



Strategy Science

Publication details, including instructions for authors and subscription information:
<http://pubsonline.informs.org>

Generational Transitions in Platform Markets—The Role of Backward Compatibility

Tobias Kretschmer, Jörg Claussen

To cite this article:

Tobias Kretschmer, Jörg Claussen (2016) Generational Transitions in Platform Markets—The Role of Backward Compatibility. *Strategy Science* 1(2):90–104. <https://doi.org/10.1287/stsc.2015.0009>

This work is licensed under a Creative Commons Attribution 3.0 United States License. You are free to copy, distribute, transmit and adapt this work, but you must attribute this work as “*Strategy Science*. Copyright 2016 The Author(s). <http://dx.doi.org/10.1287/stsc.2015.0009>, used under a Creative Commons Attribution License: <http://creativecommons.org/licenses/by/3.0/us/>”

Copyright © 2016, The Author(s)

Please scroll down for article—it is on subsequent pages



With 12,500 members from nearly 90 countries, INFORMS is the largest international association of operations research (O.R.) and analytics professionals and students. INFORMS provides unique networking and learning opportunities for individual professionals, and organizations of all types and sizes, to better understand and use O.R. and analytics tools and methods to transform strategic visions and achieve better outcomes. For more information on INFORMS, its publications, membership, or meetings visit <http://www.informs.org>

Generational Transitions in Platform Markets— The Role of Backward Compatibility

Tobias Kretschmer

Institute for Strategy, Technology and Organization, and Organizations Research Group,
Ludwig-Maximilians-Universität Munich, Munich 80539, Germany, t.kretschmer@lmu.de

Jörg Claussen

Copenhagen Business School, Department of Innovation and Organizational Economics, Frederiksberg 2000, Denmark,
jcl.ino@cbs.dk

The introduction of a new product generation forces incumbents in platform markets to rebuild their installed base of complementary products. Using three different data sets on the U.S. market for video game consoles, we show that incumbents can, to some extent, substitute for rebuilding their new installed base by making their new products backward compatible, which lets them draw on the installed base of software for the parent generation. However, while this positive direct effect of backward compatibility dominates in our setting, we also observe a (weaker) negative indirect effect working through the reduced supply of new software. We find that both effects are moderated by the age of the new technological generation and by the technological leap between generations: backward compatibility becomes less important with increasing console age and larger technological improvement between generations.

Keywords: backward compatibility; platform markets; installed base; video game industry

History: Received August 12, 2014; accepted August 23, 2015. Published online March 24, 2016.

1. Introduction

Successful firms in platform markets will strive to maintain their leading position even as new platform generations emerge. This is challenging because new, technologically superior generations may render some of the factors that made a firm successful in the first place obsolete. However, several mechanisms may help firms transfer their market position across platform generations. For example, since expectations matter greatly in the initial phases of the new generation, an established brand or reputation can make up for the lack of an actual installed base of users (Schilling 2003). Similarly, production processes of earlier generations may generate learning curve effects (Amit 1986) and give firms a cost advantage in the new generation if the production processes are sufficiently similar (Schilling et al. 2003). Moreover, by having been active in a prior generation, firms may have built relationships either with developers of complementary products, e.g., software, or distribution channels (Schilling 2003). Finally, the installed base of an existing platform generation (the “parent” generation) can be used as an asset by making the new generation backward compatible (Adner and Kapoor 2010, Zhu and Iansiti 2012).

In platform markets, making a new platform generation backward compatible—that is, the installed base (of hard- and/or software) of the old generation also works with the new generation—is an important strategy of passing some of the previous generations’ success on to the new generation

(Adomavicius et al. 2012). We will focus on this while accounting for many of the other mechanisms. We are particularly interested in identifying some of the contingencies of backward compatibility—that is, when is backward compatibility an especially beneficial strategy for competing across platform generations? Since much of the benefits of backward compatibility come from the availability of complementary products, i.e., indirect network effects, we study the role of parent installed base of software on hardware demand and software supply.

In our empirical setting—the home video game console industry—ensuring sufficient supply of software through backward compatibility is especially challenging since the other side of the market, video games, is supplied largely by independent firms that are not controlled by the hardware manufacturer. Hence, the effect of backward compatibility depends crucially on the reaction of the population of independent software developers (Adner and Kapoor 2010). We study the effect of backward compatibility on both sides of the market as well as the moderators of these effects. While the (direct) demand-enhancing effect of backward compatibility is well-established in the literature, we go beyond this baseline effect to address the following questions.

1. What is the effect of backward compatibility on the supply of complementary products?

2. Are the effects of backward compatibility moderated by technological progress and technological age?

We examine the U.S. market for home video game consoles from 1995 to 2010.¹ Game consoles exhibit different degrees of technological change across generations, so we can analyze the tradeoff between backward compatibility and technological progress across generations (Shapiro and Varian 1999). We estimate demand for game consoles using data sets at the product and consumer level, respectively. When exploiting variation across generations and over time in the size of the parent installed base for different backward compatible consoles, we find that backward compatibility has both the expected demand-enhancing effect on consoles (hardware) as well as a supply-reducing effect on games (software) for the new generation. However, the demand-enhancing effect of backward compatibility clearly outweighs the supply-reducing effect in our setting. Using information on the different technological generations, we can compare the effects of backward compatibility with varying installed bases and increases in console performance and find that the effect of backward compatibility (both on hardware demand and software supply) is strongest when the technological leap from the parent generation to the new generation is moderate and when the new generation has just been released. As the new generation is more technologically advanced and has been on the market longer, the effects of backward compatibility weaken.

We extend and adapt the semistructural methods developed in Clements and Ohashi (2005) and Corts and Lederman (2009) to address a completely different question than theirs: they focused on competition within a single generation and on identifying indirect network effects (Clements and Ohashi 2005) and the role of software exclusivity on hardware competition (Corts and Lederman 2009), but we study the effect of backward compatibility and its moderating factors on competition across generations. Thus, our study is closest in spirit, if not in method, to Schilling (2003), who discusses backward compatibility as a strategy for incumbents in fighting off competition from technologically superior challengers.

Our main contribution, therefore, is to identify and quantify an important channel by which firms can carry over competitive advantage across technological generations: making their products backward compatible. We identify important contingencies for which this strategy can be especially beneficial and show that there is also a negative effect of backward compatibility. More generally, by considering the effect of backward compatibility on the evolution of a system of complements, we contribute to the broader agenda toward a dynamic, consumer-centric view of strategy. We also add to the growing literature on firm strategies in

platform markets by explicitly recognizing the interdependency of the consumer and the software market and show that firms face a tradeoff between the benefits of backward compatibility and those of technological improvement in their choice of introducing a new technological generation.

2. Industry Background

The market for home video game consoles dates back to the introduction of the *Odyssey* console by Magnavox in 1972 (Forster 2005). Game consoles are part of a platform industry in which hardware manufacturers supply consoles and often also software titles, whereas software providers concentrate on developing and distributing games. Given indirect network effects (Clements and Ohashi 2005), hardware suppliers encourage the development of complementary products, namely game titles. Since the ‘Atari shock’ in the early 1980s (when the console market collapsed due to a flood in poor game titles), hardware suppliers actively manage software quality: developers must sign detailed licensing contracts which are enforced by legal and technological means (Genakos 2001). This also prevents hardware manufacturers from developing consoles that play games for other platforms.

Our sample ranges from 1995–2010. Industry observers typically consider generations of consoles. In industry terminology, we study generations IV to VII (Forster 2005). Table 1 gives an overview of the consoles we cover. We now describe the competitive landscape in each generation.

Generation IV comprised Sega’s *Genesis* and Nintendo’s *SNES*. At the start of our sample in 1995, these consoles had already been on the market for some time. Both consoles were very successful, reaching, respectively, 14 million and 20 million units sold in the United States.

Five new consoles were introduced in Generation V. While the *3DO*, the *Jaguar* from Atari, and Sega’s *Saturn* were all commercially unsuccessful, first-time entrant Sony scored a hit with their *PlayStation* being the first console to support 3D graphics. Nintendo was the last to enter the fifth generation console market last. Although their *N64* console was technologically powerful, it could not catch up sales-wise with the *PlayStation*.

The next generation (VI) started with the launch of Sega’s *Dreamcast*, which failed and prompted Sega to exit the console market altogether. Next, Sony launched their *PlayStation 2* in late 2000 and continued their enormous success from the last generation. The *PlayStation 2* was the first console offering backward compatibility: the DVD reader could also read and play CDs released for the first *PlayStation*. Nintendo’s *GameCube* was released a year later without backward compatibility,

¹ For the remainder of the paper, we will refer to the “game console” industry for brevity.

Table 1 Video Consoles Sold Between 1995 and 2010

Console	Backward compatibility	U.S. launch	Manufacturer	CPU [MHz]	Units sold [million]
<i>Generation IV</i>					
Genesis	No	8/1989	Sega	7.6	14.0
SNES	No	8/1991	Nintendo	3.6	20.0
<i>Generation V</i>					
3DO	No	3/1993	3DO	12.5	2.0
Jaguar	No	11/1993	Atari	26.6	0.1
Saturn	No	5/1995	Sega	28.6	1.4
PlayStation	No	9/1995	Sony	33.9	30.2
Nintendo 64	No	6/1996	Nintendo	93.8	18.0
<i>Generation VI</i>					
Dreamcast	No	9/1999	Sega	200	4.0
PlayStation 2	Yes	10/2000	Sony	294.9	45.0
GameCube	No	11/2001	Nintendo	485	11.6
Xbox	No	11/2001	Microsoft	733	14.3
<i>Generation VII</i>					
Xbox 360	Yes	11/2005	Microsoft	3,200	19.1
PlayStation 3	Yes	11/2006	Sony	3,200	11.3
Wii	Yes	11/2006	Nintendo	729	27.8

Note. Units sold until 2/2010 and including estimated sold units of consoles launched prior 1/1995.

and despite being state-of-the art technologically, was much less successful than the *PlayStation 2*. Finally, Microsoft entered the console market with their *Xbox* and fared quite well for a new entrant.

Generation VII did not see any new entrants, but new consoles from Microsoft, Sony, and Nintendo were introduced. Microsoft released their *Xbox 360* a year ahead of the competition and gained considerable ground compared to the less successful *PlayStation 3*. While the *Xbox 360* and the *PlayStation 3* competed head-to-head with very powerful hardware, Nintendo launched their *Wii* console with considerably less powerful hardware and successfully differentiated themselves from the competition by positioning their console for more casual gamers. All platforms in generation VII were backward compatible with their preceding (the “parent”) console.

3. Competing Across Generations Through Backward Compatibility: Theory and Hypotheses

Backward compatibility can shape competition in a new platform generation in a number of ways, most notably by providing an installed base for a new platform generation. Since an installed base (of consumers and/or complementary goods) can help firms maintain market dominance (Chen and Forman 2006, Church and Gandal 1996), incumbents have an incentive to commit to a large installed base of complementary goods (Church and Gandal 1996). Greenstein (1993) shows that compatibility between a new mainframe and the installed base of hardware in the firm matters for mainframe adoption, while Liikanen et al. (2004) and Koski and Kretschmer (2005) show how the

installed base of analog cellphones affected demand for 2G (digital) cellular telephony, suggesting that new technologies can be supported by an installed base for the old technologies.

Achieving backward compatibility may involve as little as choosing the same physical format (e.g., most early modular CD players were the same width as other components of conventional Hi-Fi systems to ensure they would fit into existing stereo systems), but often involve complex technological decisions (e.g., using legacy code for new software). In addition to the direct cost of achieving backward compatibility, backward compatibility can also entail a tradeoff as it may signal low quality by the new platform (Kim 2002) or it may curtail technological improvement (Shapiro and Varian 1999). Finally, even if technical compatibility is given, consumers may not view the old and new platforms as perfect substitutes, so the effect of backward compatibility is a matter of degree (Choi 1996, Farrell and Saloner 1992).

We discuss how backward compatibility can work directly (on new console demand) and indirectly (on new software supply). We then argue why we expect the effect of backward compatibility to be weaker for older consoles and for larger technological leaps. When an incumbent launches a technologically improved platform generation, it competes against both the incumbent’s parent generation and products offered by competitors. The larger the incumbent’s installed base and the more fragmented the new generation, the more difficult it is to overcome this startup problem (Farrell and Saloner 1985, Kretschmer 2008, Schilling 2002). With indirect network effects, firms face a chicken-and-egg problem: it is not enough to offer a new video console; consumers also expect to choose from a large installed base of games for it (Clements and Ohashi 2005, Corts and Lederman 2009, Gandal et al. 2000, Gupta et al. 1999).

The literature identifies three strategies to overcome startup problems in platform markets (Gandal et al. 2000). Firms can (1) subsidize hardware (Krishnan and Ramachandran 2011, Liu 2010), (2) increase software availability by forward integration (Schilling 2003), and (3) make the product backward compatible with the parent generation (Greenstein 1993). All three are used in the game console market, but we focus on the use of backward compatibility to transfer the parent installed base to the new generation.

3.1. The Direct Influence of Backward Compatibility on Hardware Demand

In the game console market, backward compatibility implies that the installed base of games for the parent generation can still be used with the new console. But exactly how will installed base work? So far, indirect network effects in the video game industry have been

measured through the demand-increasing effect by the number of game titles currently sold on the market (Clements and Ohashi 2005, Corts and Lederman 2009). One way to assess the effect of games for the parent console is to analyze if and how much the number of different game titles still available for the compatible parent generation affects demand for the new generation. Alternatively, the installed base of games sold for the parent generation proxies all games that could potentially be used with the new console. This seems plausible because buying old games for a new console generation may be unattractive. Instead, a larger installed base of compatible previous-generation games increases the likelihood that an adopter has access to some of these games; for example, if she owns the parent console or gets old games from friends or through second-hand trading.² This leads to our first hypothesis, reflecting our operationalization of the established result that backward compatibility increases demand.

HYPOTHESIS 1. *The larger the parent-installed base for a backward compatible new generation, the larger the demand for new hardware.*

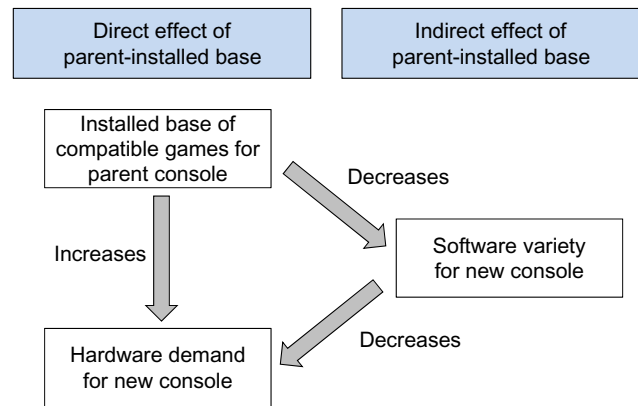
3.2. The Dark Side of Backward Compatibility

A large parent-installed base can also have a negative impact on the new generation if complementary goods from both generations are substitutes. This is because a new console can be used with games from the current generation as well as compatible games from the previous one. This affects the supply-side dynamics of game software (Adomavicius et al. 2012). Since most games are provided by independent developers, developers of new games will face more competition—not only from competitors in the same generation, but also from their predecessors (Kretschmer 2008). Given the fixed-cost nature of game development, developers will expect less revenues to cover their (sunk) fixed costs, so their incentive to develop and release new games—basically, to enter the new generation—decreases (Sutton 1998). Therefore, what may benefit the hardware market because there is an installed base of complementary goods available may harm the software market because it decreases the incentives to develop software for the new generation. To summarize:

HYPOTHESIS 2. *The larger the parent-installed base for a backward compatible new generation, the lower the supply of new software titles.*

This effect represents the “dark side” of backward compatibility. The net effect of backward compatibility on hardware success then depends on two counter-

Figure 1 (Color online) Dual Effect of Parent-Installed Base



vailing effects (Figure 1): the direct effect suggests that availability of games for the compatible parent console is a (part-)substitute for variety of new games, increasing hardware demand. The indirect effect of backward compatibility implies that the substitution of new games by old games reduces new software demand, which in turn lowers software supply, eventually lowering hardware demand.

3.3. Importance of Backward Compatibility Over Time

As discussed, backward compatibility may help solve the startup problem in network markets. The startup phase is usually characterized by a low number of available game titles for the new generation. The availability of a parent generation’s installed base of compatible games can to a certain extent compensate for the lack of a large variety of new game titles. However, users are expected to prefer game titles designed for the new generation over previous-generation titles as new games (unlike old ones) make full use of the technical features of the new console. Therefore, as more titles for the new console become available, consumers will buy the console for its supply of new games rather than for the existence of a large installed base of outdated games. This is summarized in Hypothesis 3A.

HYPOTHESIS 3A. *The positive effect of a parent-installed base for a backward compatible new generation on new hardware demand gets weaker with increasing age of the new technological generation.*

Analogous to Hypotheses 1 and 2, we expect the effect of backward compatibility on software supply to be the opposite compared to hardware demand. We therefore expect the substitutive effect between old and new games to decline over time, leading to increased software availability.

HYPOTHESIS 3B. *The negative effect of a parent-installed base for a backward compatible new generation on new software supply gets weaker with increasing age of the new technological generation.*

² There is a sizable second-hand market for console games. For example, as of January 2, 2015, a total of 1,395,890 used games were offered on eBay.com.

3.4. Backward Compatibility and Technological Progress

Our final set of hypotheses addresses the tradeoff between backward compatibility and technological progress. Kim (2002) shows that incompatibility with the parent installed base may serve as a signal of high quality, and Shapiro and Varian (1999) point to the tradeoff between “evolution” (backward compatibility with limited technological improvement) and “revolution” (no backward compatibility at drastically increased performance) strategies as being determined by technological restrictions. Major performance increases can only be secured by using the latest technology, which makes it more difficult or costly to draw on the parent installed base. In our setting, however, backward compatibility is not technically restricted and product quality is largely known.³ Moreover, an old game runs just as well on a new console as on an old one, so technological improvements may affect demand in general, but not the strength of the effect of backward compatibility. However, the degree of substitutability rests on the extent to which games exploit the technical capabilities of a console (Claussen et al. 2015). Since games for the old generation were designed with a different set of technological restrictions, new games will differ in their performance, especially if the set of restrictions imposed by the current generation has changed considerably (Shy 1996). In our setting, we can identify the relative importance of technological improvement and backward compatibility if both are present.

The effects of technological progress and backward compatibility may be substitutes even absent a technological tradeoff. Instead, we test for a consumer-driven tradeoff between these effects. As technological improvement on the hardware side permits the design of better (i.e., more elaborately programmed) games, an old game will be a worse substitute as the technological frontier is pushed out. We thus expect technological progress to have a moderating effect on both the demand and supply side effects of the parent installed base, summarized in Hypotheses 4A and 4B.

HYPOTHESIS 4A. *The positive effect of a parent-installed base for a backward compatible new generation on new hardware demand gets weaker with increasing technological progress between generations.*

HYPOTHESIS 4B. *The negative effect of a parent-installed base for a backward compatible new generation on new software supply gets weaker with increasing technological progress between generations.*

³ Consoles typically perform as advertised and a large part of consumer utility comes from the quality and variety of available games.

4. Data and Estimation Model

4.1. Data

4.1.1. Data Sources. The core data set for our analysis comes from the market research firm NPD Group and consists of monthly unit sales and revenues in the market for game consoles in the United States from the period 1/1995–2/2010.⁴ Data on games are also from NPD Group. The software data consists of monthly unit sales and revenue data for all available titles. For each title, the associated console is reported.

We also match data on a console’s processing power measured as CPU speed in megahertz (MHz). The main data source for this is Forster (2005), completed with data from suppliers’ websites, console databases, and console information websites. Prices are deflated using the U.S. deflator by the International Monetary Fund to enable comparison of console and game prices over the sample period.⁵ We use monthly population estimates from the U.S. census to proxy for market potential. Finally, we use USD-JPY exchange rates from the Pacific Exchange Rate Service⁶ for a price instrument discussed in §4.3.1. Two other data sets used in robustness checks will be introduced in §§6.2 and 6.3.

4.1.2. Variables. Variables are described in Table 2. Summary statistics are reported in Table 3. In line with Corts and Lederman (2009), we eliminate the influence from outdated consoles selling remainders or products that never reached a wider audience by considering only devices that sold more than 1,000 units in a given month.⁷

Market shares in the market for game consoles $s_{jt|B(t)=1}$ are calculated by dividing monthly unit sales of console j by total units sold in a given month. To derive s_{jt} and s_{0t} , we have to define potential market size. In line with Clements and Ohashi (2005) we use the number of TV households to proxy for the number of potential buyers. From this, we derive s_{jt} , a console’s market share of market potential⁸ and s_{0t} , the market share of the outside good, i.e., the share of potential consumers that do not have a console and do not buy one in the given time period. By cumulating the unit sales of consoles, we also derive each console’s

⁴ We include hardware-only sales, i.e., just the console, and packages comprising a console and a game. Both are treated equally in the analysis as (i) package prices do not differ significantly from that of single consoles and (ii) a clear separation is not possible with our data. Moreover, many consoles are rarely sold on their own.

⁵ We used the International Monetary Fund’s World Economic Outlook Database for this.

⁶ Available at <http://fx.sauder.ubc.ca/>.

⁷ The mean monthly total number of units sold is 235,678.

⁸ Market potential is defined as market size minus the number of people who already bought a game console.

Table 2 Variable Definitions

Variable	Definition
s_{jt}	Market share of console j at time t (relative to market potential)
s_{0t}	Market share of the outside good (no console purchase)
$s_{jt B(t)=1}$	Within-group market share (share within the handheld market)
N_{jt}	Available software titles for current format (hundreds)
p_{jt}	Deflated console price (1995 prices)
x_{jt}^{CPU}	Normalized CPU speed of the console
IB_{jt}^{HW}	Installed base of consoles for the current console (millions)
$IB_{j-1,t}^{\text{SW}}$	Installed base of games for the compatible parent console (100 millions)
a_{jt}	Age of the console (months)
$IMPR_{j,j-1}^{\text{CPU}}$	Relative improvement of CPU to parent console

Table 3 Summary Statistics

Variable	N	Mean	SD	Min	Max
$\log(s_{jt}/s_{0t})$	816	-6.26	1.63	-11.11	-1.79
$\log(s_{jt B(t)=1})$	816	-2.06	1.38	-7.28	-0.44
N_{jt}	816	4.20	3.54	0.05	15.81
p_{jt}	816	180.77	112.82	21.24	615.35
x_{jt}^{CPU}	816	0.00	0.99	-1.36	4.41
IB_{jt}^{HW}	816	12.83	10.72	0	44.87
$IB_{j-1,t}^{\text{SW}}$	816	0.80	1.39	0	5.22
a_{jt}	816	46.35	33.45	0	134.00
$IMPR_{j,j-1}^{\text{CPU}}$	816	5.06	7.13	0	25.19

hardware installed base IB_{jt}^{HW} .^{9, 10} Finally, we divide revenue by units to calculate each console's average monthly price p_{jt} . All prices are in 1995 USD.

Software variety N_{jt} is taken from the NPD data. For every platform we count the number of game titles with positive sales to obtain N_{jt} . Therefore, N_{jt} can decline over time if game titles are no longer sold. We also create the software installed base of the compatible parent generation $IB_{j-1,t}^{\text{SW}}$.

The last set of variables concerns the processing power of the consoles. The data set covers a period in which technological progress for video consoles was remarkable: the CPU of the SNES ran at 3.6 MHz, and PlayStation 3 ran at 3,200 MHz. As the data cover the entire period, this causes problems in comparing devices' capabilities. Comparing a recent console that is technically below average to the best device from 1995 would make the first one look far too good. We therefore normalize CPU speed by calculating yearly mean values and standard deviation and construct a z-score for each console-month. Finally, we derive

⁹ In line with Clements and Ohashi (2005), we depreciate the installed base with 5% annually.

¹⁰ At the start of our data set (1/1995), four consoles (*Genesis*, *SNES*, *3DO*, and *Jaguar*) have already been on the market. We collected data on their total U.S. unit sales from various Internet sources and deducted our observed sales to calculate hardware installed base in 1/1995.

$IMPR_{j,j-1}^{\text{CPU}}$ as the percentage improvement of the CPU speed compared to the CPU speed of the compatible parent generation.¹¹

4.2. Model Specification

We estimate hardware demand and software supply. We use a structural model to estimate hardware demand and a reduced-form model for software supply (Clements and Ohashi 2005, Corts and Lederman 2009, Nair et al. 2004). Using a structural model allows us to compare and interpret the coefficients for our variables of interest quantitatively. This is useful for our purposes because we want to be able to interpret the relative strengths of different effects and precisely identify potential moderators.

4.2.1. Hardware Demand. We model hardware demand using a structural model that extends the standard discrete-choice model for differentiated products by measures of parent-installed bases. We assume that each potential adopter i of video consoles maximizes utility by choosing the highest u_{ijt} where $j \neq 0$ represents the different consoles and $j = 0$ denotes the outside option of not buying a console. The consumer's utility function has the following (additive) functional form:

$$u_{ijt} = \beta x_{jt} + \alpha p_{jt} + \omega N_{jt} + \xi_{jt} + v_{ijt} + \gamma_1 IB_{j-1,t}^{\text{SW}} + \gamma_2 IMPR_{j,j-1} + \gamma_3 [IMPR_{j,j-1}^{\text{CPU}} \cdot IB_{j-1,t}^{\text{SW}}] + \gamma_4 a_{jt} + \gamma_5 [a_{jt} \cdot IB_{j-1,t}^{\text{SW}}]. \quad (1)$$

The first part of the utility function represents the baseline model without accounting for backward compatibility: utility depends on observed product characteristics x_{jt} , console price p_{jt} , software variety N_{jt} unobserved characteristics ξ_{jt} , and an idiosyncratic error term v_{ijt} that can be interpreted as the difference between consumer i 's valuation and mean utility.

We extend this model to capture the effects of backward compatibility. First, we add the installed base $IB_{j-1,t}^{\text{SW}}$ of the prior generation's compatible games. We use this to test Hypothesis 1 and expect it to have a positive influence on the buyer's selection decision. Second, we add the improvement factor over the compatible parent $IMPR_{j,j-1}^{\text{CPU}}$ and its interaction with parent-installed base $IMPR_{j,j-1}^{\text{CPU}} \cdot IB_{j-1,t}^{\text{SW}}$. The improvement factor expresses the relative increase in CPU speed compared to the CPU speed of the parent generation. Following Hypothesis 4A, we expect the interaction term to have a negative effect on buyer utility. Further, we add console age a_{jt} as well as an interaction term of a parent installed base and console age $a_{jt} \cdot IB_{j-1,t}^{\text{SW}}$. For

¹¹ We set this variable to zero if there is no active parent console.

console age, we expect a negative effect as older consoles are less attractive to the remaining nonadopters. In line with Hypothesis 3A, we expect a negative coefficient for the interaction term between console age and parent installed base, as we expect the effect of backward compatibility to be more important in the launch phase of a new platform generation.

As in Clements and Ohashi (2005), we assume v_{ijt} to be identically and independently distributed with an extreme value distribution function to generate a nested logit model (Berry 1994). Potential adopters decide first to buy a handheld game console or not, and if they decide to buy one, they then select a specific console. In contrast to a simple logit model, substitution patterns can therefore differ between the decision of buying a console and the decision about which console to buy. Setting the utility of the outside good equal to zero (Berry 1994), we get a linear regression equation:

$$\begin{aligned} \ln(s_{jt}) - \ln(s_{0t}) &= \beta x_{jt} + \alpha p_{jt} + \omega N_{gt} + \xi_{jt} + \sigma \ln(s_{jt|B(t)=1}) + \gamma_1 IB_{j-1,t}^{SW} \\ &+ \gamma_2 IMPR_{j,j-1} + \gamma_3 [IMPR_{j,j-1}^{CPU} \cdot IB_{j-1,t}^{SW}] \\ &+ \gamma_4 a_{jt} + \gamma_5 [a_{jt} \cdot IB_{j-1,t}^{SW}]. \end{aligned} \quad (2)$$

4.2.2. Software Supply. We follow prior literature when estimating software supply (Clements and Ohashi 2005, Corts and Lederman 2009). Software supply is expressed by the variety of different game titles N_{jt} available for a specific platform. We estimate the following reduced-form equation:

$$\begin{aligned} N_{jt} &= \alpha_b + \gamma_1 IB_{jt}^{HW} + \gamma_2 a_{jt} + \gamma_3 [a_{jt} \cdot IB_{jt}^{HW}] + \eta_{jt} \\ &+ \gamma_4 IB_{j-1,t}^{SW} + \gamma_5 IMPR_{j,j-1}^{CPU} \\ &+ \gamma_6 [IMPR_{j,j-1}^{CPU} \cdot IB_{j-1,t}^{SW}] \\ &+ \gamma_7 [a_{jt} \cdot IB_{j-1,t}^{SW}]. \end{aligned} \quad (3)$$

The first line of the equation is the base model with α_b being brand-specific dummies, IB_{jt}^{HW} the installed base of console of the current generation, a_{jt} console age, and η_{jt} an error term. We interact hardware installed base with console age and extend the model with the same measures of parent-installed base as our hardware demand equation. Following Hypothesis 2, we expect $IB_{j-1,t}^{SW}$ to negatively affect software supply as the parent installed base of software might partly substitute for demand for new game titles. Further, we interact the parent installed base with console age to test Hypothesis 3B. Moreover, console age can proxy for developers' expectations regarding future sales. From Hypothesis 4B we expect the interaction term of $IB_{j-1,t}^{SW}$ with the relative performance increase to be positive since this reduces the importance of backward compatibility on the demand side so we expect less substitution.

4.3. Endogeneity

4.3.1. Hardware Demand. The potential endogeneity of within-group share $s_{jt|B(t)=1}$, price p_{jt} , and software variety N_{jt} requires the identification of appropriate instruments. We use the same instruments as Clements and Ohashi (2005) and Corts and Lederman (2009). Within-group share is correlated with the error term ξ_{jt} as it contains part of the dependent variable s_{jt} . The error term ξ_{jt} is known to firms and consumers in the market (but not the econometrician), therefore differences in unobserved quality might lead to different price setting and thus a correlation of the console price p_{jt} and ξ_{jt} . Finally, autocorrelation of ξ_{jt} leads to a positive correlation between ξ_{jt} and the measure of software variety N_{jt} .

We use USD-JPY exchange rates as a cost side instrument for prices because many consoles come from Japan. Exchange rates seem a valid price instrument as their change would lead to price adjustment in the U.S. market. However, it does not let us identify effects at the console level.

Further, we use the average age of software titles currently available on the market to instrument for within-group share and console price. A high average age of games is a sign for missing supply of new game titles. Hence, we expect negative correlations of average software age, both with within-group share as a lack of new games reduces the console's relative attractiveness, and with console price as console manufacturers may try to counter this adverse effect by lowering prices.

Finally, we construct several instruments measuring the competition faced by a platform (Berry et al. 1995). We use the sum of competing consoles' cumulative CPU speed, the total number of competing platforms, the number of competing platforms by one manufacturer and the number of competing platforms within the same generation as instruments. Following Corts and Lederman (2009), we expect these instruments to be correlated with each of the three endogenous variables: with within-group share as they affect utility of different options, with software variety as they influence incentives to provide game titles, and with price as they affect the ability to raise prices.

Another concern could be that console launches are not exogenous, i.e., that they are chosen according to the demand and supply situation of the current generation. While theoretically possible, we feel that this is not a major issue in our setting for two reasons: first, we study the decisions of consumers and developers, and for both, the launch was exogenous because they did not control it. However, if purchase and development decisions are made in anticipation of future console releases, and releases are made with these expectations in mind, our results might be biased. We address this in a robustness test in our results section (Footnote 16).

Second, release dates may get shifted by weeks or months but not years, since the lifecycle of a (successful) console is around four years, and because the speed of progress is dictated by (fairly predictable) advances in CPU technology. Given that our key independent variable of interest, installed base, builds up over several years, we do not feel that such relatively minor shifts play a major role in our results.

4.3.2. Software Supply. The installed base of hardware IB_{jt}^{HW} is possibly endogenous as unobserved shocks in the software market might lead to increased software entry but also to increased hardware adoption. We again use the instruments proposed by Clements and Ohashi (2005) to account for this. The average age of software titles on the market serves as an instrument, although the direction in which the instrument works is not clear. A high average software age could either indicate profitable opportunities or tough competition. We also use squared console age and an interaction term between console age and average software age as supply-side instruments. Finally, while the theoretical possibility of endogenous console launches also exists for game developers, we run a robustness test in §6.1 that suggests endogeneity does not bias our results.

5. Results

Our 2-stage least squares (2SLS) estimation results are reported in Table 4.¹² Columns 4a-1 and 4b-1 report results without parent-installed base, 4a-2 and 4b-2 include just the linear term of parent-installed base, and 4a-3 and 4b-3 include the interaction terms and the hardware improvement factor. In all specifications, we use brand dummies to control for unobserved brand-specific effects as well as calendar month dummies to control for the strong seasonality in console sales. All 2SLS estimations are robust to arbitrary heteroskedasticity and arbitrary autocorrelation.

We first discuss results for the main effect of backward compatibility (Hypotheses 1 and 2) before turning to the moderating effects of console age (Hypotheses 3A/3B) and technological progress (Hypotheses 4A/4B).

Our control variables have the expected signs across specifications. With increasing age, both hardware demand and software supply go down. The industry exhibits indirect network effects as the availability of more software variety N_{gt} positively influences demand, and the availability of a larger hardware installed base in turn increases software variety. Price elasticity of demand is negative and there is a strong positive seasonal effect (not reported) in November

and December for both demand and supply.¹³ Higher CPU speed increases demand.

5.1. Effect of Backward Compatibility on Hardware Demand and Software Supply

We now discuss the first-order effect of parent-installed base $IB_{j-1,t}^{SW}$ on hardware demand and software supply separately.

5.1.1. Hardware Demand. Base $IB_{j-1,t}^{SW}$ has a positive and significant coefficient for both specifications (4a-2) and (4a-3), supporting Hypothesis 1. For specification (4a-2), we compare the effect of parent-installed base with indirect network effects from software variety N_{jt} : one game title for the current generation has the same impact on demand as 617,391 game titles sold for the parent generation.¹⁴ At the launch of the Xbox 360 in November 2005, the installed base of 118 million compatible Xbox games corresponded to 192 available game titles for the new generation in the demand equation. In the actual event, only 19 titles were actually available at launch and it took until October 2007 for 192 titles to be available.

5.1.2. Software Supply. Adding $IB_{j-1,t}^{SW}$ to the baseline specification in estimation (4b-2) and in the full model (4b-3), we obtain a significant negative effect on software variety. The estimates in model (4b-2) suggest that every million copies in the parent-installed base leads to 0.172 fewer game titles offered on the market. Looking again at the Xbox 360, the installed base of 118 million compatible Xbox games would reduce software supply by 20 titles at its launch date. This implies that absent a parent-installed base, 39 games would have been available at the launch of the Xbox 360.

As reduced software supply also translates into reduced demand, we can compare the strength of the direct demand-enhancing effect of backward compatibility with the indirect demand-reducing effect. When using the estimates from model (4a-2) and (4b-2), we see that the coefficient for the direct effect in model (4a-2) of 0.230 clearly outweighs the size of the indirect effect of -0.027 .¹⁵ The dominance of the direct effect over the indirect effect also holds when comparing the relative coefficient sizes in the full models (4a-3) and (4b-3).

¹³ Because the right-hand side of the hardware demand model is the mean utility of console j in month t , the magnitudes of the coefficients for the demand model cannot be interpreted in a meaningful way (Corts and Lederman 2009). We therefore compare the strengths of different effects or discuss marginal effects from changes in a console's backward compatibility.

¹⁴ The average unit sales of games in our sample are 196,606.

¹⁵ The strength of the demand-reducing indirect effect is calculated by multiplying the coefficient for parent installed base of -0.172 from model (4b-2) with the coefficient for number of available games of 0.157 from model (4a-2).

¹² The corresponding ordinary least squares (OLS) regression results are available from the authors and show the same signs and significance for our hypothesis tests.

Table 4 Estimates for Hardware Demand and Software Supply

Panel A: Hardware demand, dependent variable: $\ln(s_{jt}) - \ln(s_{0t})$			
	(4a-1)	(4a-2)	(4a-3)
SW installed base $IB_{j-1,t}^{SW}$ [100 millions]		0.230*** (0.0512)	0.989*** (0.161)
Interaction term $IB_{j-1,t}^{SW} \cdot a_{jt}$			-0.00540*** (0.00157)
Interaction term $IB_{j-1,t}^{SW} \cdot IMPR_{j,j-1}^{CPU}$			-0.0674*** (0.0118)
HW improvement $IMPR_{j,j-1}^{CPU}$			-0.00520 (0.00336)
Console age a_{jt}	-0.0199*** (0.00676)	-0.0107*** (0.00368)	-0.00200 (0.00218)
No. of available games N_{jt} [hundreds]	0.332*** (0.0699)	0.157*** (0.0339)	0.142*** (0.0349)
Deflated price p_{jt}	-0.00198 (0.00157)	-0.00237* (0.00123)	-0.00147 (0.000909)
$\ln(\text{within-group share } s_{jt B(t)=1})$	0.476*** (0.105)	0.712*** (0.0526)	0.738*** (0.0447)
Normalized CPU speed x_{jt}^{CPU}	0.602*** (0.146)	0.295*** (0.0707)	0.395*** (0.0857)
Observations	816	816	816
R^2	0.757	0.900	0.934
Hansen's J	2.198	6.032	15.48
Panel B: Software supply, dependent variable: N_{jt} [hundreds]			
	(4b-1)	(4b-2)	(4b-3)
SW installed base $IB_{j-1,t}^{SW}$ [100 millions]		-0.172*** (0.0418)	-2.150*** (0.189)
Interaction term $IB_{j-1,t}^{SW} \cdot a_{jt}$			0.0189*** (0.00174)
Interaction term $IB_{j-1,t}^{SW} \cdot IMPR_{j,j-1}^{CPU}$			0.173*** (0.0215)
HW improvement $IMPR_{j,j-1}^{CPU}$			-0.103*** (0.00841)
Console age a_{jt}	-0.0182*** (0.00451)	-0.0213*** (0.00467)	-0.0132*** (0.00487)
HW installed base IB_{jt}^{HW} [millions]	0.552*** (0.0209)	0.564*** (0.0212)	0.523*** (0.0227)
Interaction term $IB_{jt}^{HW} \cdot a_{jt}$	-0.00215*** (0.000224)	-0.00219*** (0.000234)	-0.00269*** (0.000190)
Observations	816	816	816
R^2	0.855	0.856	0.914
Hansen's J	76.37	74.70	61.80

Notes. 2SLS estimates. Standard errors in parentheses are robust to arbitrary heteroskedasticity and arbitrary autocorrelation. Brand dummies, calendar month dummies, and constant are included but not reported.

*** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

5.2. Importance of Backward Compatibility Over Time

In our Hypotheses 3A and 3B, we argued that the influence of backward compatibility declines over time as more games for the current generation become available. Therefore, we add an interaction term between console age and the size of the parent generation's compatible installed base.

5.2.1. Hardware Demand. The significant and negative sign of the interaction term $IB_{j-1,t}^{SW} \cdot a_{jt}$ supports

Hypothesis 3A. Combining the effects of the installed base with the interaction term for specification (4a-3), we see that the demand-enhancing effect of backward compatibility declines by 6.6% per year.

5.2.2. Software Supply. The interaction term $IB_{j-1,t}^{SW} \cdot a_{jt}$ is positive and significant, supporting Hypothesis 3B. Comparing again the effect strength of the main effect $IB_{j-1,t}^{SW}$ with the interaction term, we see that the supply-reducing effect of the installed base declines by 10.5% per year.

Table 5 Estimates for Different Rolling Windows of $IB_{g-1,t}^{SW}$ as Well as for Considering Only Superstar Games for $IB_{g-1,t}^{SW}$ (Panel A) and for Software Supply Only by Third Parties (Panel B)

Panel A: Hardware demand, dependent variable: $\ln(s_{jt}) - \ln(s_{0t})$				
	(5a-1)	(5a-2)	(5a-3)	(5a-4)
Length of rolling window	3 years	2 years	1 year	Superstar
SW installed base $IB_{j-1,t}^{SW}$ [100 millions]	1.423*** (0.362)	1.831*** (0.324)	1.926*** (0.323)	1.938*** (0.336)
Interaction term $IB_{j-1,t}^{SW} \cdot a_{jt}$	-0.0109*** (0.00385)	-0.0104*** (0.00318)	-0.0108*** (0.00318)	-0.00959*** (0.00286)
Interaction term $IB_{j-1,t}^{SW} \cdot IMPR_{j,j-1}^{CPU}$	-0.0896*** (0.0276)	-0.125*** (0.0243)	-0.131*** (0.0237)	-0.146*** (0.0267)
HW improvement $IMPR_{j,j-1}^{CPU}$	-0.00342 (0.00390)	-0.00518 (0.00355)	-0.00538 (0.00345)	-0.00493 (0.00344)
Console age a_{jt}	-0.00310 (0.00272)	-0.00269 (0.00237)	-0.00235 (0.00226)	-0.00105 (0.00224)
No. of available games N_{jt} [hundreds]	0.194*** (0.0483)	0.158*** (0.0382)	0.151*** (0.0361)	0.148*** (0.0374)
Deflated price p_{jt}	-0.000495 (0.00102)	-0.00152 (0.000949)	-0.00155* (0.000937)	-0.000843 (0.000884)
$\ln(\text{within-group share } s_{jt B(t)=1})$	0.705*** (0.0572)	0.730*** (0.0476)	0.733*** (0.0458)	0.740*** (0.0475)
Normalized CPU speed x_{jt}^{CPU}	0.396*** (0.106)	0.405*** (0.0919)	0.405*** (0.0883)	0.395*** (0.0895)
Observations	816	816	816	816
R^2	0.911	0.928	0.932	0.929
Hansen's J	21.10	16.46	15.84	17.49
Panel B: Software supply, dependent variable: N_{jt} [hundreds]				
	(5b-1)	(5b-2)	(5b-3)	(5b-4)
Length of rolling window	3 years	2 years	1 year	3rd party
SW installed base $IB_{j-1,t}^{SW}$ [100 millions]	-3.062*** (0.362)	-3.870*** (0.364)	-4.096*** (0.373)	-2.439*** (0.208)
Interaction term $IB_{j-1,t}^{SW} \cdot a_{jt}$	0.0324*** (0.00347)	0.0342*** (0.00337)	0.0359*** (0.00346)	0.0209*** (0.00187)
Interaction term $IB_{j-1,t}^{SW} \cdot IMPR_{j,j-1}^{CPU}$	0.241*** (0.0409)	0.320*** (0.0408)	0.334*** (0.0424)	0.201*** (0.0222)
HW improvement $IMPR_{j,j-1}^{CPU}$	-0.0964*** (0.00830)	-0.102*** (0.00839)	-0.102*** (0.00840)	-0.0881*** (0.00643)
Console age a_{jt}	-0.0130*** (0.00505)	-0.0147*** (0.00488)	-0.0142*** (0.00487)	-0.0178*** (0.00326)
HW installed base IB_{jt}^{HW} [millions]	0.496*** (0.0241)	0.517*** (0.0231)	0.520*** (0.0229)	0.424*** (0.0151)
Interaction term $IB_{jt}^{HW} \cdot a_{jt}$	-0.00240*** (0.000185)	-0.00255*** (0.000188)	-0.00261*** (0.000189)	-0.00193*** (0.000147)
Observations	816	816	816	813
R^2	0.908	0.912	0.913	0.924
Hansen's J	68.58	64.26	62.97	52.87

Notes. 2SLS estimates. Standard errors in parentheses are robust to arbitrary heteroskedasticity and arbitrary autocorrelation. Brand dummies, calendar month dummies, and constant are included but not reported.

*** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

5.3. Backward Compatibility and Technological Progress

We now turn to the interaction between parent-installed base and technological progress.

5.3.1. Hardware Demand. Our results support Hypothesis 4A; the interaction term has a significantly

negative coefficient. Combining the counteracting effects of a parent-installed base and the interaction term for specification (4a-3), we see that parent-installed base has a positive effect if the percentage increase in CPU speed compared to the compatible parent generation is smaller than 1,467%. The largest technological leap between two

contiguous generations in our data set is the switch from the *PlayStation 2* to *PlayStation 3*. For this generation change, CPU speed increased from 294.9 MHz to 3,200 MHz, an increase of 985%. Here, compatibility with the parent installed base played a much weaker (although still positive) role. This coincides with the observation that Sony lost its dominant position in the game console market to the *Xbox 360* and the *Wii*.

5.3.2. Software Supply. The results from specification (4b-3) supports Hypothesis 4B that higher technological progress between generations reduces the supply-decreasing effect of a large parent installed base. We see a substitutive effect from a parent-installed base as long as the technological leap is smaller than 1,242%. Thus, the *PlayStation 3* still experienced reduced game supply through backward compatibility, but the effect was much weaker than for consoles with smaller technological improvements.

6. Robustness Tests

Our results show a strong effect of backward compatibility on the demand of new hardware generations. Even though our measure of parent installed base also changes within each console as console generations usually overlap and software for the old generation is still sold while the new generation is already on the market, we only observe a limited number of different consoles. We therefore want to rule out that backward compatibility simply proxies for other unobserved factors. We address this in three ways: First, we discuss if producer-specific effects might drive our results. Second, we re-run our analysis with data from the adjacent industry of handheld video game consoles. Third, using a consumer-level data set, we exploit consumer-level heterogeneity to clearly attribute the effect of backward compatibility on demand to parent-installed base.¹⁶

6.1. Producer-Specific Effects

We control for effects specific to the console producer by including brand dummies in all specifications. These brand dummies capture all time-invariant effects such as reputation, distribution networks, or technological capability. One possibility would be that unobserved (by the econometrician) brand attractiveness or relationships to retailers may have grown over time and that the parent installed base simply proxies for this increase rather than a “real” effect of backward compatibility. To alleviate this possible bias, we run our preferred regressions (4a-3 and 4b-3) using the rolling software installed base $IB_{j-1,t}^{SW}$ of the three years, two

years, and one year before the observation month instead of the overall installed base. Results are shown in Table 5 and show a qualitatively similar picture as our baseline results. Unless reputation or retailer relationships closely follow recent (not generational) sales, this renders these alternative explanations unlikely. For hardware demand, we run an additional robustness test (5a-4) in which only superstar games with more than 500,000 copies sold count towards the parent installed base $IB_{g-1,t}^{SW}$. Finally, as game release patterns of console manufacturers could differ from third-party developers and to rule out issues of console launches chosen endogenously to maximize joint console and game profits, we run an additional software supply estimation (5b-4) in which we only consider games published by 3rd parties and not the console manufacturers themselves. Our results are highly robust to all these variations.

6.2. Handheld Consoles

To make sure that our results are not driven by the peculiarities of the specific submarket of the video game industry, we repeat our analysis in the adjacent, but competitively different, industry of handheld video game consoles. Handheld consoles, like regular consoles, are platforms of hard- and software, but they have built-in screens and are battery-powered and therefore portable.

The generations in the handheld console industry evolved parallel to the video console industry and we also observe Generations IV–VII. The fourth generation was dominated by Nintendo’s *Game Boy/Game Boy Pocket*¹⁷ consoles with Sega’s *Game Gear* being the only competitor. Nintendo maintained their dominant position in the next generation with the backward compatible *Game Boy Color* but also released the 3D console *Virtual Boy*, which was a commercial failure. The competing *game.com/game.com Pocket Pro* consoles could not challenge Nintendo’s dominant position. Nintendo’s success continued in the sixth generation with the *Game Boy Advance/Game Boy Advance SP* consoles that were again backward compatible. New competition in the form of the *Neo Geo Pocket Color* and Nokia’s *N-Gage/N-Gage QD* did not succeed. The only strong competitor for Nintendo emerged in Generation VII with Sony’s *PlayStation Portable/PlayStation Portable Slim* consoles being as successful as Nintendo’s *DS/DS Lite*.

We construct the data for this robustness test from NPD data, including all handheld console and software

¹⁶ We also ran robustness tests (available from the authors) regarding the potential impact of consumer and developer expectations by including forward-looking installed base, the current growth trajectory, and excluding the months immediately preceding a new console’s launch. Our results are qualitatively unchanged.

¹⁷ In the handheld console industry, manufacturers often release two versions of a console, with the second one still playing the same games but being more lightweight. For example, the original *Game Boy* weighs 300 g while the (technically identical) *Game Boy Pocket* weighs 148 g.

Table 6 Demand and Supply Estimates for Handheld Video Consoles

Panel A: Hardware demand, dependent variable: $\ln(s_{jt}) - \ln(s_{0t})$			
	(6a-1)	(6a-2)	(6a-3)
SW installed base $IB_{g-1,t}^{SW}$ [100 millions]		1.492*** (0.125)	1.411** (0.708)
Interaction term $IB_{g-1,t}^{SW} \cdot a_{jt}$			−0.0314*** (0.00956)
Interaction term $IB_{g-1,t}^{SW} \cdot IMPR_{g,g-1}^{CPU}$			−0.388*** (0.139)
HW improvement $IMPR_{g,g-1}^{CPU}$			0.897*** (0.197)
Console age a_{jt}	−0.0239*** (0.00432)	−0.0109*** (0.00235)	−0.00489** (0.00233)
No. of available games N_{gt} [hundreds]	0.458*** (0.0608)	0.0775** (0.0301)	0.117** (0.0534)
Deflated price p_{jt}	−0.00885* (0.00454)	−0.00897*** (0.00256)	−0.00708** (0.00356)
$\ln(\text{within-group share } s_{jt B(t)=1})$	0.795*** (0.116)	0.737*** (0.0617)	0.655*** (0.0931)
Normalized console weight x_{jt}^{weight}	0.261* (0.155)	−0.254*** (0.0921)	−0.322*** (0.102)
Normalized CPU speed x_{jt}^{CPU}	0.174 (0.119)	0.157** (0.0690)	0.169* (0.0895)
Observations	502	502	502
R^2	0.856	0.952	0.958
Hansen's J	8.171	34.37	34.45
Panel B: Software supply, dependent variable: N_{gt} [hundreds]			
	(6b-1)	(6b-2)	(6b-3)
SW installed base $IB_{g-1,t}^{SW}$ [100 millions]		−0.110 (0.0840)	−1.278*** (0.285)
Interaction term $IB_{g-1,t}^{SW} \cdot a_{gt}$			−0.000489 (0.00386)
Interaction term $IB_{g-1,t}^{SW} \cdot IMPR_{g,g-1}^{CPU}$			0.510*** (0.0615)
HW improvement $IMPR_{g,g-1}^{CPU}$			−0.198 (0.123)
Format age a_{gt}	−0.0158*** (0.00156)	−0.0160*** (0.00157)	−0.0216*** (0.00120)
HW installed base IB_{gt}^{HW} [millions]	0.346*** (0.00571)	0.352*** (0.00597)	0.382*** (0.0121)
Interaction term $IB_{gt}^{HW} \cdot a_{gt}$	−0.00132*** (0.000105)	−0.00138*** (0.000104)	−0.00148*** (0.000128)
Observations	417	417	417
R^2	0.979	0.978	0.983
Hansen's J	12.93	10.69	19.33

Notes. 2SLS estimates. Standard errors in parentheses are robust to arbitrary heteroskedasticity and arbitrary autocorrelation. Brand dummies, calendar month dummies, and constant are included but not reported.

*** $p < 0.01$, ** $p < 0.05$, and * $p < 0.1$.

sales in the United States from 1/1995 until 11/2007. Using the same estimation model as for the video consoles,¹⁸ we repeat the baseline specifications from Table 4 in Table 6 for the handheld industry. The results are in line with our earlier results: a compatible parent-

installed base increases demand (Hypothesis 1), we find partial confirmation for the supply-reducing effect of backward compatibility (Hypothesis 2) and the importance of backward compatibility over time (Hypotheses 3A/3B), and strong support for the moderating role of technological progress (Hypotheses 4A/4B).

6.3. Micro-Level Evidence

We used aggregated console-specific monthly data in our baseline analysis. To get an even deeper understanding of the mechanisms driving the installed base

¹⁸ The only difference in notation is that we distinguish between consoles j (e.g., *Game Boy Pocket*) and console generations g (e.g., *Game Boy* and *Game Boy Pocket*) since we can distinguish hardware at the console level, but software is the same within each console generation. We also add console weight as an additional control variable.

Table 7 Micro-Level Evidence for Hardware Demand

Dependent variable: Purchase of console j		
	(7-1)	(7-2)
<i>Coefficients</i>		
SW installed base $\ln(IB_{j-1,i}^{SW})$	0.513*** (0.00400)	0.582*** (0.00701)
Interaction term $\ln(IB_{j-1,i}^{SW}) \cdot IMPR_{j,j-1}^{CPU}$		-0.0125*** (0.00102)
<i>Marginal effects of $\ln(IB_{j-1,i}^{SW})$</i>		
At the mean	0.0264*** (0.000541)	
At $IMPR_{j,j-1}^{CPU} = 0.50$		0.0303*** (0.000690)
At $IMPR_{j,j-1}^{CPU} = 9.85$		0.0234*** (0.000544)
Observations	886,214	886,214
Individuals	63,301	63,301
Pseudo R^2	0.202	0.202

Notes. Logit estimates with standard errors in parentheses clustered on the level of the individual. Platform dummies and constant are included but not reported. The main effect of $IMPR_{g,g-1}^{CPU}$ in specification (7-2) is absorbed by the platform dummies.

*** $p < 0.01$.

effect, we collected additional consumer-level data on game console adoption. Using this data, we can exploit consumer-level heterogeneity to clearly attribute the effect of backward compatibility to the installed base of compatible software.

The user-level data set comes from the video gaming community Gamespot.com. Users on this platform self-report their portfolio of owned games, therefore letting us track their long-term purchasing behavior. Specifically, if a user reports owning games for a certain platform, we assume she owns this platform. We observe game possession for all 14 game consoles in Table 1 for 63,301 individuals. These individuals own on average 4.0 game consoles, and we estimate the binary purchase decision of each individual for each console. For each individual-console purchase decision, we observe the individual-specific installed base of compatible games of the parent console $IB_{j-1,i}^{SW}$ and ask if owning games for a previous console makes consumers more prone to purchasing a new, compatible one. Logit results are reported in Table 7. Specification (7-1) shows results for the main effect of backward compatibility while specification (7-2) interacts it with hardware improvement.¹⁹

As the coefficients in nonlinear models cannot be directly interpreted (Ai and Norton 2003), we follow Wiersema and Bowen (2009) to calculate marginal effects. At the mean, a one standard-deviation increase

in parent installed base increases adoption probabilities by around 2.6%, in line with Hypothesis 1. The strength of the effect is moderated by technological progress between generations: while the 50% increase in computing power between the *GameCube* and the *Wii* console leads to an installed base effect of 3.0%, this goes down to 2.3% for the 985% increase in computing power between the *PlayStation 2* and *PlayStation 3*. We thus obtain consistent results on hardware demand from a different data set using a different method, giving us further confidence in our results.²⁰

7. Conclusion

We study the effects of backward compatibility in a platform market, the U.S. home video game console market. Being able to draw on a sizable installed base through backward compatibility helped game consoles carry over their success in a prior generation into a new one. Here, backward compatibility works through the installed base of games for a compatible parent generation and the effect of backward compatibility is moderated by the rate of technological improvement between generations and the generation's age.

On the hardware demand side, the installed base of compatible games for the parent generation increases demand for the new generation. However, large technological improvements across generations come at the cost of consumers valuing backward compatibility less as their utility from using the old complementary products is comparatively low. Therefore, benefits from large technological improvement are partially offset by the reduced benefits from backward compatibility, offering a new mechanism as to why superior technological performance does not always yield a competitive edge (Anderson et al. 2014). On the software supply side, we find that backward compatibility lowers the supply of new software, and that this effect is less pronounced for consoles with higher technological progress, which suggests that there is a (previously not identified) “dark side” to a parent installed base through backward compatibility. Moreover, we find that both the demand-enhancing and the supply-reducing effects wear off as the console gets older.

By jointly analyzing hardware demand and software supply, we identify a demand-enhancing effect of backward compatibility directly affecting hardware demand and a demand-reducing one that works indirectly through reduced software variety for a platform. The demand-increasing effect clearly outweighs the demand-decreasing effect in the industry we study, but could also be weaker in markets where supply of new complementary goods has a stronger influence on demand.

¹⁹ The interaction with console age cannot be added as we do not observe when individuals adopt a console.

²⁰ The software supply decision cannot be estimated at the micro-level.

Backward compatibility can be important for strategies in platform business models if platforms exhibit generational technological change that could “reset the clock” and make it difficult for incumbents to maintain a strong market position in the new generation. Examples of firms successfully defending their market position (at least partly) through backward compatibility are Microsoft’s strategy of allowing all prior-generation Windows programs to run on the newest version, or iPhone apps running on the iPad.

Our results also have broader implications for the longevity of competitive advantage. Maintaining a competitive advantage is challenging if technological progress renders existing sources of competitive advantage obsolete or at least depreciates them (Lee et al. 2010, Sørensen and Stuart 2000). Firms can draw on two broad mechanisms to counteract the depreciation of their market position. First, incumbent firms can possess dynamic capabilities developed from prior generations that are useful in the new generation (Chen et al. 2012, Danneels 2002, Eggers 2012, de Figueiredo and Silverman 2007, Kotha et al. 2011). For example, similar production processes for contiguous technological generations helps transfer learning curve effects to the new generation. Second, firms may also use assets acquired in a previous generation (Hill and Rothaermel 2003, Jones 2003, Rothaermel and Boeker 2008, Tripsas 1997). Such assets could be an established reputation and brand loyalty by consumers (Jacoby and Kyner 1973), or ongoing relationships with suppliers of complementary products or retailers (Lee et al. 2010, Wade 1995). Our work suggests that a large parent installed base is also such an asset that can be leveraged through backward compatibility to provide an intergenerational competitive advantage.

Our findings on the role backward compatibility has on hardware demand and software supply as well as the moderating effects can be generalized to industries in which generational change occurs but complementary products of adjacent generations substitute for each other. This is given for many platform industries such as smartphones where new generations of smartphone operating systems trigger development of a new wave of apps, while apps designed for the previous generation can still be used and migrated to the new generation. In a different context and emphasizing the consumers’ perspective, seasonal cycles in fashion mean that consumers will typically simultaneously possess clothing from different collections. If fashion changes over time, consumers will consider last season’s clothing imperfect substitutes to this season’s, but it is still in the choice set of consumers. Given budget constraints, consumers will weigh up which new items they want to buy and for which they can still use last season’s.

Our results have important implications for managers. Managers in platform markets must consider

backward compatibility to a parent installed base an important parameter that helps carry over a strong competitive position across generations. This strategy is most beneficial in situations where the new generation offers moderate technological advancements over the established one. Because the effect is strongest when the new console has just been released, managers can use backward compatibility as an effective way to overcome the startup problem for new platform generations. Judiciously managing the tradeoff between drawing on an established installed base and achieving technological progress is thus a key challenge for technology strategists in many network industries with rapid (and possibly discontinuous) technological progress.

Acknowledgments

The authors thank participants at the Academy of Management meetings, the European Association for Research in Industrial Economics Conference, the International Industrial Organization Conference, and the Economics of Information and Communication Technologies Conference in Oporto, seminar participants at Bocconi, Cambridge Judge Business School, Carlos III Madrid, Copenhagen Business School, European Business School, EM Lyon, ESMT, Hebrew University Jerusalem, HEC Paris, IFN Stockholm, INSEAD, Linköping University, LMU Munich, TU Munich, Tel Aviv University, Tokyo University, University College London, and Albert Banal-Estanol; Mélisande Cardona, Sofronis Clerides, Thorsten Grohsjean, Erik Lehmann, Tim Simcoe, Thomas Spengler, Mariana Stamm, Jan Tonon, Stefan Wagner, and Martin Watzinger for helpful comments and discussions. Finally, the authors thank the editor Javier Gimeno and three anonymous reviewers for their very valuable input. The authors acknowledge financial support from Deutsche Telekom Foundation and Vodafone R&D.

References

- Adner R, Kapoor R (2010) Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. *Strategic Management J.* 31:306–333.
- Adomavicius G, Bockstedt J, Gupta A (2012) Modeling supply-side dynamics of IT components, products, and infrastructure: An empirical analysis using vector autoregression. *Inform. Systems Res.* 23:397–417.
- Ai C, Norton EC (2003) Interaction terms in logit and probit models. *Econom. Lett.* 80:123–129.
- Amit R (1986) Cost leadership strategy and experience curves. *Strategic Management J.* 7:281–292.
- Anderson EG Jr, Parker GG, Tan B (2014) Platform performance investment in the presence of network externalities. *Inform. Systems Res.* 25:152–172.
- Berry S (1994) Estimating discrete-choice models of product differentiation. *RAND J. Econom.* 25:242–262.
- Berry S, Levinsohn J, Pakes A (1995) Automobile prices in market equilibrium. *Econometrica* 63:841–890.
- Chen P-L, Williams C, Agarwal R (2012) Growing pains: Pre-entry experience and the challenge of transition to incumbency. *Strategic Management J.* 33:252–276.
- Chen P-Y, Forman C (2006) Can vendors influence switching costs and compatibility in an environment with open standards? *MIS Quart.* 30:541–562.

- Choi JP (1996) Do converters facilitate the transition to a new incompatible technology? A dynamic analysis of converters. *Internat. J. Indust. Organ.* 14:825–835.
- Church J, Gandal N (1996) Strategic entry deterrence: Complementary products as installed base. *Eur. J. Political Econom.* 12:331–354.
- Claussen J, Essling C, Kretschmer T (2015) When less can be more—Setting technology levels in complementary goods markets. *Res. Policy* 44:328–339.
- Clements M, Ohashi H (2005) Indirect network effects and the product cycle: Video games in the U.S., 1994–2002. *J. Indust. Econom.* 53:515–542.
- Corts KS, Lederman M (2009) Software exclusivity and the scope of indirect network effects in the U.S. home video game market. *Internat. J. Indust. Organ.* 27:121–136.
- Danneels E (2002) The dynamics of product innovation and firm competences. *Strategic Management J.* 23:1095–1121.
- de Figueiredo JM, Silverman BS (2007) Churn, baby, churn: Strategic dynamics among dominant and fringe firms in a segmented industry. *Management Sci.* 53:632–650.
- Eggers JP (2012) All experience is not created equal: Learning, adapting, and focusing in product portfolio management. *Strategic Management J.* 33:315–335.
- Farrell J, Saloner G (1985) Standardization, compatibility, and innovation. *RAND J. Econom.* 16:70–83.
- Farrell J, Saloner G (1992) Converters, compatibility, and the control of interfaces. *J. Indust. Econom.* 40:9–35.
- Forster W (2005) *The Encyclopedia of Game-Machines: Consoles, Handhelds and Home Computers 1972–2005* (Gameplan, Utting, Germany).
- Gandal N, Kende M, Rob R (2000) The dynamics of technological adoption in hardware/software systems: The case of compact disc players. *RAND J. Econom.* 31:43–61.
- Genakos C (2001) Game wars—The home video game industry. Case Study, London Business School.
- Greenstein S (1993) Did installed base give an incumbent any (measurable) advantages in federal computer procurement? *RAND J. Econom.* 24:19–39.
- Gupta S, Jain DC, Sawhney MS (1999) Modeling the evolution of markets with indirect network externalities: An application to digital television. *Marketing Sci.* 18:396–416.
- Hill CWL, Rothaermel FT (2003) The performance of incumbent firms in the face of radical technological innovation. *Acad. Management Rev.* 28:257–274.
- Jacoby J, Kyner DB (1973) Brand loyalty vs. repeat purchasing behavior. *J. Marketing Res.* 10:1–9.
- Jones N (2003) Competing after radical technological change: The significance of product line management strategy. *Strategic Management J.* 24:1265–1287.
- Kim J-Y (2002) Product compatibility as a signal of quality in a market with network externalities. *Internat. J. Indust. Organ.* 20:949–964.
- Koski H, Kretschmer T (2005) Entry, standards and competition: Firm strategies and the diffusion of mobile telephony. *Rev. Indust. Organ.* 26:89–113.
- Kotha R, Zheng Y, George G (2011) Entry into new niches: The effects of firm age and the expansion of technological capabilities on innovative output and impact. *Strategic Management J.* 32:1011–1024.
- Kretschmer T (2008) Splintering and inertia in network industries. *J. Indust. Econom.* 56:685–706.
- Krishnan V, Ramachandran K (2011) Integrated product architecture and pricing for managing sequential innovation. *Management Sci.* 57:2040–2053.
- Lee CH, Venkatraman N, Tanriverdi H, Iyer B (2010) Complementarity-based hypercompetition in the software industry: Theory and empirical test, 1990–2002. *Strategic Management J.* 31:1431–1456.
- Liikanen J, Stoneman P, Toivanen O (2004) Intergenerational effects in the diffusion of new technology: The case of mobile phones. *Internat. J. Indust. Organ.* 22:1137–1154.
- Liu H (2010) Dynamics of pricing in the video game console market: Skimming or penetration? *J. Marketing Res.* 47:428–443.
- Nair H, Chintagunta P, Dube J (2004) Empirical analysis of indirect network effects in the market for personal digital assistants. *Quant. Marketing Econom.* 2:23–58.
- Rothaermel FT, Boeker W (2008) Old technology meets new technology: Complementarities, similarities, and alliance formation. *Strategic Management J.* 29:47–77.
- Schilling M (2002) Technology success and failure in winner-take-all markets: The impact of learning orientation, timing, and network externalities. *Acad. Management J.* 45:387–398.
- Schilling MA (2003) Technological leapfrogging: Lessons from the U.S. video game console industry. *California Management Rev.* 45:6–32.
- Schilling MA, Vidal P, Ployhart RE, Marangoni A (2003) Learning by doing something else: Variation, relatedness, and the learning curve. *Management Sci.* 49:39–56.
- Shapiro C, Varian H (1999) *Information Rules: A Strategic Guide to the Network Economy* (Harvard Business School Press, Cambridge, MA).
- Shy O (1996) Technology revolutions in the presence of network externalities. *Internat. J. Indust. Organ.* 14:785–800.
- Sørensen JB, Stuart TE (2000) Aging, obsolescence, and organizational innovation. *Admin. Sci. Quart.* 45:81–112.
- Sutton J (1998) *Technology and Market Structure: Theory and History* (MIT Press, Cambridge, MA).
- Tripsas M (1997) Unraveling the process of creative destruction: Complementary assets and incumbent survival in the typesetter industry. *Strategic Management J.* 18:119–142.
- Wade J (1995) Dynamics of organizational communities and technological bandwagons: An empirical investigation of community evolution in the microprocessor market. *Strategic Management J.* 16:111–133.
- Wiersema MF, Bowen HP (2009) The use of limited dependent variable techniques in strategy research: Issues and methods. *Strategic Management J.* 30:679–692.
- Zhu F, Iansiti M (2012) Entry into platform-based markets. *Strategic Management J.* 33:88–106.

Tobias Kretschmer is a full professor of strategy, Technology, and organization and co-director of the Organizations Research Group (ORG) at Ludwig-Maximilians-University (LMU) Munich. He received his PhD in economics from London Business School. His research interests include competitive strategies in dynamic industries (especially platform markets) and the role of technology in the internal organization of the firm.

Jörg Claussen is an assistant professor in the Department of Innovation and Organizational Economics at Copenhagen Business School. He received his PhD in management from the Ludwig-Maximilians-University Munich. His research interests include questions of organization design as well as of applied industrial organization.



This work is licensed under a Creative Commons Attribution 3.0 United States License. You are free to copy, distribute, transmit and adapt this work, but you must attribute this work as “Strategy Science. Copyright 2016 The Authors(s). <http://dx.doi.org/10.1287/stsc.2015.0009>, used under a Creative Commons Attribution License: <http://creativecommons.org/licenses/by/3.0/us/>”