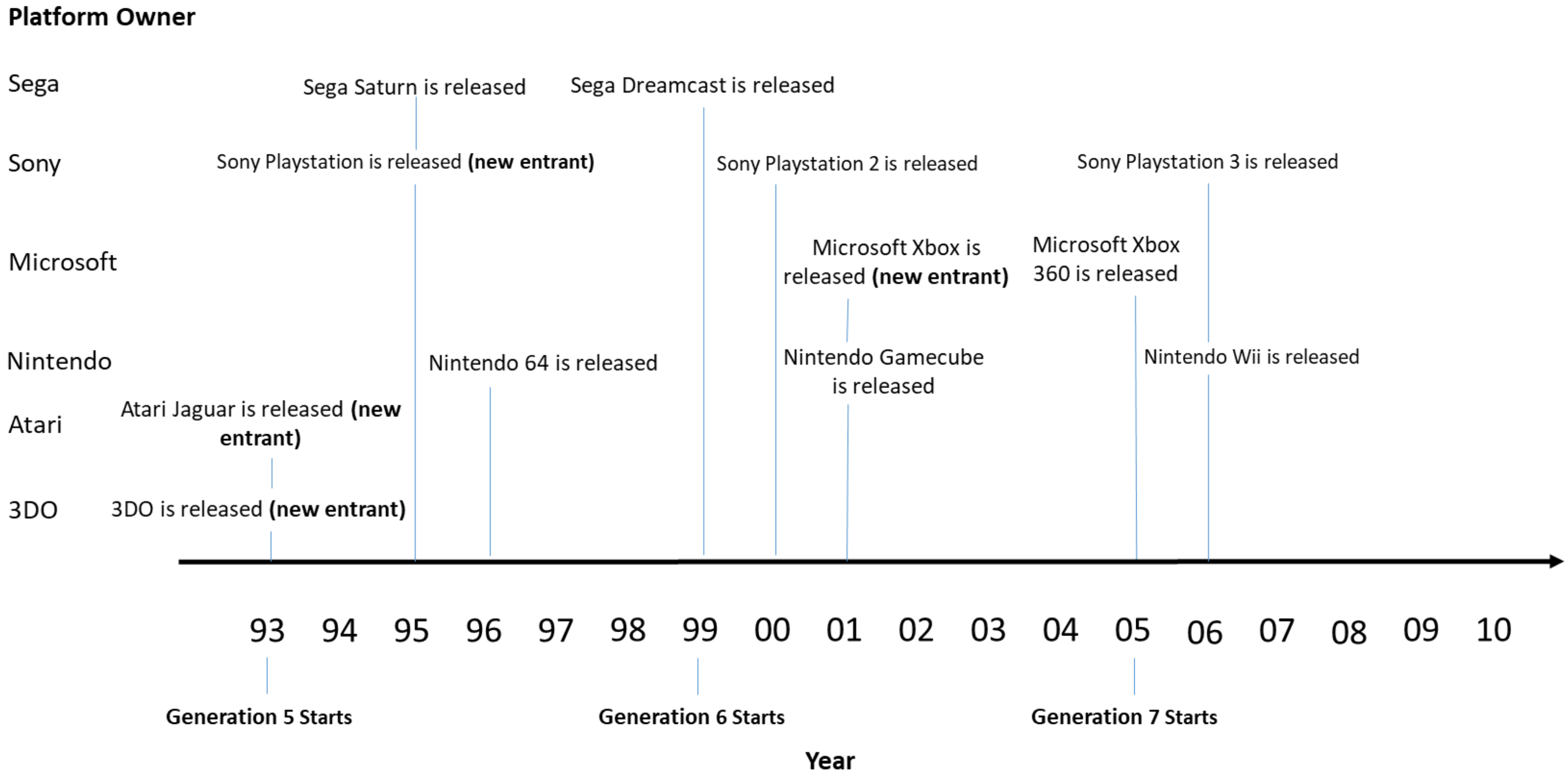

Figure 1. Timeline of US Console Releases between 1993 and 2010

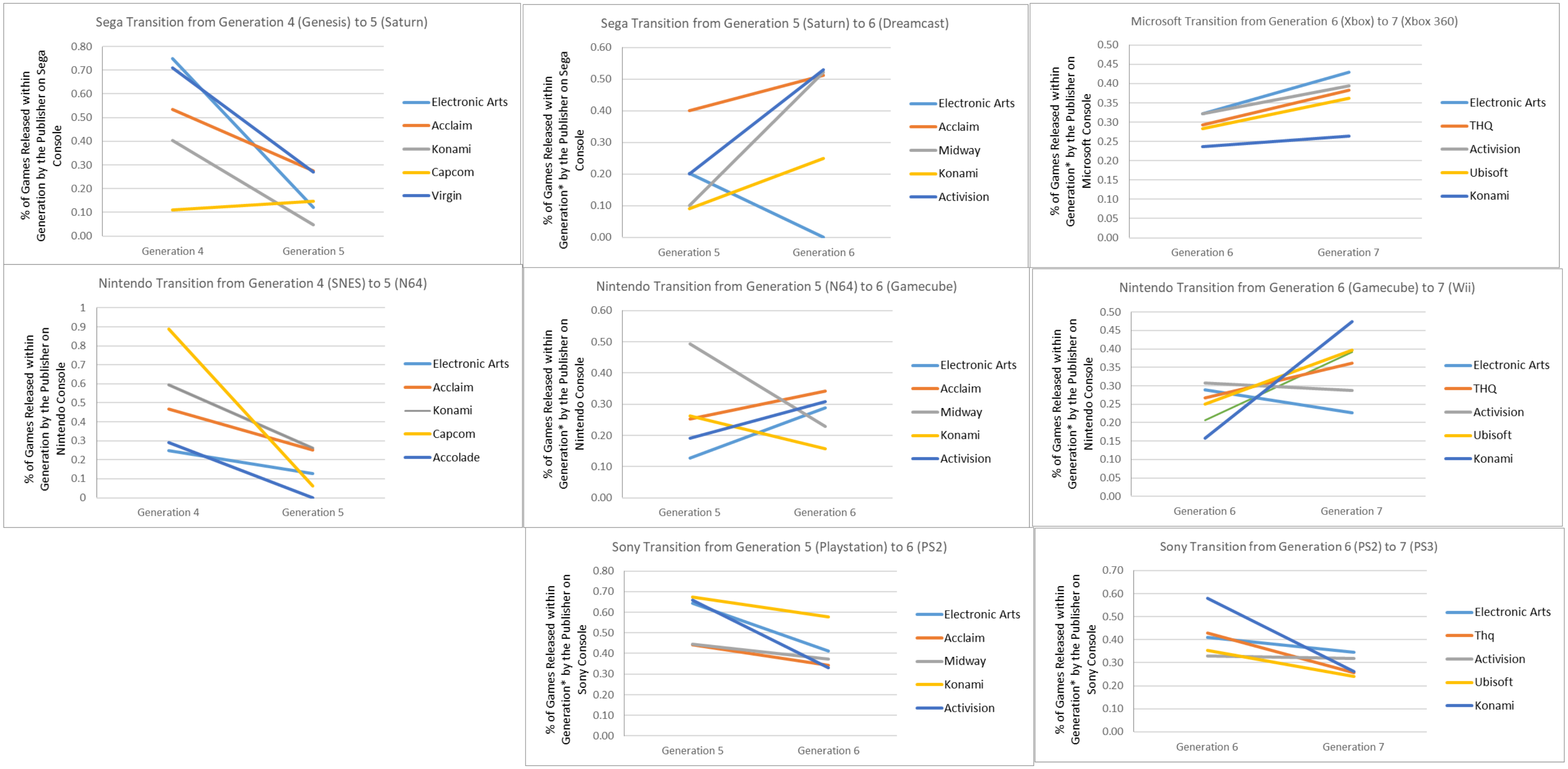

Figure 2. Evidence for Disaffection: Share of Game Releases for Top Five Publishers for Each Transition by the Platform Owner

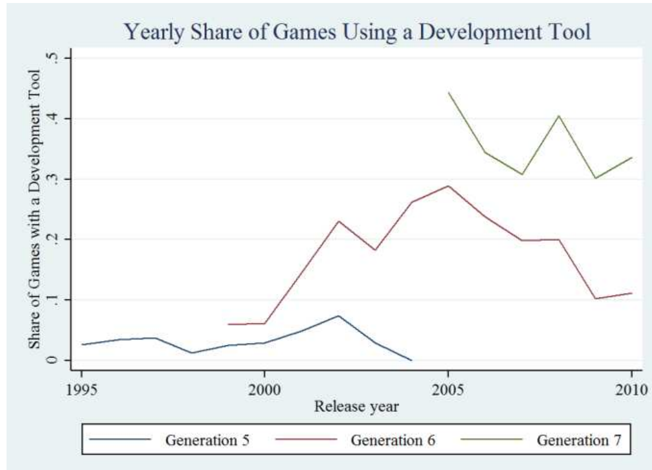

Figure 3. Share of US Console Games Using a Development Tool by Year