Dynamic Multihoming by Content Providers in Platform-Based Markets: Focus on the US Videogaming Industry

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Abstract

This study is an empirical analysis of the effect of a new platform provider entry on multihoming decisions by content providers in two-sided platform industries. I focus on the home console video game industry in the US and assess the role played by Microsoft's entry as a console manufacturer on the pattern of exclusive releases. In the home video game industry, game developers and publishers (content providers) develop game titles for consoles (platforms) and compete for the existing consumers who own those consoles. The possibility for content providers to publish their content on multiple platforms (multihoming), and eventually with timed exclusivity, is an interesting feature of two-sided platform industries. Online-gathered data show a big jump in the multihoming ratio among quarterly releases of video games on home consoles in the US, after Microsoft's entry as a console manufacturer in 2001. There are two key mechanisms influencing the extent of multihoming: (1) the size of the consumer group on each platform (installed base), and (2) the platform-specific development costs. Focusing the analysis on releases that occurred during the 1995-2016 period, I estimate a single-agent dynamic discrete choice model of platform targeting by content providers. I find that the installed base significantly impacts payoff, but requires a very large variation to shift the distribution of releases across platforms. As for the estimated costs, they are found to have the same pattern described by industry sources: platform-invariant development cost estimates increase over time, platform-specific porting cost estimates and their disparities decrease across generations. These trends mean that the cost of multihoming is declining over time. In addition, counterfactual simulations show that Microsoft's entry as a console provider has played a role in sustaining a long-term increase in multihoming, as it is estimated to have increased the ratio of multihomed video game releases by 10 to 13 percentage points.

Keywords Multihoming; content supply; indirect network effect; dynamic discrete choice

1. INTRODUCTION

Two-sided platforms are often known as entities that bring two groups of economic agents together[1] - and actively manage (cross-group) network effects between them (Belleflamme & Peitz, 2021; Rochet & Tirole, 2006). In many cases, those groups of platform adopters are known as content providers and final users. In two-sided platform industries, platforms are marketplaces where content providers compete for the platform's final users. Platforms are differentiated products for both users and content suppliers. The more important and so far most studied particularity of two-sided platform industries is the so-called "indirect network effects" (INE). Indeed, a two-sided platform industry is faced with demand from two parties: the end user and the content provider. The INE is the value that any member from either side gives to the variety of members from the other side. Therefore, it is important for content providers to weigh platforms' customer bases when targeting these. Beyond their interest in the installed base, content providers are also interested in the user-friendliness and innovation of the technology implemented by platform providers for content release. As a result, it's crucial for a content provider to make an optimal choice in terms of the platforms it needs to target to release its content, and multihoming choices are the result of a trade-off between the installed base and development costs across all existing platforms. In other words, in the e-commerce sector, depending on this trade-off, a seller may have an interest in offering their product on Amazon only, eBay only, or both online marketplaces. In the case of home console video games, some games are launched exclusively on Sony consoles, while others are marketed on both Sony and Microsoft consoles.

In this paper, I study the multihoming decision of content providers in a single-agent dynamic discrete choice model with a focus on the home console video game industry. Video game providers decide on the home consoles (platforms) on which to release their video games by considering that the expected installed base of console users and development costs across consoles are the main incentives for releasing video games. The study is based on the following assumptions: consumers have a static demand for content with a taste for variety, their demand is static and exogenous for consoles; content providers are in a monopolistic competition market where companies have similar price-quality ratios. I estimate the structural model using data collected online on video game releases and console installed bases, mainly from the Vgchartz and Fandom websites. I estimate the installed base effect - on their choice of consoles - and the development costs that they undergo when releasing video games on the chosen consoles. I then run a counterfactual analysis to study the effect of Microsoft's entry as a console provider in 2001. More specifically, I estimate the difference in the multihoming ratio calculated between the choices we observe when Microsoft

[1] By reducing transaction costs such as searching and matching costs.

consoles are present in content providers' choice alternatives and the choices I simulate in the counterfactual environment where Microsoft consoles are excluded from choice alternatives. The results of the model's estimations confirm that both installed bases and development costs are relevant for content providers when considering which platform to target. Indeed, it turns out that additional console users have a positive effect on current content profitability. However, it takes a very large increase in the installed base to force video game providers to change their decisions and therefore to significantly change the distribution of releases across platforms. For instance, a 10% increase in the observed installed base of any given console doesn't affect significantly the distribution of all-time releases, whereas doubling the installed base of any given console increases the share of this console in all-time releases by up to 10 percentage points. Moreover, an analysis of the installed base cross-effects highlights that Sony's platforms are close substitutes to other platforms while Nintendo's platforms are poor substitutes. As for development costs, the following trends are derived from the estimated costs: platform-invariant development cost estimates increase over time while platform-specific porting cost estimates decrease and get closer across generations of consoles. The increase in platform-invariant cost and the decrease in platform-specific cost are consistent with cost trends described by industry sources and represent a decrease in the multihoming cost over time. Moreover, the decreasing disparity between platform-specific porting costs is a sign of increasing competition over time between console manufacturers in their development architectures designed for video game providers. In addition to the lower cost of multihoming, factors specific to Microsoft's entry as a console manufacturer played a role in the sustained increase in multihoming, as shown by the counterfactual analysis. Indeed, counterfactual simulations show that Microsoft's presence in the sector as a console provider raised the ratio of multihoming video game releases to total releases on Generation 5, 6, and 7 consoles by between 10 and 13 percentage points; and prevented Sony from concentrating three-quarters of the market share in home console video game releases.

The home video game console industry is well-known as a hardware-software industry (Lee, 2012) or, more broadly, a two-sided platform sector (Belleflamme & Peitz, 2021; Rochet & Tirole, 2006), where home consoles are platforms or hardware and game developers are content or software providers. Since Microsoft's entry as a console manufacturer with its Xbox console in 2001, video games have become increasingly less exclusive to a single home console. Indeed, online-gathered data on video game releases show that the share of non-exclusive titles among quarterly releases went from around 5% before the Xbox launch to around 10% a few months after the Xbox launch. It kept increasing consistently over time and across generations to reach around 40% in the early quarters of 2012, just before the release of Nintendo's WiiU (the first of the 8th generation of consoles). Such an increase in the multihoming ratio in the video game industry may be of interest for the two following reasons:

(i)- there is an interesting variation in the set of available platforms across time; (ii) - the structure of development costs changes over time in favor of an increase in platform-invariant costs, and (iii) - multihoming by content providers has consequences on platform competition. The first reason lies in the fact that platform providers in the video game industry regularly launch new consoles while existing consoles are still operational. As a result, the sets of available consoles that game suppliers can target overlap and vary over time, which can have consequences for the multihoming pattern. For instance, Sony and Nintendo were the two main console manufacturers before Microsoft entered the market. Since Microsoft launched its Xbox console, game developers have been faced with more and more multihoming possibilities, both within a single generation and across generations. The second reason is linked to existing observations and statements from Cennamo et al. (2018), Corts and Lederman (2009), Lee (2012), and Steinberg (2007) and various industry sources such as Fandom (n.d.), Koster (2018), and Loftus (2003) and REIMER (2005). These sources highlight that development costs have been increasing over time (see Figure 3). This is mainly due to platform-invariant development costs: video games require more memory and their development process is split into more tasks and needs more high-skilled workers. Meanwhile, the share of more platform-specific development costs - often referred to as porting costs - is declining over time as a proportion of total development cost[2]. As a result of the increase in the ratio of platform-invariant development costs, the total development cost per host platform decreases over time, which may give more incentives for game providers to multihome their titles.

In addition to the motives behind the study of multihoming, it may also be interesting to consider the dynamics involved in the analysis. The main reasons are that (a)- the video game release costs are high and paid only once (i.e. before sales start); and (b)- installed bases of console users - which determine video game providers' sales expectations - vary over time, as new users of each console are added to the installed base every period, until the console is depreciated and made unavailable. As a result, today's decisions will have consequences for tomorrow's choices, leading to a trade-off between current and future decisions. Indeed, a video game provider may face a trade-off between (i)-the decision to release the video game today on certain platforms and pay higher development costs but gain earlier access to the users of these platforms; and (ii)- the decision to pay lower release costs in the future but not gain earlier access to their customer bases and get closer to the end of the platforms' limited lifespan. When video game providers face different release costs, some choose to release their games within a given period, while others prefer to wait. Two observed facts support these trade-offs in the home video game industry: video game providers have differing interests in the month of the release year; and almost no releases or new users are observed on dying platforms. The months of the year matter to developers when it comes to choosing

[2] Corts and Lederman (2009) and Lee (2012).

launch dates for their titles, as industry sources point out. Some choose to launch at the beginning of the year (in winter), others in summer, and most developers choose the fall, taking into account their expectations of the platform's installed user base and the fact that they face different development costs. Moreover, as there are no new users nor new titles on a platform when said platform reaches the end of its lifetime, developers anticipate that each platform's lifetime is finite and they won't consider releasing titles on dying platforms. Content providers therefore have finite-horizon expectations, which is the reason for this study's interest in finite-horizon dynamics.

In section 2, I describe the existing literature on content supply in two-sided platform industries. In section 3, I provide an overview of the video game industry - an example of two-sided platform industries - followed by a presentation of the data in section 4 and an overview of the evidence for increased multihoming in section 5. After modeling content providers' dynamic discrete choice of platforms in section 6, I present estimation and counterfactual results in section 7.

2. LITERATURE

Existing literature has extensively studied content supply, mainly in hardware-software industries[3] such as the home console video games (Binken & Stremersch, 2009; Clements & Ohashi, 2005; Corts & Lederman, 2009; Gretz, 2010; Kim et al., 2014; Lee, 2013; Shankar & Bayus, 2003), the videocassette recorders (Ohashi, 2003; Park, 2004), CD players (Gandal et al., 2000), DVD players (Karaca-Mandic, 2011), personal digital assistants (Nair et al., 2004), etc[4]. There is a general interest in quantifying INE by simultaneously analyzing how consumers value content in their demand for platform and how content providers value consumers in their content supply.

The workhorse model to study indirect network effects in two-sided platform industries is Nair et al. (2004). Clements and Ohashi (2005) rely on this model to analyze product lifecycle-dependent INE in the home console videogaming industry. The consumer demand for the platform is a Berry (1994) style of discrete choice and content supply is understood as the number of content products that enter a platform in relation to the platform's installed base. The specification of the content supply in their framework relies on the following main assumptions: *1- a static environment for all decision makers; 2- consumer demand for a portfolio of content products within a platform is CES type and independent across platforms; 3- free entry of new content products onto the platform; 4- market equilibrium restricted to symmetric pricing; and 5- each content product is small enough to have little effect on the market aggregate price.*

[3] A sub-category of two-sided platform industries.

[4] Content supply can also relate to studies on technology adoption such as in Augereau et al. (2006).

An implicit assumption that is common in early studies on INE is that releases of the same content product on different platforms are independent releases. This assumption can be supported based on the data related to the periods used in these studies (late 1990s and early 2000s). Indeed, during those periods, market structures were exclusivity-oriented. This means that content providers primarily targeted single platforms out of all those under consideration[5]. Meanwhile, the barriers of non-exclusivity seem to have broken down over time, as we witness an increase in multihomed releases, at least in the home console video game sector. Therefore, it would be appropriate for studies on releases registered from 2005 onwards, for instance, to consider multihoming by content providers as an important element. Some studies have looked at multihoming as either an exogenous factor (Corts & Lederman, 2009) or an endogenous factor (Lee, 2013) that reduces differentiation between platforms, and therefore as a determinant of console market share. Corts and Lederman (2009) extend the content supply specification of Clements and Ohashi (2005) and Nair et al. (2004) to account for cross-platform indirect network effects (INE). Indeed, the number of content products released on a given platform depends on both that platform's installed base and total installed bases of other platforms from the same "technological generation". They relate this extended scope of the INE to exclusivity by estimating separately the content supply by exclusive third-party titles and the content supply by non-exclusive third-party titles. However, cross-platform INE in content supply is more of a reduced-form relationship, while the own-platform INE as in Nair et al. (2004) is more structural. This cross-platform INE could also result from a structural framework in a dynamic discrete choice of combinations of platforms by content providers. Indeed, a current decision to target a given platform would depend on current and common-knowledge information, which includes installed bases of all available platforms. Consequently, targeting a platform depends on the installed bases of all platforms.

In Lee (2013) though, multihoming is endogenously determined by consumer and firm choices. The multihoming is considered on both the consumer side and the content provider side. In the latter case, it is also refered to as multiporting. This multihoming by content providers is part of a broader model used by the author to analyze the effect of exclusivity and vertical integration on market structures in the video game industry. Indeed, Lee runs a counterfactual analysis by simulating market outcomes in an environment where exclusive releases would not be allowed. His results show that eliminating exclusive agreements would have had a positive impact on both platform and content sales and on consumer welfare; and exclusivity favored the entrant platform. Even though dynamics and forward-looking behaviors are fully considered in the consumers' choices of consoles and video games, they

[5] Shankar and Bayus (2003) data covered the releases registered during the period 1993-1995; Clements and Ohashi (2005) data covered the period 1994-2002; and Nair et al. (2004) data covered the period 1999-2002.

are not in the case of a content supplier that has a single decision period[6]. Therefore, there is no account for timed exclusivity - a multiperiod release of a content product on different platforms, starting with a single platform - and its related costs. Moreover, it doesn't account for changes in development cost over time and it focuses on the sixth generation of consoles, excluding cross-generational overlaps.

This paper studies the endogenous multihoming in the content supply side, as a result of decisions made by content providers to target platforms where to release their content products. There are two key mechanisms influencing the extent of multihoming: (1) the size of the consumer group on each platform (installed base), and (2) the platform-specific release costs. This endogenous multihoming is analog to Lee (2013), who is one of the first to perform a structural analysis of multihoming by content providers and therefore one of the first attempts to recover release costs. The present paper differs from Lee (2013) in considering finite horizon dynamics and in allowing content providers to choose between platforms from different technological generations. In opposite to Lee (2013), this paper abstracts for the consumer demand for platforms, considered as exogenous, but relies on Clements and Ohashi (2005) and Nair et al. (2004) for a structural specification of the consumer demand for content products in platform-based monopolistic competition markets. The analysis presented here fits settings in which sales of content products are not observed and the emphasis is put on recovering the investment costs incurred by content providers when they adopt platforms.

3. AN OVERVIEW OF THE HOME CONSOLE VIDEOGAMING INDUSTRY

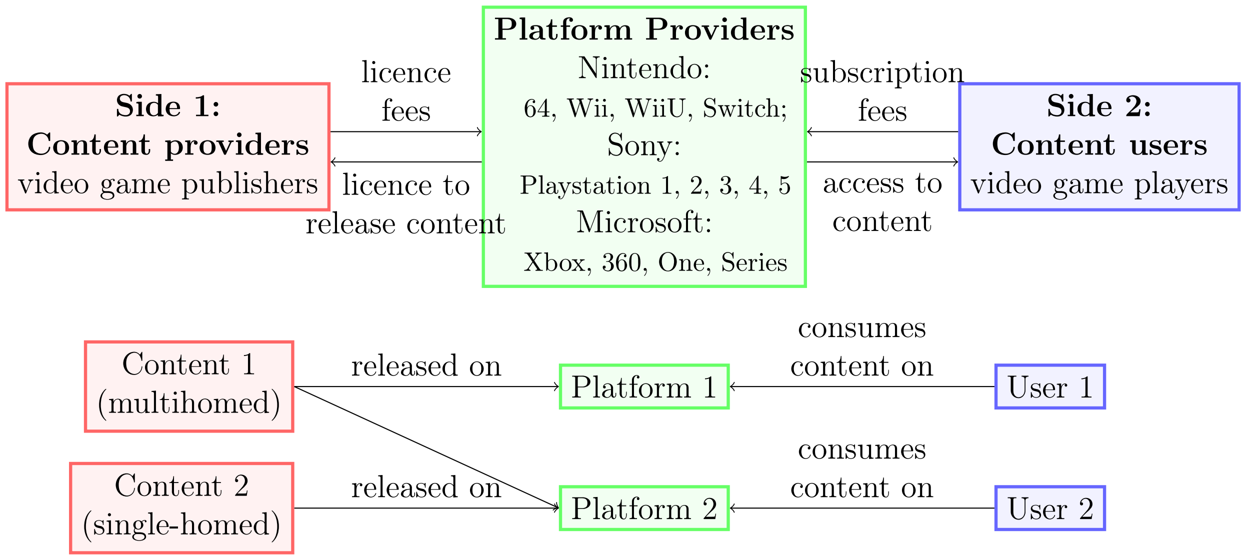
Before introducing the data and the model, I present in this section the main players and the main characteristics of the home console video game industry, which are essential for understanding the modeling assumptions. The home console video game industry, like any two-sided platform industry, is made of three groups of players: console manufacturers (platform providers); video game providers (content providers), and final consumers[7]. The interactions between those players are summarized in Figure 1. It must be noted that while this industry is around half a century old as shown in Figure 2, its main players have evolved over time and across generations.

3.1. Console manufacturers

Console manufacturers produce and sell video game consoles to consumers. They also decide on giving licence to video game providers for publishing titles that are compatible with the

[6]The content supplier has expectations on the console's installed base though.
[7]Buying both consoles and video games.

Figure 1: Interacting players in the video game industry as a two-sided platform industry



consoles. A console manufacturer provides the architecture that game makers use to develop titles for the console in question. As a result, these development architectures are specific to each platform and lead to different development costs. In the early stages of the industry, exclusive video games were the norm as titles were essentially owned by the console providers. Over time, video game makers became more separated from console makers but were still forced to produce exclusive titles by console manufacturers. This forced exclusivity led to complaints and lawsuits in the 1990s, especially against Nintendo, then the leading console manufacturer.. However, the rise of big independent game providers, starting with Activision and Electronic Arts, and the arrival of Sony in 1995 and Microsoft in 2001 as console makers, triggered the takeoff and the rise of multihomed video games. From 1995 onwards, Sony, Nintendo and Sega were the three main console manufacturers, until Sega left and Microsoft entered the console market in 2001. Since then, Sony, Nintendo, and Microsoft have been the main console manufacturers.

As with two-sided markets in general, the business model of console manufacturers is to charge end users a lower price and video game suppliers a higher one. End users are charged when they buy consoles and video game providers are charged for each copy sold of their video games.

3.2. videogame providers

Video game providers are made of two collaborating groups of players: video game developers and video game publishers. Video game developers are firms that actually create video game titles. As most of them lack financing and advertising, they turn to video game publishers for publishing contracts. The role of publishers is to finance the development process, obtain licences from console providers to publish titles, and advertise video games. I use the term "video game providers" to refer to both developers and publishers, although only video game publishers will be considered in the data sample. Indeed, as both agents cooperate on the decision to release video games and since publishers are also in charge of the distribution process, we can consider publishers as video game providers. Video games are themselves classified into three categories according to the degree of relationship between developers and console manufacturers: a video game released on a given console is said to be first-party when its developer is owned by the console provider; second-party when the developer is independent but the video game is bound by exclusivity agreements with the console manufacturer; third-party when the developer is independent and decides without binding contracts what platforms to target. First-party titles are excluded from the analysis in this paper because they are generally exclusive to the platform provided by their owner.

Video game providers develop and publish video games for specific platforms. The choice of platforms is a dynamic decision that determines the multihoming pattern. The dynamics come from the dynamic evolution of the main incentives for game development: the installed base of users that game developers expect to reach for each console and the development costs. Indeed, the decision to target a combination of multiple platforms depends on the trade-off between the high costs of releasing on those multiple platforms and the access to their customer bases. As the contribution of each platform to development costs - known as platform-specific porting cost - decreases over time[8], a resulting decrease in the cost of multihoming may incentivize more content providers to target many platforms.

3.3. Generations

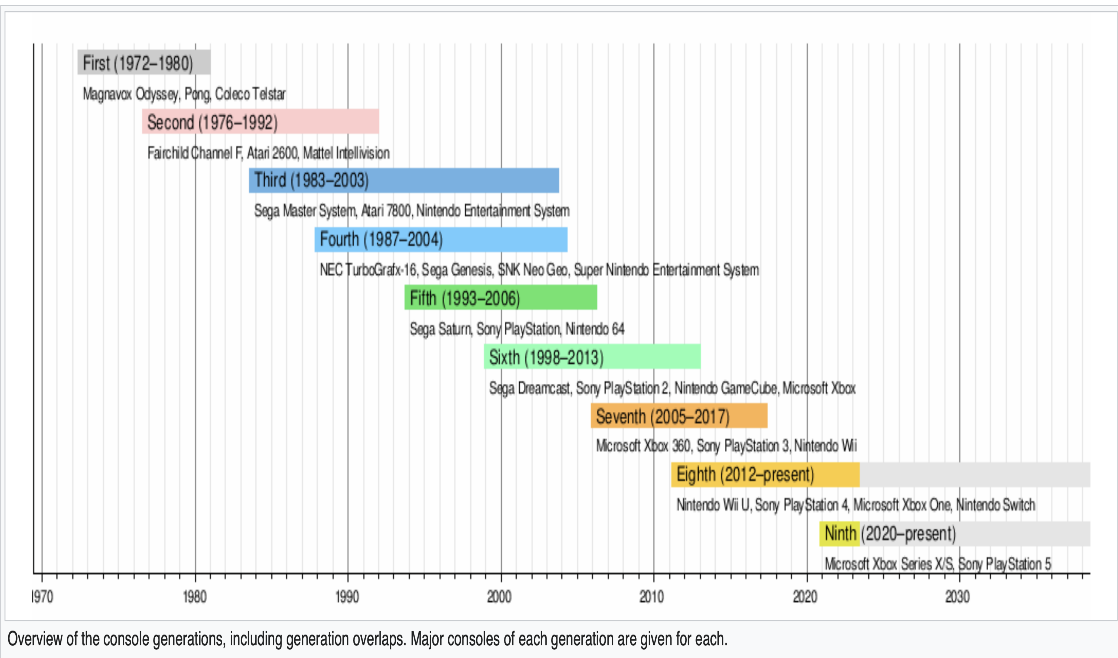
A generation of consoles represents a set of consoles that are launched during the same time frame with upgraded technological capabilities compared to existing consoles. All existing consoles become « old » and belong to previous generations when new consoles are released. For example, the Saturn, Playstation, and Nintendo 64 are all generation 5 consoles that were launched around 1995, and they become out of date when the new generation 6 consoles (Dreamcast, Playstation 2, GameCube and Xbox) were launched around 5 years later. Therefore, as new generations of consoles always appear over time, there are always overlaps between new and old generations consoles. The presence of such technological generations and their overlaps is an interesting characteristics of the dynamics in the console video game industry. Indeed, such dynamics may affect the dynamics of content provision through the changes in the structures of costs and console users between generations.

Figure 2 shows details on the lifespans of all home consoles generations and Table 1 shows generation overlaps in video game releases. Consoles of a given generation are more likely

[8] See subsection 3.5.

to attract a greater number of video games during their generational period, i.e. during periods when they are among the most recent consoles available. In my analysis, I consider 3 console manufacturers (Sony, Nintendo, and Microsoft) over 3 generations (5, 6, and 7). As this study focuses on the video game industry in the United States (US), release dates are taken as the console launch dates. Consequently, the fifth generation of home consoles considered includes the Playstation (PS) and the Nintendo 64 (N64), and begins with the release of the PS in 1995- Q3. The Playstation 2 (PS2), GameCube (GC), and Xbox (XB) are part of the sixth generation of home consoles which begins with the release of the PS2 in 2000-Q1. The seventh generation of home consoles are Xbox 360 (X360), Playstation 3 (PS3), and Wii, starting with the launch of X360 in 2005-Q3. PS, PS2, and PS3 consoles were manufactured by Sony, which first entered the industry as a home console provider with the launch of PS in 1995. The XB and X360 consoles are supplied by Microsoft, which entered the sector as a console manufacturer with the launch of the XB in 2001. Industry veteran Nintendo is the supplier of the N64, GC and Wii consoles. Even though it is not considered in this analysis, the launch of the Wii U console by Nintendo in 2012-Q4 opened the door to the 8th generation of consoles and rendered the existing 7th generation consoles of that period outdated. Let's note that Sega was also a player before Microsoft's entry in 2001. It launched its Saturn console in 1995-Q2 and Dreamcast console in 1999-Q3 which belong respectively to the fifth and sixth generation of consoles (see Figure 2. However, Sega faced financial losses from Dreamcast and exited the platform market in 2001. As this exit occurred early in the sixth generation, Sega is excluded from the analysis.

Figure 2: Console Generations from a screenshot of Wikipedia



3.4. Platform differentiation

Video game consoles are differentiated products because they are incompatible platforms in the sense that a consumer who owns a Sony console cannot play video games that are developed to be compatible with a Nintendo console; and a video game maker that develops a title for a Sony console can only make it available for a Nintendo console through additional costs that are known as porting costs. Moreover, the difference in the console user base between consoles also supports differentiation between platforms. However, the degree of differentiation may differ depending on whether one considers only consoles from the same manufacturer or consoles from different manufacturers. Indeed, some consoles from the same manufacturers are more or less backward compatible (e.g. the Wii with the GameCube), whereas consoles from different manufacturers are not compatible. However, most consoles from the same manufacturers are generally partially compatible with earlier versions. Consequently, a major source of differentiation between consoles comes from the user base, the console features and the game development architecture.

3.5. Trends in development costs

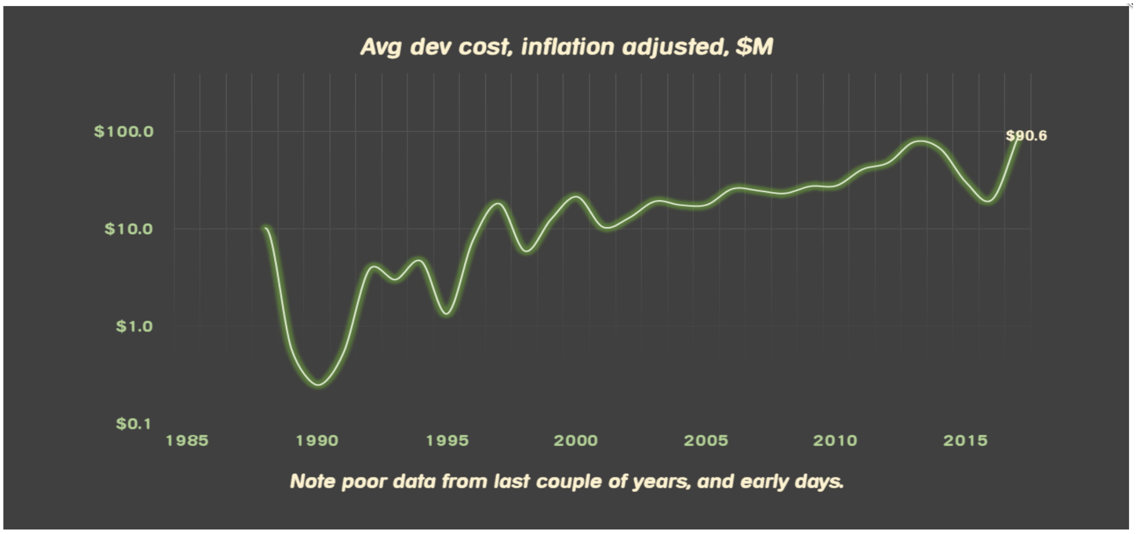
Cennamo et al. (2018), Corts and Lederman (2009), Lee (2012), and Steinberg (2007) and various industry sources such as Fandom (n.d.), Koster (2018), and Loftus (2003) and REIMER (2005) highlight that development costs have been increasing over time in the videogaming industry (see Figure 3). This is mostly due to platform-invariant development costs: video games require more memory and their development are split into more tasks and requires more high-skilled workers. It takes more time and more tasks to take advantage of features from sophisticated technology provided by the new generations of consoles (e.g. increased CPU, GPU and RAM capacities[9]). In addition, a growing share of development costs comes from activities such as "music licensing or composition and performance, motion-capture studies, and background art and design" (See Corts and Lederman, 2009; Loftus, 2003; REIMER, 2005). In the meantime, parts of development costs that are more specific to platforms - often known as porting costs - are decreasing over time as a ratio of total development costs[10].

Console-specific development costs stem from any complexity in the development technology supplied by console manufacturers. For example, while Sony (with the Playstation) followed Sega (with the Saturn) in innovating the video game development architecture by introducing optical media (CD-ROMs) as physical content storage, Nintendo stuck with cartridges. Even though cartridges were renowned for their safety and higher loading speed,

[9] CPU: Central Processing Unit; GPU: Graphic Processing Unit; RAM: Random Access Memory.

[10] Corts and Lederman (2009) and Lee (2012).

Figure 3: Trend in development cost (a screenshot from Koster (2018)'s webpage)



CDs were more attractive to game makers because of their higher memory and lower production cost. Sony also used CDs as physical content storage and added memory cards to save the game state, considerably enhancing the attractiveness of the Playstation to game makers. This difference in development technologies provided by Sony and Nintendo made video games less costly to develop on Playstation platform compared to the Nintendo 64. Platform providers have more control over these porting costs through the development infrastructure they make available to game developers. They can leverage porting costs to get a comparative advantage. It is often said that Microsoft had comparative advantage in porting cost with its first console, the Xbox, by providing a development infrastructure which was close to the one provided to software developers for its Windows operating system. This made video game porting to Microsoft Xbox quite easy for existing PC software developers[11]. As a result from the increase in the ratio of non-platform specific development costs, the total development cost per host platform decreases over time, which may further incentivize for game providers to multihome their titles. In fact, Cennamo et al. (2018) point out that the increase in multihoming is partly related to both rising development costs and the evolution of their structures.

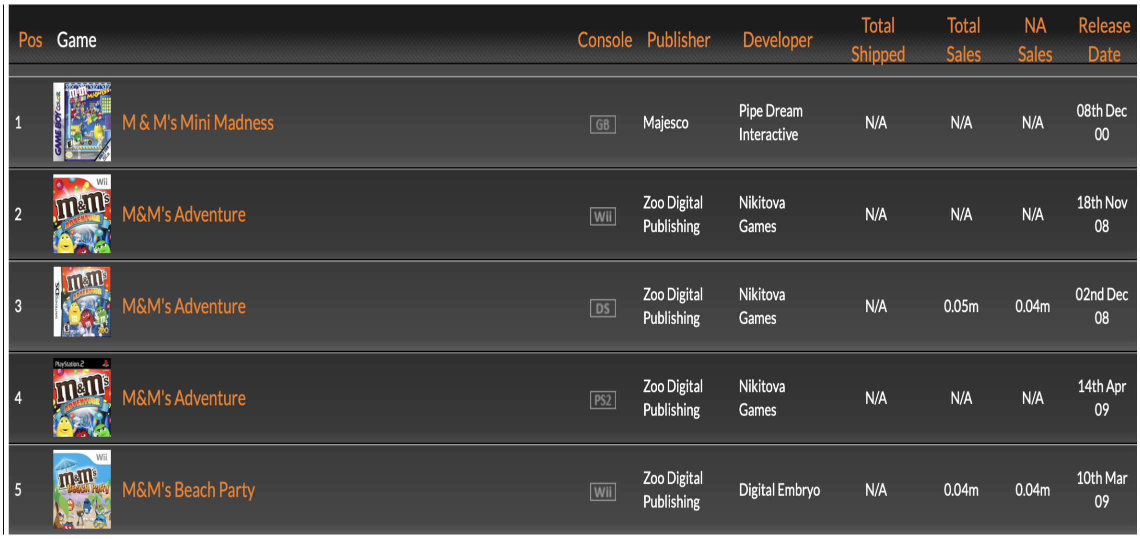
4. DATA

The data comes from online websites that are well-known for tracking video game releases and console performances in the United States. video game releases are collected from the VGChartz (n.d.) website. By the year 2023, the website has tracked around 60 thousand releases, including releases from the 1980's. Those releases target various types of platforms

[11]See Lee (2012) and Takahashi (2002).

(mainly home consoles, handheld consoles, mobile devices and PCs). For each release, we observe the name of the released title, the host platform, the release date and the genre. If a title has targeted two different platforms, this is a title with two releases which are presented in two different rows. I collected from the website data on monthly sales of home consoles. However, those console sales displayed in the website only start from 2005 and are not available for consoles of generations 6 and below. I therefore obtained additional data from the Fandom website and from sales reports by platform manufacturers. First-party titles receive preferential treatment from console manufacturers and are not subject to the same release decision process, since they are only released on their owner's console. That's why I'm concentrating solely on third-party titles, i.e. titles that are not released by platform providers upon their first release.

Figure 4: Samples of game titles from a screenshot of VGChartz (n.d.)



Pos	Game	Console	Publisher	Developer	Total Shipped	Total Sales	NA Sales	Release Date
1	M & M's Mini Madness	GB	Majesco	Pipe Dream Interactive	N/A	N/A	N/A	08th Dec 00
2	M&M's Adventure	Wii	Zoo Digital Publishing	Nikitova Games	N/A	N/A	N/A	18th Nov 08
3	M&M's Adventure	DS	Zoo Digital Publishing	Nikitova Games	N/A	0.05m	0.04m	02nd Dec 08
4	M&M's Adventure	PS2	Zoo Digital Publishing	Nikitova Games	N/A	N/A	N/A	14th Apr 09
5	M&M's Beach Party	Wii	Zoo Digital Publishing	Digital Embryo	N/A	0.04m	0.04m	10th Mar 09

Table 1: Number of releases per generation of host platforms and per generational period

	Generations of host platforms				
Generational periods of releases	G5	G6	G7	G8	G9
P5: 1995/09 -> 2000/09	2019	0	0	0	0
P6: 2000/10 -> 2005/10	687	2996	0	0	0
P7: 2005/11 -> 2012/10	5	1759	3698	0	0
P8: 2012/11 -> 2020/10	1	2	1107	4484	0
P9: 2020/11 -> 2023/07	0	3	53	666	316

Notes The table provides counts of all video game releases that occur on home consoles manufactured by Sony, Nintendo and Microsoft. A generational period is a time interval between the releases of two consecutive platform generations. Hence, two platforms from different generations may have overlapping generational periods, i.e. periods when they were both available. e.g. availability periods for PS and PS2 - from generations "G5" and "G6" respectively - overlap during generational period "P6".

For each video game, I consider a stream of eight (quarterly) decision periods with releases happening in a few of them. For each decision period of a given title, I observe the inventory as the cumulative set of platforms that have already hosted the title prior to the decision period. The study focuses only on releases that were registered in periods ranging from 1995-Q1 to 2016-Q4, on home consoles from the fifth, sixth and seventh generations. These three generations are enough to account for generation overlaps. Another reason for focusing on these generations is the fact that Sony began supplying consoles in the fifth generation, and the eighth generation has a hybrid console, the Nintendo Switch, a home console that is also a handheld. The choice of 2016-Q4 as the final observation period is due to the fact that there are risks that some video games may not yet be added to the VGChartz site in more recent periods. In addition, there are virtually no new releases, and the installed base of users is stable for the eight platforms concerned from 2017 onwards (see Figure 5).

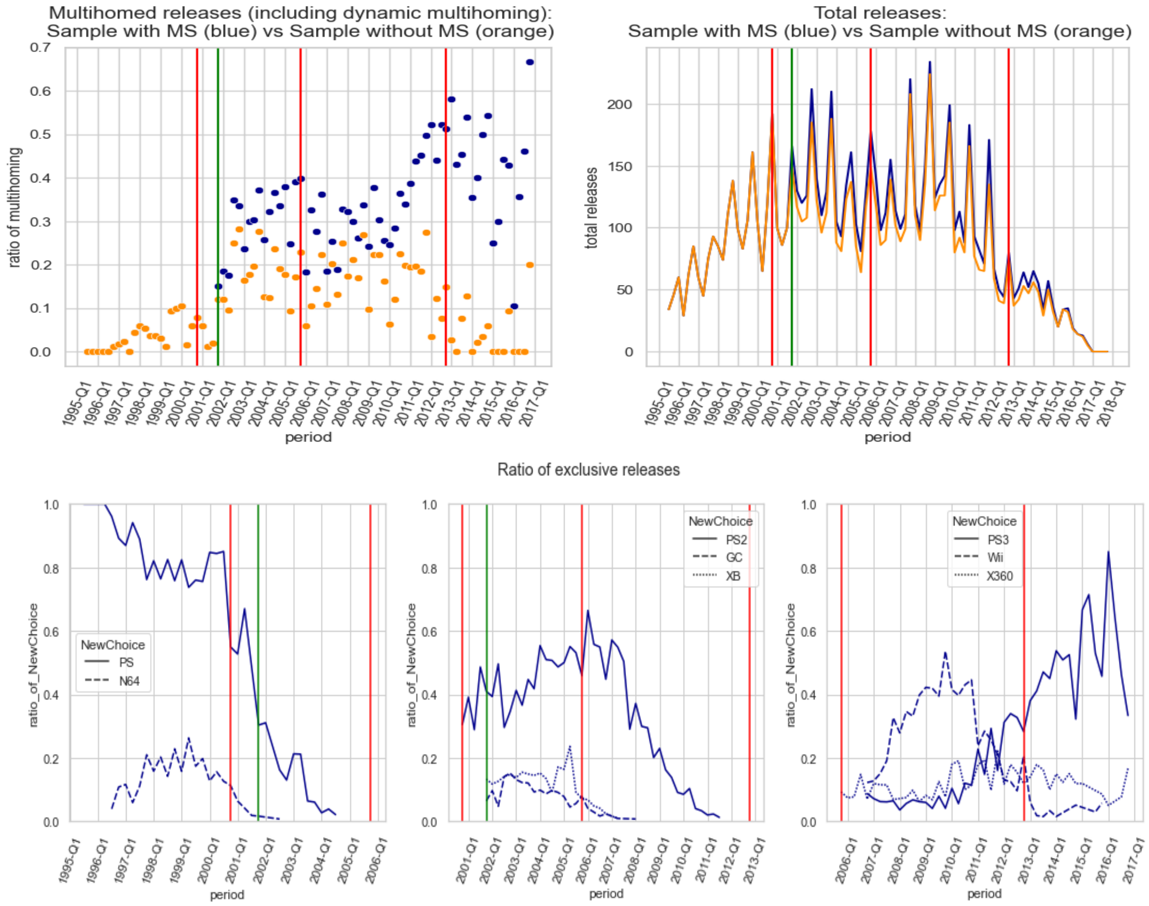
A title is multihomed in a period t if it is launched on more than one platform during period t, among the platforms selected in this paper. Multihoming options are therefore different possible combinations of platforms. They depend on the set of available platforms that are not deprecated and the set of platforms that are part of the inventory. If a title is released on platforms provided by the same platform firm, this still counts as multihoming. In this scenario, the host platforms belong to different generations. In order to match the observed timing of platform phase-outs by their suppliers, I assume that each platform only lives for two generations, i.e. a platform j that belongs to generation g will be excluded from available platforms as soon as the first new platform starting generation $g + 2$ is launched. This assumption is consistent with the lifespan shown in Figure 2 for generations 5, 6 and 7. In addition, first-party titles are excluded from the analysis as they are generally exclusive to their owner's platform (Nintendo, Sony or Microsoft).

Table 2 summarizes the main statistics on the base of console users, the base of console video games and the multihoming pattern.

5. EVIDENCE OF INCREASING MULTIHOMING BY VIDEO GAME PROVIDERS AND RELATION WITH MICROSOFT'S ENTRY

The first row of graphs in Figure 5 shows the trend in the ratio of non-exclusive releases - also called multihomed releases - alongside the same trend when Microsoft consoles are excluded from the sample. Only home consoles from Nintendo, Sony, and Microsoft, starting with the fifth generation, are considered. Non-exclusive releases are those launched on more than one platform, including re-releases that occur in a later period. From 1995-Q3 to 1996-Q2, only the PlayStation (PS) was present in the industry. From 1996-Q3 to 2000-Q3, the PS and the Nintendo 64 (N64) were the only available platforms. Non-exclusive releases began to appear in 1997, and their share grew steadily until the release of the PlayStation 2 (PS2). Around the time of the PS2's launch, the rate of multihoming declined and remained relatively low until the debut of Microsoft's Xbox (XB) in 2001-Q4. The launch of the XB marked a turning point, as the non-exclusivity ratio began rising at a relatively fast pace. Overall, we observe a consistent increase in the multihoming ratio over time—particularly after Microsoft's entry as a console manufacturer—reaching about 50% in 2012. These findings align with Corts and Lederman (2009), who reported that the fraction of titles released on more than one console had grown from about 14% twenty years earlier to roughly 40% in 2009.

Figure 5: Trends in Multihoming and exclusivity



Notes The two graphs in the first row present: (i)— on the left, the ratio of multihomed releases among all releases; (ii)— on the right, the total releases. The three graphs in the second row present - for each platform j - the ratio of j exclusive releases among total releases on all platforms. The three red lines represent the beginnings of 6th, 7th and 8th generations. The green line represents the launch period of Microsoft XB, its first home console.

Just as we observed an increase in the multihoming rate after the start of the 6th generation and the arrival of Microsoft, we also observe another increase a few years after the start of the 7th generation. As a result, it's not clear whether these significant changes observed on two occasions are linked to Microsoft's entry, or are simply effects of the new generation. A counterfactual analysis from a specified structural model will enable us to distinguish the effects of Microsoft's presence as a console manufacturer from new-generation effects.

One can have a clue when considering the trend of multihoming ratio in the absence of Microsoft. Indeed, when Microsoft consoles are excluded from sample, the new trend of multihoming shows that there might not be such generation shifts. Indeed, the new trend picks from 2003 and stagnates until 2010, before beginning a downward trajectory. This means that, non-exclusive releases that do not involve XB nor X360 consoles also took off and increased after Microsoft's entry but not in the long run as we can see with the general multihoming trend - the one that takes Microsoft consoles into account. In general, two observations can be made from the comparison of the two trends. First, the multihoming ratio trend is higher than the trend of multihoming without Microsoft consoles. Secondly, the multihoming trend continues to rise, with a few downward pauses as new console generations are released, while the trend without Microsoft picks, stagnates and declines before the launch of the 7th generation of consoles. These differences in trends hinge a potential effect of Microsoft's arrival on the multihoming trend.

The second row of graphs in Figure 5 presents exclusivity shares by platform among all releases. For instance, the exclusivity share of the PS2 in 2006-Q1 (67%) corresponds to the ratio of PS2-exclusive releases to total releases during that quarter. The graphs indicate that Sony consoles—particularly the PS and PS2—dominated exclusive releases for much of the period. However, this dominance was temporarily overturned by Nintendo's Wii, especially between 2008 and 2010.

In addition to having the largest number of exclusive titles on the PS and PS2, Sony consoles also exhibit the highest exclusivity rates among intra-platform releases for these systems (see Figure 6). As shown in the first row of Figure 6, releases on the PS and PS2 were less likely to be multihomed than releases on other consoles of the same generation. In other words, video game releases on Sony consoles were more likely to be single-homed compared to those on competing platforms. This pattern, however, was reversed in Generation 7, when Nintendo's Wii became the console with the highest likelihood of single-homed titles.

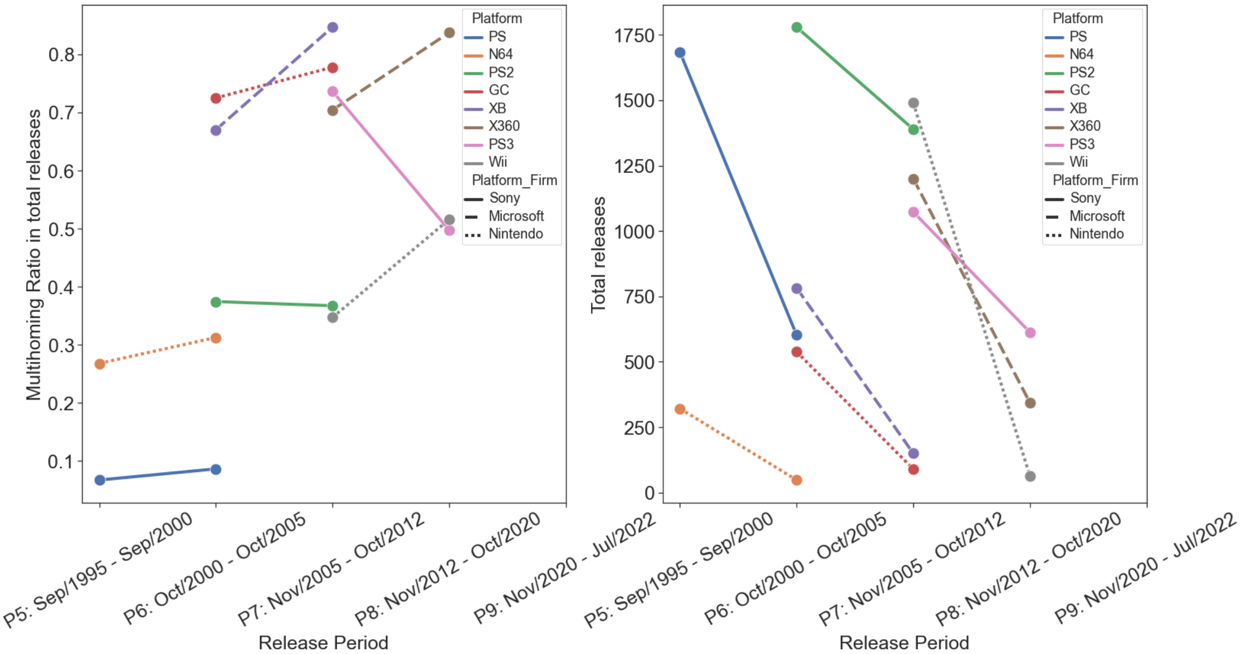
Not only do we observe a change in the multihoming pattern after Microsoft's entry as a platform provider, but we also notice a high concentration of non-exclusive releases among content products on Microsoft platforms. Indeed, we present a simple reduced-form logit regression of the multihoming status of a release r - a binary variable - on following factors (X_r): the generation in which the release occurred (denoted $Release\_Period\_$), the genre of the title released, the host platform provider (denoted $Platform\_Firm$), the total releases registered during the same month as r, the installed base of the host platform.

Denotes $y_r = 1$ if r is a release of a title that is multihomed some point in time; 0 otherwise. We estimate the following conditional multihoming probability in this reduced-form regression:

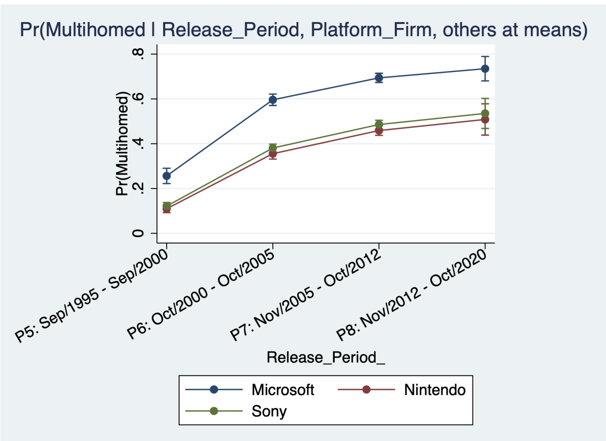
$$Prob(y_r = 1|X_r) = \frac{1}{1 + exp(-\kappa' X_r)}$$

Figure 6: Within-platform multihoming ratio and logit results

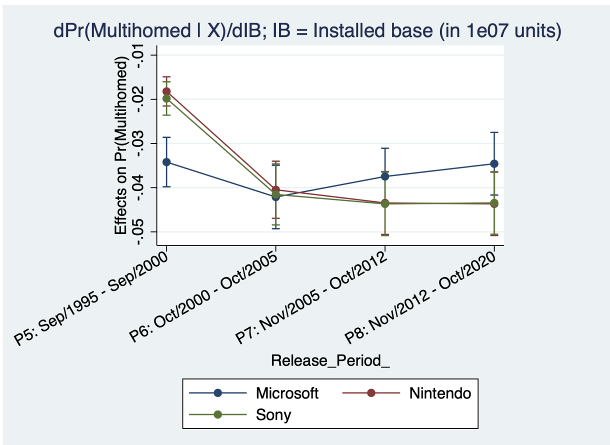
(a) Within-platform multihoming ratio by platform



(b) Predicted probability of multihoming



(c) Average marginal effect of installed base



Notes The upper-left graph shows the ratio of ever-multihoming among all new content products for each platform. The upper-right graph displays the total number of new content products on each platform. The two graphs at the bottom present results from simple logit estimates of the within-platform probability of ever-multihoming. Specifically, $multihomed = 1$ for release r if a title has additional releases beyond r in its lifetime, and $multihomed = 0$ if r is the only release ever made. The covariates include release generation, host platform firm, installed base (IB), and total releases on the platform (observed in the same month as r). The bottom-left graph plots the predicted probability of multihoming by release generation (Release_Period) and host platform firm, while the bottom-right graph illustrates the average marginal effect of the host platform's installed base on that probability.

where κ is the vector of parameters. The title multihoming dummy y_r indicates whether or not a given release r - observed in a given period - is from a title that has had more than one host console throughout its lifetime.

From the first row of Figure 6, the first graph shows the ratio of releases of multihomed titles among all new releases of each platform, with the period considered here being the generation period. The total releases shown on the right are high enough to ensure the consistency of estimated ratios on the left. The ratio of multihoming within a single platform seems to be consistently high for Microsoft platforms (XB and X360). Interestingly, the ratio is also high for Nintendo's N64 and GC compared to platforms of the same generations.

From the second row of Figure 6, the first graph shows the reduced-form probability that a given release comes from a title that has had more than one release in its lifetime, conditional on the generation of the release (denoted $Release\_Period$) and the company's platform. After controlling for other factors, It appears that releases on Microsoft consoles have very high rates of multihomed titles compared to releases on Nintendo and Sony consoles. This is evidence that content products on Microsoft consoles are more likely to be non-exclusive compared to those on Sony and Nintendo. To be cautious, this is not to say Microsoft consoles have a higher number of non-exclusive releases than Sony consoles. But it is clear that Microsoft is somewhat linked to the increasing rate of non-exclusivity illustrated in Figure 5.

From the second row of Figure 6, the second graph shows a negative correlation between title multihoming and installed base. This means that content on platforms with a larger installed base is less likely to be distributed on more than one platform during its lifetime. It seems that multihoming on other platforms has a cost when the host platform has a higher IB. For example, 10 million additional users of the host platform lead to a 0.02-0.05 drop in the probability that the release will be that of a title that will be multihomed on other platforms in its lifetime. This correlation is most significant for the periods after Generation 6, when Microsoft began supplying consoles, compared to Generation 5, when Microsoft was not a console supplier. This suggests that after Microsoft's entry, the cost of multihoming associated with a larger host-platform installed base became even higher.

6. MODEL

This study relies on core assumptions that content providers target platforms based on their expectations on the volume of platform users and that the content market is a static monopolistic competition market. The decisions considered in the models are made according to following timeline: First, platforms are launched, then each consumer joins the platform while each content provider targets platforms and publishes content products on the targeted platforms. Afterward, content providers (sellers) and consumers (buyers) on the same platform meet in that platform's content marketplace, where sellers decide on the price and buyers decide on portfolios of content products to buy. Following conditions on agent behavior and market equilibrium are assumed throughout the model:

Assumption 1. *Platform entry is exogenous and deterministic.*

Assumption 2. *Platform demand is exogenous and stochastic.*

Assumption 3. *Content providers operate as single-product firms, and each platform constitutes a monopolistically competitive market for content products.*

Assumption 4. *Consumers single-home and exhibit static, additive constant elasticity of substitution (CES) preferences for content products.*

Assumption 1 means that content providers know what is the set of available platforms for each current or future period. Indeed, with a 2-year decision lifetime, the change in the set of platforms matters for a content provider only if the decision-making process begins less than 2 years before the first launch of the next generation consoles. For content providers, it's logical to assume that they're aware of the upcoming launch of next-generation consoles, as the suppliers of these consoles make announcements in advance of public launches. In addition, prior to the current 9th generation (with the Xbox Series and PlayStation 5 consoles), the intervals between generations were fairly regular, making the launch dates of next-generation consoles by games suppliers more predictable. The evolution over time in the set of available platforms is explained by the fact that each platform is considered to have a lifespan of two generations, after which it is deprecated, along with all its content products.

Assumption 2 states that content providers believe that the current installed base of users on each platform updates itself by adding a new demand shock to the past installed base. Since most of releases in the data concern video games that are not big enough to individually alter market outcomes, their suppliers' choices will not individually affect demand for the platforms. According to assumption 3, in each period, there are many differentiated content products on a given platform that compete in prices to attract users of that same platform. These platform users are also content consumers with a preference for variety as they want to consume as many desired content products as possible. These preferences are highlighted by assumption 4. In addition, firms competing in monopolistic competition markets are assumed to be single-product firms. This means that each content provider offers only one content product[12]. Assumption 4 states that, within the same decision process, consumers are not

[12] Many video game providers have an inventory of numerous content products that have already been released in the past. However, because of tractability issues related to multiproduct firms when there is a large number of firms and products, I assume that firms provide only one product. This assumption is realistic if the company team assigned to the publication of a given title is independent of the teams assigned to the publication of previous titles.

allowed to purchase content products from more than one platform. It further specifies that the value a consumer assigns to a portfolio of content products is equal to the sum of the values assigned to each individual content.

In this study, I estimate the content supplier's decision to enter a group of platforms from a revealed preference approach as in Lee (2013). This means, content providers' actual choices are revealed as those that maximize their payoffs. Therefore, this relaxes the free entry assumption[13] that is very much present in studies that rely on the specification of software supply that is similar to Nair et al. (2004).

6.1. Static demand for content and pricing

Consumer demand for content products — In each quarterly period t, user i of platform j expresses demand for a portfolio of platform j content products following a CES preference, i.e. a Dixit-Stiglitz type of preference (Dixit and Stiglitz (1977)). Consumer i solves the following program:

$$\begin{cases} \max_{\{x_{ijkt}\}_k} & \left[\sum_k (q_{jk} x_{ijkt})^{1/\beta_j}\right] + z_{it} \\ \text{s.t.} & \sum_{k=1}^{N_{jt}} p_{jkt} x_{ijkt} + z_{it} = y_{it} - p_{jt}^{hw} \\ & \beta_j > 1 \end{cases} \tag{1}$$

x_{ijkt} and q_{jk} are respectively the consumer i demand index for title k and the quality index for k. This consideration for quality is also present in Gretz (2010). Variables z_{it}, y_{it}, p_{jkt} and p_{jt}^{hw} are respectively the numeraire good, the income, the price of title k and the price of platform j[14]. N_{jt} is the number of available titles. β_j is the substitution parameter. Indeed, the substitution elasticity between titles is given by $-\frac{\beta_j}{\beta_j-1}$. The higher β_j is the lower substitute titles are. The restriction that β_j shouldn't be lower than one ensures preference convexity and therefore a decreasing demand curve. The restriction that β_j should be strictly greater than one prevents perfect substitution so that the consumer has positive demand index for each title. This specification relies on Nair et al. (2004), except that I consider the consumer i has value for content quality.

Pricing — Denote mc_{jkt} the marginal cost incurred for each copy of content k sold to users of platform j, B_{jt} the installed base of users of platform j, and $Q_{jkt} \equiv Q_{jkt}(p_{jkt})$ the demand

[13]In practice, the free entry assumption refers to a zero profit condition.

[14]hw means "hardware", which refers to the home console in the videogaming industry, and refers to "platform" in general.

function. A content provider k chooses price p_{jkt} so so as to maximize current gross profit[15]

$$\max_{p_{jkt}} \pi_{jkt} \equiv (p_{jkt} - mc_{jkt})\, Q_{jkt}(p_{jkt}) \tag{2}$$

Denote B_{jt} the size of platform j's users in period t - also known as the installed base of users. The proposition 1 states that the market demand for content and the gross profit earned by a content provider are proportional to the installed base of users of platform j.

Proposition 1. *Under assumptions 1 – 4;*

(i) — The equilibrium market sales quantity of content k is given by

$$Q_{jkt} = x_{jkt} B_{jt}.$$

(ii) — The gross revenue earned by a firm from offering content k on platform j is

$$\pi_{jkt} = \alpha_{jkt} B_{jt}.$$

where $x_{jkt} = \beta_j^{\frac{-\beta_j}{\beta_j-1}} p_{jkt}^{\frac{-\beta_j}{\beta_j-1}} q_{jk}^{\frac{1}{\beta_j-1}} = \beta_j^{\frac{-2\beta_j}{\beta_j-1}} mc_{jkt}^{\frac{-\beta_j}{\beta_j-1}} q_{jk}^{\frac{1}{\beta_j-1}}$ *and* $\alpha_{jkt} = (\beta_j - 1)\beta_j^{\frac{-2\beta_j}{\beta_j-1}} \left(\frac{mc_{jkt}}{q_{jk}}\right)^{\frac{-1}{\beta_j-1}}$.

Proof of Proposition 1 — Denote $\tilde{x}_{ijkt} = q_{jk} x_{ijkt}$ and $\tilde{p}_{jkt} = \frac{p_{jkt}}{q_{jk}}$. The maximization problem in 1 becomes $\max_{\{x_{ijkt}\}_k} z_{it} + \sum_{k=1}^{N_{jt}} \tilde{x}_{ijkt}^{1/\beta_j}$ *s.t.* $\sum_k \tilde{p}_{jkt}\tilde{x}_{ijkt} + z_{it} = y_{it} - p_{jt}^{hw}$, which is the same problem as in Nair et al., 2004 when we set their utility curvature parameter to 1. The first order conditions of the maximization problem is $\frac{1}{\beta_j}\tilde{x}_{ijkt}^{\frac{1}{\beta_j}-1} - \tilde{p}_{jkt} = 0$, which gives the expression for the individual demand x_{jkt} for each of the B_{jt} users of platform j. Moreover, the optimal price as solution of problem 2 is $p_{jkt} = \beta_j mc_{jkt}$. These optimal demand and pricing lead to the result (i). Then, (ii) is obtained by replacing these in the firm's gross profit in problem 2. Let's note that assumption 2 implies B_{jt} is exogenous and therefore not related to price in the maximization problem 3. □

The installed base effect α_{jkt} is interpreted as an indirect network effect (INE) parameter, because it gives the marginal value that platform users bring in the content's current gross profit and therefore represents the current value that content providers give to platform users. Proposition 1 shows that the INE parameter depends on various factors. α_{jkt} decreases with the cost/quality ratio $\frac{mc_{jkt}}{q_{jk}}$ of content products within the platform. The marginal cost mc_{jkt} includes any incremental cost incurred for each unit of content product k sold, such as license fees paid to platform j's provider and the cost of recording the content product on a CD or a cartridge. The content quality includes content features that are of value to consumers. In addition, α_{jt} increases with the parameter β_j for consumer substitution between titles on the

[15]Doesn't account for entry costs from launching title k.

platform. The higher β_j is, the lower is the substitution effect. Therefore, the INE parameter decreases with the degree of substitution between content products.

6.2. Dynamic supply of content products

6.2.1 Setting

At each period t of its lifetime, content provider k adds a new set of platforms a_{kt} to its portfolio of platforms I_{kt} that host title k, given the following state variables: t, J_t, I_{kt}, B_{jt}. t is the time index, a quarterly period. J_t is the set of available platforms during t. It is exogenous and deterministic by assumption 1. Let's denote J the set of all 8 platforms to consider in this study. I_{kt}: the inventory state. This is the inventory of platforms that were already hosting k before time t and are still part of the set of available platforms J_t at time t. The inventory has the following evolution process: $I_{kt+1} = I_{kt} \cup a_{kt}$; and both the inventory and action satisfy: $I_{kt} \subseteq J_t$ and $a_{kt} \subseteq J_t - I_{kt}$. B_{jt} represents the installed base (IB) of platform j. This is the total number of console j users, and is proxied by the cumulative sales of console j. Let us provide a more detailed version of Assumption 2, which specifies how the installed base evolves stochastically and exogenously.

Assumption TP-B. *(transition process for the installed bases)* — Let μ_{jt} denote the platform demand shock with non-zero mean, assumed to be independent over time, drawn from a stationary distribution F_{μ_j}, and i.i.d. across platforms $j \in J$. The installed bases evolve according to the following stochastic process:

$$\begin{aligned} B_{jt+1} = &\quad B_{jt} + \Delta B_{jt+1} \\ \Delta B_{jt+1} = &\quad \exp(QuarterFE_t + PlatformFE_j + \rho_{1,j} Age_{jt+1} \\ &\qquad + \rho_{2,j} Age^2_{jt+1} + \rho_3 P^{hw}_{jt} + \rho_4 M_{jt} + \mu_{jt+1}) \end{aligned} \tag{3}$$

$QuarterFE_t$ is a quarter-of-the-year fixed effect and captures the relevance of seasonality in the content providers' beliefs. $PlatformFE_j$ is a platform fixed effect, capturing the relevance of the platform's brand. Age_{jt} is the console's age and represents the brand-specific life-cycle effect. M_{jt} is the number of models for console j. P^{hw}_{jt} is the price for console j, observed as a simple price average across models of console j. Let $F_{t,\boldsymbol{\mu}}$ denote the joint distribution of $\boldsymbol{\mu}_t \equiv \{\mu_{jt}, j \in J_t\}$. Then, assumption TP-B implies $F_{t,\boldsymbol{\mu}} = F_{\mu_1} \times \cdots \times F_{\mu_{J_t}}$. All observable states are placed in the vector $X_{kt} = (Z_{kt}, I_{kt})$ where Z_{kt} is a vector of observable states other than inventory - including the set of available platforms and their installed bases of users.

The decision process has a finite horizon with 8 decision periods for each decision maker.

This choice of 8 quarterly periods is based on the average lifecycle of video game sales. Indeed, the majority of a video game sales occur within the first 3 months after release and very few video games are still sold after 6 months from release Lee (2012). Moreover, as shown in Figure 13, one can say that multiperiod releases can be said to be polarized on titles with up to 4 quarters between the first and last release. For these reasons, I consider a decision lifespan of 8 quarters for each title[16]; even if lifespan of home console video games is around 4 years as highlighted by Clements and Ohashi (2005).

6.2.2 Current payoff

The decision maker's current payoff from taking action a_{kt} is given by

$$U\left(X_{kt}, a_{kt}\right) + \epsilon_{kt}(a_{kt}) = R\left(X_{kt}, a_{kt}\right) - C\left(X_{kt}, a_{kt}\right) + \epsilon_{kt}(a_{kt})$$

$U\left(X_{kt}, a_{kt}\right)$ is the observable part of the current payoff. $R\left(X_{kt}, a_{kt}\right)$ is the current gross revenue earned from platforms that host title k:

$$R(X_{kt}, a_{kt}) = \sum_{j \in I_{kt} \cup a_{kt}} \alpha_{jkt} B_{jt} = \alpha \sum_{j \in I_{kt} \cup a_{kt}} B_{jt}$$

α_{jkt} is considered to be time-invariant and similar across content products and platforms ($\alpha_{jkt} = \alpha$). This is convenient if we assume gamers have the same behavior and titles have comparable price/quality ratios across platforms. However, this is a strong assumption as gamers' demographics are different across platforms: Nintendo consoles are known to be mostly played by families, children or elders, while Sony and Microsoft consoles are popular among old teenagers and young adults. $C\left(X_{kt}, a_{kt}\right)$ is the title k's fixed cost from releases on new host platforms a_{kt}. $\{\epsilon_{kt}(a_{kt})\}_{a_{kt}}$ are choice-specific unobserved costs and are assumed to be iid type-1 extreme value errors. These error terms include heterogeneous release costs that are unknown to the content provider until realisation and that are unobserved by the researcher. These cost shocks make it possible to account for differences in development costs - also called investment costs - between content products.

The cost specification is related to the trend of video game development cost structure. As highlighted by Cennamo et al. (2018), Corts and Lederman (2009), Lee (2012), and Steinberg (2007) and various other sources from the industry such as Fandom (n.d.), Koster (2018), Loftus (2003), and REIMER (2005), the share of platform-invariant development costs has been increasing over time while porting costs have been decreasing. Therefore, the cost of releasing title k on platforms a_{kt} is separable between platform-invariant development costs

[16] Considering that a title's first release may occur up to 4 quarters after the first decision period. This is the case for titles whose first releases are registered in a year that is different from the year of launch of the first host console.

and platform-specific porting costs.

Platform-invariant investment costs — These investment costs are time-varying and do not depend on platforms. As platform-independent activities, such as designing a video game, may differ when a title is being released in its first time compared to its subsequent releases, platform-invariant development costs are expected to differ depending on whether or not the title is in its first release. In other words, platform-invariant development costs differ depending on whether or not the inventory is empty. Therefore, I consider platform-invariant development costs for releases with empty inventories as different from platform-invariant development costs for releases with non-empty inventories.

— Development costs for first releases (i.e. with empty inventory):

$$DC1\left(X_{kt}, a_{kt}\right) = 1_{\{I_{kt}=\emptyset\}} 1_{\{a_{kt}\neq\emptyset\}} \sum_{\tau} 1_{\{t\in\tau\}} \times dc1_{\tau}$$

Where τ is a range of periods. $dc1_{\tau}$ represents the additional cost to pay for investing in new releases (i.e., $a_{kt} \neq \emptyset$) of content product k, conditional on having no inventory of previous releases of k (i.e. $I_{kt} = \emptyset$).

— Development costs for subsequent releases (i.e. with non-empty inventory):

$$DC2\left(X_{kt}, a_{kt}\right) = 1_{\{I_{kt}\neq\emptyset\}} 1_{\{a_{kt}\neq\emptyset\}} \sum_{\tau} 1_{\{t\in\tau\}} \times dc2_{\tau}$$

$dc2_{\tau}$ represents the additional cost to pay for investing in new releases ($a_{kt} \neq \emptyset$) of content product k, conditional on having a history of previous releases of k (i.e. $I_{kt} \neq \emptyset$).

Platform-specific porting costs — Porting costs are time-invariant and platform-specific. Platforms have different porting costs as they have different technological architectures. A content product can be difficult and more costly to distribute or port to a platform which offers a complex architecture for content delivery (Cennamo et al., 2018). Assuming platform-specific activities are roughly the same whether or not the inventory set is empty, the porting cost is given by:

$$PC\left(X_{kt}, a_{kt}\right) = \sum_{j\in a_{kt}} pc_j$$

Total investment cost — Finally the overall fixed cost for releasing on platforms a_{kt} is given by

$$C\left(X_{kt}, a_{kt}\right) = DC1\left(X_{kt}, a_{kt}\right) + DC2\left(X_{kt}, a_{kt}\right) + PC\left(X_{kt}, a_{kt}\right)$$

pc_j represents the additional cost of releasing a content product k on platform j (i.e., $j \in a_{kt}$), no matter the state of inventory I_{kt}.

6.2.3 Lifetime payoff: the value function

Let $\theta = (\alpha, \{pc_j\}_{j\in J}, \{dc1_\tau\}_\tau, \{dc2_\tau\}_\tau)$ denote the parameter vector in the current payoff function. Let F_X denote the cummulative distribution function (CDF) of the observable state X_{kt}, $F_{X,\epsilon}$ the joined CDF of the observed and unobserved states (X_{kt}, ϵ_{kt}), and $F_{t,\mu}$ the CDF of the demand shock μ_t. For identification purposes, let's consider the following assumptions from Aguirregabiria and Mira (2010) and Rust (1987):

Assumption AS. *(Additive Separability of current payoff)* — The current payoff is additively separable into observed payoff and unobserved cost $\boldsymbol{\epsilon}$

$$U\left(X_{kt}, a_{kt}, \boldsymbol{\epsilon}_{kt}; \theta\right) = U\left(X_{kt}, a_{kt}; \theta\right) + \boldsymbol{\epsilon}_{kt}(a_{kt})$$

Assumption IID. *(iid Unobservables)* — $\{\boldsymbol{\epsilon}_{kt}\}_{kt}$ are iid over agents and over time

Assumption CI-X. *(Conditional Independence of Future X)* — Conditional on the current observable state and action, the cumulative distribution function (CDF) of the future observable state is independent from the current unobservable state

$$CDF_X(X_{k,t+1}|X_{kt}, a_{kt}, \boldsymbol{\epsilon}_{kt}) = F_X(X_{k,t+1}|X_{kt}, a_{kt})$$

Assumption CLOGIT — $\{\epsilon_{kt}(a)\}_a$ are independent across alternatives and have a type-1 extreme value distribution

Let γ denote the discount rate, whose value is fixed at $\gamma = 0.98$. This value is equivalent to a 2% quarterly interest rate, which itself is deduced from a 5% annual interest rate. The proposition 2 gives the closed-form expression of the lifetime payoff earned by the content provider k from being in a state X_{kt}.

Proposition 2. *Under assumptions TP-B, AS, IID, CI-X, and CLOGIT,*

(i)— The conditional choice probabilities (CCPs) in decision period t have the following expression:

$$P(a|X_{kt};\theta) \equiv Probability(a_{kt} = a|X_{kt};\theta) = \frac{exp\left(\delta(X_{kt}, a)\right)}{\sum_{a'\subseteq J_t - I_{kt}} exp\left(\delta(X_{kt}, a')\right)} \tag{4}$$

(ii)— The integrated value function of the content provider has the following expression

$$V_t(X_{kt};\theta) = Log\left[\sum_{a|a\subseteq J_t - I_{kt}} exp\left(\delta_t(X_{kt}, a; \theta)\right)\right] + \kappa \tag{5}$$

where

$$\delta_t(X_{kt}, a; \theta) = U\left(X_{kt}, a; \theta\right) + \gamma \int_{\boldsymbol{\mu}_{t+1}} V_{t+1}(X_{k,t+1}; \theta) dF_{t,\boldsymbol{\mu}}(\boldsymbol{\mu}_{t+1}) \tag{6}$$

and $\kappa = 0.57$ *is the Euler constant.*

Proof of Proposition 2 — From assumptions TP-B, IID and CI-X, the transition cumulative distribution function becomes:

$$\begin{aligned} F_{X,\epsilon}(X_{k,t+1}, \boldsymbol{\epsilon}_{k,t+1} | X_{kt}, \boldsymbol{\epsilon}_{kt}, a_{kt}) = & \quad F_X(X_{k,t+1}|X_{kt}, a_{kt}) F_{\boldsymbol{\epsilon}}(\boldsymbol{\epsilon}_{k,t+1}) \\ \equiv & \quad F_{t,\boldsymbol{\mu}}(\boldsymbol{\mu}_{t+1}) F_{\boldsymbol{\epsilon}}(\boldsymbol{\epsilon}_{k,t+1}) \end{aligned}$$

Given vector X_{kt} of observed state variables and the unobserved state $\boldsymbol{\epsilon}_{kt}$ the choice-specific stochastic value function under assumption AS is:

$$v_t\left(X_{kt}, \boldsymbol{\epsilon}_{kt}, a_{kt}\right) = U\left(X_{kt}, a_{kt}\right) + \epsilon_{kt}(a_{kt}) + \gamma E\left[W_t\left(X_{k,t+1}, \boldsymbol{\epsilon}_{k,t+1}\right) | X_{kt}, \boldsymbol{\epsilon}_{kt}, a_{kt}\right]$$

The stochastic value function W_t is the solution of the dynamic programming problem:

$$W_t(X_{kt}, \boldsymbol{\epsilon}_{k,t}) = \max_{a_{kt} | a_{kt} \subseteq J_t - I_{kt}} \left\{U\left(X_{kt}, a_{kt}\right) + \epsilon_{kt}(a_{kt}) + \gamma E\left[W_{t+1}\left(X_{k,t+1}, \boldsymbol{\epsilon}_{k,t+1}\right) | X_{kt}, \boldsymbol{\epsilon}_{kt}, a_{kt}\right]\right\}$$

where

$$\begin{aligned} & E\left[W_{t+1}\left(X_{k,t+1}, \boldsymbol{\epsilon}_{k,t+1}\right) | X_{kt}, \boldsymbol{\epsilon}_{kt}, a_{kt}\right] = \\ & \qquad \int_{\boldsymbol{\mu}_{t+1}} \int_{\boldsymbol{\epsilon}_{t+1}} W_{t+1}(X_{k,t+1}, \boldsymbol{\epsilon}_{t+1}) dF_{\boldsymbol{\epsilon}}(\boldsymbol{\epsilon}_{t+1}) dF_{t,\boldsymbol{\mu}}(\boldsymbol{\mu}_{t+1}) \equiv \\ & \qquad \int_{\boldsymbol{\mu}_{t+1}} \int_{\boldsymbol{\epsilon}_{t+1}} W_{t+1}(J_{t+1}, I_t \cup a_{k,t}, \boldsymbol{B}_t + \boldsymbol{\mu}_{t+1}, \boldsymbol{\epsilon}_{k,t+1}) dF_{\boldsymbol{\epsilon}}(\boldsymbol{\epsilon}_{t+1}) dF_{t,\boldsymbol{\mu}}(\boldsymbol{\mu}_{t+1}) \end{aligned}$$

The integrated value function V_t is a fixed point solution of the integrated dynamic programming problem:

$$V_t(X_{kt}) = \int_{\boldsymbol{\epsilon}} \max_{a_{kt} | a_{kt} \subseteq J_t - I_{kt}} \left\{U\left(X_{kt}, a_{kt}\right) + \epsilon_{kt}(a_{kt}) + \gamma E\left[V_{t+1}\left(X_{k,t+1}\right) | X_{kt}, a_{kt}\right]\right\}$$

where the expected future value function is defined as:

$$
\begin{aligned}
E\left[V_{t+1}\left(X_{k,t+1}\right)|X_{kt},a_{kt}\right] = & \int_{\boldsymbol{\mu}_{t+1}} V_{t+1}(X_{k,t+1})dF_{t,\mu}(\boldsymbol{\mu}_{t+1}) \\
\equiv & \int_{\boldsymbol{\mu}_{t+1}} V_{t+1}(J_{t+1}, I_t \cup a_{k,t}, \boldsymbol{B}_t + \boldsymbol{\mu}_{t+1})dF_{t,\boldsymbol{\mu}}(\boldsymbol{\mu}_{t+1})
\end{aligned}
$$

$V_t(X_{kt})$ represents the expected maximum utility in a discrete choice problem where the decision consists of choosing among options $a \subseteq J_t - I_{kt}$. The observable component of utility in this problem is $\delta(X_{kt}, a) = U(X_{kt}, a_{kt}) + \gamma\, E[V_{t+1}(X_{k,t+1}) \mid X_{kt}, a_{kt}]$ while the unobservable component is $\epsilon_{kt}(a_{kt})$. Therefore, the results from the discrete choice literature apply. In particular, following McFadden (1972, 1974, 1977), the CLOGIT assumption implies the following closed-form expression for the conditional choice probabilities:

$$
\Pr(a_{kt} = a \mid X_{kt}) = \frac{\exp(\delta(X_{kt}, a))}{\sum_{a' \subseteq J_t - I_{kt}} \exp(\delta(X_{kt}, a'))}.
$$

The corresponding expression for the ex-ante expected utility is

$$
V_t(X_{kt}) = \log\left[\sum_{a \subseteq J_t - I_{kt}} \exp(\delta_t(X_{kt}, a))\right] + \kappa
$$

where

$$
\delta_t(X_{kt}, a) = U(X_{kt}, a) + \gamma \int_{\boldsymbol{\mu}_{t+1}} V_{t+1}(X_{k,t+1})\, dF_{t,\boldsymbol{\mu}}(\boldsymbol{\mu}_{t+1})
$$

and $\kappa \approx 0.5772$ is Euler's constant, as given in the corollary of Theorem 1 in McFadden (1977). $\square$

6.2.4 Estimation

The parameter vector to estimate is $\theta = (\alpha, \{dc1_\tau\}_\tau, \{dc2_\tau\}_\tau, \{pc_j\}_j) \in \Theta$; where Θ is the parameter space. Its identification relies mainly on variations in the set of available platforms J_t, their installed bases B_{jt}, choices a_{kt} and inventories I_{kt} as observed in the data.

Following assumptions AS, IID, CI-X and CLOGIT, θ is identified and is estimated using the maximum likelihood method within the same nested fixed point (NFXP) procedure found in Rust (1987). This nested fixed point algorithm can be summarized as follows: given a value of θ, the inner step consists in computing the integrated value function by solving the integrated dynamic programming problem using a value function iteration. In the outer step, the value of θ is updated by the root of the likelihood maximization equations using a BHHH iteration proposed by Berndt et al. (1974). More about this NFXP procedure can be found Aguirregabiria and Mira (2010).

The main estimation challenge in this study is known as the large state space issue. Since the installed bases are the only non-discrete observed states, and since there are 8 consoles to consider, there are also 8 non-discrete state variables. In order to lower computation costs, I rely on the forward simulation and approximation procedures of Arcidiacono et al. (2013) and Keane and Wolpin (1994). Indeed, instead of solving the time-specific value function from the whole space $\mathcal{F}$ of feasible functions which is computationally impossible, the idea is to approximate this intractable space with a sieve space (Arcidiacono et al. (2013)). The sieve space $\mathcal{F}_n$ is a function space from which we can find a good approximation of any function in $\mathcal{F}$, and thus a good approximation of the optimal value functions $\{V_t(\cdot)\}_t$. The approximation of $V_t(\cdot)$ is the function from $\mathcal{F}_n$ with the lowest distance to $V_t(\cdot)$, using an L2 distance. $\{\mathcal{F}_n\}_n$ is an increasing sequence that is dense in $\mathcal{F}$ and n represents the exactness of the approximation. The higher n is, the closest to the actual value function the approximation is. The higher the n the more complex the approximation. Following Arcidiacono et al. (2013), I consider the space of polynomial functions, defined on a subset of the state space[17], as the sieve space. The degree of complexity is defined by the polynomial degree and the finite subset of state space used for computing the approximation. In this study, two-degree polynomial approximations are obtained on states with 200 possible vectors of installed bases. In practice, value functions V_{t+1} at a given period t+1 are regressed on a subset S_{t+1} of possible states during that period, using the least square method, which is equivalent to finding the closest approximation $\hat{V}_{t+1}$ of V_{t+1} from the space of two-degree polynomial functions as $\hat{V}_{t+1} = f_{t+1}(S_{t+1})$. As the value function for period t V_t depends on expected future values $\int V_{t+1}(S_t + \eta_{t+1})$ where η_{t+1} is a state shock, the approximation function f_{t+1} is used to interpolate the values $V_{t+1}(S_t + \mu_{t+1}) = f_{t+1}(S_t + \mu_{t+1})$. The value function iteration algorithm described in the appendix A gives more details on how this procedure is implemented and on how it also applies to solve for derivatives of value functions w.r.t parameters.

What is different in this approach used to solve the large state space issue compared to Arcidiacono et al. (2013) and Keane and Wolpin (1994) is that I allow the subset of states S_t used for approximating value functions V_t to differ across decision times. This is similar to Ishihara and Ching (2016) who suggest an algorithm in which they approximate the current value function at a single state point and use values saved from previous iterations[18] to approximate the expected future value in the current iteration. However, their algorithm - a Bayesian Markov chain Monte Carlo (MCMC) procedure - is different from what is used in this study.

[17]That subset of state space is built from the observed IB values, which are used to form all possible 8-sized vectors of IB values.

[18]Iterations on parameters in the outer algorithm

7. RESULTS

7.1. Parameter estimates

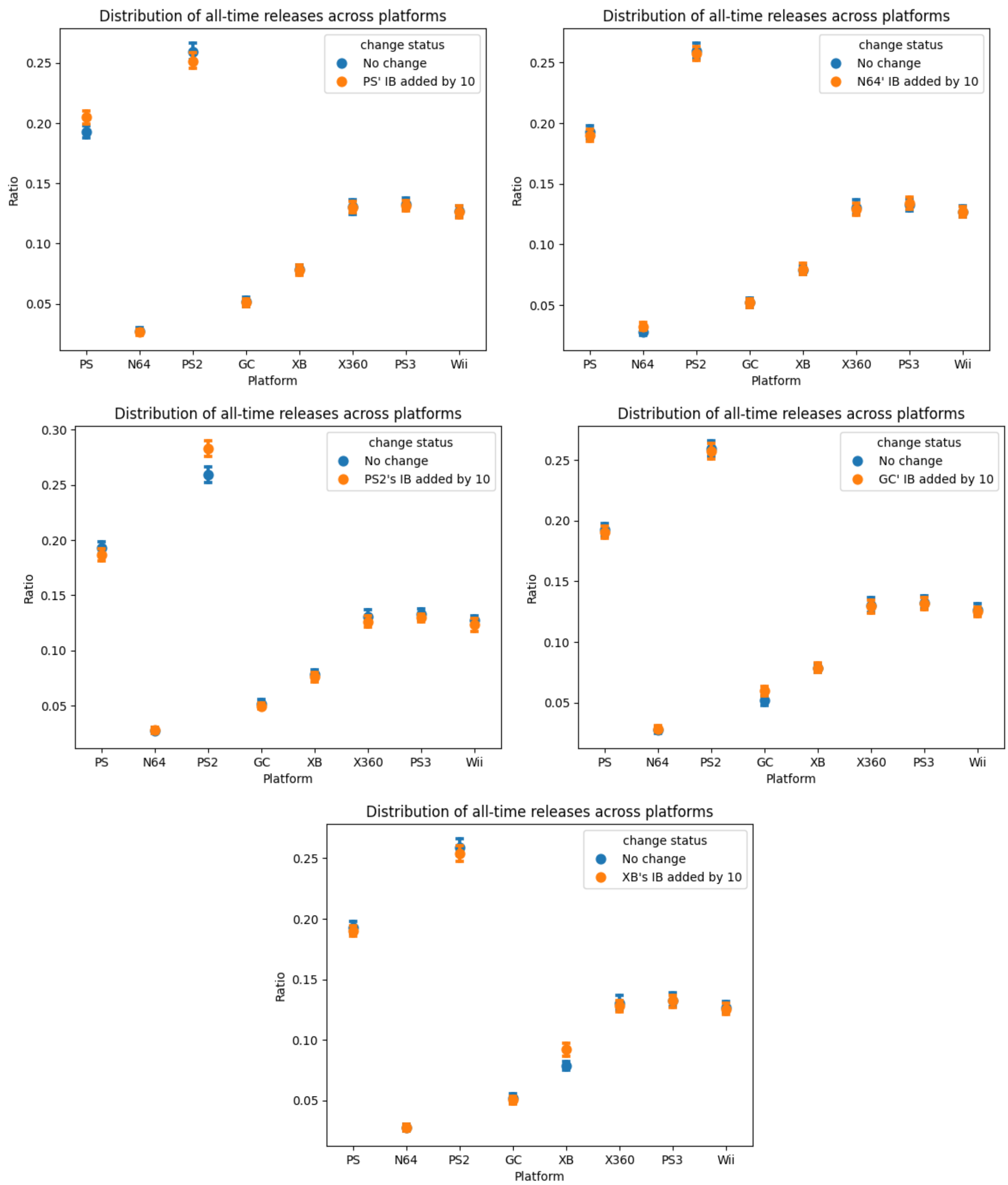
The parameter vector θ was estimated under four specifications. In these specifications, (i) the INE parameter is either time-invariant or time-varying; and (ii) the platforms' installed-base transition is either informed—i.e., a function of observable console characteristics and demand shocks, as in Assumption TP-B—or uninformed—i.e., a function of demand shocks only. Results for two of these specifications are reported in Figures 9 and 14 and in Table 3: Case 1— time-invariant INE with an uninformed installed-base transition; Case 2 — time-varying INE with an informed transition. Because all cases yield similar qualitative results for the investment cost estimates and the counterfactual analysis, the analysis below focuses on Case 1.

Installed base effect The IB parameter α represents the marginal effect of the platform's installed base on current profit. It is estimated at 0.0033, as given in Table 3 in the Appendix. Since the IB values are expressed in 10^7 console units, this means a ten million increase in a platform base of users raises the current profit that the game provider gains from having a title on that platform by around 33000 utils. Since the estimated value of α is positive and statistically significant, this highlights the positive effect that IB of users plays on the decision by content providers to target platforms. However, it takes a very large increase in the installed base to force video game providers to change their decisions and therefore to significantly change the distribution of releases across platforms. Indeed, as shown in Figure 7 estimates of the average effects of a 10 million increase in the number of console users on the distribution of outputs show little effect on the distribution of releases between platforms. The effect of an increase of 10 million users of a platform is analyzed by comparing the average distribution of releases using 50 simulated data samples without taking into account the change in IB and the average distribution of releases using another 50 simulated samples taking into account the change in IB. These IB effects are long-run effects, as the increase in IB of 10 millions users for a platform is represented by an upward shift in the overall IB trend for that platform. This way of analyzing the IB effect shares some similarities with Donna (2021) in their estimates of the "long-run gasoline price elasticities in urban travel demand".

Study of IB effects is focused on platforms from 5th and 6th generations[19] and results from simulations show that increasing PS2' IB by 10 million users increases the share of PS2 on all-time releases by roughly 2.2 percentage points, while shares of other consoles undergo a small but non-significant decrease. Increasing the PS' IB by 10 million users increases PS

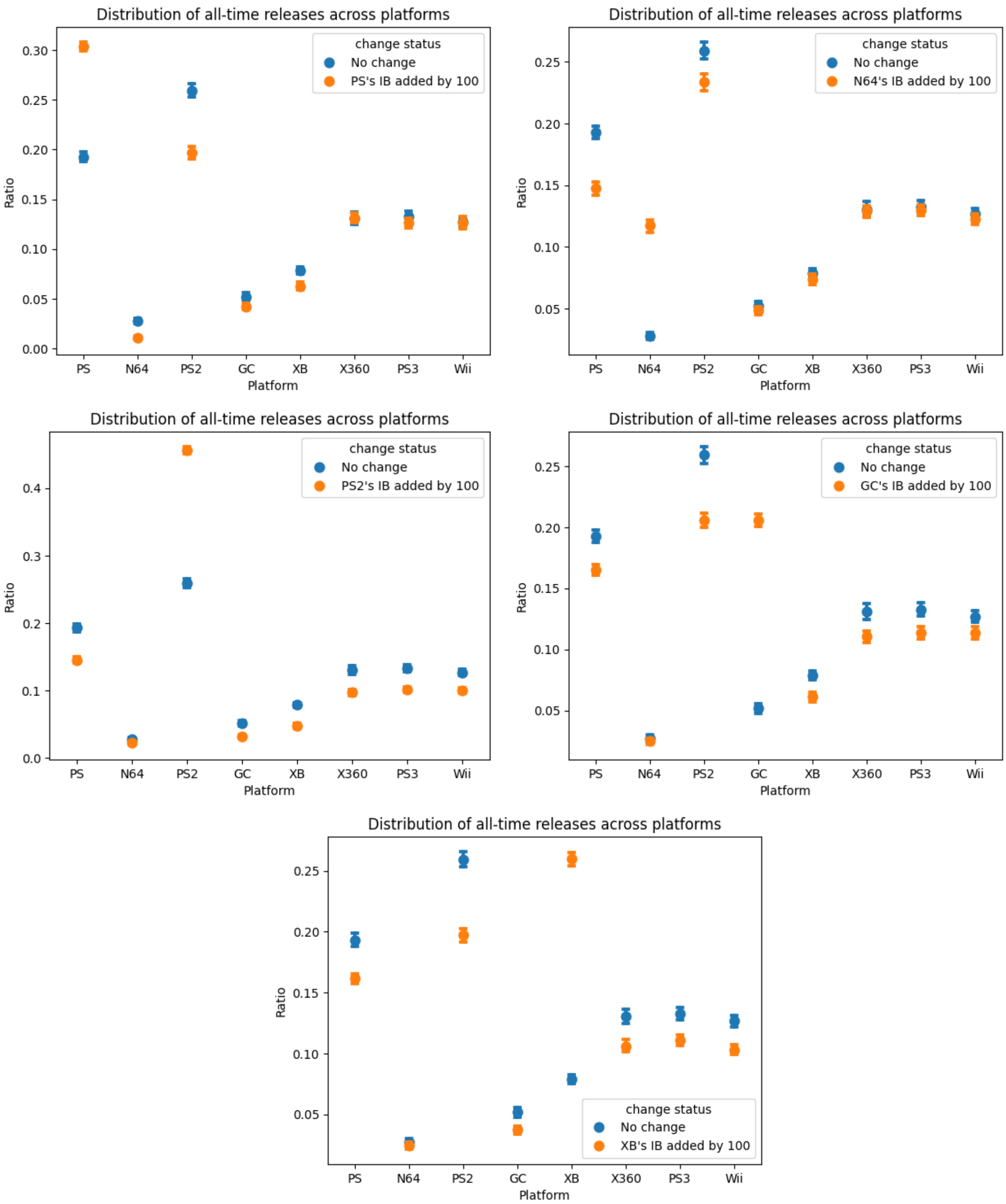
[19]We exclude generation 7 (X360, PS3, Wii) because the estimated model poorly predicts the shares of these platforms on total releases, as shown in Figure 18 in Appendix B

Figure 7: Effects of increasing a platform's installed base by 10 million users



Notes Estimates are represented with 95% confidence intervals.

Figure 8: Effects of increasing a platform's installed base by 100 million users



Notes Estimates are represented with 95% confidence intervals.

share by around 1 percentage point, reduces the PS2 share insignificantly, and keeps the shares of the other platforms unchanged. Increasing the IB of N64 or GC platforms has no significant impact on the distribution of releases across platforms. However, a very large IB increase of 100 million users significantly alters the distribution of releases between platforms, as shown in Figure 8. Indeed, adding 100 million users to the PS increases the PS's share of total releases by 11 percentage points, and reduces the share of all the other consoles that were available at the same time as the PS at certain periods, i.e. the N64, PS2 or XB. In general, the addition of 100 million users to a platform induces a very sharp increase in that platform's own share and decreases the share of other platforms that were available at the same time as the platform in question. Interestingly, these cross-effects are not homogeneous as the IB of any platform has a larger cross-effects on Sony platforms than on non-Sony platforms. As a result, content products moving to a new platform provider such as Microsoft would be more likely to move from Sony platforms than from Nintendo platforms. In addition, cross-effects on Nintendo platforms are low, underlining the specificity of Nintendo platforms (high investment costs). Moreover, there are large cross-effects between Sony platforms (PS and PS2) while there are no cross-effects between Nintendo platforms (N64 and GC). Thus, Sony's platforms are strong substitutes for content providers, while Nintendo's platforms are poor substitutes. Figures 19 and 20 in Appendix B give details of these direct and crossover IB effects over time following an increase in XB's IB.

To ensure that the above description provided on the direct and crossover IB effect is qualitatively robust to the size effect, I compute the effects of increasing by 10% the IB of any given console. Figure 15a in the Appendix B presents the distribution of all-time releases across consoles when there is no change and in multiple cases where there is an increase in the IB of a given platform. Figure 15b presents the distribution of all-time releases following an increase by 100% in the IB of a given platform in the same cases mentioned above. Increasing the observed IB of a given platform by 10% has no significant effects on platforms' shares in all-time releases while doubling the IB of a given platform increases by up to 10 percentage points the share of the same platform in all-time releases. These positive direct effects are associated with small negative cross-effects.

Development costs: platform-invariant investment costs The graphs 9a and 9b show estimates of the platform-invariant investment costs for both first and subsequent releases. Conditional on not having previous releases, the platform-invariant additional cost to pay for making first releases increases over time, as shown in the graph 9a, meaning that it becomes increasingly costly to invest in a first release when a content provider keeps delaying this first action. Consequently, it can be more expensive to publish a product in December than in January of the same year if the decision to proceed with a first release is delayed from January to December. This trend remains valid for content products that have already been released a few times in the past (see the graph 9b)[20]. This result is consistent with the cost trends described in the literature and industry sources. Estimates of platform-invariant development costs are apparently quite high for later versions compared with early versions. This gap rationalizes the quite low percentage (5%) of subsequent releases observed in the data (see table 4). However, it doesn't mean that it's more costly to invest in subsequent releases than it is in first releases. Indeed, These estimates are only estimating additional costs, not actual values of cost. Additional costs for first releases are estimated conditional on not having previous releases, while additional costs of subsequent releases are estimated conditional on having previous releases. Since these estimated costs must be added to the unidentified costs of non-release to obtain the actual cost of release, they can only be compared if the opportunity cost[21] of non-release was similar in both cases of having previous releases and not having previous releases.

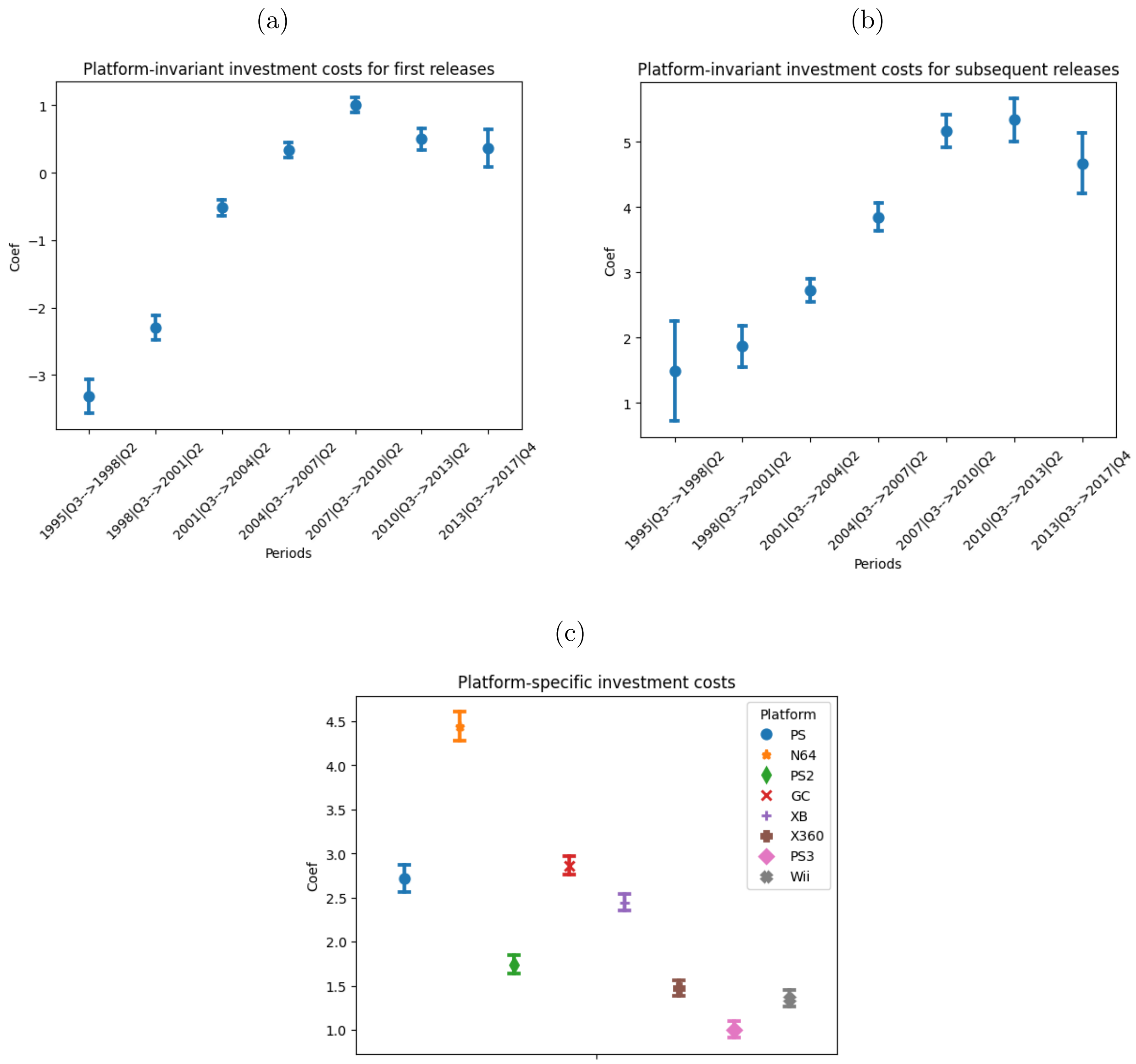
A logical explanation for the increasing trend is that, over time, there are new console models with new technologies, and in order to take advantage of these sophisticated technologies, video game manufacturers have to adapt the development process. For example, the increased memory capacities of consoles thanks to advances in chip manufacturing lead to larger video games, requiring more time, more tasks or more personnel. However, the rationale behind the explanation is that there are new technologies every time. When video game makers are only allowed to target consoles with older technologies, they are expected to continue using old, non-platform-specific development processes, which are less expensive than new ones. This could be a logical explanation for the turning point observed after 2010. A slight decrease (for early releases) or stagnation (for later releases) occurs during periods when only 7th generation consoles are still included in the dataset. During these periods, new 8th generation consoles were manufactured and are not included in the dataset. This suggests that the increase in non-platform-specific development costs continues as long as there are old and new generation consoles on the market.

Porting costs: platform-specific investment costs The graph Figure 9c shows estimates of the platform-specific investment costs. The N64's porting cost is quite high, which is consistent with Nintendo's strategy to strengthen conditions for game release as stated in Van Dreunen (2020), pages 34-38. Among those conditions, each developer should release no more than 5 titles per year on the platform and each release should be exclusive for at least two years. Access policy was not the only barrier for developers, but also N64 features. The

[20]Most titles in data sample have only one release period. Roughly 5% of releases are dynamic multihomed releases (see Table 4), i.e. releases of titles which already had releases in past periods.

[21]This opportunity cost of not releasing a title that is not identified could include the cost of releasing other titles.

Figure 9: Investment cost estimates $^{(*)}$



Notes $(*)$ When considering time-invariant INE parameter α and an uninformed transition process for the installed bases, i.e. the expectations on the changes in IB are completely driven by believes in demand shocks and are not related to observed variables. Estimates under specification with time-varying INE parameter α_t and an informed transition process are reported in Figure 14 and Table 3. Estimates are represented with 95% confidence intervals. The estimated value for the constant INE parameter α is 0.0033 (see Table 3). The estimated costs are actually cost gaps w.r.t choosing $a_{kt} = \emptyset$. Platform-invariant development costs increase over time. Platform-specific porting costs decrease across consoles from older to newer generations.

N64 required video games to be developed and manufactured in cartridge form, while the PS made a revolution by introducing video game production in CD form. The CD format was very popular, as it reduced the cost of developing and manufacturing games. In general, we're seeing a reduction in porting costs between old and new-generation consoles. PS, PS2 and PS3 are 5th, 6th and 7th generation consoles built by Sony; XB and X360 are 6th and 7th generation consoles built by Microsoft; N64, GC and Wii are 5th, 6th and 7th generation consoles built by Nintendo. This result is entirely consistent with the trend in cost structure as described in the literature and industry sources.

Interestingly, the heterogeneity of porting costs across the same console manufacturers diminishes across generations. Indeed, from a very high-cost advantage for Sony and Nintendo's 5th generation consoles (PS and N64), the porting costs are fairly similar for all generation 7 consoles (PS3, X360 and Wii). This suggests that competition between platform providers to attract content developers has improved considerably across technological eras. The decrease in platform-specific porting costs and in their heterogeneity across generations might be the result of platform providers battling to innovate and provide more user-friendly development kits and catch up with leaders. Indeed, the most popular innovation recorded from generation 7 onwards was initiated with the launch of the Wii console, with the other platforms (PS3 and X360) subsequently catching up. With its Wii platform, Nintendo introduced motion control to hardware devices for the first time. It was a revolutionary innovation that was much appreciated by gamers and developers alike, particularly for sports games. Nintendo also boosted the Wii's popularity by releasing and attracting exclusive titles - especially sports games - that could take advantage of the innovation. The proximity of porting costs during generation 7 is somewhat linked to the high occurrence of multihomed releases from launch periods of generation 7 consoles.

Among the 6th generation consoles, Sony's PS2 seems to have a cost advantage over Microsoft's XB and Nintendo's GC. However, the opposite is true in Lee (2013) when we focus on exclusive releases. Indeed, Lee (2013) found that releasing a video game exclusively on XB or GC is cheaper than releasing it exclusively on PS2.

7.2. Counterfactual analysis of the Microsoft effect

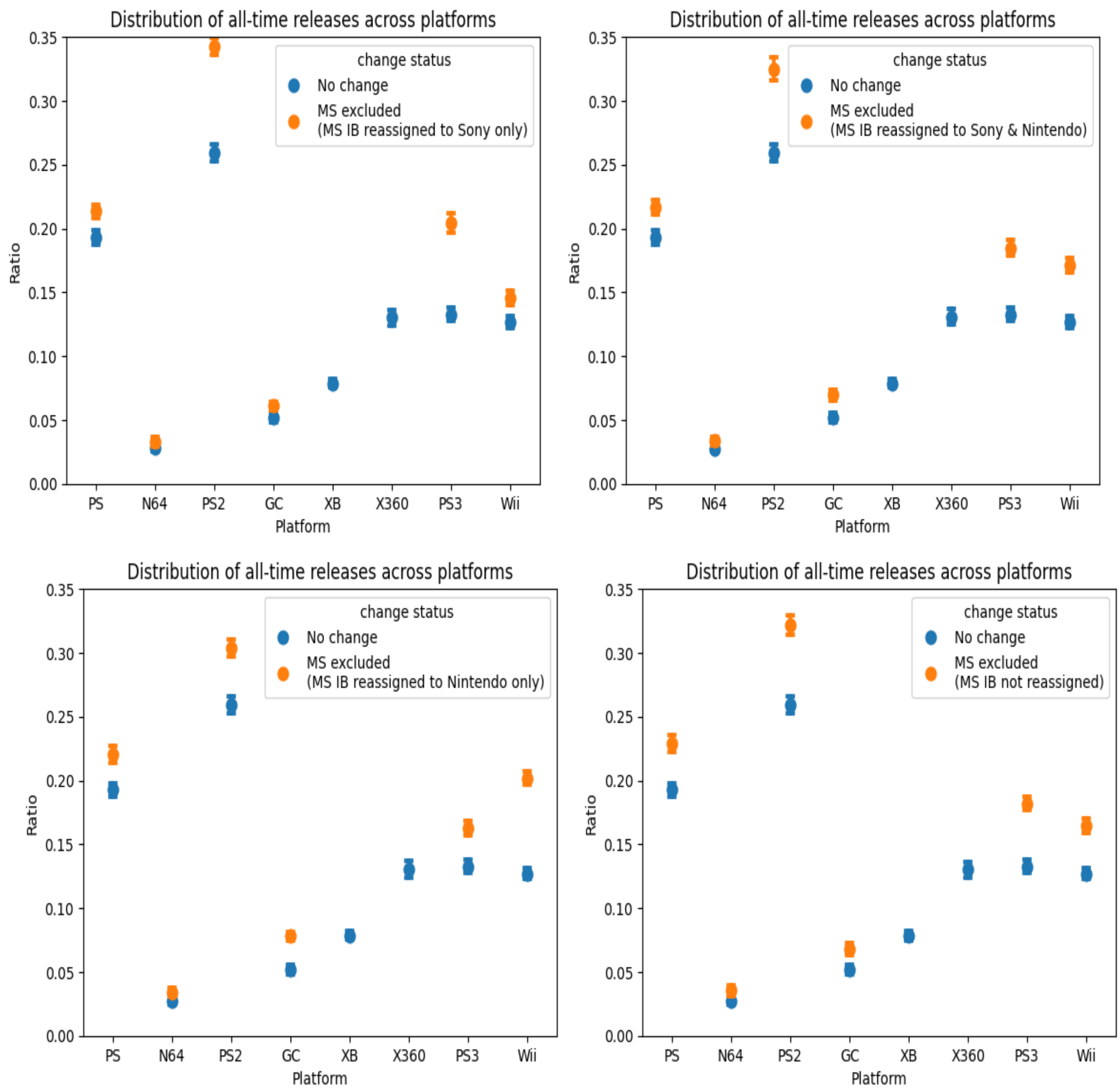
The Microsoft's effect on the distribution of releases is analyzed by comparing the distribution of releases between simulated samples in the presence of Microsoft and simulated samples in the absence of Microsoft. 50 simulations are carried out for each of the two settings and the computed outcomes of interest are averaged across those 50 simulations. For simulations in which Microsoft is excluded, Microsoft consoles are excluded from the choice and state spaces. Then initial states are adjusted to account for the absence of Microsoft's consoles (e.g., XB and X360 are removed from the available platforms J_t). Various scenarios are considered for the reallocation of Microsoft users. The XB's user base is only allowed to be shared between same generation consoles, i.e. PS2 and GC. Likewise, the X360's user base is only allowed to be shared between same generation consoles, i.e. PS3 and Wii. In the first scenario, Sony and Nintendo share Microsoft's user base equally. In a second scenario, Sony obtains Microsoft's entire user base. In a third scenario, Microsoft is excluded with all its user base. Each scenario gives rise to a different simulation exercise.

A simulation exercise is carried out after having estimated the parameter vector. Considering the same set of content products that are in the original dataset, their initial state spaces are adjusted to account for the simulation setting (e.g. the absence of Microsoft). The estimated parameter vector $\hat{\theta}$ is then used to compute transition probabilities, choice probabilities and lifetime payoffs - from equations 4, 5 and 6 - in the simulation setting. Finally, a sequence of decisions and states are drawn for each content product, using previously computed choice and transition probabilities.

Table 4 - in Appendix B - summarizes the distribution of releases across platforms and across the multihoming status, computed under different scenario. Comparisons of the distribution across platforms in different scenarios are also shown in Figure 10. In general, between Sony and Nintendo, the console manufacturer that obtains all the users of the excluded Microsoft consoles obtains a higher share of releases - in the absence of Microsoft - compared to the scenario in which it only obtains half or no Microsoft users. Excluding Microsoft consoles and assigning all XB users to PS2 and all X360 users to PS3 leads to a raise in Sony's share by 2 percentage points for the PS (from a 19% share to 21%), 9 percentage points for the PS2 (from a 26% share to 34%) and 7% percentage points for the PS3 (from 13% to 20%). However, when we assign all Microsoft users to Nintendo consoles, i.e. all XB users to GC and all X360 users to Wii, the increase in the PS' share is limited to 1 percentage point; the increase in the PS2's share is limited to 4 percentage points and the increase in the PS3's share is limited to 3 percentage points. Results also change in other reallocation scenarios.

Furthermore, the shares of Sony consoles (PS, PS2, PS3) in attracting video game releases always increase more compared to the shares of Nintendo consoles (N64, GC, Wii), except in the scenario of the redistribution of all Microsoft users to Nintendo, in which the Wii console benefits from a greater increase. However, this scenario is less likely because the demographics of Microsoft users (families, children) are closer to those of Sony users than to those of Nintendo users (older teenagers, young adults). Therefore, excluding Microsoft implies a very large dominance of Sony consoles - with a cummulated share of around 72% compared to 58% in the presence of Microsoft - when it comes to attracting video game releases. In particular, Sony's PS3 would have dominated the 7th generation of consoles in attracting content had Microsoft been absent. These findings suggest that Microsoft's

Figure 10: Effects of excluding platforms of Microsoft (MS) on the distribution of all-time releases across platforms



Notes Estimates represented with 95% confidence intervals.

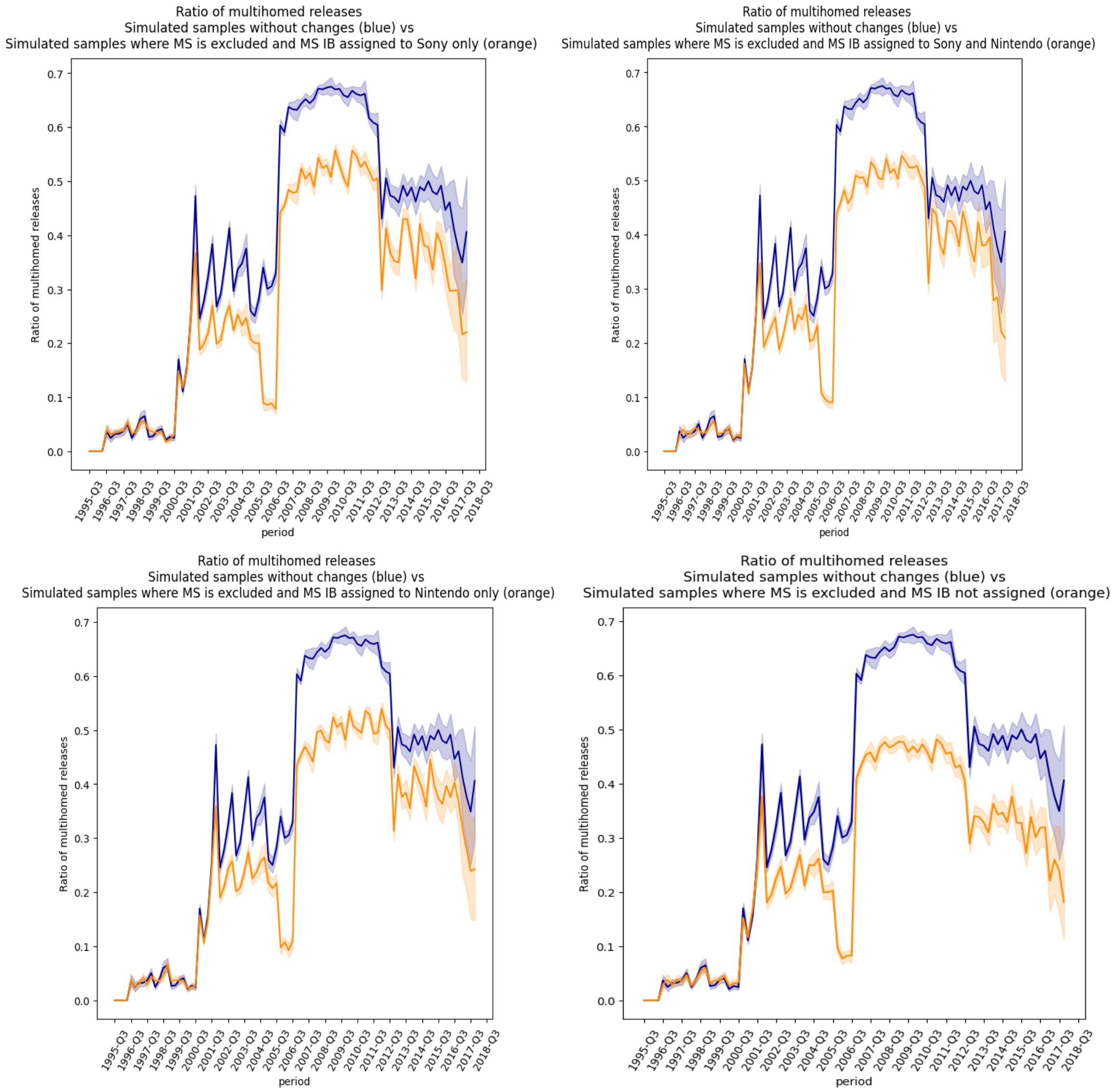
presence fostered greater competition by preventing a near-monopoly by Sony in attracting content products in the home console industry.

Figure 11 shows a trend in the ratio of multihomed releases and Table 4 in Appendix B gives this ratio on all-time releases. Multihomed releases are both first releases on several platforms simultaneously, and later releases of titles with an inventory of previous releases. In general, the ratio of multihomed releases in the absence of Microsoft (around 32% of all releases ever) is much lower than that calculated in the presence of Microsoft (around 42% of all releases ever), and does not change under Microsoft user reassignment scenarios, as long as all Microsoft users remain in the industry. However, in the extreme case where all Microsoft users are lost, the ratio of multihomed releases is lower (around 29% of all releases ever). Therefore, Microsoft's presence in the industry has likely led to an increase of 10 to 13 percentage points in the ratio of multihomed releases, depending on whether of not users of Microsoft's platforms are reallocated to the remaining platforms. The trend in the ratio of multihomed releases increases in both cases (including and excluding Microsoft consoles). Part of the upward trend in the ratio of multihomed releases is disconnected from Microsoft's presence, and is linked to a downward trend in multihoming costs, stemming from the downward trend in platform-specific investment costs.

To assess whether the effect of Microsoft entry on the multihoming is solely a Microsoft-specific effect or a general effect of the entry of a new platform provider, a similar counterfactual exercise is performed on Nintendo. Figure 16 presents the multihoming ratio in three cases: (1) there is no change in the available platforms; (2) Microsoft's consoles are excluded and their user bases are reallocated to Sony consoles from the same generations; (3) Nintendo's consoles are excluded and their user bases are reallocated to Sony consoles from the same generations. The counterfactual multihoming ratios obtained in cases (2) and (3) are close to each other and they are significantly distant to the multihoming ratio obtained in case (1) in periods ranging from 2007 and onward. These periods coincide with the 7th generation periods and onward. Meanwhile, the counterfactual multihoming ratios obtained in cases (2) and (3) are as distant to each other as they are to the multihoming ratio obtained in case (1) in periods ranging from 2001 to 2006. These periods coincide with the 6th generation periods. As a result, The effect of the Microsoft entry has both a Microsoft-specific component and a general effect of an entry of a new platform provider in the 6th generation periods following the entry. The Microsoft-specific component tends to disappear in the remaining periods. This can be related to the fact that platform-specific costs are close to each other for the 7th generation platforms, which are the most targeted during the 7th generation periods.

As multihoming by content providers implies less differentiation between platforms in their base of exclusive titles, it leads to strong competition between platforms in attracting consumers. The results of the present study show that the arrival of a new console

Figure 11: Effects of excluding platforms of Microsoft (MS) on the ratio of multihomed releases



Notes Estimates represented with 95% confidence intervals.

manufacturer is one of the sources of the increase in multihoming by content providers - alongside a downward trend in platform-specific porting costs as another source - which may have helped foster competition to attract console users. Furthermore, although the presence of exclusives has helped lower barriers to entry in the console market (Lee, 2013), the entry of a new platform provider such as Microsoft on the home console market has helped maintain post-entry competition between console manufacturers regarding their content base in the long term. For instance, it prevented Sony from taking advantage of the fact that Nintendo consoles are poor substitutes and from dominating the industry for three consecutive generations (5, 6 and 7). If Microsoft had not been a console supplier, Sony's consoles would have had a virtual monopoly with three quarters of the market share in content releases.

8. CONCLUSION

The aim of this study is to perform a structural analysis of content provision across platforms, focusing on the home console video game industry, and to use structural primitives to estimate the effect that the entry of a new platform provider like Microsoft has on content providers' multihoming pattern. Using dynamic discrete-choice estimation of a single-agent model in which content providers target portfolios of platforms and decide on the timing of release on these platforms, the effect of the installed base of users and development costs are estimated as the incentives driving the agents' decision. The results show that the installed base has a positive effect on gains earned from launching content products following the indirect network effect literature. This installed base effect is limited regarding the distribution of releases as it takes a very large increase in a platform's installed base to significantly shift the distribution of releases across platforms. For example, an increase of 10 million users in the installed base of a given platform is found to have a direct effect of up to 2 percentage points on its own market share and almost no effects on cross-market shares of releases, while an increase of 100 million users has a direct effect of 9 to 20 percentage points on its own shares and significant cross-makret effect of up to 7 percentage points. In addition, analysis of the cross-effects of the installed base shows that Sony platforms are close substitutes for other platforms, while Nintendo platforms are poor substitutes. Estimates of development costs reflect observations shared by industry sources. Indeed, the estimates first show an increase in platform-invariant development costs over time, whether for the cost of the first version of a new item of content, or the cost of a new version of an existing item of content. Secondly, the estimates suggest that platform-specific porting costs decrease consistently over generations, highlighting a downward trend in multihoming costs. Thirdly, the heterogeneity of platform-specific porting costs between platform providers reduces over generations, suggesting that, in the long term, platform providers compete intensely for content due to less differentiation in their console features and development architectures. The estimated primitives are then used to perform a counterfactual analysis to study the impact of a new platform provider's entry such as Microsoft which joined the console manufacturing sector in 2001. The results first show that Microsoft's absence with the withdrawal of its Xbox and Xbox 360 consoles, would have consolidated the market shares of Sony's consoles in the content delivery market to a near-monopolistic position, to the detriment of Nintendo's consoles, which are poor substitutes for the Microsoft and Sony platforms. Secondly, the results show that Microsoft's presence increased the ratio of multihomed releases by between 10 and 13 percentage points, whether in a single period or in subsequent release periods. The impact varies slightly depending on the scenarios in which Microsoft's user base is reallocated between consoles of the two remaining firms: Nintendo and Sony. This study's findings have several implications. Indeed, they suggest that one can determine the trends in investment costs in the industry from data on content releases and platforms' market sales. Due to a decrease in the multihoming costs resulting from lower platform-specific investment costs, platform providers can less rely on third-party exclusive content products to differentiate themselves. In addition, a new platform provider such as Microsoft is welcome as it can bring more non-exclusive content, especially if its platforms are not poor substitutes for the platforms offered by a dominant legacy platform provider such as Sony.

A. THE NESTED FIXED POINT PROCEDURE

The parameter vector of interest to be estimated is: $\theta = (\alpha, \{pc_j\}_{j\in J}, \{dc1_\tau\}_\tau, \{dc2_\tau\}_\tau)$. Given the transition cumulative distribution functions (CDFs) and the conditional choice probabilities (CCPs) used in proposition 2, the contribution of content k to the Log-likelihood is expressed as:

$$\begin{aligned} L_k(\theta) = & \sum_{t}^{T_k} LogP(a_{kt}|X_{kt};\theta) + \sum_{t=1}^{T_k-1} Logf_X(X_{k,t+1}|a_{kt}, X_{kt};\theta) \\ = & \sum_{t=1}^{T_k} LogP(a_{kt}|X_{kt};\theta) + \sum_{t}^{T_k-1} LogF_B(B^\tau_{t+1}|B^\tau_t) \end{aligned} \tag{7}$$

where f_X is the distribution function that corresponds to the CDF F_X. The transition probabilities are non-parametrically estimated from the empirical distribution of shocks with the assumption that demand shocks are iid. Therefore, only contributions $\sum_{t=1}^{T_k} Log\bar{P}(a_{kt}|X_{kt};\theta)$ to partial log-likelihood are relevant. The estimation process relies on Aguirregabiria and Mira (2010) and Rust (1987) and is run according to following steps.

A.1. States, actions and shocks

Given the time series of the installed base of users (IB) $B_{j\tau}$ for all platforms $j \in J$; we build different state, action and shock spaces for each of the 90 observation periods in the data, ranging from the first Quarter of 1995 to the fourth quarter of 2016. Indeed, a series of shocks is computed for each platform as $\mu_{j\tau} = B_{j\tau} - B_{j\tau-1}$ with $\mu_{j0} = B_{j0} = 0$. Then, a stationary and per-platform distribution $F_{\mu_j} \equiv F_\mu$ of shocks is estimated through the frequency count approach. Combining this distribution with platform availability yield to a distribution $F_{\tau,\boldsymbol{\mu}}$ that varies across the 90 observation periods. In parallel, compute a frequency-count estimate of the distribution of IB.

For each period;

— Define the set of available platforms J_τ.

— Draw a set $\mathcal{B}_\tau$ of 200 eight-dimensional vectors B_τ from the estimated stationary distribution of IB; set coordinates $B_{j\tau}$ for unavailable platforms $j \notin J_\tau$ to zero.

— Draw a set $\mathcal{M}_\tau$ of 30 eight-dimensional vectors $\boldsymbol{\mu}_\tau$ (with weights) from the estimated stationary distribution of IB shocks; set coordinates $\mu_{j\tau}$ for unavailable platforms $j \notin J_\tau$ to zero.

— Obtain the set $\mathcal{I}_\tau$ of all possible inventories as a partition of J_τ.

— For each inventory $i \in \mathcal{I}_\tau$, obtain the set $\mathcal{A}_{\tau,i}$ of all possible actions as the partition of $J_\tau - i$.

A.2. Value function iteration

The decision makers have T consecutive decision times that belong to a set of 90 observation periods considered in the data. If we fix the initial decision time t_0 to be equal to an observation period τ_0, then, for a given value of the parameter vector θ, the Bellman equation is solved through the following steps:

- For the last decision time T; which corresponds to observation period $\tau = \tau_0 + T$
  - For each inventory $i \in \mathcal{I}_\tau$
    - Compute current payoff matrix $U_{T,i}$ with dimension $(|\mathcal{B}_\tau|, |\mathcal{A}_{\tau,i}|)$.
    - Compute derivative array $\nabla_\theta U_{T,i}$ of current payoff w.r.t to parameters with dimension $(|\mathcal{B}_\tau|, |\mathcal{A}_{\tau,i}|, |\theta|)$
    - Compute the value $V_{T,i}$, a $|\mathcal{B}_\tau|$-dimension vector
    - Compute array of choice probabilities $CCP_{T,i}$ of dimension $(|\mathcal{B}_\tau|, |\mathcal{A}_{\tau,i}|)$
    - Get derivatives $\nabla_\theta V_{T,i}$ of values $V_{T,i}$ w.r.t parameters, an array of dimension $(|\mathcal{B}_\tau|, |\theta|)$.
  - Stack values $V_{T,i}$ across inventories into a vector V_T of dimension $(|\mathcal{B}_\tau| \times |\mathcal{I}_\tau|)$
  - Stack value derivatives across inventories into a matrix $\nabla_\theta V_T$ of dimension $(|\mathcal{B}_\tau| \times |\mathcal{I}_\tau|, |\theta|)$
  - Regress V_T on polynomial transforms $p(Z)$ of Z using the mean-square method. Z is an array of dimension $(|\mathcal{B}_\tau| \times |\mathcal{I}_\tau|, |\mathcal{B}_\tau| + |\mathcal{I}_\tau|)$. Store regression parameters p.
  - Regress $\nabla_\theta V_T$ on polynomial transforms $q(Z)$ of Z using the mean-square method. Z is an array of dimension $(|\mathcal{B}_\tau| \times |\mathcal{I}_\tau|, |\mathcal{B}_\tau| + |\mathcal{I}_\tau|)$. Store regression parameters q.
- For each decision time $t < T$; which corresponds to observation period $\tau = \tau_0 + t$
  - For each inventory $i \in \mathcal{I}_\tau$
    - Compute current payoff matrix $U_{t,i}$ with dimension $(|\mathcal{B}_\tau|, |\mathcal{A}_{\tau,i}|)$.
    - Compute derivative array $\nabla_\theta U_{t,i}$ of current payoff w.r.t to parameters with dimension $(|\mathcal{B}_\tau|, |\mathcal{A}_{\tau,i}|, |\theta|)$
    - Compute the value $V_{t,i}$, a $|\mathcal{B}_\tau|$-dimension vector
      - Since the expected future values $\int V_{t+1,i} dF_{\tau+1,\boldsymbol{\mu}}$ are needed, interpolate by

$$\int V_{t+1,i}(\boldsymbol{B}_t + \boldsymbol{\mu}_{t+1}) dF_{\tau+1,\boldsymbol{\mu}} = \sum_{\boldsymbol{\mu}_{t+1} \in \mathcal{M}_{\tau+1}} \omega_{\tau+1,\boldsymbol{\mu}_{t+1}} p(\boldsymbol{B}_t + \boldsymbol{\mu}_{t+1})$$

        where $\omega_{\tau+1,\boldsymbol{\mu}_{t+1}}$ is the probability weight of $\boldsymbol{\mu}_{t+1}$ within $\mathcal{M}_{\tau+1}$
    - Compute array of choice probabilities $CCP_{t,i}$ of dimension $(|\mathcal{B}_\tau|, |\mathcal{A}_{\tau,i}|)$ using formula 4
    - Get derivatives $\nabla_\theta V_{t,i}$ of values $V_{t,i}$ w.r.t parameters, an array of dimension $(|\mathcal{B}_\tau|, |\theta|)$.

— Since future expected value derivatives $\int \nabla_\theta V_{t+1} dF_{\tau+1,\boldsymbol{\mu}}$ are needed, interpolate by

$$\int \nabla_\theta \bar{V}_{t+1,i}(\boldsymbol{B}_t + \boldsymbol{\mu}_{t+1}) dF_{\tau+1,\boldsymbol{\mu}} = \sum_{\boldsymbol{\mu}_{t+1} \in \mathcal{M}_{\tau+1}} \omega_{\tau+1,\boldsymbol{\mu}_{t+1}} q(\boldsymbol{B}_t + \boldsymbol{\mu}_{t+1})$$

where $\omega_{\tau+1,\boldsymbol{\mu}_{t+1}}$ is the probability weight of $\boldsymbol{\mu}_{t+1}$ within $\mathcal{M}_{\tau+1}$

- — Stack values $V_{T,i}$ across inventories into a vector V_t of dimension $(|\mathcal{B}_\tau| \times |\mathcal{I}_\tau|)$
- — Stack value derivatives across inventories into a matrix $\nabla_\theta V_t$ of dimension $(|\mathcal{B}_\tau| \times |\mathcal{I}_\tau|, |\theta|)$
- — Regress V_t on polynomial transforms $p(Z)$ of states Z using the mean-square method. Z is an array of dimension $(|\mathcal{B}_\tau| \times |\mathcal{I}_\tau|, |\mathcal{B}_\tau| + |\mathcal{I}_\tau|)$. Store regression parameters f.
- — Regress $\nabla_\theta V_t$ on polynomial transforms $q(Z)$ of states Z using the mean-square method. Z is an array of dimension $(|\mathcal{B}_\tau| \times |\mathcal{I}_\tau|, |\mathcal{B}_\tau| + |\mathcal{I}_\tau|)$. Store regression parameters q.

This algorithm is repeated for all possible initial decision times.

A.3. Parameter updates

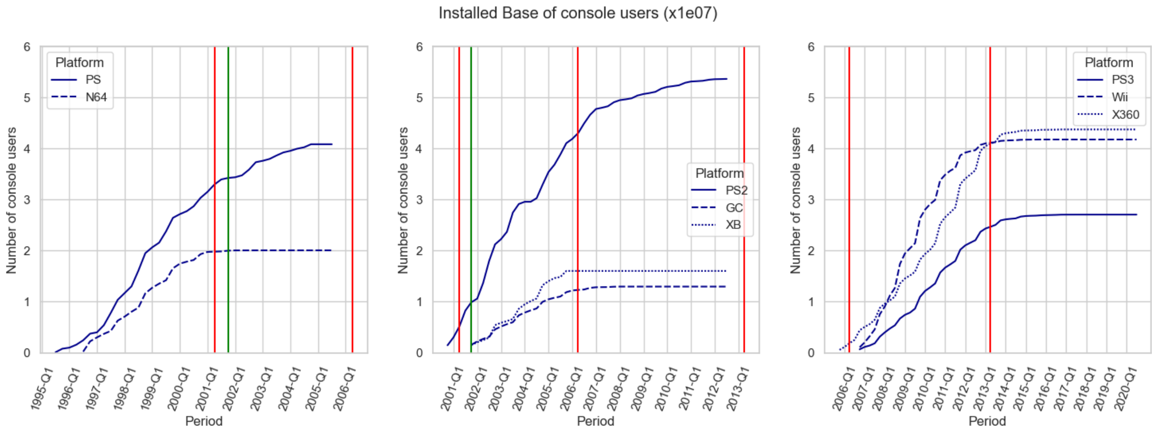
The parameter vector is estimated using partial maximum likelihood estimation and the optimization process relies on a gradient descent algorithm, namely the BHHH algorithm (Berndt et al. (1974). This estimation is summarized in following steps:

- — initialise the parameter vector to $\theta = \theta_0$;
- — iterate: for $\theta = \theta_l$;
  - — Solve for the value function and its derivatives (apply the value function iteration described above),
  - — Get the gradient $\nabla_\theta L(\theta_l)$ of (partial) log-likelihood $L(\theta_l) = \sum_k \sum_{t=1}^{T_k} LogP(a_{kt}|X_{kt};\theta_l)$,
  - — update θ,
    - — $\theta_{l+1} = \theta_l + \lambda_l \left(\nabla_\theta L(\theta_l) \nabla_\theta L(\theta_l)'\right)^{-1} \nabla_\theta L(\theta_l)$ where λ_l is a step size, updated within the iterative step to speed up the algorithm.
- — stop when $\theta_{l+1} \approx \theta_l$.

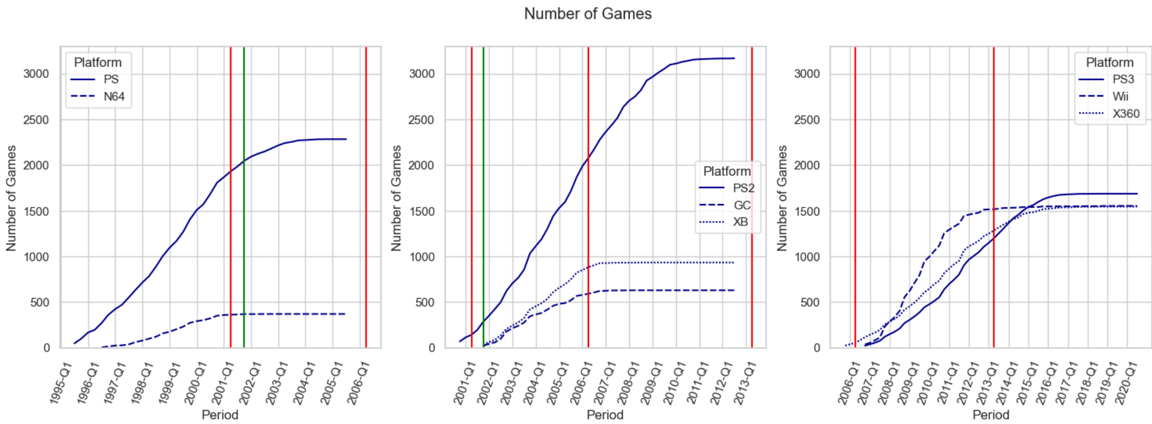
B. AUXILIARY RESULTS

Figure 12: Trends in installed base, number of content, and exclusive releases.

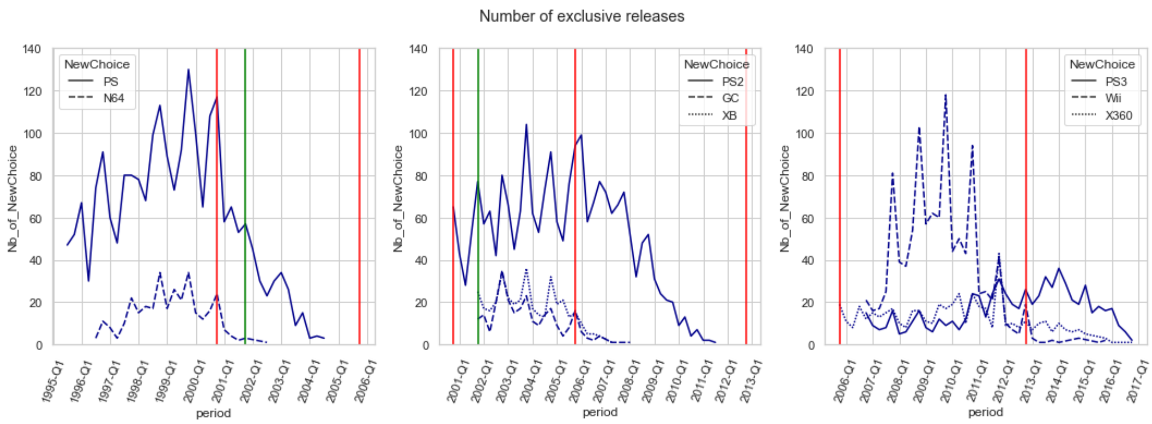
(a)



(b)



(c)



Notes Red vertical lines represent the starts of 6th, 7th and 8th generations; green line represents the Xbox launch. `Nb_of_NewChoice` for platform j in quarter t counts new releases that occur *exclusively* on j during t.

Figure 13: Distribution of inter-release intervals for titles with multi-period releases

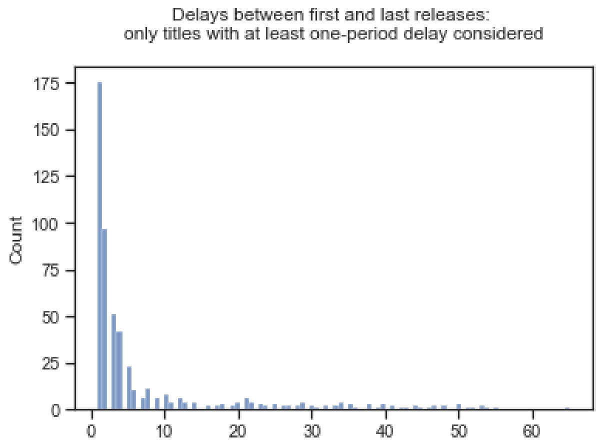
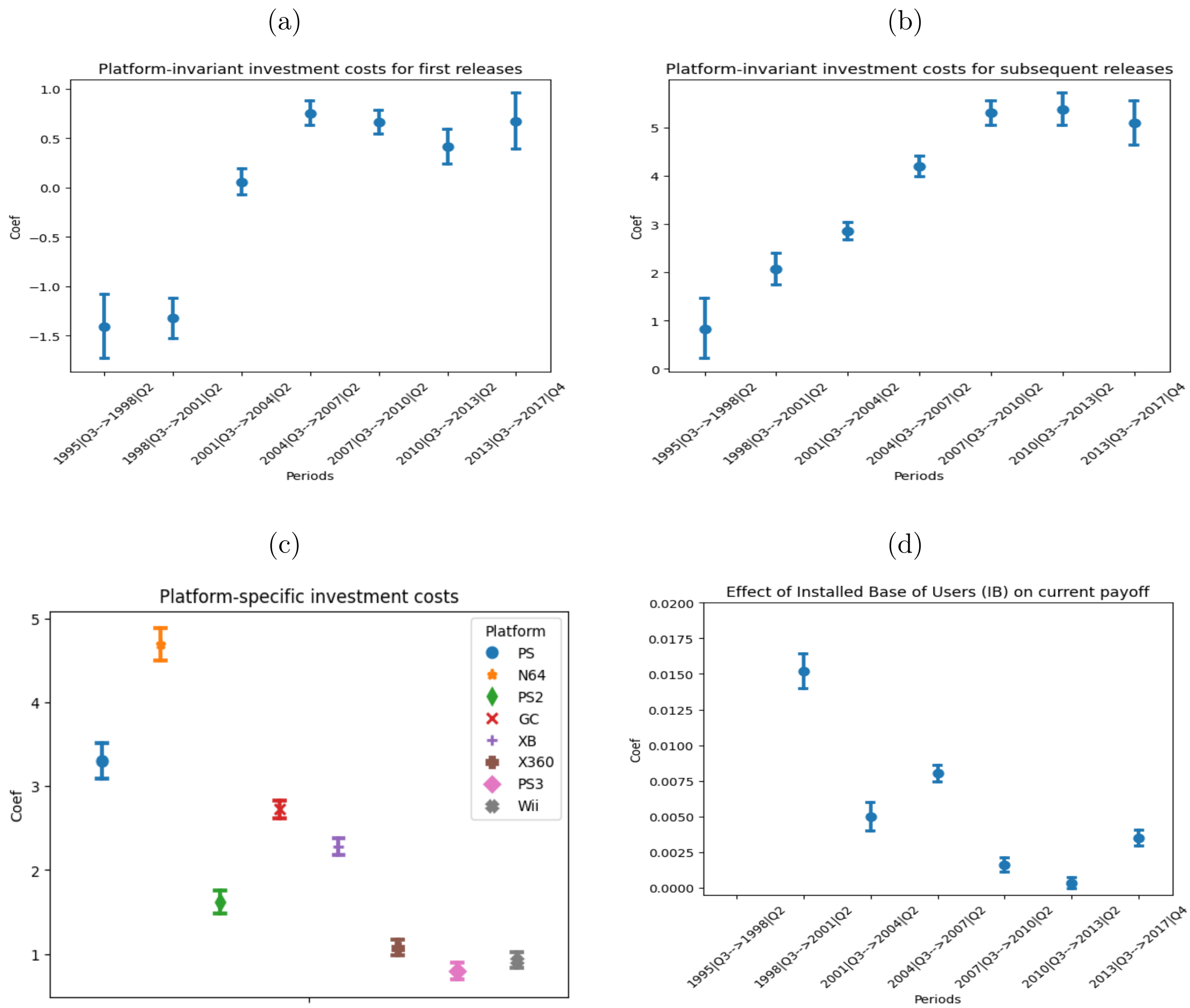


Figure 14: Estimate results when considering time-varying INE parameter and a more informed transition process$^{(*)}$



Notes (∗) i.e., expectations on changes in IB depend on console price, quarter-of-the-year, number of console models, console's age. Estimates are represented with 95% confidence intervals. In graph 14c, consoles are ordered from left to right according to their release dates and therefore their generations. The estimated costs are actually cost gaps w.r.t choosing $a_{kt} = \emptyset$. Platform-invariant development costs increase over time. Platform-specific porting costs decrease across consoles from older to newer generations.

Figure 15: Effects of IB increases on platform shares in all-time releases

(a) (b)

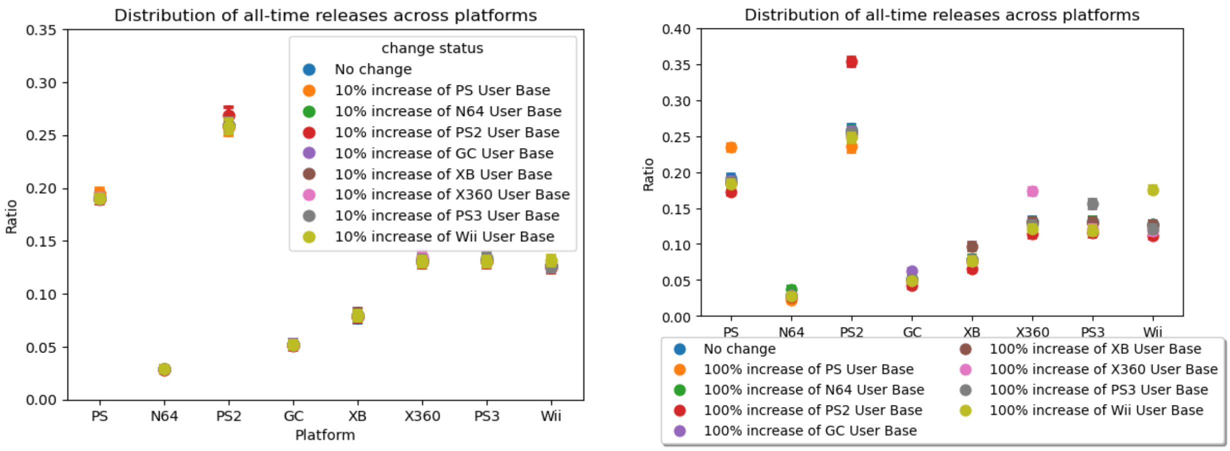


Figure 16: Effect of Microsoft vs Nintendo on the multihoming ratio

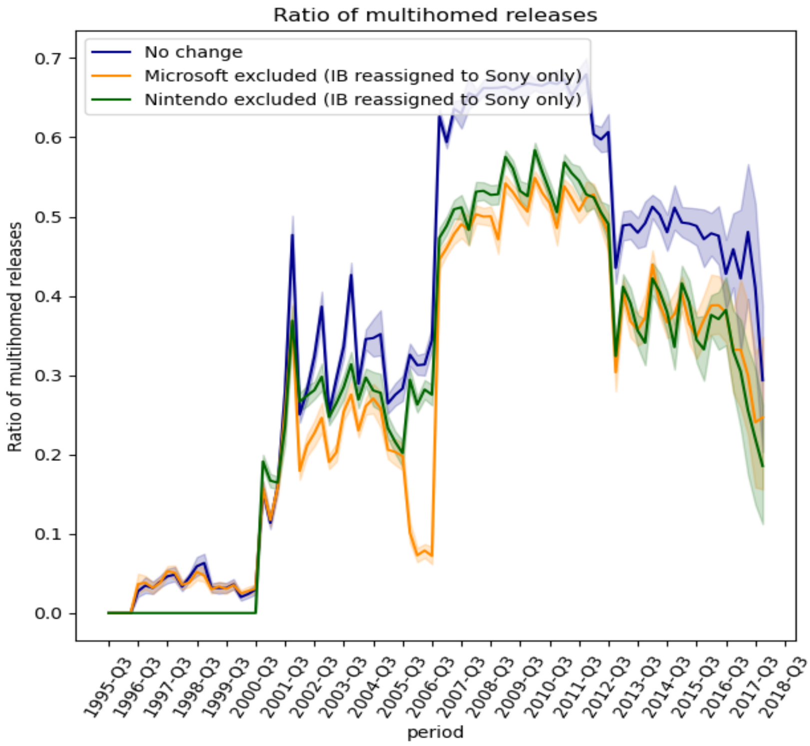


Figure 17: Effect of a 100% increase in the IB on the multihoming ratio

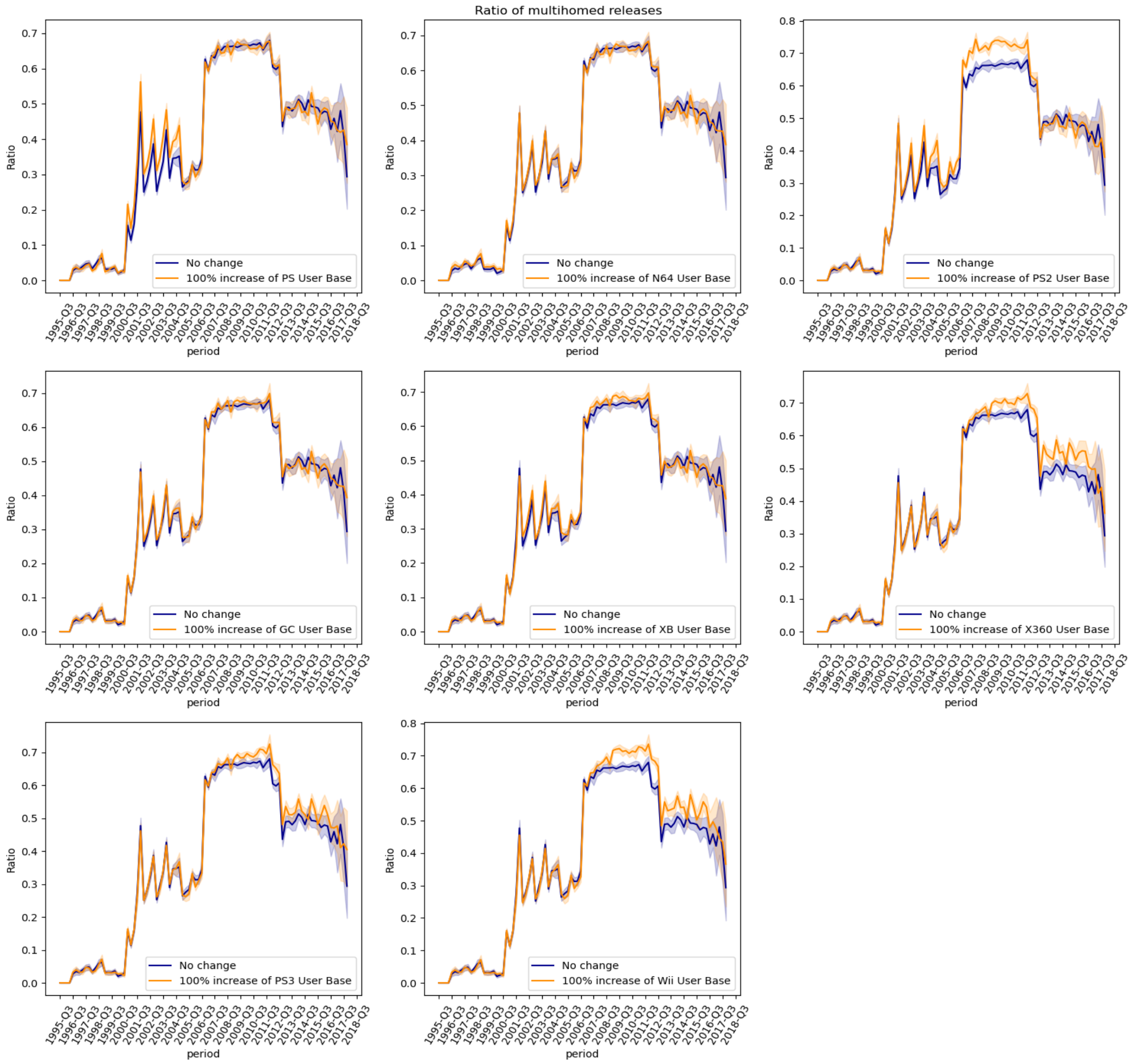


Figure 18: Market shares of platforms in the market for third-party content releases

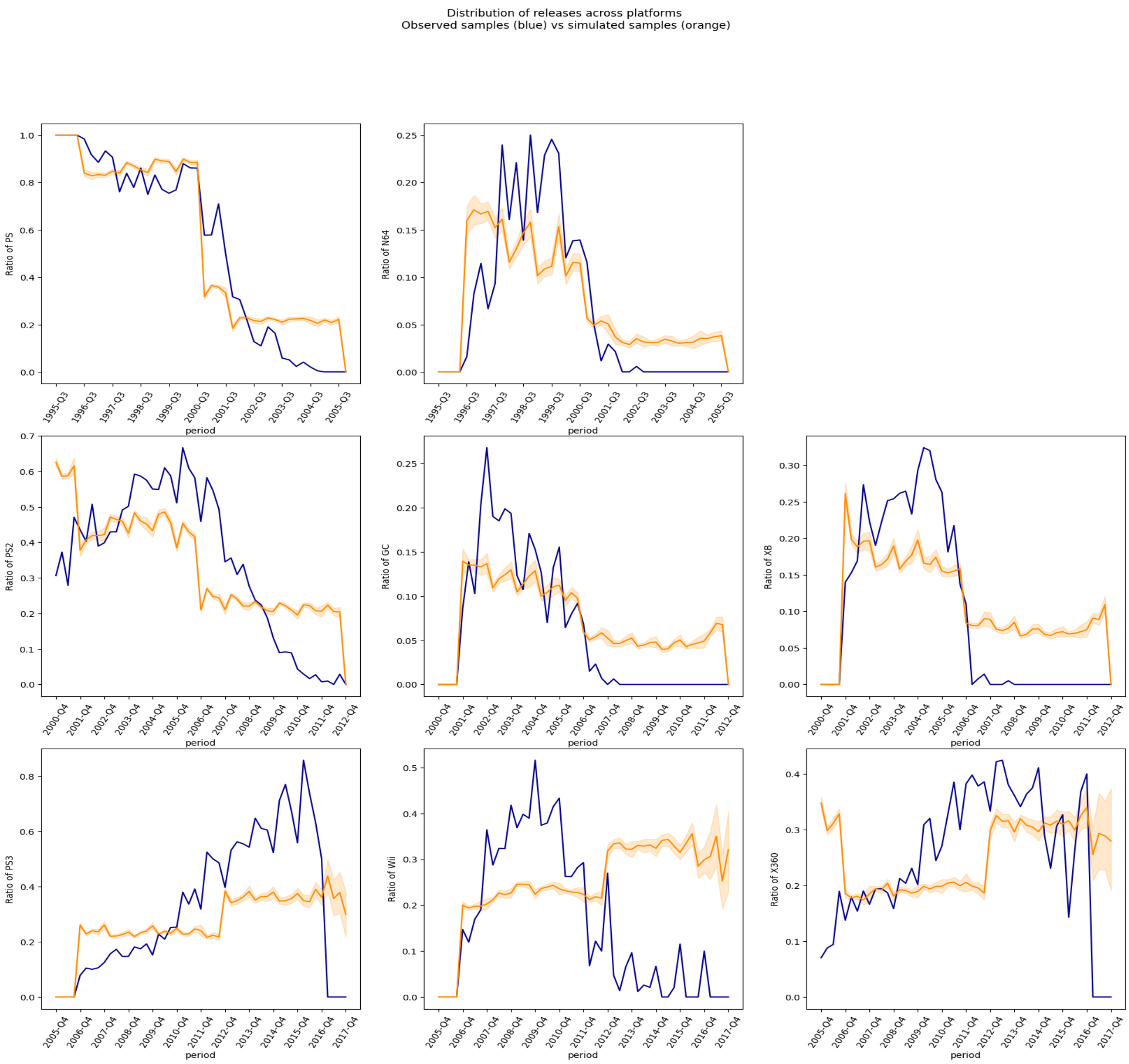


Figure 19: Effect of increasing PS2's IB by 10 millions users

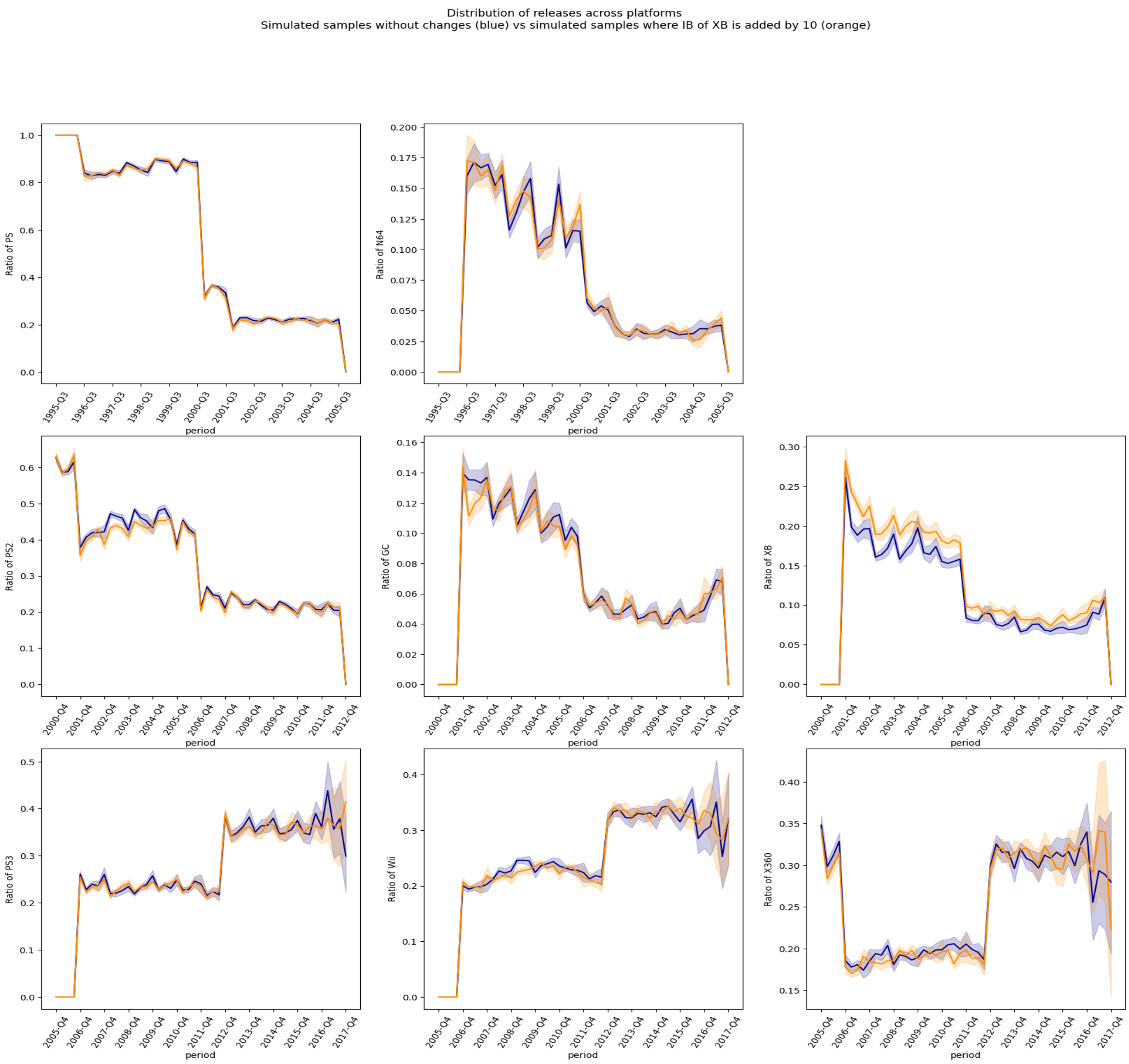


Figure 20: Effect of increasing XB's IB by 100 millions users

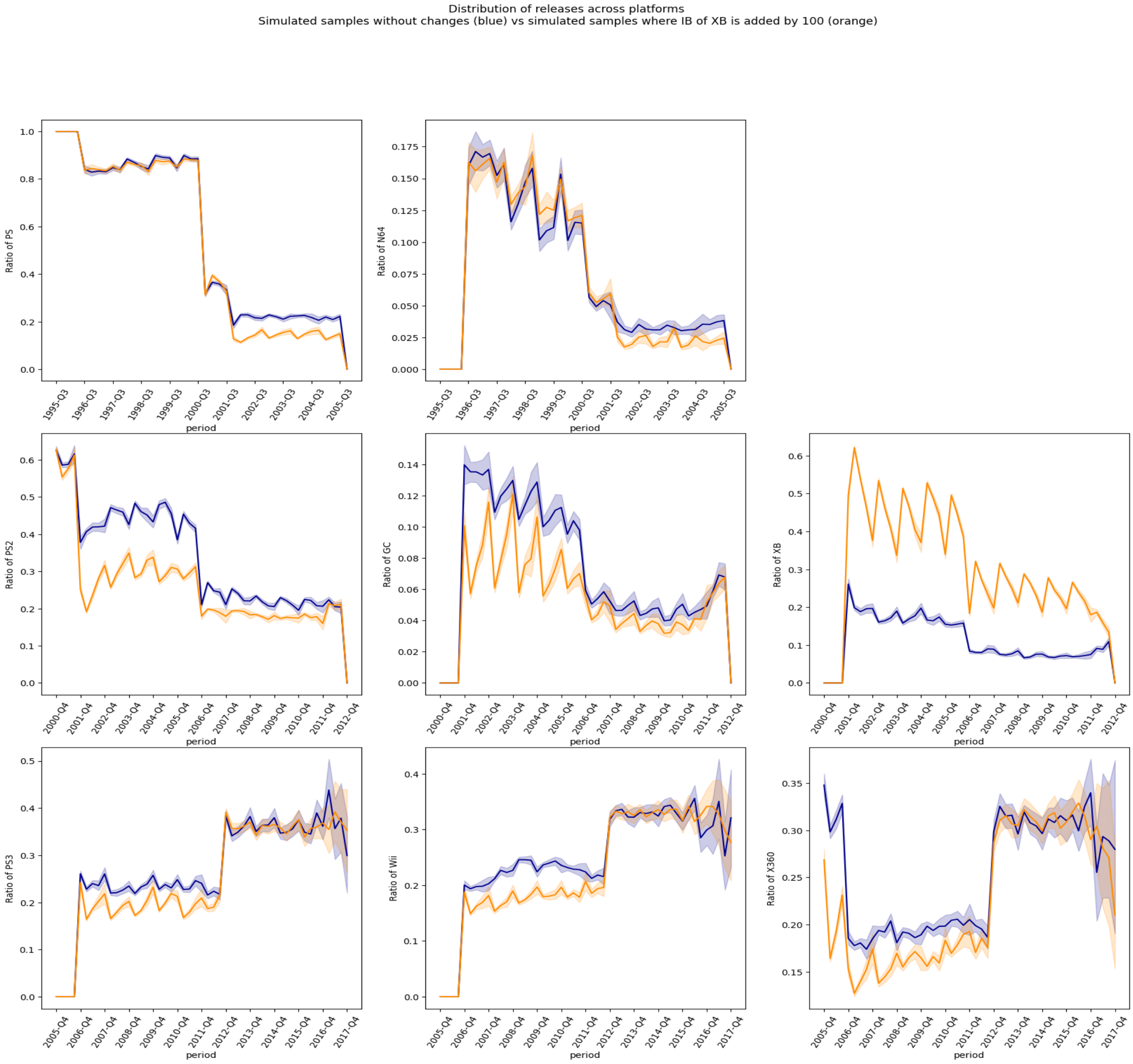


Table 2: Summary statistics

Variables		Obs	mean	std	min	25%	50%	75%	max
Installed Base (IB): in 10 millions units	PS	41	2.47	1.43	0.01	1.17	2.87	3.75	4.08
	N64	37	1.53	0.65	0.02	1.16	1.97	2.00	2.00
	PS2	48	3.80	1.63	0.15	2.87	4.57	5.12	5.36
	GC	44	1.05	0.36	0.16	0.86	1.28	1.29	1.29
	XB	44	1.31	0.47	0.15	1.05	1.60	1.60	1.60
	X360	60	3.06	1.56	0.06	1.57	4.06	4.37	4.38
	PS3	56	1.97	0.92	0.07	1.26	2.55	2.70	2.70
	Wii	56	3.34	1.29	0.11	2.88	4.13	4.17	4.17
Number of titles	PS	41	1449.95	796.53	47.00	713.00	1683.00	2217.00	2285.00
	N64	37	263.24	135.65	3.00	156.00	357.00	369.00	369.00
	PS2	48	1964.33	1101.02	69.00	987.75	2227.00	3064.25	3168.00
	GC	44	499.30	192.12	20.00	408.50	624.50	628.00	628.00
	XB	44	721.89	301.82	34.00	522.25	927.00	932.00	932.00
	X360	60	1032.55	547.06	23.00	533.25	1264.00	1536.00	1544.00
	PS3	56	1087.64	608.23	22.00	502.00	1277.50	1679.50	1686.00
	Wii	56	1228.61	497.50	35.00	1042.25	1527.00	1549.00	1554.00
Ratio of first and singlehomed releases w.r.t all releases		86	0.62	0.23	0.20	0.45	0.55	0.85	1.00
Ratio of first and multihomed releases w.r.t all releases (a)		86	0.16	0.11	0.00	0.04	0.18	0.25	0.34
Ratio of subsequent releases w.r.t all releases (b)		86	0.03	0.03	0.00	0.01	0.03	0.05	0.13
Multihoming (a+b)		86	0.19	0.12	0.00	0.08	0.23	0.27	0.40
Total nb of releases (c)		86	99.22	51.56	6.00	60.50	98.00	128.75	234.00

Notes. Observations are quaterly periods.

Table 3: Parameter estimates

	Coef (s.e.)[(a)]	Coef (s.e.)[(b)]
α	0.0033 (0.0002)	
$\alpha_{\tau=0}$ (1995|Q3–>1998|Q2)		0.0395 (0.0044)
$\alpha_{\tau=1}$ (1998|Q3–>2001|Q2)		0.0152 (0.0006)
$\alpha_{\tau=2}$ (2001|Q3–>2004|Q2)		0.0050 (0.0005)
$\alpha_{\tau=3}$ (2004|Q3–>2007|Q2)		0.0080 (0.0003)
$\alpha_{\tau=4}$ (2007|Q3–>2010|Q2)		0.0016 (0.0003)
$\alpha_{\tau=5}$ (2010|Q3–>2013|Q2)		0.0003 (0.0002)
$\alpha_{\tau=6}$ (2013|Q3–>2017|Q4)		0.0035 (0.0003)
pc_0 (PS)	2.7196 (0.0761)	3.2970 (0.1065)
pc_1 (N64)	4.4434 (0.0839)	4.6889 (0.0962)
pc_2 (PS2)	1.7397 (0.0529)	1.6142 (0.0698)
pc_3 (GC)	2.8636 (0.0509)	2.7216 (0.0535)
pc_4 (XB)	2.4439 (0.0455)	2.2765 (0.0488)
pc_5 (X360)	1.4712 (0.0462)	1.0736 (0.0497)
pc_6 (PS3)	1.0022 (0.0481)	0.7900 (0.0509)
pc_7 (Wii)	1.3571 (0.0457)	0.9218 (0.0486)
$dc1_{\tau=0}$ (1995|Q3–>1998|Q2)	-3.3161 (0.1262)	-1.4110 (0.1642)
$dc1_{\tau=1}$ (1998|Q3–>2001|Q2)	-2.3028 (0.0929)	-1.3246 (0.1037)
$dc1_{\tau=2}$ (2001|Q3–>2004|Q2)	-0.5169 (0.0597)	0.0513 (0.0674)
$dc1_{\tau=3}$ (2004|Q3–>2007|Q2)	0.3399 (0.0573)	0.7514 (0.0634)
$dc1_{\tau=4}$ (2007|Q3–>2010|Q2)	1.0032 (0.0561)	0.6613 (0.0605)
$dc1_{\tau=5}$ (2010|Q3–>2013|Q2)	0.4981 (0.0842)	0.4133 (0.0898)
$dc1_{\tau=6}$ (2013|Q3–>2017|Q4)	0.3650 (0.1419)	0.6688 (0.1466)
$dc2_{\tau=0}$ (1995|Q3–>1998|Q2)	1.4947 (0.3883)	0.8279 (0.3126)
$dc2_{\tau=1}$ (1998|Q3–>2001|Q2)	1.8702 (0.1651)	2.0635 (0.1642)
$dc2_{\tau=2}$ (2001|Q3–>2004|Q2)	2.7276 (0.0896)	2.8484 (0.0906)
$dc2_{\tau=3}$ (2004|Q3–>2007|Q2)	3.8475 (0.1090)	4.1945 (0.1092)
$dc2_{\tau=4}$ (2007|Q3–>2010|Q2)	5.1640 (0.1284)	5.3033 (0.1286)
$dc2_{\tau=5}$ (2010|Q3–>2013|Q2)	5.3372 (0.1676)	5.3821 (0.1680)
$dc2_{\tau=6}$ (2013|Q3–>2017|Q4)	4.6768 (0.2331)	5.0970 (0.2349)
LL	-32973	-32282

(a): Model with time-invariant INE parameter α (used for subsequent analysis).
(b): Model with time-variant INE parameter α_τ.

Table 4: Distribution of all-time releases across multihoming status and across platforms

Categories of releases (by multihoming status, by platform)	Simulated samples with no changes	Simulated samples without MS — IB users of Microsoft (MS) consoles reassigned to			
		Sony only	S (50%) & N (50%)	Nintendo only	IB users of MS not reassigned
	mean (std)	mean (std)	mean (std)	mean (std)	mean (std)
first single releases	0.5764 (0.0064)	0.6788 (0.0059)	0.6788 (0.0056)	0.6834 (0.0067)	0.7110 (0.0056)
first simultanous releases	0.3780 (0.0064)	0.2937 (0.0063)	0.2940 (0.0058)	0.2896 (0.0069)	0.2625 (0.0057)
upper releases	0.0455 (0.0022)	0.0274 (0.0016)	0.0272 (0.0017)	0.0270 (0.0016)	0.0265 (0.0017)
multihomed releases	0.4236 (0.0064)	0.3212 (0.0059)	0.3212 (0.0056)	0.3166 (0.0067)	0.2890 (0.0056)
PS	0.1927 (0.0027)	0.2136 (0.0032)	0.2162 (0.0027)	0.2204 (0.0031)	0.2288 (0.0034)
N64	0.0276 (0.0014)	0.0337 (0.0017)	0.0336 (0.0017)	0.0340 (0.0017)	0.0354 (0.0022)
PS2	0.2593 (0.0034)	0.3421 (0.0038)	0.3247 (0.0046)	0.3033 (0.0034)	0.3213 (0.004)
GC	0.0517 (0.002)	0.0605 (0.0022)	0.0694 (0.0023)	0.0782 (0.0019)	0.0679 (0.0024)
XB	0.0786 (0.0018)				
X360	0.1305 (0.0031)				
PS3	0.1326 (0.0026)	0.2061 (0.0028)	0.1847 (0.0033)	0.1625 (0.0029)	0.1818 (0.0026)
Wii	0.1269 (0.0024)	0.1440 (0.003)	0.1714 (0.003)	0.2017 (0.0028)	0.1648 (0.0028)
first exclusive on PS	0.1727 (0.0025)	0.1920 (0.0033)	0.1953 (0.0028)	0.1996 (0.0029)	0.2077 (0.0036)
first exclusive on N64	0.0216 (0.0012)	0.0268 (0.0016)	0.0269 (0.0016)	0.0276 (0.0015)	0.0289 (0.0019)
first exclusive on PS2	0.1621 (0.0033)	0.2463 (0.0046)	0.2333 (0.0045)	0.2165 (0.0042)	0.2363 (0.0042)
first exclusive on GC	0.0246 (0.0014)	0.0327 (0.0016)	0.0385 (0.002)	0.0445 (0.002)	0.0397 (0.002)
first exclusive on XB	0.0384 (0.0015)				
first exclusive on X360	0.0547 (0.0025)				
first exclusive on PS3	0.0528 (0.0019)	0.1150 (0.0033)	0.0974 (0.0028)	0.0815 (0.0027)	0.1058 (0.0026)
first exclusive on Wii	0.0495 (0.0018)	0.0660 (0.0024)	0.0874 (0.0025)	0.1137 (0.003)	0.0926 (0.0029)
total releases (ratio)	1. (0)	1. (0)	1. (0)	1. (0)	1. (0)
total releases (number)	10876.1 (64.6801)	9552.84 (48.37)	9511.44 (44.79)	9454.52 (46.92)	9208.4200 (48.63)
nb of simulated samples	50	50	50	50	50

Notes MS = Microsoft, S = Sony, N = Nintendo. Xbox's IB is reallocated between same generation consoles, i.e. PS2 and GC. Xbox360's IB is reallocated between same generation consoles, i.e. PS3 and Wii. mean (std) refers to simple average (standard deviation), computed across simulations.

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