PLATFORM ARCHITECTURE AND QUALITY TRADEOFFS OF MULTIHOMING COMPLEMENTS

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Abstract

Multihoming – the decision to design a complement to operate on multiple platforms – is becoming increasingly common in many platform markets. Perceived wisdom suggests that multihoming is beneficial for complement providers as they expand their market reach, but it reduces differentiation among competing platforms as the same complements become available on different platforms. We argue that complement providers face tradeoffs when designing their products for multiple platform architectures – they must decide how far to specialize the complement to each platform technological specifications. Because of these tradeoffs, multihoming complements can have different quality performance across platforms. In a study of the US video game industry, we find that multihoming games have lower quality performance on a technologically more complex console than on a less complex one. Also, games designed for and released on a focal platform have lower quality performance on platforms they are subsequently multihomed to. However, games that are released on the complex platform with a delay suffer a smaller drop in quality on complex platforms. This has important implications for platform competition, and for managers considering expanding their reach through multihoming.

Keywords: Platforms, Video Games, Multihoming, Complement quality, Co-specialization, Platform complexity, Platform architecture

1. INTRODUCTION

Platform technologies such as Apple's iPhone, Microsoft's Xbox, or SAP Netweaver are increasingly common as the infrastructure for transactions between producers, like providers of complements, and consumers (Hagiu and Wright 2015, Parker and Van Alstyne 2005, Rochet and Tirole, 2006). While consumers mostly tend to prefer one platform,[1] complement providers increasingly "multihome"—that is, they develop products for multiple platforms, aiming to reach as many potential consumers as possible (Bresnahan et al.2015, Corts and Lederman 2009). The literature generally treats the multihoming choice as weighing up the benefits of increasing market size against the technical and commercial cost of multihoming, and mainly studies the implications of multihoming complements on platform pricing and affiliation decisions (Armstrong and Wright 2006; Bresnahan et al. 2015; Corts and Lederman 2009; Lee 2013; Rochet and Tirole, 2003).

The logic is that multihoming offers potential additional revenues at limited costs for complementors, implicitly assuming that complements are the same on different platforms. But many platforms are not simple (two-sided) markets enabling transactions; they are also technology infrastructures whose features shape the development of third-party complementary products (Anderson et al. 2014; Gawer 2014, Tiwana et al.2010, Yoo et al. 2010).[2] Complements frequently must be tailored to a platform's core technological functions and interface specifications to take full advantage of its performance (Anderson et al. 2014, Claussen et al. 2015b, Tiwana 2015). In developing for multiple platforms, complementors must decide how far to specialize the complement to one platform (Schilling, 2000, Tiwana 2015, Yoo et al. 2010). We ask how the tradeoffs complementors face when designing products for multiple platforms affect the quality performance of multihoming complements across platforms.

[1] Clearly, consumers do use multiple platforms; but when it comes to choosing among functionally similar platforms, they tend to single-home, or largely use one of them as their preferred platform of choice, even when consumers affiliate with multiple platforms (see Armstrong 2006 and Rochet and Tirole 2003 for a discussion of cases where consumers can multi-home and complementors single-home).
[2] A platform's technological architecture shapes its core functionalities (Baldwin and Woodard 2009, Gawer 2014), which can affect both competitive performance (Gawer and Cusumano 2002, Zhu and Iansiti 2012) and incentives of independent firms to develop complements (Anderson et al. 2014, Tiwana et al. 2010, Gawer 2014). As a system comprises the platform and its complements, the effect of platform architecture on both platform performance and complement supply matters for value creation at the system level (Cennamo 2016).

Platform architecture –i.e., the technological capabilities of a platform, and the way platform technological components function and connect to platform complements (Baldwin and Woodard, 2009; Tiwana 2015; Yoo et al. 2010) – can make it easier or more difficult and costly to develop complements for it (Anderson et al. 2014). Consequently, the same complement can integrate differently with each platform system and, if it is multihomed, have different quality performance (i.e., how well the complement integrates with and runs on the target platform as perceived by users) across platforms with different technological architectures. Platforms differ in their technological performance and complexity for complementors (Baldwin and Woodard 2009; Anderson et al. 2014). *Platform complexity,* as we define it, refers to the number of interdependent components of the platform's core technology that interact with the platform's complements through specialized interfaces (Baldwin and Clark 2000; Kapoor and Agarwal 2017). The greater the interdependencies among programming tasks and the core technology components (e.g., processor cores), and the larger the number of specialized processors requiring a specific programming language for optimal utilization (i.e., no clean interface to handle the interdependencies), the more complex the platform. Complement developers must therefore choose to either use that language to optimally "conform" (Tiwana 2015) to the complex platform's specifications at the expense of integration and performance on other platforms, or to design the complement so it uses the lowest common denominator across platforms at the expense of optimal performance on the most complex one.[3] Thus, complementors face two tradeoffs from co-specialized design of their complements. First, complements designed for and released on one platform will have lower quality performance on platforms they are subsequently multihomed to; and second, multihoming complements will have lower quality performance on more complex platforms compared to (relatively) less complex platforms.

We study these tradeoffs in the U.S. videogame industry.[4] Videogame consoles are platforms with strong indirect network effects and ongoing technological progress (Clements and Ohashi 2005, Cennamo 2016, Kretschmer and Claussen 2016) and significantly increased use of multihoming in recent years (Corts and

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[3] Tiwana (2015) considers the extent each complement (which he refers to as "extension") conforms to the platform interface specifications, and exploits the variance among complements in their degree of coupling and interface conformance within *one single* platform. We instead exploit the inherent tension in coupling and conforming to each platform system *across* multihomed platforms.

[4] Multihoming complements are especially interesting in this context, as their across-platform performance differences is not down to layout, genre, or other complement-specific factors but rather to the complement-platform nexus.

Lederman 2009). Focusing only on multihoming games, we use game fixed-effects regressions to isolate within-game, cross-platform differences in quality performance, and run several robustness tests to rule out alternative explanations. We find our expectations confirmed; multihoming games perform worse on complex consoles and if they are released with a delay. However, these tradeoffs do not accumulate: the negative effect of a delay is less severe for games on complex platforms.

We address three issues often overlooked in the literature. First, existing work on multihoming largely neglects the technological dynamics common to many platform markets (Anderson et al. 2014, Cennamo 2016, Gawer 2014), and with them, some of the costs of innovation. We address those costs. Second, multihoming costs are often taken as exogenously given and uniform across platforms. We suggest that the true costs of multihoming are determined indirectly by platform owners via technological architecture, and thus possibly heterogeneous across platforms. This has important implications for platform evolution and competitive performance (Cennamo 2016, Tiwana et al. 2010; Wareham et al. 2014), and for platform strategy (Cennamo and Santaló 2013, Claussen et al. 2013). Third, some work suggests that multihoming renders platforms more similar because users can use the same complement on different platforms (Landsman and Stremersch, 2011). We show that the quality and value of the same complement can differ across platforms, and that these differences are not random. This offers new insights on how multihoming complements may affect platform competition.

2. MULTIHOMING: THE BENEFITS AND IMPLICATIONS

Much of the literature on multihoming draws on the broader literature on two-sided (or platform) markets (McIntyre and Srinivasan 2017, Parker and Van Alstyne 2005) to explain the dynamics of platforms and their complementary products. Early theoretical studies (Armstrong 2006; Armstrong and Wright 2007; Caillaud and Jullien 2003; Rochet and Tirole 2003) focus on which side multihomes and who takes most of the surplus. These papers find that there will typically be one multihoming side (e.g., buyers use multiple platforms or sellers offer their product on multiple platforms), and that price competition is highest for the single-homing side, whereas most of the surplus of the multihoming side is appropriated by the platform. When consumers multihome, platforms compete more intensely to attract complements, so the price structure favors complementors (Rochet and Tirole 2003). Conversely, Armstrong (2006) shows that when consumers single-home and complementors multihome, the platform charges complementors high prices to access its exclusive consumer base.

Recent studies model the endogenous (multi-)homing decision and competition within two-sided markets. Athey et al. (2016) and Ambrus et al. (2016) study endogenous homing in media markets on the ad-side (keeping the consumer side exogenously fixed), whereas Jeitschko and Tremblay (2017) model competition between platforms to attract agents on both market sides and allow both to make their homing decisions endogenously. The authors find that the multihoming decision depends on a number of market parameters, including the elasticities on both market sides, cross-side externalities and multihoming costs (assumed fixed and exogenous), and that multiple equilibria (single-homing on both sides, buyers or sellers only multihoming, or both) can emerge.

To date, few empirical studies explore the implications of multihoming (Bresnahan et al., 2015; Corts and Lederman 2009; Landsman and Stremersch 2011; Lee 2013; Rysman 2007). This is surprising given that multihoming affects competition between platforms on the one hand, and the interaction between platform owner and complementors on the other. The few studies chiefly explore the implications of multihoming for platform competition. Corts and Lederman (2009) investigate the scope of indirect network effects[5] in the video game industry. They find that owing to the changing economics of game development, the increased prevalence of nonexclusive (i.e., multihoming) software creates indirect network effects between users of competing platforms. The core logic is that in an environment where non-platform-specific fixed costs are increasing and multihoming costs ("porting costs") are decreasing, multihoming will increase. This reduces the likelihood that one platform will become dominant in the market. Landsman and Stremersch (2011) argue that multihoming reduces the differentiation of competing platforms, and they find that platform-level multihoming decreases sales of a focal platform. By contrast, Lee's (2013) findings suggest that multihoming can reinforce the leading position of incumbent platforms. For smartphones, Bresnahan et al. (2015) find that multihoming can be neutral with regards

[5] Indirect network effects imply that complement providers tend to choose platforms with a large existing (or expected) user base (Clements and Ohashi 2005, Kretschmer and Claussen 2016), while consumers join platforms with many (current or expected) high-quality complements (Binken and Stremersch 2009, Cennamo 2016). Indirect network effects can also be driven by higher willingness to pay of complementors, which then creates a larger subsidy to the user side, which increases user adoption (Seamans and Zhu 2013).

to the market share between Android and iOS, since apps that are more attractive and thus have many users will multihome to both platforms.

Most of these studies focus primarily on market factors, so that multihoming decisions are driven primarily by the installed base and market share of the focal platform. For example, Bresnahan et al. (2015) consider the cost of multihoming to be negligible for complement providers with sufficient quality, compared to the expected gains, and Corts and Lederman (2009) highlight this difference as the main factor encouraging multihoming decisions.

Another implicit assumption is that multihoming complements have the same quality performance on different platforms. If this holds, multihoming complements can "level out" competition among platforms and mitigate asymmetric market outcomes (Corts and Lederman 2009). This role of exclusive and multihoming complements in determining market outcomes at the platform level creates subtle dynamics between platform owners and complementors as platforms need exclusive content to solidify a lead (Cennamo and Santaló 2013), and this involves fierce competition among rival platforms for participants on both market sides.

However, because multihoming complements can reduce differentiation across platforms, platform owners may invest heavily in technology design to gain an edge (Zhu and Iansiti 2012); platform architecture differences may thus become pronounced (Anderson et al. 2014). These differences, in turn, can increase multihoming costs, impose important tradeoffs on complementors, and manifest in differences in quality performance of the multihoming complement across different platforms.

3. THE TRADEOFFS FROM MULTIHOMING

A core assumption in the multihoming literature is that once complement providers decide to multihome, the complement performs equally well on all platforms, with no further investment needed to tailor the product to the specific workings of the platform. The costs of multihoming are thus assumed to be negligible compared to the up-front costs of developing the product, and the enlarged market benefits (Bresnahan et al. 2014; Corts and Lederman 2009) inevitably cause multihoming to increase (Corts and Lederman 2009). One implication is that complements are designed to look, feel, and perform the same across platforms, and there are no additional costs of specialization in the multihoming process. We challenge this assumption because platform architectures differ in the performance of their core functions (Anderson et al. 2014; Zhu and Iansiti 2012), and in how they affect complement performance (Anderson et al. 2014; Claussen et al. 2015a).

3.1. Sequential vs. Simultaneous Development

Complementors multihome to achieve greater sales per complement, conditional on minimizing the costs of multihoming (Bresnahan et al. 2015; Corts and Lederman 2009). The quality performance of the complement, determined by its key features, as well as the extent it integrates with the platform technology (i.e., the degree of coupling – Tiwana, (2015)), is highly instrumental to this objective (Claussen et al. 2015b). Ultimately, platform users judge the innovative value of the complement in terms of its overall quality (Cennamo 2016; Zhu and Iansiti 2012). We thus refer more specifically to *complement quality performance* – how well the complement integrates with and performs on each platform, as assessed by its users.

When designing multihoming complements, complementors must choose the extent to which they integrate with and conform to each platform technological specifications (Tiwana 2015), which implies that complements vary in the extent of co-specialization to a given platform system. We define *complement co-specialization* to a platform as the extent to which a complement design conforms to a platform's technology and interface specifications. The more a complement design is tailored to the specific workings of a platform technology and its interfaces, the more the complement becomes specialized to that platform. Our conceptualization of complement co-specialization is based on the idea that, while a modular architecture can increase flexibility through substitutions of components, "modularization reduces but does not eliminate interdependence" (Tiwana 2015: 269). Components still have some level of co-specialization; their design is driven by the functional requirements within the context of the system (Yoo et al. 2010). Thus, while a modular architecture can increase interoperability of complements, by itself it does not make complements fungible *across* systems. So, while there is increasing fungibility (i.e., substitutability) between similar complements within a platform system, a focal complement might be more specialized to a focal platform system than others (Jacobides et al. 2006, 2017). Accordingly, "there can be considerable heterogeneity among extensions [i.e., complements] in how closely they conform to a platform's prescribed interface specifications" (Tiwana 2015: 269).

Complementors can follow two main strategies in designing products for multiple platforms. They may develop and release their products simultaneously across platforms, which allows for economies of scale in marketing and distribution costs, instrumental to achieve the economic benefits of multihoming (Bresnahan et al. 2015; Corts and Lederman 2009). In our context, this is important, according to *Electronic Arts* (EA) executive Rich Hilleman who indicated that EA "now typically spends two or three times as much on marketing and advertising as it does on developing a game".[6] Releasing a game for multiple platform simultaneously precludes specialization on a particular platform and inevitably compromises the extent to which the complement integrates with the specific workings of each platform. Alternatively, complementors may develop and release the product sequentially on different platforms, tailoring the design more to the first platform of release, which can be used to test the market and gain visibility for the complement, and later releasing versions for other platforms (Klompmaker et al. 1976). This has the advantage of being able to focus development and marketing efforts on the initial release, but since everything depends on success of the initial release, developers are motivated to exploit the first platform's unique capabilities (e.g., operating speed, optimization of graphics) as much as possible. The complement may then conform perfectly to the first platform specifications but adjust poorly to other platforms, especially if the firm is trying to minimize the costs of porting.

Simultaneous and sequential release both entail complement quality tradeoffs; but we expect them to be stronger for complements originally designed for a focal platform and thus more specialized for that platform system. Complement providers can make additional platform-specific investments on the ported (i.e. second) platform to conform more to its specifications and achieve the same level of quality performance as for the original release. However, this may increase the costs of multihoming to a level that might offset the benefits of extra demand, so the optimal level of investment into the delayed platform is lower. In contrast, a simultaneous release

[6] http://venturebeat.com/2009/08/26/eas-chief-creative-officer-describes-game-industrys-re-engineering/ (*EA's chief creative officer describes game industry's re-engineering*), Consulted 30/05/2017.

strategy may reach a better compromise in design and greater consistency in performance across the different platforms it operates in, possibly at the expense of maximum performance on the focal platform. Given these tradeoffs of specialization, we expect:

HYPOTHESIS 1 (H1). *Complements that are multihomed sequentially have lower quality on the subsequent multihomed platforms than on the platform of original release.*

3.2. Complex vs. Simple Platform Technology

Some platforms are more technologically demanding than others (Anderson et al. 2014), and entail different degrees of complexity for complementors. We define *platform complexity* as the number of interdependent components of the platform's core technology interacting with the platform's complements through specialized interfaces. This rests on the idea that the larger the number of unique components interacting with a complement (Kapoor and Agarwal 2017), and the higher the interdependence between system components that cannot be easily abstracted by standardized interfaces (Baldwin and Clark 2000; Sorenson et al. 2006), the more complex the system. Modular architectures reduce complexity by decomposing the product into independent (i.e., loosely coupled) components interconnected through pre-specified interfaces (Baldwin and Clark 2000; Schilling 2000; Yoo et al. 2010).

Rather than differentiating between integral and modular systems, we emphasize relative *differences in degree* of complexity across platform systems of the same type (all are modular, layered architectures – see Yoo et al. 2010). While modularity of the platform architecture can generally help reduce complexity of the whole system by separating the core technology sub-system from the independent complements sub-system (Yoo et al. 2010), platforms do vary in the level of complexity of their core technology and interfaces (Anderson et al. 2014). These differences across platforms create an important tradeoff for multihoming complements.

Anderson et al. (2014) document that in the software industry, more advanced, technologically capable platforms involve greater development hurdles and increased costs for complementors. This is also because they often require complementors to use specific language coding, i.e., specialized interfaces, to optimize software-platform integration and get the most out of the platform's features (Tiwana 2015). Thus, the resulting costs and delays cannot be eliminated through platform interfaces and development tools that platform owners provide for complementors (Schilling 2000; Tiwana 2015). This is also the case because platform owners themselves face a tradeoff between investing in the core technology performance of the platform and investing in the tools that facilitate development of complements for it by third parties (Anderson et al. 2014).

Given these platform-level choices by the platform owner,[7] complement providers will face tradeoffs when allocating development resources in the design of complements that multihome across platforms differing in complexity. These multihoming tradeoffs will be particularly strong for complex platforms because they require greater conformity to their technology specifications and interface requirements, and thus greater costs and specialization for optimal integration of the product with the platform. Our argument is not about the absolute level of complexity of a given platform and the absolute level of investments required from complementors to develop products for the platform. Rather, the difference in complexity between the platforms creates tradeoffs in the level of dedicated resources among the different platforms. As this quote (drawn from our research context) highlights, "…*the real question is not which architecture is better but which one developers will spend the time and effort to optimize for.*[8]" Multihoming complements must compromise between optimizing the product for each platform architecture but duplicating integration costs, and reusing resources across platforms but integrating sub-optimally with the complex platform. Hence, all else equal, a multihoming complement is likely to run less smoothly on complex than on less complex platforms. We thus expect that:

> HYPOTHESIS 2 (H2). *Multihoming complements have lower quality on the more complex platform than on less complex ones.*

3.3. Sequential-Complexity Interaction

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[7] Platform complexity does not depend on complementors' complement design decisions. It is a structural element resulting from the technology design decisions by the *platform owner*; thus, it is given to complementors once the platform is launched. Also, it is *relative* to other platforms in the market.

[8] Reimer, 2007, "Sony PS3 defense: developers can do more with it", https://arstechnica.com/gaming/2007/06/sony-ps3-defense-developers-can-do-more-with-it/

We argue above that complements suffer a decline in quality on the platforms they are multihomed to sequentially (H1) and that, independently of whether versions for different platforms are released concurrently or sequentially, they perform worse on complex than on simple platforms (H2). Combining these two claims, one might expect quality to be worst when a complement is released on a complex platform with a delay. However, a deeper look at the logic behind both hypotheses suggests that delay and complexity may interact in subtle ways. Specifically, in addition to the technical challenges of developing a complement that operates on different platforms and the inability to tailor the complement to multiple platforms, simultaneous releases also put high demands on development resources that must contribute to two (albeit related) development processes. For simpler platforms, complementors can use the available standardized interfaces and adopt a "plug-and-play" approach to integrate the complement with the system across the different platforms; this is not possible for more complex platforms (Anderson et al. 2014; Claussen et al. 2015). A complex platform architecture forces developers to invest more in customizing the complement to the inner workings of the platform to improve platform-complement fit.[9] When developers can concentrate their effort exclusively on the integration process with the complex platform, they can alleviate the technical challenges of multihoming to complex platforms.

This logic is grounded on the idea that complement developers are capacity constrained in terms of programming capabilities (Anderson et al. 2014; Tiwana 2015) when multihoming to complex platforms. Dealing simultaneously with multiple integration processes across the different platforms will increase cognitive demands on the developer, which can limit the attention (and effort) that goes into improving the quality of the complement for the target platform (Tiwana 2015). A complement for a complex platform may therefore benefit from a delay because this frees up the attention and programming resources required for integration with the platform as compared to simultaneous development. This is critical for complex platforms because of the greater interface conformance and co-specialization needed in the multihoming process for software-platform integration. Thus, while it does not become simpler to develop for a complex platform, multihoming sequentially to the complex

[9] As this quote from one game developer exemplifies for the PlayStation 3 the more complex console platform of 7th generation consoles, "Many developers had a hard time wrapping their heads around the PS3 […] those who had the time and the resources to learn how to code for the Cell were able to squeeze out a lot of power, but for others, dealing with this chip was a headache. […] And so for an independent developer [like us], a lot of times … we have one version. How much effort do we need to put into the other version to make it look as good and work as well?" *Venturebeat*, http://venturebeat.com/2014/07/06/last-gen-development/. Accessed 13 September 2016.

platform makes the process of integration less time compressed, which may offset the quality decline of a complement for a complex platform to some extent. This leads to our third hypothesis:

HYPOTHESIS 3 (H3). *If released with a delay, multihoming complements experience a smaller drop in quality on the more complex platform (compared to simpler platforms).*

3.4. Summary of Hypotheses

We hypothesize that both delayed release and release on a complex platform lead to lower complement quality performance, but that delayed release can help offset the expected drop in quality for a complex platform to some extent. We define $\Delta(.) = Q(.) - Q(0)$, where $Q(0)$ is the quality of a complement released without delay and on a simple platform and the three scenarios we consider are simple delayed (D), complex non-delayed (C), and complex delayed (CD) complements. We show these scenarios in Figure 1 below, and we expect that H1: $\Delta(D) < 0$, H2: $\Delta(C) < 0$, and H3: $\Delta(D) + \Delta(C) < \Delta(CD)$.

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4. DATA AND METHODS

4.1. Setting: The US Video Game Industry

We study multihoming games in the U.S. Video Game Industry from 1999 to 2010. The video game industry displays strong indirect network effects, with games (i.e., complementary products) contributing significantly to the value of the entire system (Clements and Ohashi 2005, Cennamo and Santalo 2013, Cennamo 2016; Kretschmer and Claussen 2016). The rise of multihoming in the videogame sector is well-documented (Corts and Lederman 2009; Landsman and Stremersch 2011) and is attributed to a decrease in the costs of porting games to different consoles relative to the upfront, fixed costs of developing the game. However, while the relative multihoming costs may have been decreasing and are a small percentage of the overall development and marketing cost of a game, Lee (2013) shows that porting costs vary significantly across consoles. This is because video game consoles have core technologies with varying designs, affecting the way the game looks and performs on each console (Anderson et al. 2014). Games must be customized to these different designs to maximize performance on a console. While developers use standard console interfaces and middleware tools to adjust to the different consoles' technologies and reduce porting costs, these do not eliminate the differences across console architectures; developers must choose how much to optimize a game for each console, which might then create the tradeoffs of specialization identified above.

Video game consoles are (typically incompatible) systems that compete in technological generations (Anderson et al. 2014; Cennamo 2016). Each generation represents a group of consoles with comparable hardware specifications (Cennamo 2016). There have been eight generations of platforms in the video game industry from 1972 to date. We focus on the years 2005 to 2010, which covers the launch and evolution of seventh-generation (G7) consoles. In some robustness tests, we also use data from sixth-generation consoles (G6), which include the 1999-2005 period. Table 1 presents the platforms and key characteristics.

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G7 consoles represent a big improvement over G6 consoles in their technical specifications. New hardware allowed more content and improved graphics, which also increased the fixed costs of game development (Anderson et al. 2014). A blockbuster game in 1995 had a 1.5m USD budget, in 1999 it had around 3-4m USD budget, whereas a blockbuster game in 2010 cost on average 60m USD to develop (Kotaku 2014). Moreover, games vary in terms of production and marketing costs as well as in innovation outcome (game quality) and sales performance. Only 3.9% of games become blockbusters in our sample, selling more than 1m copies (the mean is 226,896 units). This high concentration in sales mirrors the skewed distribution of game quality: the average game receives a quality score of 70 out of 100 from professional reviewers, and only 3% of titles achieve "superstar" status – i.e., a score of 90 or above (Binken and Stremersch 2009). These superstars have average sales of 48m USD compared to the 8.6m USD average sales of the rest of the titles. In fact, the top 10 titles for each platform make up 13 to 20 percent of game sales (Lee 2013). Development time of games has also increased: average development time required for fifth-generation consoles was 6 to 9 months (Pachter et al. 2014), in G7 this has risen to 19 months (ESA of Canada 2013).

The use of licensed content (such as movie- or sport-based characters and similar) has also increased over the years, contributing to rising platform-independent development costs (e.g., voice acting, music…). For instance, licensing a motion picture today can account for up to 15 to 20 percent of sales, with royalties typically amounting to $7.20-$9.60 per unit for a $60 retail game (Pachter et al. 2014). These increases, along with a decrease in multihoming costs have made multihoming more attractive (Corts and Lederman 2009) and common in the industry. Figure 2 gives descriptives on multihoming for G7 consoles between 2005-2010. On average, multihoming game titles are developed by older (Figure 2a) and larger publishers (i.e., those with a larger number of individual developers) (Figure 2b) compared to games exclusive to a single platform. Also, multihoming games are larger projects in terms of the average number of individual developers assigned to the project (Figure 2c).

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Our empirical context also lets us address our questions because of two other aspects. First, each game's performance is assessed on each platform, reflecting possibly distinct graphics or smoothness of gameplay between platforms for the game. This is important as it lets us isolate empirically the difference in performance of the game attributable to differences across consoles (i.e., the within game difference across consoles) from the absolute level of performance of the game (and hence avoid omitted variable bias arising from between-game differences). Put simply, we can take the exact same game (e.g., publisher, developer, genre, and so on), and look at how the same game performed across platforms. Second, building on Anderson et al. (2014)'s study in the same setting, we identify the variation between platforms in terms of their technological complexity.

4.2. What Characterizes a Complex Console?

When releasing new consoles, platform owners aim for high hardware power to push cutting-edge graphics games and attract both users and developers alike (Kretschmer and Claussen 2016, Claussen et al. 2015a, Zhu and Iansiti 2012). Three main components of platform architecture affect hardware performance: CPU (including co-processors), Graphics Processor (including co-processors), and RAM. Emerging theory (Anderson et al. 2014) and industry reports show that advanced hardware is also more technologically demanding, making the development of complements more costly and difficult (Kent 2001; Reimer 2005). Building on Anderson, Parker and Tan (2014) and on industry experts' assessment, we identify the most complex (technologically demanding) console in each generation – PS3 for G7 and PS2 in our robustness test for G6. Details on the different technical architectures of the consoles in our study are in the Appendix. For most platforms, technological complexity arises from the need to manage an increasing number of interdependencies to utilize the architecture optimally.[10] For video game consoles, technological complexity is driven by the number of interdependent and specialized processors, which affect the extent a specific programming language is required to optimize the game code for the focal console (Pettus 2013, Roth 2013). This is necessary when the platform contains a specialized or new processor for which no interpreter ("compiler") exists or when the platform has multiple processors (Kent 2001, Pettus 2013, Parish 2014).[11] Table 2 gives information on the level of complexity for all G6 and G7 consoles.

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An example is helpful to illustrate the sources of variation in console complexity. Consider the technical architectures of the Xbox 360 and PS3 in Figures 3a and 3b. Both look similar at the highest architectural level (a CPU, a graphics unit – GPU, RAM, and an interface to connect the system to the output and the optical drive). However, the PS3 is more complex as it uses a CPU with one main generic core (PPE) and seven specialized cores (SPE), requiring a careful allocation of tasks from the main core to these specialized cores by the programmer. The specialized cores also have their own programming language. Conversely, the Xbox 360 uses a CPU design with three generic cores (PPE), which are easier to handle both because of the lower number of cores and the more standardized programming languages (see Anderson et al. 2014, and the Appendix for details).

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4.3. Data

[10] "Trying to program for two CPUs has its problems. … The two CPUs start at the same time but there's a delay when one has to wait for the other to catch up... I think that only one out of 100 programmers is good enough to get that kind of speed out of the Saturn." (Yuji Naka, lead programmer and creator of the "Sonic the Hedgehog"; Pettus, 2013; p.193h).

[11] Referring to Sega Saturn: "Saturn had eight processors… to get that platform to do what it was designed to do was a very complex and painful learning process for developers, including the best and sharpest minds that Sega had to bring to bear on it, in both Japan and the U.S.", Interview: Joe Miller (Sega of America Senior VP of Product Development), http://www.sega-16.com/2013/02/interview-joe-miller/, accessed 07 September 2016.

Our primary data source is MobyGames, the world's largest online video game archive on the Internet. MobyGames provides detailed game information on the dates of each platform release, publisher and developer, characteristics (e.g., genre), and the use of development tools in production (e.g., middleware and game engines). For one of our robustness checks, we complemented MobyGames with information on parent–subsidiary relationships between publisher and developer manually collected from GiantBomb, official firm websites, and Factiva. Our second main data source is the GameRankings website, "a site dedicated to aggregating review scores from both online and offline sources, to give users an overall picture of a game's score."[12] The site has review information for over 14,000 games, with over 300,000 individual reviews from professional critics. To ensure accuracy of review scores, GameRankings has strict requirements on which review outlets (and their scores) are included.[13] It standardizes review scores across outlets and produces one aggregate score for each game.

Our initial matched dataset includes 4,662 title-platform releases, which includes all G6 and G7 games released in the US from 1999 to 2010. In our estimations, we include only multihoming games on their respective platforms and exclude download-only game titles and add-ons, titles with incomplete information on review scores, first-party games,[14] and games released for the Sega Dreamcast.[15] Finally, we drop games released across generations (four unique titles for G7) since our focus is on multihoming strategies among consoles in the same generation.[16] We run our main regressions for 790 G7 console title-platform observations and use 1,427 G6 console title-platform observations in a robustness check.

Dependent Variable

We study the quality of multihoming games across different platforms. We measure quality by using the average GameRankings score with the variable *Title-Platform Quality*. Therefore, the quality of a game on a specific

[12] Gamerankings Help, available at http://www.gamerankings.com/help.html, accessed 27 May 2017.
[13] "The requirements for adding a new site are: Sites must have at least 300 archived reviews for a multi-system/multi-genre sites, or 100 reviews for single-system or genre sites; Sites must publish a minimum of 15 reviews a month; Sites must be visually appealing and look professional; Sites must review a variety of titles; Sites must have a dedicated domain name with professional hosting; Site reviews must be well written; Sites must conduct themselves in a professional manner.", available at http://www.gamerankings.com/help.html, accessed 23 August 2016.
[14] First-party games have very different economic rationales as they may be released to help sell consoles.
[15] Most Dreamcast games were Sega games, and only 16 third-party games were multihoming. These were initially Dreamcast exclusives as Dreamcast was launched one year before the Playstation 2. These games performed much better on Dreamcast.
[16] Differences across generations are more pronounced; so, we expect quality differences across platforms to be even stronger.

platform indicates how well a game runs on that platform. If there are differences in the game-console fit for the multihoming game across the distinct consoles, we expect differences in the quality of the game across the consoles. The quality score varies between 0 and 100, and the average quality score is around 70. Only 6% of games receive the same quality score on different platforms, which suggests quality variations across consoles.

Independent Variables

Delayed Release. This dummy is set to 1 if a game is released on the focal platform after it has been released earlier on another platform within the console generation. Thus, if a game is released simultaneously on all of its platforms, the variable is 0 for all observations for that game. If a game is released sequentially, it is 0 for the first platform(s) of release, and 1 for each subsequent release.

Complex Platform. We capture the relative complexity of platform architecture by using a *Complex Platform* dummy that is 1 if a game is released on PS3 (for G7) or PS2 (for G6).

Control Variables

We use two variables to rule out possible spurious relationships of delayed release and platform complexity on game quality. *Average Quality of 1st Party Exclusives* and *Average Quality of 3rd Party Exclusives* measure the average quality score of exclusive games released by the platform owner in a year and 3rd party publishers in a year, respectively. These variables address two effects: first, reviewers may compare games released on a platform with each other, so that the quality of exclusive games on the platform sets the benchmark with which multihoming games are compared.[17] The quality of exclusive games may also affect investments by multihoming game producers to optimize games for the focal platform (Cennamo 2016), which could correlate with both independent variables. This effect could go in either direction as multihoming games may either "step up" to match the quality of exclusive games or "give up" and occupy a lower quality segment. In robustness analyses, we include additional controls at platform and publisher level to rule out alternative explanations for our main effects.

4.4. Estimation Approach

[17] Wii has been an interesting case: Commentators blamed reviewers of Wii games for downgrading the score of any release on the platform due to reviewers being "hard-core" gamers, and Wii having a large portfolio of "family games". We address this issue in our robustness check with a platform level control. "Wii reviewers are the problem – Braben", http://www.eurogamer.net/articles/wii-reviewers-are-the-problem-braben, accessed 27 May 2017.

We want to find out how differences in the integration of complements with different platforms affect the quality performance of multihoming complements across platforms. In particular, we are interested in the expected quality of a game originally developed for one platform and released on another platform with a delay, and the quality of a game released on complex platform vis-à-vis other, simple platforms. Ideally, we would like multihoming complements to be distributed randomly across simple and complex platforms and types of release (delayed vs. simultaneous). For example, if a class of games depended on a peripheral piece of equipment that only becomes available for a specific platform at a later point (so that sequential development and release are exogenously given), while other games using generic peripherals are released simultaneously, the release type would be somewhat random by game. Similarly, if one platform experienced an exogenous change in complexity through a new programming language compiler reducing the amount of specific investment needed to develop a game for that platform, the assignment to "complex" or "simple" would be random. Absent such a setting, there can be several sources of bias, which we discuss below.

We study differences in quality performance of the same game across platforms, conditional on the decision of the game developer to multihome. The decision to multihome depends on a number of factors at the firm-game and platform level so that multihoming complements might be systematically different from those singlehoming. Comparing multihoming to singlehoming games then would create selection bias. We focus only on multihoming complements and look at within-game differences to compare like with like. A bias would exist only if the factors affecting the decision to multihome also affect the quality differences of multihoming games across the platforms. For example, if only less technological demanding games are multihomed, the quality difference across complex and simple platforms may be lower than for demanding ones. Similarly, if certain organizational features that enable firms to multihome also reduce or increase the benefits from specialization (e.g., if multihoming firms are generalists with modest benefits from specialization), our results would be biased. To address this, we use game fixed effects in all our estimations and include two candidate variables (in-house development and the use of middleware) as control variables in a robustness test.

Another concern could be the differences in the samples of delayed multihoming games (vs. non-delayed release). There might be unobserved variables that may explain the choice of specializing first on a focal platform and porting the game to other platforms later which may influence the quality difference of the multihoming game. For instance, the gameplay story and character of the game might fit the customer preferences on the focal platform better; or the developer might have greater experience of developing games for the focal platform. In some cases, there are even temporary clauses that mandate a period of singlehoming before the game can be ported. Whatever the underlying reasons, for our test to be valid, we must assume that delayed releases are the result of some degree of specialization on the platform of first release. Note also that using game fixed effects will capture any potential game-level specific factor that does not change between releases (e.g., suitability for a particular consumer group). Moreover, in our robustness checks, we control for platform-level factors that may explain complement-platform match (such as the genre focus of the platform), which further accounts for any potential biases.

We thus take as unit of analysis the multihoming game on a platform of release (i.e., title-platform) and model the quality of game *i* on each of the platforms *j* it was released on as follows:

$$\boldsymbol{Quality_{ij}} = \boldsymbol{a_i} + \boldsymbol{Average\ Quality\ of\ 1st\ Party\ Exclusives_j} + \boldsymbol{Average\ Quality\ of\ 3rd\ Party\ Exclusives_j} + \boldsymbol{Delayed\ Release_{ij}} + \boldsymbol{Complex\ Platform_{ij}} + \boldsymbol{Complex\ Platform_{ij}} * \boldsymbol{Delayed\ Release_{ij}} + \varepsilon_{ij}$$

Our dependent variable, game quality, is time invariant; however, a game can launch on multiple platforms at different points in time. To compare them, we pool the data into cross-sections and run a linear regression analysis. Our regression contains game fixed effects ($\boldsymbol{a_i}$), which capture factors that do not change between releases of the same game across different platforms, so we identify within-game, cross-console differences. Specifically, *Delayed Release* captures differences in game quality on the delayed release compared to the quality of the game in its first release, whereas *Complex Platform* captures differences in game quality on the complex console compared to the mean quality of the game across all other consoles it was released on.

5. RESULTS

5.1. Descriptive Evidence

We first offer some descriptive evidence on the two sources of multhoming tradeoffs. Table 3 shows a 2x2 matrix defined by complex vs. simple platforms and delayed vs. non-delayed releases. For each cell, we compare the difference of the average quality of titles in the cell with the mean quality of each title across all platforms. A negative number then implies that a game in this cell performs worse than the same game, on average, across all platforms. We can see that delayed releases perform worse in general. Also, games released on a complex platform perform worse ($p<0.01$) than games released for a simple platform without delay, and games released on a complex platform with delay perform worse than games released without delay on a complex platform ($p<0.05$), but better than delayed games on a simple platform ($p<0.05$).

We present further details of games in each of these quadrants in Table 4, reflecting the mean values on key characteristics for games like in-house development (whether the game is developed and published by the same parent company), licensed middleware (whether the game uses a licensed middleware tool), licensed content (whether the game uses a licensed brand or franchise) and publisher experience with the platform owner (the extent to which the game publisher has developed for the platforms of the platform owner). Interestingly, only publisher experience with the platform owner shows significant differences ($p<0.01$) across cells (based on the most significant t-test between pairs of cells). Hence, we include publisher experience and other additional control variables to check the robustness of our results.

Summary statistics and pairwise correlations for our main regression model (G7 consoles) are in Table 5. *Complex Platform* shows strong correlation with the *Average Quality of 3rd Party Exclusives* variable (0.90). The highest variance inflation factor (VIF) is for *Complex Platform* (9.35), still below the cutoff value of 10, and the mean VIF is far below (2.17). In a robustness test we run a separate regression on a combined sample of both G6 and G7 and show that the results are not driven by multicollinearity.

------------- INSERT TABLES 3, 4 AND 5 ABOUT HERE -------------

5.2. Main Results

------------- INSERT TABLE 6 ABOUT HERE -------------

The main results from our econometric analysis are given in Columns 6-1 to 6-5 in Table 6. The first model includes just the control variables. None of the controls are significant in our main regressions. Model 6-2 shows that *Delayed Release* has a negative and statistically significant coefficient (-3.365; p<.001), indicating that complements that multihome with a delay on a platform (i.e., sequentially) have lower quality on the delayed platform compared to the platform of original release. This effect remains significant when we include the *Complex Platform* variable (the second source of tradeoff). In fact, it becomes stronger in terms of magnitude (-5.340; p<.001), with a significant difference in coefficients between Model 6-2 and Model 6-5 (p<0.05). These results provide strong support for our hypothesis H1.

We also find support for the prediction that multihoming complements have lower quality on the complex platform compared to the other platforms they are released on (H2). Model 6-3 shows that *Complex Platform* has a negative and statistically significant coefficient (-2.062; p<.01), which remains almost unchanged in the full Model 6-5. Finally, we interact the *Complex Platform* and *Delayed Release* dummies in model 6-5 to test whether the quality drop of delayed releases on the complex platform is smaller relative to the drop on simpler platforms as predicted in H3. The interaction coefficient is positive and significant (3.978; p<.001). Comparing the coefficients in Model 6-5 shows that when multihoming sequentially to the most complex platform, the game declines in quality by 1.4 points on the complex platform compared to the game's quality on the platform of original release, with a predicted average quality of 69.6. Comparing this value with the decline in quality of 5.3 points when delayed to a simple platform (with a predicted average quality of 66.2 on the delayed simple platform), we can see that delayed releases experience greater quality drops when multihoming to simple platforms than to the complex platform, and a lower average level of quality. This supports Hypothesis 3. Because of the complexity of the platform architecture, complementors must dedicate significant resources to porting to make it work on the complex platform. Thus, they may tailor the multihoming version of the game more to the complex platform than they would to a simple one, and experience a smaller quality decline.

To assess the economic significance of this effect, we ran game fixed-effects regressions with logged title-platform sales as dependent variable.[18] One point of review scores creates a 4.5% difference in the cross-platform sales of a title. Using the results from our full model 6-5, all else equal, compared to simultaneous titles on simple platforms, delayed titles on simple platforms have 24% lower sales, simultaneous titles on complex platforms have 9% lower sales, and delayed titles on complex platforms have 15% lower sales.

5.3. Robustness Checks

In Table 7, we first replicated our baseline regression for the combined sample of consoles in Model 7-1[19] to rule out the possibility that differences in the quality of multihoming games across these consoles are due to generation specific dynamics. In this regression, the *Complex Platform* dummy represents games released on PS2 or PS3 (the complex platforms in their respective generations). Results are qualitatively unchanged. In Model 7-2, we adopt a more stringent definition of *Delayed Release*, only considering games that are delayed more than 30 days to capture games that have undergone substantial changes on top of marketing considerations. Our results remain similar in magnitude, although the interaction term is relatively less significant. Model 7-3 runs the main regression with standard errors clustered at the title level, with unchanged results.

------------- INSERT TABLE 7 ABOUT HERE -------------

Model 7-4 introduces additional control variables. There is consensus in the industry that the *Wii* was not just a simpler machine; it was also underpowered in terms of graphics and processor, given the deliberate strategy of Nintendo of targeting casual gamers rather than the hard-core gamers targeted by *PS3* and *Xbox 360*. To capture this idiosyncrasy of *Wii*, we calculated the number of games in the focal title's genre relative to the total number of games available for the platform to reflect the relevance of the focal genre for the console and its market positioning (Cennamo and Santaló 2013, Seamans and Zhu 2014). We also included the publisher's experience

[18] We used quality scores as the independent variable, and the logged installed base of the console in the year of release for the title-platform as a control variable. The dependent variable is logged cumulative 12-month sales of the title-platform from its release date. Our multihoming sales data is available for a more limited number of observations, in total for 412 title-platforms and 190 unique titles in 7G. Results are available in the Appendix, Table A1.

[19] After merging, we excluded 34 observations that were multihomed cross-generation as our analysis focuses on comparing platform complexity across platforms of the same technological generation.

with a platform. Our results are not affected by these additional controls. In Models 7-5 and 7-6, we split the sample between hardware demanding genres (such as Shooter, Sports, Action, Fighting, Racing, RPG and Flight) that intensively use graphics and processor power, and less demanding genres (such as Family Games, Children's Games, Strategy, Platformer, and Arcade) for which hardware power matters less for gaming experience. The negative main effect of Complex Platform is significant in both samples. For casual games this reflects differences between PS3 and Wii, whereas in cutting-edge genres this captures differences between PS3 and Xbox 360.[20] The interaction between Complex Platform and Delayed Release variable is only significant for the cutting-edge genre sample, which suggests that games targeting these genres are those that tend to dedicate greater resources for multihoming on the complex platform. This is intuitive, given that games targeting cutting-edge genres can benefit more from the advanced functionalities (e.g., graphics and computational power) of the complex platform.

Our delay variable does not distinguish between games that have first been released to a complex platform and then ported to a simple (non-complex) platform and vice versa.[21] In Table A2 in the Appendix, we run models with separate delay variables for different sequencing of delayed titles, using both our main and the combined sample and find that results remain qualitatively unchanged. Lastly, we test for two key factors specific to the development of game titles for game consoles that may impact multihoming performance: in-house development and licensed middleware. First, game development can be done by the same company marketing the game that decides which consoles to release on, or it can be done by independent companies (external development studios) and then published by the marketing company (i.e., the publisher). We capture this distinct way of organizing for complementary innovation through a dummy variable, *in-house development*, that takes value 1 for games developed and published by the same parent company. In our sample, about 70% (52 out of 74) of all the multihoming delayed games, and about 61% (202 out of the 333) of the multihoming titles released on the complex platform are developed in-house. Developers also often use licensed middleware tools designed to be platform-agnostic to develop the game such that they can easily adjust the software code for each target platform supported by the middleware. About 16% (22) of the multihoming delayed games, and 17% (56) of the multihoming titles

[20] We ran further regressions (available from the authors) with the individual platform dummies which support this.
[21] We thank a reviewer for alerting us to this.

released on the complex platform use middleware tools. In principle, these tools should help reduce the hurdles and costs of integrating a game with a platform. As shown in Models 7-7 and 7-8, our main results remain unchanged. This suggests that the quality tradeoffs due to differences in platform architectures cannot be easily mitigated via these tools: In fact, the quality decline for delayed releases using middleware tools is even greater.[22]

6. DISCUSSION AND CONCLUSION

We study the impact of platform architecture on the quality of multihoming complements, and focus on the tradeoffs of multihoming complements across platforms of differing platform architectures (after controlling for game-specific factors). We look at multihoming video games in the seventh generation of video game consoles from 2005 to 2010 and find support for our main prediction that games receive lower quality scores on complex platform architectures. Put simply, it is more difficult to port a game onto a complex platform; quality performance of the complement on that platform is therefore lower. This confirms that differences in platform architectures, particularly technological complexity, matter for the decisions and outcomes of complement providers to port their complements to specific platforms.

We answer recent calls to bring the IT artifact to the core of theory development to understand “how platform architecture influences the evolutionary dynamics of ecosystems and modules [complements] in platform settings” (Tiwana et al. 2010:678). We focus on differences in the complexity of the underlying platform technology as a key dimension of platform architecture, extending the multihoming literature that has mainly looked at the implications of multihoming for platform competition, with the implicit assumption that multihoming complements have the same quality performance on different platforms. We show this is not the case because differences in the platform architecture of platforms entail quality tradeoffs for multihoming complements arising from the extent their design is co-specialized to each platform. Complements designed to conform more to a focal platform’s specifications have lower quality performance on platforms they are subsequently multihomed to; and multihoming complements have lower quality performance on more complex platforms (compared to less complex ones), whether multihoming sequentially or simultaneously.

[22] The coefficients on the “direct” effects of the variables *Inhouse Development* and *Licensed Middleware* are absorbed by our game fixed effects; therefore, these terms are not present in our regression model. For a similar example, please see Boudreau et al. (2011).

This has multiple implications. First, complex platforms require higher co-specialization by third-party developers to achieve superior software performance. Using cross-platform development technology such as middleware tools does not help avoid these platform-specific investments; exclusive complements seem better suited. Post-hoc descriptive analysis on the subsample of exclusive games indeed reveals systematic differences between complex and less complex consoles. Examining the top games within the generation, the complex console tends to have the highest scores in exclusive game titles. Tables 8 and 9 show the Top 10 3rd party exclusive titles (in terms of quality ranking) for G7 and G6, respectively. These top games are the exclusive games that will affect the competitive positions of each platform and will sell platforms (Binken and Stremersch, 2009). Complex consoles have a higher number of titles in the Top 10 compared to relatively simple consoles.[23]

------------- INSERT TABLES 8 AND 9 ABOUT HERE -------------

Second, our results provide indicative evidence of the opportunities that more complex platforms offer to complementors that *do* specialize on the platform. However, as per our empirical results, platform complexity also makes it more difficult to obtain (multihoming) games of similar quality to those on competing systems. In fact, although *PS3* had most of the exclusive games in the top 10 list of its generation, it only obtained 18 exclusive games from third-party developers versus 69 for *Xbox360* and 189 for *Wii* during our observation period. Hence, platform owners face a tradeoff between i) a simpler platform architecture with more standardized interfaces that can enable greater innovation "in the complement" (Baldwin and Clark 2000, Schilling 2000), but also increase fungibility of the complement across competing platforms, reducing complement-based differentiation of the platform, and ii) a more technologically demanding platform architecture that renders the system more unique, but requires greater co-specialization by complement providers to achieve higher integration between complements and platform. The owner of a complex platform may offer incentives to exclusive complementors (Cennamo and Santaló, 2013) or produce exclusive complements itself (Cennamo 2016) to leverage its architecture rather than rely on lower-quality multihoming complements. Given the high financial risks involved,

[23] Other statistics such as the top percentile and the mean quality score confirm this pattern of complex consoles attracting higher-quality exclusive games.

the higher level of co-specialization and the resulting hold-up problems (Kretschmer and Reitzig 2013), we expect more interventions by the owner of a complex console such as co-marketing and co-development activities. The extent to which this is the case is an interesting question for future work, not least because we know little about the mechanisms used by platform owners to incentivize investments by complementors besides pricing and installed based mechanisms (Claussen et al. 2013; Tiwana 2015).

Third, our theoretical logic and findings offer novel insights about the economics of multihoming, and their implications for platform competition. There are “hidden” platform-specific costs of complementary innovation and multihoming arising from the need to integrate a complement with a given platform architecture. Hence, multihoming costs are not fully exogenous and they differ across platforms. Also, multihoming complements need not equalize indirect network effects across platforms, suggesting an asymmetric effect on platform value (Cennamo 2016). Multihoming complements might *not* reduce differentiation among platforms as suggested in the literature (Landsman and Stremersch 2011) because the quality of multihoming complements differs across platforms of differing architectures. This points to another strategic dimension for platform owners, its attractiveness for high-quality multihomed games, which calls for integrating the design rules for complement providers (Baldwin and Woodard 2009, Gawer 2014; Yoo et al. 2010) with the economic incentives to multihome (Corts and Lederman 2009, Bresnahan et al. 2015).

The tradeoff between platform complexity and attractiveness for multihoming complements we identify raises the prospect of competition between a large, open (simple) platform and a smaller, exclusive (complex) platform where complex and less complex platforms may each secure distinct “spheres of influence” (Gimeno 1999) in the market. Complex platforms may offer consumers unique complements of high quality, while less complex platforms can offer a greater variety of complements. In contexts where most consumers have a strong preference for variety, platform architecture is likely to converge, whereas if consumers are heterogeneous in their preferences over quality and variety, we expect to see greater variance in the architecture of competing platforms.

Our hypotheses rest on three key mechanisms: First, the difficulty of customizing a complement for a platform depends on the platform’s complexity. Second, specialization on one platform “locks in” certain complement features, which hinders porting the complement to another platform. Third, the difficulty of developing a complement for a complex platform can be offset by spreading the process over time. In settings where platform complexity is mitigated through a standardized complement interface, our results on complexity would not hold. Similarly, if only a small share of efforts on one platform could be reused on another platform, our results on specialization through staggered development would be weaker because developing a complement for one platform would not lock in features for another. Finally, complementors that are not capacity constrained can develop complements for multiple consoles concurrently, so that separate development for a complex platform would not carry extra benefits. The validity of these assumptions are also boundary conditions of our work.

Our results have several managerial implications. First, the difference in quality performance for the same game on distinct platforms suggests additional costs of multihoming that managers might not fully anticipate when multihoming to different platforms. Since game quality is an important predictor of game sales (Zhu and Zhang 2010), when multihoming to a complex platform, managers may want to stagger the release and take more time to optimize and integrate the complement with the complex technology. Further, platform architecture can inform complement providers about the likely success of various multihoming strategies. While we show that delayed releases have lower quality than their earlier sibling, the predicted average quality (from our estimations) of the game in the original platform of release is higher than the sample average. Thus, despite the tradeoff from multihoming, there are clear returns from specialization on the platform of original release. Complementors can choose different strategies; specializing first on one platform to maximize their chances of reaching higher innovation performance, or choosing a simultaneous multihoming approach, sacrificing maximum quality on a platform to reduce variance of the complement's quality across platforms. Complementors aiming to preserve their (or the game's) brand and reputation across multiple user groups and platforms might choose this strategy.

Our results provoke new research questions at the firm- and platform-level. First, if platform complexity generates development and performance issues for complement providers, why do firms choose to design a complex architecture in the first place? More advanced platforms can offer more value to users and outperform competitors (Zhu and Iansiti 2012), also through "platform envelopment" – the bundling of functionalities from platforms in adjacent markets (Eisenman et al. 2011).[24] However, as these improvements in performance can create greater technological complexity, these platforms may also attract fewer complements (Anderson et al. 2014) or, as we find, complements of lower quality. However, while complex platforms suffer a "quality discount" vis-à-vis less complex platforms for multihoming complements, they possibly hold a "quality advantage" for their exclusive complements that represent sources of differentiation for the platform (Cennamo and Santaló, 2013). This asymmetric quality effect for exclusive and multihoming complements can help explain platform performance and dynamics beyond network effects dynamics, raising new and interesting questions.

Second, our evidence of the tradeoff from specialization and the result on delayed releases highlight how critical it is for platforms to attract and obtain complements early. This not only increases the availability of complements on the platform and thus grows the user base via network effects (Anderson et al. 2014), it also increases the quality of complements obtained (Cennamo 2016). Also, while research has assessed the role of exclusivity for platform competition (Cennamo and Santaló 2013; Corts and Lederman 2009), it is interesting to understand how the "temporary" exclusivity period between the first and delayed release affects platform competition. Given the difference in complement quality between the delayed and original release, this might create a differentiation gap between the two platforms. The question then becomes what platform owners should do to induce complementors to specialize first to their platform, i.e., how to attract complementors early.

Finally, if platform owners cannot resolve the technological dilemma of having an advanced platform that is not complex, the question becomes an organizational one (Tiwana et al. 2010; Yoo et al. 2010): How do platform owners manage this complexity with their complement providers? We have limited knowledge on the inter-organizational schemes and mechanisms used by platform providers to guarantee high-quality integration with complements (Tiwana 2015), and to govern the evolution of the ecosystem of complement providers to reduce unintended variance (in quality) and increase intended variance (variety of high-quality complements) (Tiwana et al. 2010, Wareham et al. 2014). This indicates a common strategy by platform owners to maintain control over

[24] For instance, Sony delayed the launch to the market of the PlayStation 3 to integrate Blu-Ray DVD functionality into the console. This may have given consumers extra benefits from the console, but at the cost of increasing complexity for developers, and thus their costs of multihoming to the PS3, which implied lower-quality multihoming games (as per our G7 results).

the type and quality of complementary innovations produced: they produce complements themselves. However, this has both advantages and disadvantages (Gawer and Henderson 2007). If platform owners integrate more, co-opetition with complement providers will be stronger, especially for those releasing multihoming games. This may create tensions with complement providers (Cennamo 2016). Therefore, research on platform technological infrastructures and the ecosystem of platform core, first-party and third-party complements should include both strategic and technical parameters to fully reflect the underlying dynamics of platform evolution and innovation.

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Tables and Figures

Table 1 Sample Consoles in the US Video Game Industry (1999-2010)

Console	Generation	U.S. Launch Date	Platform Parent	CPU	Total System and Graphics RAM (Mb.)
Dreamcast	6	Sept. 1999	Sega	Hitachi SH-4 RISC @ 200 MHz	24
PS2	6	Oct. 2000	Sony	Custom Made "Emotion Engine" RISC @ 294 MHz	36
Xbox	6	Nov. 2001	Microsoft	Intel Pentium III x86 @733 MHz	64
Gamecube	6	Nov. 2001	Nintendo	IBM PowerPC "Gekko" RISC @ 485 MHz	43
Xbox 360	7	Nov. 2005	Microsoft	IBM PowerPC "Xenon" RISC @ 3200 MHz with 3 Main Cores (3PPE)	512
PS3	7	Nov. 2006	Sony	IBM PowerPC "Cell Processor" RISC @ 3200 MHz with 1 Main and 7 Specialized Cores (PPE + 7SPE)	512
Wii	7	Nov. 2006	Nintendo	IBM PowerPC "Broadway" RISC @729 MHz	88

Table 2 Architectures of Consoles in the US Video Game Industry (1999-2010)

Console	Generation	U.S. Launch Date	Platform Parent	Total Number of Processors	Requirement of Low Level Language Use
Dreamcast	6	Sept. 1999	Sega	3	No
PS2	6	Oct. 2000	Sony	5	Yes
Xbox	6	Nov. 2001	Microsoft	2	No
Gamecube	6	Nov. 2001	Nintendo	2	No
Xbox 360	7	Nov. 2005	Microsoft	4	No
PS3	7	Nov. 2006	Sony	9	Yes
Wii	7	Nov. 2006	Nintendo	2	No

Table 3 Delta Review Scores (Title-platform Review Score – Average Title Review Score) and Number of Observations by Complex Platform (vs. Simple Platform) and Delayed Release (vs. Non-Delayed)

	Delayed Release = 0	Delayed Release = 1
Complex Platform = 0	0.35 (2.48) n=429	-2.94 (6.29) n=28
Complex Platform = 1	-0.13 (1.67) n=287	-0.71 (2.45) n=46

Note. Standard deviations in parenthesis.

Table 4 Mean Values and Standard Deviations on Key Game Characteristics by 2x2 Matrix Quadrant Categories

	Complex No/ Delay No	Complex No / Delay Yes	Complex Yes / Delay No	Complex Yes / Delay Yes
Inhouse Development	0.59 (0.49)	0.69 (0.47)	0.59 (0.49)	0.68 (0.47)
Licensed Middleware	0.15 (0.36)	0.14 (0.35)	0.16 (0.36)	0.23 (0.43)
Licensed content	0.52 (0.50)	0.43 (0.50)	0.49 (0.50)	0.41 (0.50)
Ln(Publisher Platform Owner Experience+1)	3.72 (1.27)	3.41 (1.60)	4.32 (1.35)	4.01 (1.52)

Table 5 Descriptive Statistics and Correlation Matrix for the G7 Console Sample

	Mean	S.D.	Min	Max	1	2	3	4
1. *Title-Platform Quality*	71.13	13.65	16	97.04				
2. *Delayed Release*[a]	0.09	0.29	0	1	-0.02			
3. *Complex Platform*[a]	0.42	0.49	0	1	0.03	0.13**		
4. *Average Quality of 1st Party Exclusives*	78.6	4.38	66.97	88.06	0.01	-0.06	0.64**	
5. *Average Quality of 3rd Party Exclusives*	68.41	4.84	58.36	75.17	0.05	0.1	0.90**	0.62**

Note. $N = 790$. [a]Dummy variable. $^{*}p < 0.05$; $^{**}p < 0.01$.

Table 6 Quality Differences across Delayed vs. First Releases and Complex vs. Non-Complex Platforms for G7 Consoles. Fixed Effect OLS Regression Model with Games as Focus. DV = Review Score of the Game on the Focal Platform.

	6-1	6-2	6-3	6-4	6-5
Delayed Release		-3.365***		-3.174***	-5.340***
		(0.565)		(0.571)	(0.805)
Complex Platform			-2.062**	-1.378^	-2.065**
			(0.725)	(0.712)	(0.724)
Complex Platform x Delayed Release					3.978***
					(1.056)
Average Quality of 1st Party Exclusives	-0.031	-0.045	0.018	-0.012	0.042
	(0.040)	(0.039)	(0.044)	(0.042)	(0.044)
Average Quality of 3rd Party Exclusives	0.005	0.041	0.182*	0.157*	0.160*
	(0.035)	(0.034)	(0.071)	(0.069)	(0.068)
Constant	73.183***	72.188***	58.184***	62.216***	57.950***
	(2.486)	(2.398)	(5.821)	(5.677)	(5.706)
Observations	790	790	790	790	790
R-squared (within)	0.002	0.077	0.020	0.085	0.115
Number of Titles	354	354	354	354	354
Game FE	Yes	Yes	Yes	Yes	Yes

Notes. Standard errors in parentheses. *** p<0.001, ** p<0.01, * p<0.05, ^ p<0.10

Table 7 Robustness Checks

	7-1 Combined Sample (6G and 7G)	7-2 Delayed Release>=30 Days	7-3 Clustered Std. Errors	7-4 Additional Controls	7-5 Casual Genres	7-6 Cutting-Edge Genres	7-7 Inhouse Development	7-8 Licensed Middleware
Delayed Release	-2.522***	-5.717***	-5.340**	-5.325***	-5.124***	-5.697***	-6.311***	-4.613***
	(0.286)	(1.003)	(1.945)	(0.807)	(1.353)	(0.995)	(1.213)	(0.839)
Complex Platform	-0.572**	-1.830*	-2.065*	-2.085**	-2.632*	-2.008*	-2.320**	-1.999**
	(0.192)	(0.712)	(0.812)	(0.747)	(1.261)	(0.875)	(0.815)	(0.724)
Complex Platform x Delayed Release	1.001*	3.102*	3.978*	3.977***	0.980	4.846***	4.103***	4.172***
	(0.503)	(1.284)	(1.917)	(1.059)	(1.769)	(1.307)	(1.063)	(1.051)
Average Quality of 1st Party Exclusives	0.038^	0.020	0.042	0.043	0.093	0.044	0.052	0.043
	(0.022)	(0.043)	(0.037)	(0.044)	(0.087)	(0.052)	(0.045)	(0.044)
Average Quality of 3rd Party Exclusives	-0.000	0.164*	0.160^	0.162*	0.211^	0.147^	0.166*	0.155*
	(0.029)	(0.068)	(0.088)	(0.068)	(0.115)	(0.083)	(0.068)	(0.068)
ln(Publisher Platform Owner Experience)				-0.043				
				(0.394)				
Platform Genre Focus				0.025				
				(0.051)				
Complex Platform X Inhouse							1.302	
							(1.223)	
Delayed Release X Inhouse							0.239	
							(0.515)	
Complex Platform X Middleware								-0.130
								(0.680)
Delayed Release X Middleware								-3.789**
								(1.358)
Constant	68.722***	59.367***	57.950***	57.501***	50.466***	58.839***	56.897***	58.271***
	(1.805)	(5.641)	(6.681)	(5.910)	(9.827)	(6.919)	(5.780)	(5.665)
Observations	2,183	790	790	790	154	636	790	790
R-squared (within)	0.073	0.103	0.115	0.115	0.187	0.110	0.118	0.132
Number of Titles	955	354	354	354	60	294	354	354
Game FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes. Standard errors in parentheses. *** p<0.001, ** p<0.01, * p<0.05, ^ p<0.10

Table 8 Platform Distribution of Top 10 3rd Party Exclusive Games (G7)

Top 10 3rd Party Exclusives[1]		
Platform	ReviewScore	Title
PlayStation 3	93.53	METAL GEAR SOLID 4: GUNS OF THE PATRIOTS
PlayStation 3	89.72	DEMON'S SOULS
Xbox 360	89.44	LEFT 4 DEAD
Xbox 360	89.05	LEFT 4 DEAD 2
Wii	87.35	BOOM BLOX BASH PARTY
PlayStation 3	87.22	VALKYRIA CHRONICLES
PlayStation 3	86.72	NINJA GAIDEN SIGMA
Xbox 360	86.5	TOM CLANCY'S SPLINTER CELL: CONVICTION
Wii	85.99	TATSUNOKO VS. CAPCOM ULTIMATE ALL-STARS
Wii	85.98	ZACK & WIKI: QUEST FOR BARBAROS' TREASURE

1. Exclusive = A game that is only released on the focal console (may still be released on PC), regardless of its generation. Period of observation is November 2006 (availability of all platforms within the generation)-December 2010 (final observation for our data).

Table 9 Platform Distribution of Top 10 3rd Party Exclusive Games (G6)

Top 10 3rd Party Exclusives[1]		
Platform	Review Score	Title
PlayStation 2	95.09	METAL GEAR SOLID 2: SONS OF LIBERTY
Xbox	94.21	STAR WARS: KNIGHTS OF THE OLD REPUBLIC
PlayStation 2	92.97	WORLD SOCCER: WINNING ELEVEN 7 INTERNATIONAL
Xbox	92.54	NINJA GAIDEN
PlayStation 2	91.96	GUITAR HERO
PlayStation 2	91.77	METAL GEAR SOLID 3: SNAKE EATER
PlayStation 2	91.59	VIRTUA FIGHTER 4: EVOLUTION
PlayStation 2	91.33	VIRTUA FIGHTER 4
PlayStation 2	90.54	WORLD SOCCER WINNING ELEVEN 6 INTERNATIONAL
Xbox	90.36	PANZER DRAGOON ORTA

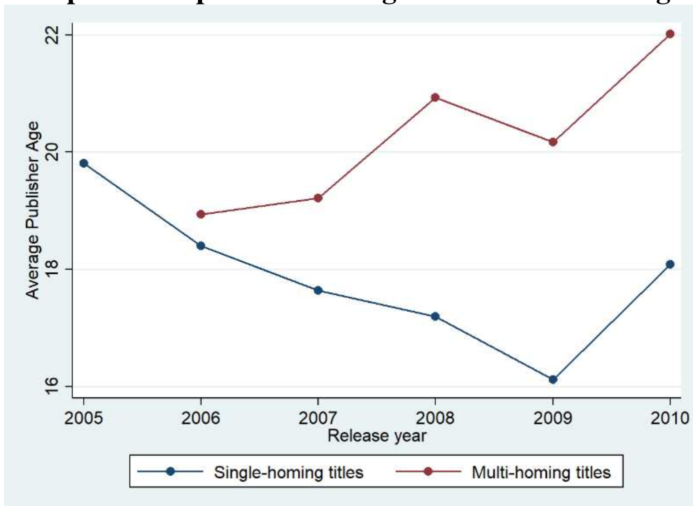
1. Exclusive = A game that is only released on the focal console (may still be released on PC), regardless of its generation. Period of observation is November 2001 (availability of all platforms within the generation)-December 2005 (final full year for Xbox before migration to Xbox 360).

Figure 1 Summary of Hypotheses

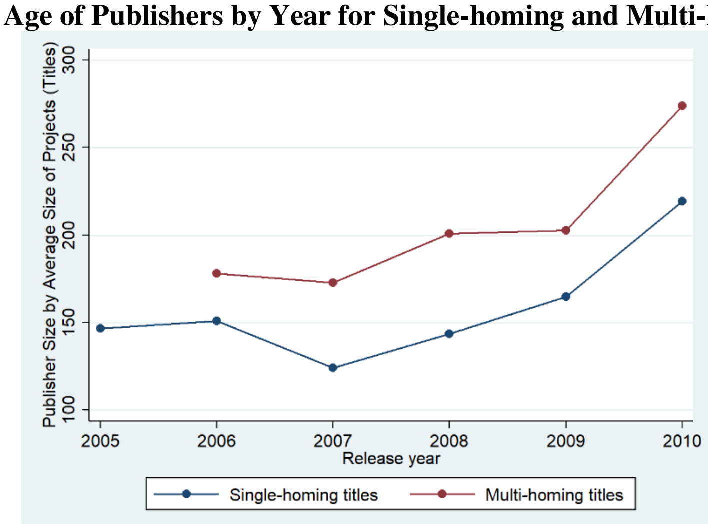
PLATFORM ARCHITECTURE

MULTIHOMING	SIMPLE	COMPLEX
SIMULTANEOUS	0	$\Delta(C) < 0$ (H2)
SEQUENTIAL	$\Delta(D) < 0$ (H1)	$\Delta(CD) > \Delta(C) + \Delta(D)$ (H3)

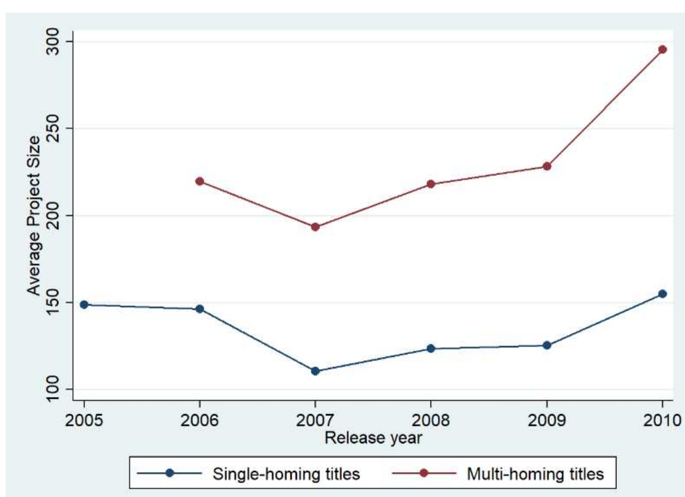
Figure 2 Descriptive Comparisons of Single- and Multi-Homing Game Titles



2a Average Age of Publishers by Year for Single-homing and Multi-homing Titles

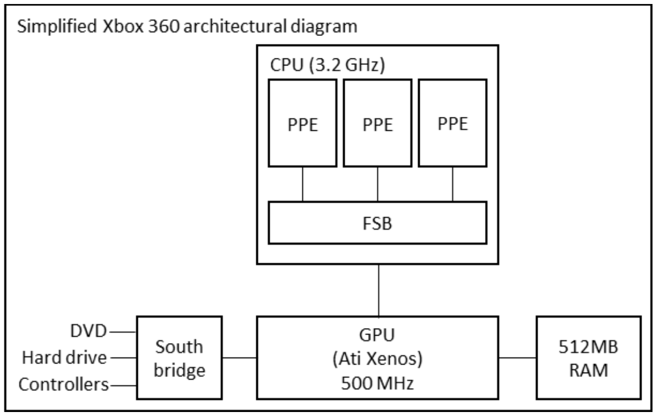


2b Average Size of Publishers (Measured by Average Project Size of Game Titles) by Year for Single-homing and Multi-homing Titles

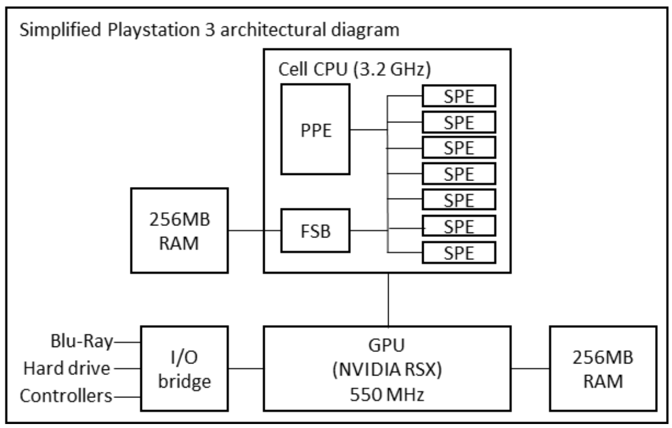


2c Average Project Size of Games for Single-homing and Multi-homing Titles

Figure 3 Xbox 360 and PlayStation 3 Architectural Diagrams



3a Xbox 360 Architectural Diagram



3b PlayStation 3 Architectural Diagram

Source. Adapted from Reimer (2005).