Don't look back? Backward compatibility in the video gaming industry*

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Abstract

Backward compatibility is a governance strategy that can be adopted by platform owners to build indirect network effects and encourage owners of older compatible software to update to newer hardware models. Previous research has shown backward compatibility has a positive effect on hardware sales. However, there is limited evidence concerning the other associated costs and benefits. In particular, there is a lack of evidence on the effect of backward compatibility on software sales, despite its importance in understanding the full range of possible network and sales displacement effects associated with the strategy. Using weekly software-level sales data from the US video gaming industry, we find that backward-compatible hardware associates with increased sales of software released for the previous hardware generation. However, we find that the introduction of backward compatibility may not increase the sales of new hardware if the feature is not available immediately at launch. Further, we show that the increased sales of software for the old hardware platform may cannibalize software sales for the new platform. Overall, our results suggest that backward compatibility is time-sensitive and involves several important trade-offs. We therefore conclude that the use of backward compatibility needs to be carefully considered by platform owners prior to implementation.

Key words: Video games; backward compatibility; product development; innovation; two-sided markets; platform governance.

*We are grateful for the comments of the Editor-in-Chief, Senior Editor and an anonymous reviewer that have improved this manuscript. We thank participants of (i) 21st Association of Cultural Economics International Conference, online (July, 2021), (ii) 97th WEAI Annual Conference, Portland (July, 2022), and (iii) 10th European Workshop on Applied Cultural Economics, Turin (September, 2022) for comments. All remaining errors are our own. Declarations of interest: none. Link to publisher version of this paper: https://doi.org/10.1287/stsc.2022.0177

"If you're backwards compatible, you're really backward" - Don Mattrick, Microsoft President of Interactive Entertainment, 2013

1 Introduction

The video gaming industry experienced a watershed moment in 2013. In that year, the game *Grand Theft Auto V* set a record for the highest revenue ever generated by an entertainment product at launch, earning $1bn during the first three days of its release. The title went on to generate $6bn in revenue up to 2018, making it the most profitable entertainment product of all time. The commercial success of the industry is not limited to this solitary case, as video gaming was estimated to gross $159bn worldwide in 2020 versus a global movie box office of $43bn and music revenues of $57bn during 2019. These figures suggest that video gaming is larger than the global music and movie industries combined.

The video gaming industry is a two-sided market characterized by an oligopolistic structure and indirect network effects between content providers and consumers (Marchand and Hennig-Thurau, 2013). Typically, between three to five platform owners of incompatible hardware models compete at any one time in an attempt to establish a dominant technical standard. This process repeats itself as new 'generations' of hardware platforms are introduced, each with a life cycle of between five and ten years. Each successive generation improves upon the technical specifications of the last, allowing the use of more sophisticated software products and offering more advanced graphics and game play features. As a result of strong indirect network effects, the dynamics of the video gaming market have been argued to be predominantly quality-driven, meaning that first mover advantage in the hardware market is insufficient to protect incumbents against entrants with superior quality software (Zhu and Iansiti, 2012).

Given the importance of software compatibility for the commercial success of hardware platforms, a crucial governance decision faced by platform owners is whether to offer backward compatibility with software designed for previous generations (Burgleman and Grove, 2007). Backward compatibility has been argued to be unambiguously welfare enhancing for consumers (Kende, 1994) and creates an incentive to purchase new hardware models in order to maintain existing network benefits (Chau and Desiraju, 2017). As a result, the presence of backward compatibility has been argued to accelerate rates of adoption, resulting in a socially optimal rate of technological progress (Gandal, 2002). However, the decision as to whether to offer backward compatibility is not straightforward from the perspective of platform. On one hand, backward compatibility may help to overcome an initial shortcoming in the availability of software for new hardware models, as well as providing a second lease of life for old software titles. On the other hand, adding backward compatibility might also create negative externalities for complementors through displacing the sales of software designed for new hardware models and also associates with increased manufacturing costs. An ambiguity therefore exists as to whether and under what circumstances the use of backward compatibility is welfare-enhancing for platform owners.

Our study investigates these trade-offs and ambiguities in the context of the US video games market. Prior studies of backward compatibility in technology markets have focused almost exclusively on its effect on hardware sales, or have aggregated software sales to such a point so as to lose any distinction in the backward and forward effects of sales for old and new hardware platforms, respectively.[1] In the specific context of the video gaming industry, studies such as Clements and Ohashi (2005); Corts and Lederman (2009); and Kretschmer and Claussen (2016) tend to focus exclusively on demand for new hardware, counting only the number of software titles available for each model as opposed to measuring their sales performance. By not explicitly taking into account the impact of backward compatibility on the sales of software for both old and new hardware platforms, these studies neglect an important element of market dynamics that play a key role in determining the ultimate success or failure of the strategy. The only study of which we are aware that focuses on the implications of backward compatibility on software sales is a recent working paper by

[1]Examples include Kretschmer (2008), Kretschmer and Claussen (2016), and Nahm (2008).

Narang and Shankar (2020). However, even this particular study is limited given their use of a relatively small sample comprising sales data for 28 backward compatible software titles obtained from a single retail chain.

Our study addresses this gap in the literature, taking a unique perspective on the issue of backward compatibility by looking both forwards and backwards in estimating its effect on software sales and considering how this fits with theory on backward compatibility. As well as making a contribution to the literature on backward compatibility, our research also adds to the growing body of literature examining platform governance. As noted by Teh (2022), a platform's governance design decisions influence how competition between complementors unfolds. Chen et al. (2022a)) examine the implications of ecosystem complexity resulting from a platform's governance design and find that increased platform complexity can impose additional costs on complementors. Similarly, Kapoor and Agarwal (2017) demonstrate that a platform's governance decisions can play a significant role in the complementors' ability to appropriate value over time. Governance policies have also been found to affect complementors' value creation activities (Constantinides et al., 2018). Our study contributes to the platform governance literature by exploring the costs and benefits of a particular platform governance strategy adopted by platform owners, as well as the ways in which these strategies affect the overall portfolio of products offered by complementors (Rietveld et al., 2021).[2]

Using weekly US sales figures, we examine the period of transition between the seventh and eighth generations of video game hardware platforms. During this era, Nintendo introduced the fully backward-compatible WiiU in December 2012 and Microsoft introduced the partially backward-compatible Xbox One in November 2013.[3] Sony, on the other hand,

[2] This study also contributes to the broader literature examining the strategic decision making of platform owners in a variety of settings. Such studies have investigated issues relating to platform migration (Xu et al., 2010), competition between platforms (Cennamo, 2021), network effects (Shankar and Bayus, 2003; Venkatraman and Lee, 2004) and the drivers of innovation (Adner and Kapoor, 2010).

[3] As we discuss in detail in subsequent sections, the Xbox One was not initially backward compatible with any seventh-generation Xbox 360 software at time of release. This modification occurred for selected games from June 2015 onward.

released the PlayStation 4 also in November 2013, which was not at all backward compatible with software designed for their previous hardware platform. We find that the introduction of backward-compatible hardware increases the sales of old software. However, we find mixed evidence on the extent to which this increase in sales was driven by consumers who contemporaneously purchased new hardware. While the sales of old software for the Nintendo Wii are found to associate positively with sales of the new WiiU hardware, we find no such evidence that increased sales of old Microsoft Xbox 360 titles associates with increased sales of the new Xbox One hardware. Relatedly, we also provide evidence that Xbox One hardware sales did not increase from the introduction of backward compatibility for select Xbox 360 titles. Given that backward compatibility was available from launch for the WiiU but introduced post-launch for the Xbox One, our findings suggest that the timing of introduction of backward compatibility significantly affects the extent to which it is beneficial to platform owners. Furthermore, we find the increase in software sales for old hardware models partially displaces software sales for the new model, resulting in a 'cannibalization effect'. Taken together, our results suggest that there are important trade-offs involved in the use of backward compatibility and that the net benefits of doing so may be time-dependent. The implementation of backward compatibility should therefore be considered carefully by platform owners before adoption.

Our paper is structured as follows. The next section provides some additional background on the video gaming industry and also outlines some theoretical insights relating to the use of backward compatibility in this particular context. We then describe the details of our data set and outline our methodological approach before presenting the results from our analysis. We then present a discussion of our findings, highlighting the relevance for both theory and practice and finish by offering an overall conclusion.

2 Industry Description

Video games consoles are hardware platforms that leverage network technology to connect and facilitate exchange between two sides of the software market (Zhou, 2017). The owners of these platforms earn money from one side of the market (software publishers) through charging royalties on software sales and selling fixed-fee development kits, treating the other side of the market (consumers) as a loss leader (Rochet and Tirole, 2003). However, in managing these two sides of the market, platform owners face a crucial 'chicken and egg' problem, whereby they cannot sell the hardware without accompanying software, but can't attract software developers without an installed user base. Conventional wisdom therefore dictates that winner-take-all strategies based around the number, variety and exclusivity of compatible software represent important determinants of market outcomes (Cennamo and Santalo, 2013). It is therefore unsurprising that compatibility with a wider range of 'hit' software has been shown to represent a significant determinant of demand for hardware platforms (Corts and Lederman, 2009; Lee, 2013; Haviv et al., 2020). As an added consideration, platform owners can also develop their own software, and the three largest software publishers (Microsoft, Nintendo and Sony) are also themselves platform owners (Marchand and Hennig-Thurau, 2013).

A summary of the hardware models released by the three platform owners covered by this study can be found in Table 1, which contains information on the model and manufacturer name, year of release and respective hardware generation. Additionally, the table reports whether each particular hardware platform offered backward compatibility at the time of release, or added/subtracted the functionality at a later date. In cases where backward compatibility is offered, the table further summarizes whether the functionality was achieved via software emulation or through the inclusion of additional hardware components, which in some respects can be thought of as a proxy for increased manufacturing cost. Of the three platform owners currently operating in the industry, Nintendo was the first to enter the market in 1985 with the Nintendo Entertainment System (NES), which was part of the third hardware generation. Throughout the third and fourth hardware generations in the late 1980s and early 1990s, Nintendo primarily battled for market dominance with rivals Sega and the two companies effectively operated a duopoly in the video games market until the entry of Sony in 1995. Sony's fifth generation PlayStation console would go on to have a major impact on the industry, significantly eroding Nintendo's market share and leading Sega to cease producing video games hardware altogether in the early 2000s.

Although Sony's success was partly due to their early adoption of CD technology and favorable terms offered to software developers (Williams, 2002), another potential reason is that several of their subsequent hardware platforms have offered backward compatibility. In particular, backward compatibility is acknowledged to have been critical to the success of the sixth generation PlayStation 2 console, which was fully backward compatible with software designed for the original PlayStation model through the inclusion of dedicated hardware components (Alvisi, 2006). Although some of the earliest PlayStation 3 models did initially offer backward compatibility with PlayStation 2 software (also via hardware), the functionality was soon dropped once a wider variety of software titles became available for the new platform, combined with a desire on Sony's part to reduce manufacturing costs.[4] This decision has been cited as one of the reasons why the PlayStation 3 ended up struggling against a resurgent Nintendo and industry newcomers Microsoft during the seventh hardware generation, both of whom offered backward compatibility through their competing hardware platforms.[5]

Since that time, the issue of backward compatibility has continued to resurface and has become a controversial aspect of subsequent hardware generations. In an interview for the Wall Street Journal, Microsoft Executive Don Mattrick explained that the initial decision not to offer backward compatibility for the eighth-generation Xbox One console was due to a belief that the feature appealed only to a relatively small proportion of consumers.[6]

[4] https://www.gamesindustry.biz/articles/the-price-is-right.

[5] https://www.wired.co.uk/article/xbox-series-x-backwards-compatibility.

[6] https://www.wsj.com/articles/BL-DGB-26963.

However, after release, it became clear that Microsoft was losing market share to Sony's PlayStation 4, possibly as the result of their decision to market the product as an all-in-one entertainment centre rather than a dedicated gaming device (Kim and Chandler, 2018). Microsoft subsequently made a significant policy u-turn, updating the Xbox One in 2015 to provide (partial) backward compatibility with software from the seventh-generation Xbox 360 console via emulation. It has since been estimated that more than half of all consumers have made use of this functionality.[7]

One of the reasons why backward compatibility may have become more of an issue in recent years is that, prior to the eighth generation, video gaming hardware was more commonly based around proprietary components and technologies such as the PowerPC-based Cell processor used in the Sony PlayStation 3. The use of non-standard CPU architecture makes it significantly more difficult for platform owners to facilitate backward compatibility through (lower cost) software emulation. Backward compatibility in such cases could therefore only realistically be achieved through the inclusion of additional hardware components, inevitably adding to manufacturing cost. By contrast, more recent video game hardware has been built on standardized CPU architecture such as x86 and ARM, making it easier and cheaper to facilitate backward compatibility via software emulation.

In the recent migration to the ninth generation, backward compatibility once again became a prominent issue in the pre-launch activities and announcements made by Sony and Microsoft and may ultimately play a significant role in determining the eventual market outcome (Chellappa and Mukherjee, 2021). Released in November 2020, the ninth-generation Sony PlayStation 5 offers backward compatibility with a majority of software titles released for the eighth-generation PlayStation 4, while the ninth-generation Microsoft Xbox Series X/S is backward compatible with a wide range of software from all earlier Xbox platforms, expanding the catalogue of compatible software to include three previous hardware generations stretching back around twenty years. At the time of writing, it remains to be seen

[7] `https://www.gamesindustry.biz/articles/2019-06-11-microsoft-ends-xbox-one-backwards-compatibility-efforts-to-focus-on-project-scarlett`.

which of these models will come to dominate the present hardware generation, although industry commentators have suggested that the focus on backward compatibility may give Microsoft an advantage over Sony.[8]

3 Backward compatibility and platform governance

A key aspect of platform management is the coordination of multilaterally dependent complementors (Jacobides et al., 2018). Previous studies in the platform governance literature, such as McIntyre and Srinivasan (2017), have tended to assume that complementors play a relatively submissive role in either accepting the costs imposed by the governance decisions of platform owners, or leaving the market altogether. More recent studies have highlighted the need to examine platform governance issues from alternative perspectives, due in part to the growing power of platform owners and imbalances with other stakeholders (Chen et al., 2021). Other authors have argued the need to move beyond the perception of platforms as two-sided markets and to regard them as 'meta-organizations', a new and distinct organizational form based around the strategic management of relationships between complementors and the collective actions between partners (Chen et al., 2022b).

In managing such relationships, platform owners need to design governance policies to control the ways in which complementors access and interact with the platform to create value (Zhang et al., 2022). In this way, platform owners also play the role of intermediaries and regulators for the markets that underpin their ecosystems (Teh, 2022). The multilateral, interdependent relationships between partners and complementors can be subject to a number of strategic tensions, which can lead to increased transaction costs and co-ordination frictions (Chen et al., 2022a). Managers therefore need to carefully consider the concerns of external participants when designing systems of governance for platforms in order to adequately incentivise their contributions (O'Mahony and Karp, 2020). These particular tensions are of even greater significance in this market context where platform owners are

[8] https://www.wired.co.uk/article/xbox-series-x-backwards-compatibility.

also themselves software developers. By operating as both 'umpires and players', platform owners may otherwise be incentivised to make design decisions that benefit themselves while directly or indirectly harm third-party developers (Teh, 2022).

The strategic decision as to whether to offer backward compatibility represents a key platform governance issue with associated costs and benefits. Beginning with the benefits, backward compatibility increases the volume of software titles that are compatible with respective hardware platforms (Gallagher and Park, 2002). As a result, the new hardware product can benefit from the old product's established network (Choi, 1994) and thus exploit pre-existing network effects (Lee et al., 2003; McIntyre and Srinivasan, 2017). In turn, this increase in user value creates a 'forward effect' of increased sales of the new hardware platform (Hann, Koh and Niculescu, 2016). Conversely, backward compatibility may also lead to a 'backward effect' by offering a fresh lease of life for old software, leading to increased sales of titles originally designed for older platforms. These benefits are likely to be especially pronounced in the presence of the asymmetric network cross-side network effects that have been found between software and hardware platforms (Song et al., 2018).

Despite the advantages offered by backward compatibility, there are important costs involved in its adoption. One such cost is the sales displacement of new software resulting from compatibility with a wide range of older titles. This displacement effectively results in a 'cannibalization effect' whereby consumers substitute their purchase of new with old software (Norton and Bass (1987), Miao (2010); Hann et al. (2016)). The implementation of backward compatibility also imposes a range of other technical and productive constraints (Zhou, 2011), which inevitably lead to an increase in production costs. This issue is especially pertinent given that platform owners operate on very tight profit margins and often incur substantial losses during the period following the launch of a new product (Liu, 2010, p.429). The increased production costs associated with backward compatibility are likely to be significantly lower if the compatibility can be achieved through software emulation, which in turn is more straightforward if the new hardware is technically similar to the previous model (e.g. similar CPU-architecture).

As observed more generally in other technology markets (Ellison and Fudenberg, 2000; Lee, 2006; Miao, 2010), there are likely to be particular strategic issues surrounding the timing of backward compatibility. More specifically, platform owners are more likely to benefit from the exploitation of network effects during periods of intense competition against rival(s) to increase their market share. Such situations typically occur during the launch stage of a new product when firms are first vying to establish a dominant technical standard within a given hardware generation (Kretschmer and Claussen, 2016). In this context, the use of backward compatibility can offer platform owners the means of overcoming start-up issues experienced during generational transitions, such as the 'chicken and egg' problem typically encountered in two-sided markets (Chao and Derdenger, 2013). This particular issue highlights that platforms are fundamentally dynamic and therefore require strategy that evolves over time (Wareham et al., 2014).

The benefits associated with backward compatibility might also prove to be greater if the firm finds itself at a competitive disadvantage against rival(s). In such positions, platform owners may wish to increase market share by exploiting untapped network effects from previous hardware generation(s). This proposition would explain why platform owners appear to behave somewhat inconsistently and apparently do not 'learn the lessons' associated with backward compatibility. In other words, the net benefit associated with the implementation of backward compatibility will be relatively higher or lower depending on the competitive position of each hardware manufacturer at any given point in time. The use of backward compatibility therefore becomes an important governance decision for platform owners that weigh the benefits associated with stimulating demand for new hardware and new/old software against the manufacturing costs of implementing backward compatibility and any displacement or 'cannibalization' that might occur.

These theoretical predictions fit with the reasons why Sony introduced (and later withdrew) backward compatibility from their PlayStation 3 console. As stated by Sony director Ray Maguire in a 2007 interview[9], "We felt that when we launched there was only a few games on the market so backward compatibility was quite an interesting point and we needed to have it there and then...Now as we come to our first Christmas with the PlayStation 3 there's going to be about 65 games in the marketplace so we feel now that there's sufficient choice and that we're still better off using that money...to help support bringing the price down so that people can get into the franchise". Such theoretical predictions are also helpful in understanding why Microsoft did not initially offer backward compatibility for their Xbox One console before reversing that decision once it became clear they were losing market share to Sony and their PlayStation. Finally, this theory is consistent with Nintendo's decision to offer backward compatibility for the WiiU at launch given the technical similarity with the previous Wii hardware, hence allowing relatively straightforward backward compatibility via software emulation with the associated implications for (lower) production cost.

As we describe below (Section 4), our data allow us to investigate many of these issues using a snapshot of data from 2011-2015, covering the seventh and eighth video gaming hardware generations. Given the sample includes hardware platforms that were backward compatible from launch (Nintendo WiiU), were not backward compatible at all (Sony PlayStation 4) and that introduced backwards compatibility later in the product life cycle (Microsoft Xbox One), our study is able to provide important empirical insights into the timing of backward compatibility in context of this particular hardware generation. More specifically, in the following section we investigate whether there is evidence to support the benefits (increased software and hardware sales) and costs (sales displacement) of backward compatibility outlined above.

[9] https://www.gamesindustry.biz/articles/the-price-is-right.

4 Data

The data used in our study primarily come from VGChartz, an industry standard for video games sales data. We observe both weekly unit sales of software and hardware for a number of different consoles but focus attention primarily on the major seventh- and eighth-generation consoles, i.e. Sony's PlayStation 3 (PS3) and PlayStation 4 (PS4); Nintendo's Wii (WII) and (WIIU); and Microsoft's Xbox 360 (X360) and Xbox One (XONE). The seventh-generation consoles were released during 2005 and 2006 in the US market, whereas the eighth-generation consoles were released during 2012 and 2013. We investigate whether the sales data support the benefits associated backward compatibility highlighted in the previous section, namely: 1) increased sales of old software, and 2) increased sales of new hardware. We also test investigate whether sales data indicate the presence of one of the theoretical costs associated with backward compatibility, namely: 3) sales displacement or the 'cannibalization effect'. Unfortunately we do not have access to specific data that would allow us to test claims relating to production cost. However, we explore the relevance of this cost to the equilibrium position on backward compatibility more broadly in Section 6.

As outlined in Section 2, the benefits and costs of backward compatibility can partly be conceptualized in terms of the effect on software sales for both the new and old hardware platforms. Our study primarily focuses on this issue and attempts to estimate the extent to which software from the seventh-generation consoles were impacted by the introduction of the eighth-generation consoles that allowed backward compatibility. As is well known to industry observers, the eighth-generation WIIU console had full backward compatibility with seventh-generation WII software when released in November 2012. However, at time of (almost simultaneous) release in November 2013, neither the PS4, nor the XONE were backward compatible with software from their respective seventh-generation counterparts. Over time, a number of X360 games became backward compatible with the XONE hardware as the result of Microsoft introducing a software emulator and incrementally expanding its compatibility with a larger number of X360 software titles. At present, 577 of the 2,084 X360 games can be played on the XONE.

To investigate the impact of backward compatibility on previous-generation software sales, we consider two separate sample windows. Summary statistics are provided in Table 2 for software sales of the three focal seventh-generation consoles across the two sample windows. Sample 1 covers from a year before until a year after the WIIU release and examines how WII game sales were impacted post release of the new hardware model. The one year window either side of the release was selected for two reasons. The first being that both the PS4 and XONE were released in November 2013, which would likely impact the results in various ways. By limiting the window to one year after the release of the WIIU, any potential impact from this event is avoided. The second reason is that the industry exhibits high annual seasonality, with spiked sales leading up to Christmas each year. The one year window either side thus permitted a balanced analysis in this respect. Sample 2 begins after the introduction of the XONE console and continues until the end of 2018. As mentioned above, during this time a number of X360 games were made compatible with the XONE console, commencing from June 2015.

In addition to examining potential sales impacts from backward compatibility on seventh-generation software, we also examine potential sales impacts on eight generation hardware sales and software sales. Summary statistics for these two samples are provided in Table 3, which we refer to as Sample 3 and 4. The first two rows in each panel of Tables 2 and 3 reflect weekly and total (unit) sales, respectively. In the case of the latter, we mention the caveat that the figures we observe with respect to *total* software sales are actually the maximum observed over the respective sample window. While these figures reflect the actual total sales in many cases, it will not be true in all cases where the sample window might end while software continues to accrue sales out of the sample period. As has been well documented with respect to this industry, both weekly and total sales are heavily right skewed. Weekly and cumulative sales profiles for both seventh- and eighth-generation hardware are also provided in Figures 1 and 2, respectively. Combined weekly software sales for seventh-generation software alongside the WIIU are provided in Figure 3, along with vertical lines indicating entry of the eighth-generation consoles, as well as the date from which the XONE became backward compatible for selected X360 games.

In addition to software and hardware sales, we include pricing data, age, and Metacritic reviews from users for software titles.[10] The third row in each panel of Tables 2 and 3 refers to the maximum price (in USD), which would generally be observed in the early weeks of release for a given software title. The fourth row provides the maximum observed 'age' (measured in weeks). As with maximum (total) sales, these data provides some indication about the length of time that sales are observed by VGChartz, but might also be right censored by the respective sample windows. The average (and median) age suggests that sales for many software titles continue to be recorded for several years following initial release. Finally, we also observe average user reviews from Metacritic. These data are included to capture some of the perceived variation in quality of a given software title across different hardware platforms, as well as between different software titles themselves.[11]

5 Empirical strategy and results

5.1 Backward compatibility and Wii software sales

Our empirical methodology is based on basic difference-in-difference (DiD) specifications. Given the structure of our data, we consider slightly different approaches to analysing the impact of backward-compatible eighth-generation hardware on (compatible) seventh-generation software sales. For Sample 1, we begin by investigating a two-way fixed effects DiD specifi-

[10] Monthly pricing data was obtained from `https://www.pricecharting.com/` and Metacritic data from `https://www.metacritic.com/game`.

[11] While we also observe Metacritic reviews by critics, we include user reviews in our modelling as the coverage is better. However, the results do not change by using one in preference to the other.

cation of the form:

$$\ln S_{jct} = \gamma POST_t \times WII + \beta X_{jct} + \mu_c + \Omega_t + \varepsilon_{jct}, \tag{1}$$

where S_{jct} is sales of game j on console c in week t, $POST$ is a dummy variable that takes the value one after the release of the WIIU (12 November 2012), and WII is also dummy variable that takes the value one if game j on console c is a WII game. The vector X includes game-level fixed effects, price, Metacritic user score, and a 'new' release dummy variable capturing whether a game is in its first four weeks of release.[12] Note that price, Metacritic user score and the 'new' dummy variable differ between consoles for specific games, permitting identification with game fixed effects. Finally, μ_c and Ω_t capture console and week-of-sample fixed effects, respectively.

While it is not our objective to estimate a structural demand model and make any inference based on the estimated price coefficient, we do account for the endogeneity of this variable. Specifically, we estimate Equation 1 as a two-stage least squares instrumental variables (IV) regression where the price variable is instrumented using (first-listed) developer fixed effects. Many software titles released on multiple hardware platforms also have multiple developers. These developers vary in scale and location and are therefore likely to have different costs that affect game retail prices but do not directly affect demand.[13] This instrument is therefore suitable for handling price endogeneity of a non-temporal form. Temporal price

[12]This approach allows the model to account for two important features of the game sales data: 1) Sales are typically heaviest at time of release, and 2) Most games spend multiple years in the charts. The inclusion of the 'new' dummy variable is preferred to alternate methods of capturing these features, such as using a weekly linear or quadratic decay, which impose too much rigidity on the model.

[13]For example, the game *HISTORY CHANNEL: BATTLE FOR THE PACIFIC* was released on PS3, Wii, and Xbox 360, but had three separate developers: Activision, FUN Labs, and Caulrdon Ltd., respectively. These three developers are located in different countries (USA, Romania, and Slovakia), which likely have markedly different costs that would influence software prices. Across the full sample of 964 unique games, we observe 378 unique developers located across 28 unique countries. However, because game fixed effects are used in the first-stage regression and many games have the same developer, the usable number of developers is reduced to 33 due to collinearity with the fixed effects. This set of instruments rejects both under- and weak-identification tests, but we accept the instruments may not be perfect in that they only affect games with multiple developers.

variation is primarily accounted for in the model with the 'new' release dummy variable, as well as 'month' or 'week of sample' fixed effects depending on the specification.[14]

Implicit in the analyses is that sales for non-focal hardware platforms serve as a control group for the focal hardware. That is, for Sample 1, PS3 and/or X360 games serve as the control groups with WII games considered as the treatment group (post WIIU release). Under this assumption, identification relies on software being released on the WII console as well as either the PS3 or X360 (or both). In the case that a software title is only released for one hardware model, identification is based on the other (time-variant) game-specific variables such as price, new, console, and week of sample. We revisit this discussion below.

Insofar that sales of previous generation software do increase from the release of backward-compatible hardware, it is of interest to examine whether it is the new console owners who are driving the increased software sales or whether it is the owners of old hardware. While it may seem more likely it is being driven by the new hardware owners, this is not *a-priori* certain. For example, it is possible owners of old-generation hardware increase purchases of old software if they intend to buy the new hardware at some point in the future. In this respect, the release of backward-compatible hardware affords them security that they will still be able to use old software with the new hardware if and when they decide to upgrade.

To investigate this question directly, we consider variants to the model presented above where we interact the treatment variable with the standardised (log) cumulative sales of the respective eighth-generation console to week t.[15] That is, for Sample 1, we interact the DiD interaction term in Equation 1 with standardised (log) sales of the WIIU console as follows:

$$\ln S_{jct} = \gamma POST_t \times WII + \phi POST_t \times WII \times \log WIIU_t + \beta X_{jct} + \mu_c + \Omega_t + \varepsilon_{jct}. \quad (2)$$

[14]To examine whether the 2SLS approach has any meaningful impact on our main coefficient(s) of interest, we also performed the analysis with (i) price not instrumented, and (ii) price omitted from the specification. The results are qualitatively similar with respect to the DiD coefficients estimated across the various specifications.

[15]Standardisation was undertaken to ensure that other parameter estimates were not affected by the inclusion of the new variable given the discontinuous nature of its measurement.

Intuitively, this model tests whether the sales of seventh-generation software are also related to the volume of new eighth-generation hardware sales. Results for models represented by Equations 1 and 2 are presented in Table 4. Column 1 provides the most basic DiD specification, where the week-of-sample fixed effects are replaced by a dummy variable capturing pre-/post-WIIU console release date. To capture the strong seasonality observed in the data, calendar month dummy variables are also included in this specification. Column 2 includes week-of-sample fixed effects. In both variants, the estimated DiD parameter is positive and statistically well defined. All other coefficients conform with *a-priori* intuition. Columns 3 and 4 are analogous to 1 and 2, respectively, but with inclusion of the standardised (log) of WIIU console sales. In both specifications, this additional term is also positive and statistically significant, suggesting a relation between the observed increased Wii software sales and the volume of WIIU console sales. As argued above, this is suggestive that the increased software sales are being driven by the new WIIU console owners.

We undertake a number of robustness checks to validate our main results, which are also reported in Table 4, columns 5-10. In column 5, the month of December is removed from the analysis. Given the strong seasonality observed in Figure 3, it is possible that Christmas sales could affect the analysis if they were systematically higher for WII games. In column 6, games released after the start of the sample window were dropped. Given the impending release of the PS4 and XONE, it is possible the new titles being released across the three consoles may differ, which could also impact results.

Column 7 restricts the sample to only include games released on all consoles. Many games were only released on one or two consoles, which limits the ability of the identification strategy. Given the different gaming experience between the WII and the other consoles, restricting the analysis to the same set of games also helps alleviate concerns about the credibility of the control group. Column 8 restricts the sample as described for both column 6 and column 7. Column 9 provides a placebo check by taking a two-year window from 18 November 2010 to 18 November 2012, i.e. ending at time of WIIU release. Finally, column

10 reports aggregate weekly sales for each of the three consoles, where sales are aggregated only for games released prior to 18 November 2011. With exception of the placebo model (which finds an insignificant DiD coefficient), all models support the main result with the estimated impact ranging 7-17% across the different specifications.[16]

5.2 Backward compatibility and Xbox 360 software sales

For Sample 2, because we observe multiple intervention dates given that X360 software was staggered in becoming backward compatible with the XONE hardware model via incremental updates to Microsoft's emulation software, we consider a variant of Equation 1 with differential treatment timing of the following form:

$$\ln S_{jct} = \gamma X360^{BC}_{t>t(j)*} + \beta X_{jct} + \mu_c + \Omega_t + \varepsilon_{jct}, \tag{3}$$

where $X360^{BC}_{t>t(j)*}$ is a dummy variable that takes the value one for X360 game j if and when it become backward compatible with the XONE console at date $t*$. For Sample 2, software for the PS3 and/or WII serves as the control group and backward-compatible X360 games are treatment once they have been made compatible with the XONE. In addition to the identification strategy described for Sample 1, the fact that not all X360 games were made backward compatible provides for a further level of data variation that facilitates identification. Specifically, in a given week t some X360 software titles were backward compatible and others were not. Comparison of otherwise similar X360 software in other dimensions thus assists identification.

For Sample 2 we also interact the DiD interaction term in Equation 3 with standardised (log) cumulative sales of XONE to week t as follows:

$$\ln S_{jct} = \gamma X360^{BC}_{t>t(j)*} + \phi X360^{BC}_{t>t(j)*} \times \log XONE_t + \beta X_{jct} + \mu_c + \Omega_t + \varepsilon_{jct}. \tag{4}$$

[16]These impacts are based on exponentiating the estimated coefficients from Table 4.

Again, this model tests whether the sales of seventh-generation software are related to cumulative eighth-generation hardware sales. Implicitly, it examines whether any increase in sales of X360 software are being driven by contemporaneous purchases of XONE consoles.

Results for models represented by Equations 3 and 4 are reported in Table 5 in columns 1 and 2, respectively. Again, there is evidence that sales of backward-compatible games increase. However, unlike Sample 1, these do not relate to the volume of XONE sales. Given the timing of backward compatibility did not occur at time of launch of the XONE, we conjecture the increased sales did not come from consumers who purchased new XONE consoles but rather from the existing base of XONE console owners.[17]

The remaining columns of Table 5 provide a number of robustness checks of the main result that are similar to those reported above for Sample 1. Column 3 removes December, column 4 restricts the sample to games released prior to commencement of sample window (22 November 2013), column 5 restricts the sample only to games released on all three consoles, and column 6 combines the restrictions of columns 4 and 5.[18] It is well known that the gaming experience of the WII was targeted more towards casual gamers, whereas the PS3 and X360 were targeted at more serious gamers. While the robustness models described in columns 5 and 6 seek to address this potential drawback, there is still potential concern the control group may be affected by the inclusion of WII games. Column 7 thus removes WII games and only includes PS3 games as in the control (along with the non-backward compatible X360 games). Finally, columns 8 and 9 undertake weekly analyses for games released on all consoles and excluding WII games, respectively. Again, the sample was restricted to games that were released prior to the commencement of the sample window. Across all robustness checks, the main finding is supported with positive and (mostly) statistically significant exponentiated coefficients in the range 13-36%.

[17]We provide evidence below this strategy did not have an impact on XONE console sales.

[18]We note the statistically insignificant coefficients in columns 4, 5, and 5 is a likely manifestation of the relatively small number of 'treated' observations in the respective sub-samples.

5.3 Backward compatibility and Xbox One hardware sales

Beyond the impact on software sales, our theoretical framework indicates that another benefit associated with backward compatibility is the impact on new hardware sales. A number of previous studies have found evidence of this effect and we have no reason to dispute this evidence. However, the case of the XBOX backward compatibility experiment was quite different to previous cases, such as the WIIU. First, at time of release, the XONE console was not backward compatible and it was not until almost two years post initial release that the functionality was introduced. Second, once introduced, it was only selected X360 games that were compatible with the XONE with hardware modification patches. Over time, the staggered release of such games grew but remained only a relatively small portion of the population of X360 games (less than 30% of all games). It is therefore not obvious whether this strategy increased sales compared to previous cases where new hardware was backward compatible with all previous generation games at time of release.

To examine the impact of backward compatibility of XONE consoles (for selected games) on hardware sales, we consider another DiD model applied to Sample 3 of the form:

$$\ln S_{ct} = \gamma POST_t \times XONE + \mu_c + \Omega_t + \varepsilon_{ct}. \tag{5}$$

In this specification, sales now refer to eighth-generation hardware sales for PS4, XONE, and WIIU. $POST_t$ is the date June 15, 2015, which is again the date X360 software titles started to become backward compatible on the XONE hardware.

The results of this exercise are reported in Table 6. As with the previous analyses, we report results where we use a pre-/post-treatment dummy variable as well as week-of-sample fixed effects. While the results from columns 1 and 2 find a statistically significant DiD coefficient, this is based on a comparison where WIIU hardware sales are included in the control group. There are two reasons this may impact results. First, the WIIU console provides a different gaming experience to the PS4 and XONE. Second, the sales of the WIIU were particularly low in comparison to the other eighth-generation consoles (see Table 3 and Figure 1). For these reasons, we omit WIIU console sales in columns 3 and 4, such that PS4 defines the control group. In columns 5 and 6 we restrict the sample to only one year before and after the treatment date, whereas in columns 7 and 8 we apply the same sample window restriction and also exclude WIIU console sales. In the models where WIIU is dropped, we are unable to provide any evidence of increased sales. To the extent this result is accurate, we conjecture the explanation relates to the differences with other backward compatibility experiences. Specifically, the fact it was not until two years after the initial release that backward compatibility was introduced, and then only for selected titles was not enough to improve hardware sales meaningfully beyond what would have occurred without such intervention.

5.4 Backward compatibility and Xbox One software sales

Our theoretical framework indicates that one of the costs of backward compatibility relates to potential sales displacement, or a 'cannibalization' effect, for software designed for the new-generation hardware. Thus, we investigate whether the observed increase in sales of compatible previous-generation software resulting from the release of a new backward-compatible console occurs at the expense of sales of new-generation software for that console. Given the structure of our data, we are unable to address this question for WIIU games given the WIIU console was always backward compatible and it was the only eighth-generation console on the market at the time of release. Taken together, this implies there is no obvious control group for comparison. The XONE console, on the other hand, does allow us to make headway in addressing this question. Given the implementation of backward compatibility for the XONE console occurred incrementally well after its initial release, the time profile of XONE game sales can be examined before and after the emergence of backward compatibility for X360 games. Moreover, we can also use the software sales of the other eighth-generation consoles (i.e. PS4 and WIIU) as controls.

We estimate another DiD model applied to Sample 4 of the following form:

$$\ln S_{jct} = \gamma POST_t \times XONE + \beta X_{jct} + \mu_c + \Omega_t + \varepsilon_{jct}. \quad (6)$$

In this specification $POST_t$ is the date June 15, 2015. From this date, 19 X360 software titles became backward compatible on the XONE hardware. Over the following six months, more than one hundred additional X360 titles also became backward compatible. Within a year, the total number of compatible X360 titles was slightly over two hundred. We pose the question of whether the introduction of backward compatibility in the XONE console had an adverse impact on XONE game sales. We limit our analysis to one year before and one year after the introduction of backward compatibility. We chose this time window in order to use equal size windows of eighth-generation sales (post the initial PS4 and XONE release in November, 2013), while at the same time giving equal exposure to holiday sales pre- and post-treatment date.

We report results for this exercise in Table 7. We provide four different comparison models and for each we examine the results with a standard DiD post-treatment dummy variable as well as week-of-sample fixed effects. The first pair of such models uses both WIIU and PS4 games as controls (columns 1 and 2), while the second drop WIIU games (columns 3 and 4). Similar to the argument about the difference between seventh-generation WII console vs. PS3 and X360, there are inherent differences between the eighth-generation WIIU vs. PS4 and XONE. This hints that PS4 may serve as a more appropriate control than both WIIU and PS4 together. Additional checks limit the sample to games released on all three eighth-generation consoles, as well as dropping WIIU but restricting to games released on both the PS4 and XONE. Apart from columns 1 and 2, we observe statistically significant negative coefficients, which suggest XONE software sales falling as a result of the introduction of backward compatibility. Put differently, the observed boost to X360 game sales appears to come at the expense of reduced XONE game sales.

6 Discussion

The existing literature argues that backward compatibility is unambiguously welfare enhancing for consumers, as well as for society overall given its positive effects on technical progress. By comparison, the net benefits to platform owners from adopting the strategy are less clear. Our study makes a unique contribution towards addressing this ambiguity by undertaking a detailed empirical investigation as to whether sales data support the range of costs and benefits associated with backward compatibility that are outlined in this study.

First, we find consistent evidence that the adoption of backward compatibility associates with an increase in sales of software designed for the previous hardware generation. However, we find mixed results as to whether the increase in the sales of old software is driven by contemporaneous purchases of new hardware. On one hand, we show that the increased sales of WII games associate positively with WIIU hardware sales, indicating that the increased WII sales are likely being driven by those who have purchased new WIIU consoles. However, on the other hand we find no evidence that backward compatibility for the XONE associates with any increase in sales of the new hardware, implying that the increase in software sales comes from existing rather than new XONE console purchases. This is supported by the analysis of XONE hardware sales, which did not increase as a result of Microsoft's implementation of backwards compatibility. The difference in findings between the WIIU and XONE hardware platforms is potentially (and, we believe, likely) a consequence of the timing of introduction of backward compatibility, with the WIIU being backward compatible from launch and the XONE introducing the feature later in its life cycle. As a result, it seems the benefits associated with the feature may be more likely to be realized if it is present at launch rather than introduced at a later date.

With regards to the costs of backward compatibility, our study finds evidence that the introduction of the feature to the XONE associates with a reduction in sales of software for the new platform. Hence, backward compatibility potentially results in a cannibalization effect, whereby owners of new hardware substitute their consumption of software for the new hardware model with that of the old model. Although we are unable to directly observe the increase in production cost associated with the implementation of backward compatibility and how it might vary with technical and market factors, higher such costs would intuitively make implementation of backward compatibility less likely. Our findings suggest that hardware platform owners should carefully consider whether any increase in sales of the new hardware model and old software titles might offset a potential reduction in the sales of new software, as well as any associated increase in manufacturing costs. A unique contribution of our study is that we demonstrate how in this particular context, these costs and benefits might differ according to the point in the product life cycle where backward compatibility is implemented.

Our work complements and extends prior studies investigating the application of backward compatibility in video gaming, such as that of Kretschmer and Claussen (2016). Their study finds that the practice associates with increased hardware sales, as well as a reduced supply of new software. We show that backward compatibility associates with an increase in sales of old software, which is an issue over which the authors expressed uncertainty (p. 93). Further, their study implies that backward compatibility associates with a reduced variety of titles for the new hardware model, which complements our finding relating to the cannibalization of new software sales. Furthermore, our results differ from those of Narang and Shankar (2020), who essentially arrive at the opposite conclusion regarding the effect of backward compatibility on the unit sales of old software. The difference in findings may be a result of the different type of (consumer-level) data used by the authors of that study, although it should be noted that our results incorporate national-level sales data from a wider variety of hardware and software models.

Our study is subject to some limitations. First, our findings are based on evidence drawn from a single industry. As such, it is not clear whether our findings generalize to the use of backward compatible technology in other markets. Second, our data incorporates a period including a single transition between hardware generations. It would be useful to extend this analysis to incorporate data from earlier console generations in order to determine whether the patterns we observe are specific to this particular hardware transition. However, it should be noted that backward compatibility was not really seen in home consoles before the Sony PlayStation 2 was released in 2000. Extending the sample period would therefore only realistically add a few cases of transition between backward-compatible hardware platforms that are not already captured by our data. Third, our data exclusively contains US sales figures, which may not necessarily be representative of other major video gaming territories with different cultures, such as Japan.

It is also worth noting that we encounter some difficulties identifying the DiD coefficient as part of our robustness checks, given the relatively small number of titles that are available across all available hardware platforms. Future studies into backward compatibility could address some of these limitations by using more data from a longer time period and/or capturing data from a wider range of geographical territories. Additionally, it would be beneficial to compare our findings from the video game market with those for other technologies, such as optical media players (DVD, Blu-Ray, 4K UHD etc.).

7 Conclusion

Backward compatibility is an important strategic governance issue affecting owners of hardware platforms. Although theory suggests that the practice is welfare enhancing for consumers, the effect on producers is somewhat ambiguous. In a two-sided, backward compatibility can benefit platform owners on the one hand by increasing the sales of new hardware platforms, as well as increasing the sales of software originally designed for older platforms. On the other hand, backward compatibility might impose costs on platform owners, both in terms of production and the potential displacement of demand for new software. Thus, the net welfare effect of backward compatibility is ambiguous and will depend on several contextual and market factors that influence whether the benefits outweigh the costs for any given platform owner at any given time.

Our study attempts to address these ambiguities by analyzing sales data from the US video games market. We show that backward compatibility associates with an increase in the sales of software for the previous hardware generation. We also find evidence of a positive association between the sales of old software and new hardware for one of the hardware models in our sample (Nintendo WiiU), which was backward compatible from launch. This finding implies that it is the owners of the new hardware platform that drive the increase in demand for old software, rather than the owners of old platforms. However, we find no such evidence in the case of the Microsoft Xbox One, which implemented backward compatibility several years after launch. Based on this evidence, we argue that the timing of introduction of backward compatibility is likely to play a significant role in determining whether backward compatibility benefits firms by increasing sales of new hardware platforms. Our study further demonstrates some of the costs of backward compatibility given the statistically significant reduction in software sales for the new platform we observe when the feature is offered. Thus, our findings imply a degree of cannibalization of sales between software for new and old hardware platforms.

Overall, our results suggest that the successful implementation of backward compatibility as a platform governance strategy is likely to be highly dependent on the relative magnitude of benefits and costs and therefore involves important trade-offs. We further show that the (net) benefits of backward compatibility may also be dependent on the timing of implementation, which are likely to be greater if the feature is available at the time of release. This same conclusion also appears to have been reached by both Sony and Microsoft in the recent release of their ninth-generation hardware platforms which, unlike the offerings of both companies in the previous hardware generation, offer at least some degree of backward compatibility from launch.

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Figure 1: Hardware sales (weekly)

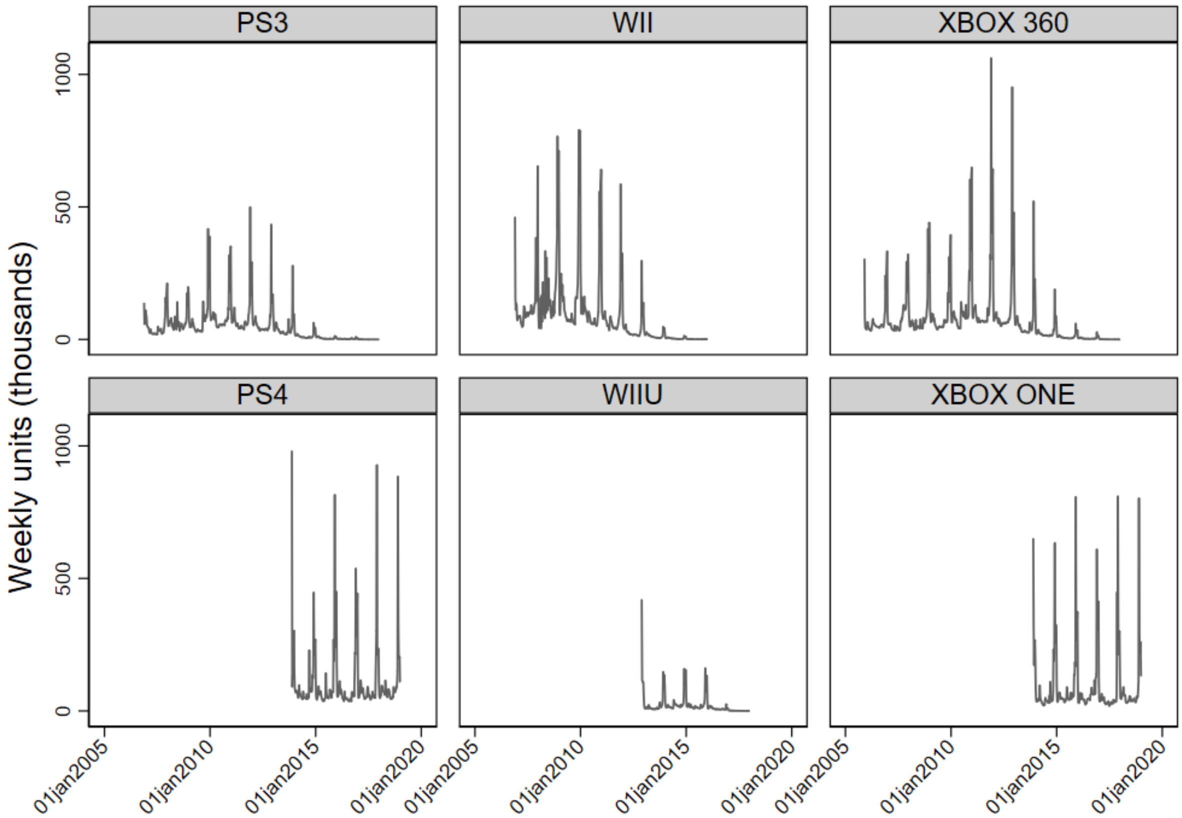

Figure 2: Hardware sales (total)

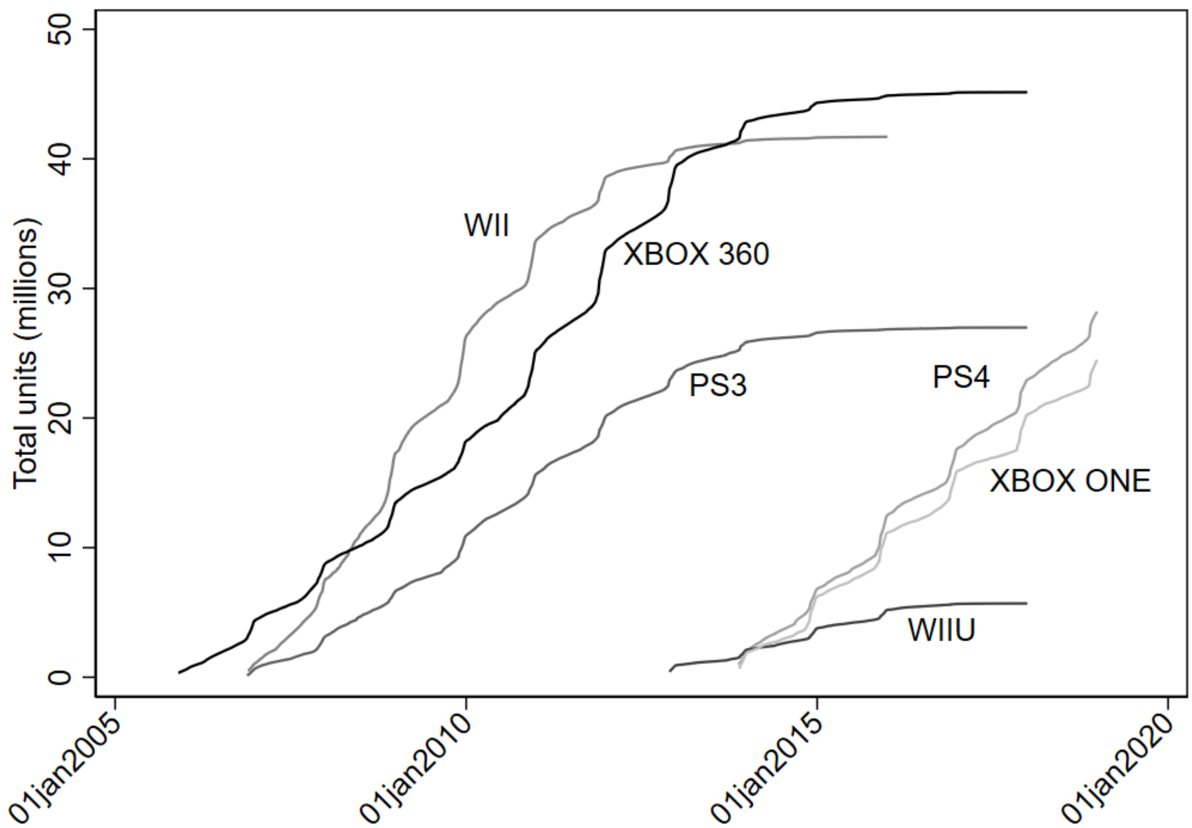

Figure 3: Software sales

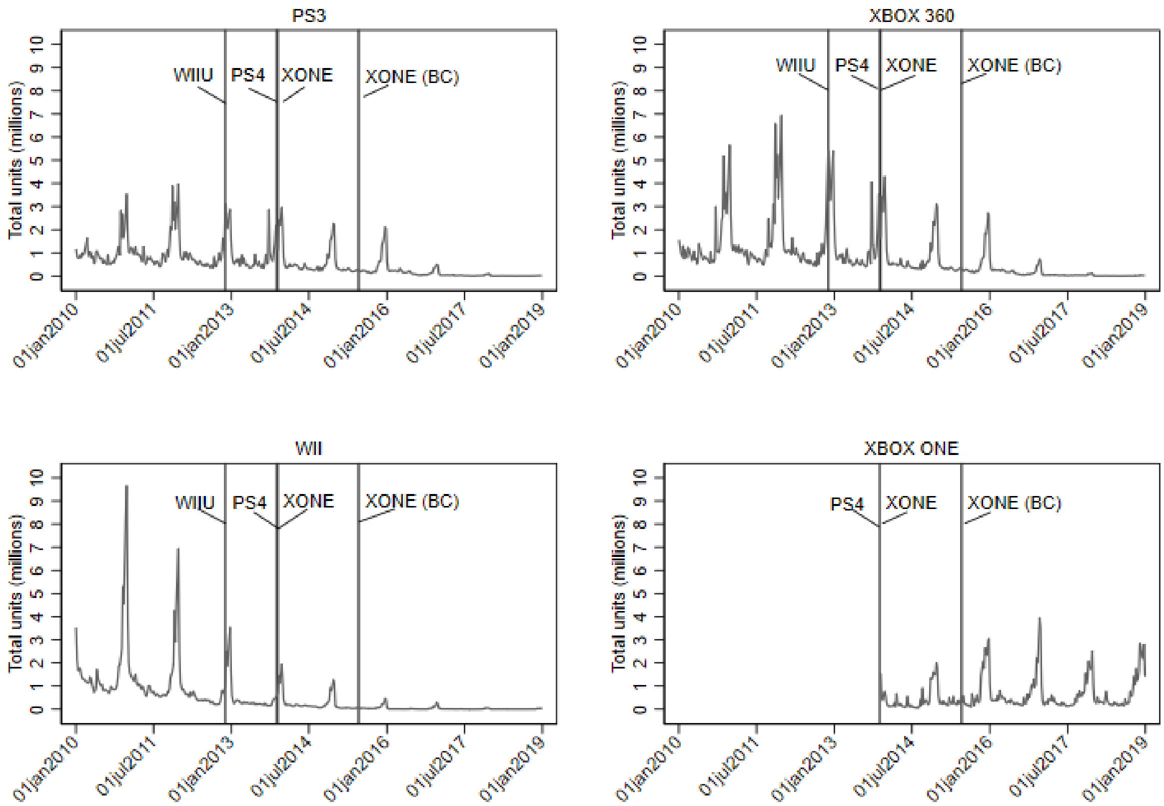

Table 1: Summary of backwards compatibility by hardware model

Console	Manufacturer	Year of US Release	Hardware Generation	Backwards Compatible (At Release)	Backwards Compatible (Post Release)	Backwards Compatibility Method
NES	Nintendo	1985	3	-		-
SNES	Nintendo	1991	4	No		-
PlayStation	Sony	1995	5	-		-
Nintendo 64	Nintendo	1996	5	No		-
PlayStation 2	Sony	2000	6	Yes		Hardware
Gamecube	Nintendo	2001	6	No		-
Xbox	Microsoft	2001	6	-		-
Xbox 360	Microsoft	2005	7	Yes[1]		Software
PlayStation 3	Sony	2006	7	Yes	Yes/No[2]	Hardware
Wii	Nintendo	2006	7	Yes	No[3]	Hardware
WiiU	Nintendo	2012	8	Yes		Software
PlayStation 4	Sony	2013	8	No		-
Xbox One	Microsoft	2013	8	No	Yes[4]	Software
Switch	Nintendo	2017	8	No		-
Xbox Series X/S	Microsoft	2020	9	Yes[5]		Software
PlayStation 5	Sony	2020	9	Yes		Software

Notes: 1) The Xbox 360 was backward compatible with most (but not all) software for the original Xbox console; 2) All PlayStation 3 models were backward compatible with PlayStation software. Early models were also backwards compatible with PlayStation 2 software, but this functionality was removed from later models; 3) Early models of the Wii were backward compatible with Gamecube software. This functionality was removed from later models; 4) The Xbox One introduced partial backward compatibility for a selection of software titles from 2015 onwards; 5) The Xbox Series X/S is fully backward compatible with software for the Xbox One and partially backward compatible with a selection of software titles from the Xbox and Xbox 360.

Table 2: Summary statistics – Samples 1 and 2

	Sample 1 (software)			Sample 2 (software)		
	N	Mean	Median	N	Mean	Median
PlayStation 3						
Weekly unit sales	37,566	1,822	313	78,171	688	151
Maximum unit sales	309	452,311	259,201	525	461,491	270,976
Maximum price	309	44.30	43.50	525	43.17	43.28
Maximum age	309	315	305	525	290	288
Metacritic user score	309	7.13	7.40	525	6.98	7.30
Wii						
Weekly unit sales	42,259	1,085	128	54,547	293	46
Maximum unit sales	410	591,307	253,741	462	588,254	256,870
Maximum price	410	38.34	33.00	462	39.40	35.49
Maximum age	410	373	374	462	369	371
Metacritic user score	410	6.86	7.30	462	6.86	7.20
Xbox 360						
Weekly unit sales	31,591	3,393	375	59,897	1,004	177
Maximum unit sales	245	1,119,610	493,766	384	1,023,029	494,458
Maximum price	245	42.90	40.28	384	43.05	41.97
Maximum age	245	378	390	384	346	352
Metacritic user score	245	7.26	7.50	384	7.11	7.40

Notes: Sample 1 covers from one year before WiiU release (18 November 2012) until one year after. Sample 2 covers from Xbox One release date (22 November 2013) until end of 2018. 'Maximum unit sales' refers to maximum observed total units sold over sample window. 'Maximum price' refers to maximum observed price of games over sample window. 'Maximum age' refers to maximum observed age in weeks of games over sample window.

Table 3: Summary statistics – Samples 3 and 4

	Sample 3 (hardware)			Sample 4 (software)		
	N	Mean	Median	N	Mean	Median
PlayStation 4						
Weekly unit sales	267	101,978	65,096	8,095	7,218	1,342
Maximum unit sales				132	653,505	351,126
Maximum price				132	47.51	47.50
Maximum age				132	150	158
Metacritic user score				132	6.67	6.90
WiiU						
Weekly unit sales	215	19,536	11,323	7,325	2,491	299
Maximum unit sales				91	349,380	157,113
Maximum price				91	46.60	45.34
Maximum age				91	165	167
Metacritic user score				91	7.04	7.30
Xbox One						
Weekly unit sales	267	91,692	45,727	8,892	5,443	973
Maximum unit sales				140	519,029	290,521
Maximum price				140	47.06	46.01
Maximum age				140	151	144
Metacritic user score				140	6.53	6.80

Notes: Sample 3 covers period where all eighth-generation consoles were on the market, i.e. from November 22, 2013. Sample 4 covers from one year before backward compatibility was introduced for the Xbox One console (15 June 2015) until one year after. 'Maximum unit sales' refers to maximum observed total units sold over sample window. 'Maximum price' refers to maximum observed price of games over sample window. 'Maximum age' refers to maximum observed age in weeks of games over sample window.

Table 4: Backward compatibility and Wii software sales

log(sales)	Base DID (1)	DiD with week FE (2)	Base DiD with WIIU sales interaction (3)	Week FE, with WIIU sales interaction (4)	Remove December (5)	Games released before 18-Nov-11 (6)	Games released PS3, X360 and WII (7)	Before 18-Nov-11 PS3, X360 and WII (8)	Placebo 18-Nov-10 to 18-Nov-12 (9)	Aggregate sales and before 18-Nov-11 (10)
Post WIIU x WII	0.110***	0.121***	0.111***	0.121***	0.153***	0.067***	0.078**	0.061*	0.015	0.072***
	(0.010)	(0.010)	(0.009)	(0.010)	(0.004)	(0.006)	(0.037)	(0.036)	(0.087)	(0.025)
Post WIIU x WII x log(WIIU)			0.076***	0.041***						
			(0.026)	(0.001)						
Post WIIU	-0.603***		-0.603***							
	(0.009)		(0.008)							
log(price)	-0.590***	-0.593***	-0.590***	-0.593***	-0.567***	-0.605***	-0.622***	-0.621***	-0.465***	
	(0.073)	(0.074)	(0.073)	(0.073)	(0.067)	(0.081)	(0.077)	(0.082)	(0.041)	
New	2.318***	2.243***	2.315***	2.238***	2.416***		1.879***		1.889***	
	(0.105)	(0.123)	(0.107)	(0.124)	(0.115)		(0.232)		(0.184)	
Metauser Score	0.218***	0.218***	0.218***	0.217***	0.214***	0.180***	0.213***	0.163***	0.185***	
	(0.012)	(0.013)	(0.013)	(0.013)	(0.013)	(0.021)	(0.014)	(0.008)	(0.023)	
Game FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
Console FE	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Month FE	Y	N	Y	N	N	N	N	N	N	N
Week of sample FE	N	Y	N	Y	Y	Y	Y	Y	Y	Y
Adj. R-sq	0.795	0.818	0.795	0.818	0.811	0.811	0.769	0.757	0.830	0.986
No. games	964	964	964	964	964	824	164	151	934	
Obs.	111,416	111,416	111,416	111,416	100,848	101,150	25,671	24,370	99,553	315

Notes: Dependent variable is (log) weekly game sales. ‘Post’ is introduction date of WIIU console (18 November 2012). ‘log(WIIU)’ is standardised (log) of cumulative sales of WIIU consoles. ‘New’ is dummy variable for first four weeks of release since game release date. ‘Metacritic User Score’ is average users score on 10-point scale. Price is instrumented with ‘first developer’ dummy variables in all models. Fixed effects (FE) include ‘game’, ‘console’, ‘month’ and ‘week of sample’. Standard errors clustered by console in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 5: Backward compatibility and Xbox 360 software sales

log(sales)	DiD with week FE (1)	Week FE, with XONE sales interaction (2)	Remove December (3)	Games released before 22-Nov-13 (4)	Games released PS3, X360 and WII (5)	Before 22-Nov-13 PS3, X360 and WII (6)	Drop WII games (7)	Aggregate sales and before 22-Nov-13 (8)	Drop WII, Aggregate sales before 22-Nov-13 (9)
BC X360 ($t > t(j)*$)	0.211**	0.212**	0.246***	0.122	0.300	0.305	0.307***	0.188**	0.263***
	(0.090)	(0.083)	(0.085)	(0.087)	(0.228)	(0.231)	(0.096)	(0.084)	(0.049)
BC X360 ($t > t(j)*$) x log(XONE)		0.004							
		(0.155)							
log(price)	-0.058	-0.062	-0.068	-0.06	-0.052**	-0.057**	-1.094***		
	(0.053)	(0.054)	(0.049)	(0.054)	(0.026)	(0.026)	(0.106)		
New	2.180***	2.183***	2.334***		1.556***		2.898***		
	(0.169)	(0.171)	(0.181)		(0.367)		(0.195)		
Metauser Score	0.043**	0.043**	0.042**	0.057***	0.067***	0.078***	0.126***		
	(0.018)	(0.018)	(0.018)	(0.018)	(0.017)	(0.016)	(0.016)		
Game FE	Y	Y	Y	Y	Y	Y	Y	N	N
Console FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Week of sample FE	Y	Y	Y	Y	Y	Y	Y	Y	Y
Adj. R-sq	0.699	0.699	0.683	0.699	0.694	0.691	0.661	0.929	0.983
No. games	1,059	1,059	1,058	968	171	166	685		
Obs.	192,615	192,615	174,402	177,024	33,331	32,670	138,068	801	534

Notes: Dependent variable is (log) of weekly game sales. 'BC X360 ($t > t(j)*$)' refers to X360 game j made backward compatible from date $t(j)*$. 'log(XONE)' is the standardised (log) of cumulative sales of XONE consoles. 'New' is dummy variable for first four weeks of release since game release date. 'Metacritic User Score' is average users score on 10-point scale. Price is instrumented with 'first developer' dummy variables in all models. Fixed effects (FE) include 'game', 'console', 'month' and 'week of sample'. Standard errors clustered by console in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 6: Backward compatibility and Xbox One hardware sales

	All consoles, base DiD	All consoles, week FE	Drop WiiU console	Drop WiiU console	12 months before and after 15-Jun-15	12 months before and after 15-Jun-15	Drop WiiU, 12 months before and after 15-Jun-15	Drop WiiU, 12 months before and after 15-Jun-15
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post XONE(compat) x XONE	0.877***	0.856***	-0.056	-0.056	0.152	0.152**	-0.085	-0.085
	(0.170)	(0.147)	(0.133)	(0.052)	(0.172)	(0.062)	(0.193)	(0.056)
Post XONE(compat)	-0.832***		0.101		-0.100		0.136	
	(0.100)		(0.094)		(0.100)		(0.137)	
Console FE	Y	Y	Y	Y	Y	Y	Y	Y
Week of sample FE	N	Y	N	Y	N	Y	N	Y
Adj. R-sq	0.517	0.643	0.03	0.855	0.415	0.924	0.015	0.917
Obs.	749	749	534	534	312	312	208	208

Notes: Dependent variable is (log) of weekly video console sales. 'Post XONE (compat)' refers to first date at which XONE consoles became backward compatible for limited X360 games (15 June 2015). Fixed effects (FE) include 'console' and 'week of sample'. Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 7: Backward compatibility and Xbox One software sales

log(sales)	All games (1)	All games (2)	Drop WiiU games (3)	Drop WiiU games (4)	Released WiiU, PS4 XONE (5)	Released WiiU, PS4 XONE (6)	Drop WiiU, Released PS4 & XONE (7)	Drop WiiU, Released PS4 & XONE (8)
Post XONE(compat) x XONE	-0.454	-0.438	-0.149***	-0.153***	-0.222***	-0.231***	-0.134***	-0.138***
	(0.310)	(0.305)	(0.002)	(0.001)	(0.070)	(0.078)	(0.002)	(0.001)
Post XONE(compat)	-1.008***		-1.480***		-1.269***		-1.542***	
	(0.255)		(0.006)		(0.021)		(0.010)	
log(price)	-1.814**	-1.699**	-2.019***	-2.008***	-2.096***	-2.097***	-2.112***	-2.099***
	(0.780)	(0.806)	(0.004)	(0.003)	(0.190)	(0.190)	(0.004)	(0.003)
New	1.927***	1.886***	1.890***	1.876***	1.696***	1.713***	1.951***	1.914***
	(0.245)	(0.224)	(0.046)	(0.042)	(0.113)	(0.123)	(0.052)	(0.047)
Metauser Score	0.013	0.016	-0.001	-0.001	0.037	0.037*	-0.003	-0.003
	(0.012)	(0.014)	(0.027)	(0.025)	(0.028)	(0.028)	(0.028)	(0.026)
Game FE	Y	Y	Y	Y	Y	Y	Y	Y
Console FE	Y	Y	Y	Y	Y	Y	Y	Y
Month FE	Y	N	Y	N	Y	N	Y	N
Week of sample FE	N	Y	N	Y	N	Y	N	Y
Adj. R-sq	0.749	0.786	0.709	0.760	0.645	0.695	0.700	0.752
No. games	249	249	180	180	26	26	127	127
Obs.	24,312	24,312	16,987	16,987	4,309	4,309	13,590	13,590

Notes: Dependent variable is (log) of weekly game sales. 'Post XONE (compat)' is date at which XONE consoles became backward compatible for limited X360 games (15 June 2015). 'New' is dummy variable for first four weeks of release since game release date. 'Metacritic User Score' is average users score on 10-point scale. Price is instrumented with 'first developer' dummy variables in all models. Fixed effects (FE) include 'game', 'console', 'month' and 'week of sample'. Standard errors clustered by console in parentheses; * $p < 0.10$, ** $p < 0.05$, ***$p < 0.01$.