HOW MUCH DO CONSUMERS VALUE INTEROPERABILITY? EVIDENCE FROM THE PRICE OF DVD PLAYERS

Kristofer Erickson[1]
CREATe, School of Law, University of Glasgow

Jesus Rodriguez-Perez
Department of Computer Science, University of Glasgow

Swagatam Sinha
Adam Smith Business School, University of Glasgow

[Working Paper 7 July 2017 – Please contact authors for latest version]

Abstract:

Digital Rights Management (DRM) systems provide manufacturers the ability to control the use of their products after sale, imposing legal and technical restrictions on the functionality available to consumers. For example, the DRM system used in consumer DVD prevents players from being interoperable with unauthorised copies and well as authorized content (films) sold in different regions of the globe. Theory on interoperability and the 'installed base' identifies local benefits to consumers who either stay with an incompatible standard or adopt an interoperable system, with welfare effects from both cases. We explore the relationship between interoperability features and consumer willingness to pay, using an original dataset on consumer media players. We hypothesize that consumers derive specific benefit from backwards interoperability which enables playback of legacy disc formats the consumer may already own. We further hypothesize that consumers value forwards interoperability between their device and new and emerging technologies.

Using a quasi-experimental setup, we use an Average Treatment Effect (ATE) estimator to evaluate the effect of interoperability features in new and used DVD players obtained from Amazon product listings. Nearest-neighbour matching is used to control for features such as manufacturer, technical specifications and condition of players. Based on analysis of the price and sales performance of 277 DVD players, we find that interoperability has a significant impact on price in the forwards direction. Players capable of playing new file formats such as Xvid command an average price which is $19.86 USD higher than the non-treated group. However, we find limited support for the impact of backwards compatibility on price, either for new or used players. The ability to play DVDs from multiple regions shows a moderately significant effect on price in our sample.

[1] Corresponding author: kristofer.a.erickson@gmail.com

1. Introduction:

Digital rights management (DRM) systems enable producers to control the circumstances under which devices may access content, interoperate with other devices or be modified by their owners. In the media industry, DRM has been applied by both content creators (for example to limit the unauthorised circulation and copying of goods) as well as by device manufacturers (for example to prevent unauthorised or 'bootleg' content to be used in conjunction with the device). In some cases, DRM is applied by content producers and device manufacturers in cooperation, such as in the case of the Digital Video Disc (DVD) standard present on both discs and players. While used in a variety of contexts and for a range of purposes, the primary appeal of DRM for producers is to protect profits by preventing consumers from accessing functionality or playback options provided by third parties from which the producer is unable to directly appropriate value.[2] The appeal of DRM for producers may be amplified in digital markets characterized by rapid circulation of content and copying of goods, however in recent years DRM has been extended to a range of product categories, from tractors to coffee makers, not considered to be subject to the effects of digitalization. As the 'Internet of Things' (IoT) progresses and copyright protectable software becomes embedded in a wider range of goods, the effect of DRM systems in economic and social processes will be significant. Furthermore, with the appearance and rise of 'maker' culture and other forms of user-led innovation as a basis for value generation, economic justifications for restricting consumer tinkering may require reexamination (Elkin-Koren, 2007; Favale, 2008; Samuelson, 2016).

[2] See Gasser & Palfrey (2007) Breaking down digital barriers: When and how ICT interoperability drives innovation. *Berkman Center Research Publication*, p. 10

DRM consists of a technological layer, commonly referred to as an access control (AC) or technological protection measure (TPM), which is applied to the content or device itself. This is further supported by a legal 'layer' which prohibits circumvention of DRM systems. The circumvention of DRM access controls is prohibited in the USA under Section 103 of the digital Millennium Copyright Act (DMCA).[3] This Act also prohibits the distribution of tools which would enable users to circumvent access controls.[4] In Europe, Directive 2001/29/EC requires Member States to provide 'adequate legal protection against the circumvention of any effective technological measures' as well as 'against the manufacture, import, distribution, sale, rental, advertisement for sale or rental, or possession for commercial purposes' of circumvention devices.[5] Controversially, the statutory protection of DRM anti-circumvention measures expands copyright protection available to rightsholders while making it difficult or impossible for consumers to benefit from exceptions to copyright in specific circumstances. For example, many countries in Europe have introduced exceptions to copyright to enable accessible copies to be made for the benefit of disabled people such as the sight and hearing impaired.[6] However, DRM may interfere with the ability to make lawful accessible copies of works for that purpose (Favale, 2008). The ability of manufacturers to apply TPMs to restrict access to content and the presence of criminal sanctions for the circumvention of DRM impedes the aim of copyright law to balance the incentives provided to creators against the public's interest in access to works.

DRM systems have also been maligned by consumer groups on the basis that these technologies can be anti-competitive. For example, it has been argued that DRM limits choice by locking consumers in to 'walled gardens' with potential for lock-in, that it hinders

[3] 17 U.S.C. §1201(a)(3)(B)
[4] 17 U.S.C. Sec. 1201 (a)(2)
[5] European Directive 2001/29/EC of the European Parliament and of the council of May 22, 2001 on the harmonisation of certain aspects of copyright and related rights in the information society.
[6] In the UK see The Copyright and Rights in Performances (Disability) Regulations 2014/1384.

innovation by preventing third party firms from providing goods and services, and that it reduces the quality of legally supplied goods by reducing utility and enjoyment below the level offered by infringing alternatives (Darroch, 2012). Specific groups of users impacted by anti-circumvention regulation have been particularly vociferous in opposition to DRM: these include educators, researchers, librarians and archivists who might otherwise benefit from fair dealing exceptions to copyright.

Certain producers have also argued against DRM. For example, the CEO of Apple, Steve Jobs enjoined in an open letter to the music industry in 2007 to drop DRM protections on digital music files. He wrote, 'Imagine a world where every online store sells DRM-free music encoded in open licensable formats. In such a world, any player can play music purchased from any store, and any store can sell music which is playable on all players. This is clearly the best alternative for consumers, and Apple would embrace it in a heartbeat.' (Jobs, 2007). It was pointed out that Apple may have been seeking a strategic advantage: it was costly to update and maintain an effective DRM system. However, beyond the strategic objectives of individual firms, there may be sound consumer welfare as well as innovative competitive justifications for limiting the legal protections afforded to DRM systems. Despite the prevalence of DRM controls on devices and content, it is surprising that there is such limited data about the effects of DRM on innovation and consumer preferences.

In this paper, we empirically investigate the extent to which consumers value interoperability in one category of media devices in order to attempt to quantify consumer welfare effects of DRM controls. We do this by using a quasi-experimental approach to compare market prices for home DVD players with and without DRM restrictions. We develop the following three hypotheses: (h1), that the absence of DRM restrictions on playback in home DVD players increases the price that consumers are willing to pay for devices; (h2), that consumers derive value from *backwards interoperability* of DVD players

which allows them to access legacy collections of content; (h3), that consumers value *forwards interoperability* of DVD players which enables them to access new unreleased types of content and features.

To evaluate the effect of DRM restrictions on market price and consumer willingness to pay, we obtained a sample of all consumer DVD players offered for sale on the retail website Amazon.com, introduced on or after 1st January 2010 (n=277). Our sample excludes automotive and other special classes of DVD players as well as players offered in combination with another device (such as those integrated within display monitors). We employ a nearest-neighbour matching technique to analyse the effect on new and used prices of DVD players both with and without DRM-circumvention features. Controlling for differences between major brands and other technical specifications, the Average Treatment Effect (ATE) estimator finds support for the main hypothesis that DVD players with interoperability features command a higher price compared to DVD players with DRM restrictions. The effect for new players is determined to be USD $19.86 on average for our sample. The effect is most significant for players which include the Xvid playback feature, suggesting support for (h3) that the interoperability value in DVD players is related to forwards rather than backwards compatibility with legacy collections or formats. The hypothesis (h2), that used DVD players with DRM-circumventing features retain their value over due to backwards compatibility cannot be supported or rejected based on the data obtained. We conclude the paper by offering some suggestions for improvements to the method of analysis.

1.1 Interoperability:

Katz & Shapiro (1985) discuss the presence of network externalities in 'products for which the utility that a user derives from consumption of the good increases with the number of other agents consuming the good' (1985: 424). Such positive consumption

externalities can be generated directly, for example through the ability to communicate with more users of a given device. Indirect effects can also arise from additional benefits provided by the number of users, for example the provision of third-party content for a popular playback device, or where costs are reduced due to after-market service availability. Importantly, networks can comprise of single or multiple firms whose products or users interact (1985: 424). Katz & Shapiro theorise the effect of consumption externalities on consumer choice in an oligopolistic condition, and find that when consumers expect a given seller (standard) to be dominant, they will be willing to pay more for the firm's product, and it will be dominant in the market (1985: 425). A problem for policy is that the private incentives for firms to offer compatible products can be lower than the social incentives for doing so under certain conditions, such as different market position.

In their influential analysis of the welfare effects of an 'installed base' in consumer goods, Farrell & Saloner (1986) identify the possibility for 'excess inertia' as well as 'excess momentum' caused by transient incompatibility costs for adopters of a new standard. There are a number of sources of benefit to consumers when a product is compatible with the same product used by others. Demand-side economies of scale arise from the features of interchangeability of complementary products (e.g. when software runs on different devices), ease of communication with other users (e.g. due to shared technical language) and cost savings arising from interchangeability of components (1986: 939).

DRM, while not considere in foundational economic theory on switching costs and network effects, might interrupt the ability of consumers to benefit from direct and indirect network effects predicted by the presence of a large installed base. For example, removing the ability to play back certain content from other regions or on legacy formats reduces the overall catalog of complementary products available to a consumer. Devices may not be able to 'talk' to each other as freely, preventing communication benefits from the presence

of a network. Marchand (2016) has found that device manufacturers can benefit in late product lifecycles from the release of complementary goods which leverage direct network effects, specifically multiplayer features in a video game. The presence of DRM restrictions on both an old and new technological standard could amplify the social costs of excess inertia, by artificially heightening transient incompatibility costs and locking out complementary overlapping goods.

We expect that consumers will place a value interoperability features because they increase the utility of the product by enabling its use with complementary products.[7] Building upon the propositions from the literature discussed above, in the context of DVD players we further propose that consumers may derive specific forms of utility from interoperability in two directions: backwards and forwards.

Backwards interoperability implies compatibility with preexisting content which may or may not be in the possession of the consumer (for example a large back-catalogue of existing titles or a collection of discs with specific regional coding). Even when content is not in the possession of a consumer, it may still provide value to prospective buyers due to network effects or economics of scale. This form of backwards interoperability may also increase the value to consumers if it allows playback of a legacy format into which the consumer has already invested significantly (sunk costs). In our sample, multi-region playback (which allows consumers to access a wider collection of films) is a common feature advertised by sellers as well as queried by consumers in Q&A sections of Amazon product pages.

Forward interoperability: By contrast, consumers may also obtain additional value over time from the ability to access content in new technologies and formats as they are

[7] van Wegberg, M. J. (2004). Standardization and Competing Consortia: the Trade-off between Speed and Compatibility. *International Journal of IT Standards & Standardization Research*, *2*, 18-34.

developed. This may occur if a manufacturer makes a pledge to adopt an open standard for which consumers believe new content or functionality will be made available. Or, it may simply occur because a follow-on innovator identifies an opportunity to interoperate with an open product. In the context of the market for DVD players, the adoption by some manufacturers of the Xvid standard and other open file formats constitutes a pledge of forward compatibility as it enables consumers to access films obtained via other means (including unlawful downloading). DVD Players which feature USB input may also enable consumers to change or update device firmware to access emerging technologies, adding functionality in the future.

1.2 Background on DRM protection

Digital Video Disc (DVD) is a video format specification first developed by a consortium of patent-holders (now named the DVD Forum) in 1995. An advantage of the format is that it is able to hold a high capacity of data (4.7 Gbytes per layer, higher than the storage capacity of Compact Discs) (Bloom et al, 1999). The DVD Forum initially consisted of 10 member companies, including manufacturers Toshiba, Hitachi, Philips, Sony, and Pioneer, as well as content owners Time Warner. Consumer DVD players were introduced to the consumer market in late 1996. Around the peak of the DVD format's popularity in 2003, the Forum consisted of 212 member companies.[8] As of 2016, the group includes 71 companies, while the composition of membership has changed to include computer device manufacturers (NVIDIA, Realtek Semiconductor) as well as a greater number of content rightsholders (Disney, Paramount, Starlight Video). The DVD Forum manages the licensing of DVD format technology as a 'pool' of patents and charges a per-unit fee on the sale of

[8] van Wegberg, M. J. (2004). Standardization and Competing Consortia: the Trade-off between Speed and Compatibility. *International Journal of IT Standards & Standardization Research*, *2*, p. 21.

discs, players and decoders to licensees. [9] The group also manages the development of the DVD format specification.

In conjunction with the DVD Forum, the DVD Copy Control Association (CCA) consists of an overlapping group of firms, and manages the DRM technical specification and licensing for manufacturers and content producers. Two forms of DRM used in DVD players are the Content Scramble System (CSS) and Regional Playback Control (RPC) system. CSS resides on the player, the drive and the disc and controls read, playback and region. For the purposes of this study, we focus primarily on playback and region restrictions enabled by DRM systems available to manufacturers of DVD players:

Read / Playback: The Content Scramble System encrypts the contents of an MPEG-2 DVD and provides compliant players with set of keys to decrypt the contents for playback. One key is stored in the header region of a CSS-enabled disc, and was designed to be read only by authorized types of players. Another key is unique to the MGEG-2 file contained on the disc. Non-compliant players from manufacturers that have not licensed CSS will be unable to play back the content of discs containing encrypted content Further, this method of encryption prevents consumers from being able to make copies of discs, since a new burned DVD would not ordinarily contain the second key contained in the header area of the disc (Bloom et al, 1999).

Region: The data contained on a DVD disc is not encoded specifically for NTSC or PAL display standards, so could conceivably be a global standard, which was not the case for content recorded on older analog VHS tapes. However, the region-control mechanism developed by the DVD-CCA divides the world into 6 regions and provides manufacturers

[9] Park & Scotchmer (2005)

the ability to prevent players sold in one region from playing back discs from another. This would mean that a disc purchased in America could not be played back, say, in France, even though the aforementioned NTSC/PAL encoding is no longer a technical impediment (see Doctorow, 2008; Yu, 2012). Technically, the system uses a series of numerical 'flags' to indicate playback rights on discs. Region '0' permits worldwide playback; 1-6 denote different territorial groupings (e.g. region 1 refers to Canada and the USA, while Mexico is in region 4 with Latin America and Australia). Region 7 is used to flag media PR and other special copies, while Region 8 is reserved for airlines and other leisure markets (Yu, 2012).[10] Technically, the system relies on matching flags encoded in the firmware of a DVD player device at the factory with flags contained in a header file on DVD discs. As of 2010, many DVD players were shipped without region locks in their firmware, or with the ability to play back DVDs from all regions. Additionally, some users have found ways to 'unlock' players or change their encoded region by inputting codes into the device.

2. Research design and methods:

We are interested in understanding the effect, if any, of interoperability features on the price that consumers are willing to pay for DVD player devices. In order to attempt this, we obtain real-world market data by crawling product pages on the Amazon.com online retail platform. This crawling approach enabled the researchers to extract structured data on every product offer in a given category (in this case, consumer home DVD players). Amazon conveniently presents product pages in machine-extractable format, with prices, product features and user reviews consistently listed across products. To analyse the results, we employ a quasi-experimental approach to estimate the Average Treatment Effect (ATE)

[10] It has been noted that region locks confer economic benefits to content producers, such as the ability to price-discriminate through 'windowing' (Doyle, 2016).

of the presence of specific interoperability features on the price of consumer DVD players which share other features in common. Given DVD player price (either used or new), seller characteristics and other information (2010-2016) in the Amazon US website, we try to determine impact of a 'treatment' on DVD players using a nearest neighbourhood matching method.

2.1 Sample:

Using a web crawling technique, we obtained a sample of all DVD players sold on the Amazon.com retail marketplace introduced on or after 1st January 2010. We used this arbitrary time period to limit possible effects of bias introduced by changing technology on the analysis, as well as to limit the presence of 'zombie' price listings in our sample (out of date listings by third-party sellers that have never been updated). This time period selection also enabled the researchers to match DVD players according to covariates which reflect more recent features of interest. For example, 1080p up-converting and the presence of USB ports are relatively recent product innovations. DVD players were considered to be for sale if their listing contained at least one new or used price (offer). This yielded a sample of 277 individual product listings. In order to ensure basic similarity across products, our sample included only DVD players for home cinema use in the 'Electronics' category and excluded automotive devices, DVD players embedded within display monitors or computer components such as DVD RW drives. Players not for home cinema use were excluded because the employ different forms of DRM restrictions and have different sets of desirable features and would therefore not be suitable for comparison using the ATE technique.

The use of Amazon.com as a site for data collection presents certain advantages and limitations in the context of this study. First, there is no public record on the website itself of changes, price history, or removal of products. Furthermore, we can determine only

when the product was first added to the Amazon.com website, not when it was first manufactured. Products may have been released, sold and removed in the time before our web crawl captured the sample in July 2016. Product pages, while conveniently structured, feature disparate levels of detail about actual product features. Some third-party and used product sellers do not follow the standard listing protocol and include or exclude product information. It is possible that products may possess features not described by Amazon or the product's seller. For the purposes of this research, we rely only on information available to users on the Amazon.com product page, so interoperability features not advertised there will be unknown to us. We make the assumption that sellers we seek to accurately describe product features and include them where possible, and that consumers will be influenced in their purchasing choice by the same information available to them on the product page. Future research could mitigate these issues partially by combining the Amazon features with third-party data about interoperability maintained by an external website. This approach is discussed in further detail in the conclusion.

2.2 Variable coding:

For each DVD player product listing, we obtained all information contained on the Amazon.com product listing page. However, for the purposes of this study, we retain only specific dependent variables, controls and other variables of interest. Specific variables and their attributes are described below and summarized in Table 1.

Table 1: Key variables and attributes

Dependent Variables

Lowest_new_price	The lowest price from any seller for a new condition DVD player on the product page.
Lowest_used_price	The lowest price from any seller for a used condition DVD player on the product page.
Lowest_combined_offer	Takes the lowest price, either new or used, for a given product listing.
Price_diff	The difference between the lowest new and used offer when both conditions were offered
DVD Player Features – Treatment	
VCD_compatible	The player features ability to play back Video CD disc format
Multi_region	The player is capable of playing DVDs from more than one region.
Xvid_compatible	The player is able to display files encoded using an open format, including unauthorised digital copies.
Any_interop	Dummy variable, 1= player includes any interoperability feature, 0 otherwise
DVD Player Features – covariates	
Is_major_brand	Dummy 1 = player is from a major manufacturer 0= otherwise
Upconvert_1080	Dummy 1 = player contains up-conversion feature, 0= otherwise
Feature_USB	Dummy 1 = player features USB input 0= otherwise N
Feature_HDMI	Dummy 1 = player features HDMI port, 0= otherwise
Date_introduced	Year of introduction of DVD player on Amazon website (proxy for age)
Used_condition	Condition of player if used. 1=acceptable, 2=good, 3=very good, 4= like new
Used_seller_rating	The cumulative rating of the seller by users of the Amazon.com website. Ranges from 1 – 5.

2.3 Dependent variables.

The main dependent variable in this analysis is the price of players in USD. The sample includes both new and used DVD players, so we collect both new and used prices for players when available, and we distinguish between these for the purposes of further analysis. In every case, we collected the lowest available new and used prices displayed on the Amazon listing for the DVD player on 15th July 2016 (the date of web crawl). For the purposes of analysing the entire sample, we used *lowest_combined_offer*, which takes the lowest price, whether new or used, for each player (n=277). We compute an additional dependent variable*, price_diff*, by subtracting the lowest used price from the lowest new price for those DVD players where both new and used options were available for purchase. Finally, for players where only a used example was offered, we record *lowest_used_price*. We assume that the listed price reflects, to a satisfactory degree, consumers' willingness to pay. Our assumption is supported by the auction-like dynamic character of the Amazon marketplace: prices set by Amazon and third-party sellers are visible to all, and sellers may under-bid one another with lower prices to attract consumers. To improve our understanding of the relationship between price and actual sales, we collected information on device sales rank and star rating, discussed below.

2.4 Independent variables:

2.4.1 Interoperability Features: The main treatment variable used in our analysis is the presence of features which provide interoperability beyond what is restricted by CSS DRM restrictions on DVD player hardware. As described above, the DVD Copy Control Association provides licensed manufacturers with a DRM standard to control both the playback of authorized content from discs made by authorized producers, and on the region of playback allowed, even when the non-local DVD disc would ordinarily be accessible on

a machine from that territory. We distinguish between different types of interoperability features in order to test hypotheses about the utility derived from forwards and backwards compatibility. First, we record information about interoperability features related to legacy disc playback. In the context of DVD players, we use the variable *is_VCD_compatible* to identify players capable of reading the non-DRM protected Video CD format, a legacy medium. Second, we record information about region playback. The CSS enables manufacturers to control the region(s) from which discs may be played on a given player. Some manufacturers advertise their players as being multi-region (playing back discs from one or more region codes) or being entirely region-free. We combine those two interoperability features in the variable *is_multi_region*, which captures any compatibility beyond a single region (in our study, the majority of advertised players are flagged for region 1: USA and Canada). Third, we consider the ability of player to access files that are not encrypted with the CSS DRM system. Some commercially sold media players are able to play back content in file formats other than the MPEG-2 video and audio on commercial DVD discs, using the disc itself, a USB drive, SD card or other storage medium. For example, Xvid is an open source video encoding library which builds upon the MPEG-4 video standard. This file format has been commonly used to rip and compress films and other content for circulation across the Internet (including unauthorised copying). We identify DVD players with this capability using the variable *is_Xvid_compatible*. Finally, we record information about whether the DVD player is equipped with USB ports or other input methods to enable future firmware updates, new file formats or new codecs to be accessed.

2.4.2 Matching covariates: Since we are interested in detecting only the price premium attributable to interoperability features, we control for other features that may be

desirable to consumers by matching using those covariates. The features that we use in this study as controls are as follows. To control for perceptions of quality related to the source of goods, we identify the manufacturer of the DVD player from the product page and record this information. We determine whether the manufacturer is considered to be a 'major brand' by its presence within the top-10 brand equity ratings in a 2012 USA consumer survey.[11] We record this as a binary variable *is_major_brand*. We record specific features not related to interoperability that may be desirable to prospective consumers. The variable *upconvert_1080p* captures those players that are equipped with software to automatically increase the output resolution of the video signal to display on HD 1080p television screens. The variable *features_hdmi* captures players which include HDMI-out ports which are capable of sending a higher video quality to newer displays. The variable *date_introduced* is the year of release of the player, used to control for general improvements in technology and manufacturing over the time period covered by the sample (January 2010 – July 2016).

2.4.3 Used condition covariates: Certain analyses focus on the used price for players where a new example is not available. In order to control for differences in the condition of used devices as well as other features related to the used offer, we collected and coded the following variables: *lowest_used_condition* is a categorical description of the condition of the device with the lowest used price as set by the seller (1=acceptable, 2=good, 3=very good, 4= like new). We also recorded the average *seller_star_rating*, which ranges from 1-5, and the variable *seller_rating_percentage* calculated by Amazon.com based on reviews of that individual seller.

[11] See Ranking of Consumer Electronics Brands in the United States by brand equity. Accessed online: https://www.statista.com/statistics/240112/brand-equity-of-consumer-electronics-brands-united-states-us/

2.4.4 User rating values: We further collected information from Amazon about the sales rank of individual products, using the variable *Amazon_sales_rank*. The method that Amazon uses for assigning this rank to product pages is non-transparent, but appears to rank the sales of items in specific categories (in this case: Electronics) for a non-disclosed trailing period of time. We further covert this to a *normalised_sales_rank* by ranking the order of DVD players as they entered our sample from 1-277.

Additional variables that were collected but are not used in the present study relate to listed prices other than the lowest, product identifier codes, warranty information, related product information, shipping time periods and shipping rates.

3. Analysis:

3.1 Estimation strategy:

The estimation strategy is as follows: First, we estimate an Ordinary Least Squares (OLS) regression model on the dependent variable *log_price* (taking the log of *lowest_combined_offer* in USD) with a variety of our treatment and control variables. We do this to observe interactions between independent variables and to identify correlations. Each of our model specifications include certain groups of variables in order to observe relationships between (i) only the independent variables of interest (treatment), (ii) the dummy variables; (iii) all variables excluding sales rank and (iv) all variables including the sales rank of products. A drawback of the OLS analysis is the low goodness-of-fit numbers (adjusted R-squared numbers), which is addressed in the following section.

Second, we evaluate our hypotheses by performing a series of Average Treatment Effect analyses. In these we observe how our dependent variables (new price, used price, price difference) vary with treatment variables, when these comparisons are carried out between closely matched DVD players. We use a nearest-neighbour matching technique,

which takes into account similarities between DVD payers, on the variables discussed in the previous section 2.4.2, titled *'Matching covariates'*.

We measure the effect of our treatment of four related price variables: (i) new price in USD, (ii) used price in USD, (iii) lowest combined offer of new or used price in USD, and (iv) the difference in price between new and used condition when both types are available. Finally, to check for the effect of treatments on other variables of interest, we perform four additional ATE analyses using the same matching covariates, but with quality-related dependent variables. These quality related variables are: (i) average star rating of the product by users, (ii) number of ratings received, (iii) sales rank as reported by Amazon, and (iv) sales rank normalized for our sample only.

3.2 Analysis using Ordinary Least Squares (OLS):

Our hypothesis 1 predicts that consumers will generally value interoperability in DVD player devices, and that this will be reflected in higher price. Table 2 presents the results of an OLS regression using the log of the lowest combined price offer as the dependent variable. We find a significant, positive influence on price for interoperability features in general (*any_interop*) and specifically for *Xvid_compatible* players, across different specifications.

We observe a significant effect of the control variable *is_major_brand*, an expected result. We also observe significance for *used_seller_rating* in certain specifications of the model which exclude user rating and sales rank data. In specifications which include the full range of variables, *user_star_rating* and *date_of_introduction* of players are significant variables. The results suggest that price is dependent on interoperability features and that specific features are significant. Interestingly, none of the main product feature controls are

significant in this analysis, although star ratings provided by users, both to rate sellers and products, are significant.

Table 2: OLS regression on *Log_price*

VARIABLES	(1) log_price	(2) log_price	(3) log_price	(4) log_price
Sample (specification:)	Full sample	Full sample Dummies	Full sample Incl user rate	Full sample Incl sale rank
VCD_compatible	0.0839		-0.136	-0.136
	(0.0979)		(0.156)	(0.1617)
Multi_region	0.0393		0.0991	0.107
	(0.1110)		(0.130)	(0.129)
Xvid_compatible	0.3178***		0.203*	0.2091*
	(0.1001)		(0.114)	(0.1153)
Any_interop		0.292***		
		(0.828)		
Is_major_brand	0.166**	0.1613**	0.268***	0.251***
	(0.0778)	(0.0757)	(0.089)	(0.089)
Upconvert_1080	-0.0169	-0.0162	-0.122	-0.109
	(0.0866)	(0.0866)	(0.1017)	(0.103)
Feature_USB	-0.0499	-0.0614	-0.0553	-0.039
	(0.092)	(0.0895)	(0.1033)	(0.102)
Date_introduced	-0.0001	-0.0001	-0.0001**	-0.0001**
	(0.0786)	(0.0000)	(0.0001)	(0.000)
Seller_rating	0.0097***	0.0092***	0.008	0.010
	(0.0035)	(0.0033)	(0.0069)	(0.007)
Used_condition	-0.0387	-0.0352	-0.0511	-0.042
	(0.0344)	(0.0334)	(0.0461)	(0.049)
Average_star_rating			0.103**	0.112**
			(0.0424)	(0.045)
Number_raters			-0.0001	-0.000
			(0.0001)	(0.000)
Amazon_sales_rank				0.000
				(0.000)
Constant	4.124***	4.121***	5.414***	5.291***
	(1.019)	(1.019)	(1.353)	(1.389)
Observations	277	277	277	277
Adjusted R-squared	0.099	0.099	0.178	0.182
p > F	0.00	0.00	0.00	0.00

*** p<0.01, ** p<0.05, * p<0.1

From these systematic correlations between interoperability-related variables and prices across all specifications, we find support for the hypothesis that consumers value

interoperability, although a complete causal relationship (as required by hypothesis 1) cannot be drawn from the OLS alone.

To investigate hypothesis 1 further, we next evaluate the results of our quasi-experimental set up using the observational data obtained from the Amazon marketplace. We try to determine impact of a 'treatment' on DVD players using a nearest-neighbour matching method, with covariates denoted by X, outcome variable as Y, and treatment dummy as D_i. Before employing the matching technique, we must check that our data satisfies the underlying assumptions required for this strategy to work. This is provided in Appendix 1, which shows us that the matching technique can, indeed, be used for the analysis at hand.

3.3 Nearest neighbour matching and estimation of the ATE:

Here, we present the results of an Average Treatment Effect (ATE) analysis on different subsamples of the data, using price as the dependent variable. Each of the ATE analyses uses a different number of total observations from the sample, because certain product pages had only new, or used offers available. Out of 277 original observations in our dataset, 181 entries had a new price listed on product pages, which is used as the outcome variable Y in column (1) of Table 3. Of the total sample, 179 products had used offers available, and we use *lowest_used_price* as the outcome variable in column (2). Column (3) takes the full sample of 277 products, using the *lowest_combined_offer* as the outcome variable. By combining both the used and new prices, while controlling for the product condition we manage to utilise our entire sample of 277 devices. Finally, 88 product pages in our sample included both a new and used product offering, and we calculate the variable *price_diff* which is used as the outcome variable in column (4). Due to absence of sufficient data, the analysis on *price_diff* could not be carried out for the full

sample, which can potentially introduce a sample selection bias. For now, we make the (admittedly weak) assumption that the data is missing in a purely random way, and no bias is introduced by going from the full sample (n=277) to the smaller sample (n=88).

When dependant variable is *new price* (column 1), the *any_interop* treatment dummy has a significant (at 10% level) and positive average treatment effect (ATE). The average impact on price for the interoperability treatment is an increase of $16.19 USD for player devices. The *Xvid_compatible* treatment has a significant (5% level) and positive effect on new price. The average impact of this treatment variable is an increase in price of $30.20 USD. When the dependant variable is *used price* (column 2), the *any_interop* treatment dummy remains significant at the 10% level, but none of the specific interoperability treatments are significant on their own. In column 3, where *lowest combined price* is the dependant variable, the *any_interop* variable is significant (5% level) and positive, producing a $19.06 USD increase in price on the treated group. In addition, the *Xvid_compatible* variable is highly significant (1% level) and produces an ATE of $30.36 USD.

In column 4, we take the difference in price between used and new DVD players (where both offers are present) as dependant variable. There are fewer observations in this analysis. The treatment *VCD_compatible* is found to have a negative impact on price difference (indicating that the used and new price approach one another), significant at the 10% level. None of the other treatment variables are found to be significant in the price differential analysis.

Table 3: Average Treatment Effect (ATE) for different DRM-circumvention features on DVD player price when different offers are present (SE in parentheses)

DVD player Attributes	(1)	(2)	(3)	(4)
	Lowest New price	Lowest Used Price	Lowest Combined	Price differential

			Offer	new - used
Any_interop	16.199*	17.881*	19.068**	2.15
	(9.701)	(10.4033)	(7.740)	(14.539)
VCD_compatible	-4.88	6.616	-0.485	-16.937*
	(9.244)	(19.317)	(8.040)	(9.585)
Multi_region	34.964	14.1752	37.558*	-9.375
	(24.496)	(23.931)	(21.942)	(12.123)
Xvid_compatible	30.2035**	8.973	30.364***	31.108
	(13.321)	(12.071)	(10.445)	(21.572)
Observations	181	179	277	88

*** p<0.01, ** p<0.05, * p<0.1

In addition to the analysis of effects of interoperability feature on price, we performed further ATE analyses on a series of dependent variables related to product popularity below. Table 4 presents a similar set of analyses to Table 3, with columns arranged according to quality variable used. We observe no significant effect on the Average star rating received by players (column 1). However, each of the interoperability features appear to have significant negative impact on the total number of ratings received by products (column 2). The *Xvid_compatible, Multi_region* variable and the *VCD_compatible* variables each have significant (at 5%) ATE on the number of ratings received. This means that DVD players with interoperability features are less frequently reviewed on the Amazon.com website. Amazon sales rank is another dependant variable that is influenced significantly (at 5% level) by the *multi_region* variable in our analysis. The negative direction of this result needs to be read as a rank, so this means that Multi region DVD players are more popular on the Amazon.com website, on average.

Table 4: Average Treatment Effect (ATE) for different DRM-circumvention features on DVD player popularity and rating (SE in parentheses).

DVD player Attributes	(1)	(2)	(3)	(4)
	Avg. Star rating	Number of ratings	Amazon sales rank	Sample rank (normalized)

Any_interop	0.0877	-111.34*	-15882.24	-12.58
	(0.2561)	(64.504)	(40359.61)	(47.276)
VCD_compatible	-0.209	-53.353**	49.68	-5.332
	(0.161)	(26.6876)	(58069.23)	(60.549)
Multi_region	0.11846	-96.107**	-89183.29**	-82.78423
	(0.274)	(47.714)	(39878.09)	(53.57148)
Xvid_compatible	0.446	-118.777**	8162.805	13.1245
	(0.300)	(52.006)	(47520.41)	(56.886)
observations	130	130	241	241

*** p<0.01, ** p<0.05, * p<0.1

4. Results:

The results of our OLS regression and ATE analyses show that prices for DVD players on the Amazon.com website are significantly positively related to interoperability features. By using a nearest-neighbor matching technique, we attempt to isolate the effect of these features on price from other possible factors, using controls such as the brand, manufacturer, technical specifications and quality of players. Our main finding is robust across most specifications and subsamples in both analyses (with the exception of *price_diff*, where we have a limited number of observations). Consequently, we find support for hypothesis 1, that consumers value interoperability features in new and used DVD players.

On the other hand, when we examine specific features of interoperability, we find significant variation in the results. The variables *VCD_compatible* and *multi_region* playback are not highly significant in either the regression analysis or ATE analyses. The negative direction of the coefficient for *VCD_compatible* in both *lowest_new_price* and *lowest_combined_offer* analyses suggests that the significant effect in *price_diff* may be attributable to presence of lower-priced new offers, rather than used products retaining their value over time (which was our prior supposition). This is consistent with VCD playback being a legacy technology at the time of the data collection period. We interpret this to

suggest that these features are not important to consumers in the American Amazon marketplace. As a result, we do not find support for hypotheses 2 that consumers value interoperability in the backwards direction with content they already own. This finding may be due to a number of factors: it has been pointed out that American consumers may not be concerned about multi-region playback because they have access to a strong market in blockbuster releases; it is possible that consumers in general do not care about multi-region or VCD playback; the age of VCD as a format may render it inconsequential to product pricing in 2016. Further research, for example a comparison of prices in territories other than USA (region 1) may shed additional light on this finding.

The most significant variable is the *Xvid_compatible* playback feature, which is positively related to price in both the OLS and ATE analyses. We calculate an effect of $30.20 USD on the new price for DVD players with this feature. This is a meaningful result, considering the average price of $63.91 USD for all DVD players in the sample at the time of data collection. It suggests that consumers value compatibility in the forward direction, that is, with content or file types that might emerge in the future. Since Xvid and other open file formats are used in online distribution of film content, this finding may indicate that consumers are interested in accessing unauthorised copies of content (the value of interoperability as well as the cost-savings from accessing free content). Further research is required to disentangle the potential value of free content (access to piratical catalogues) from other aspects of interoperability (‘authorized’ uses).

5 Conclusions:

Our findings, while preliminary, have implications for scholarship on the law and economics of interoperability in consumer devices, as well as for policy and business managers. These empirical results represent one of the first attempts to gain understanding

of the ways that consumers respond to interoperability features in products and, by contrast, DRM restrictions that may hinder interoperability in specific ways. Our findings suggest that for media players, more precise investigation is required to understand the ways that consumers approach interoperability. Backwards compatibility with investments made earlier may not be as important as future promises of connectivity or 'future proofing'. In our study, price appears to be correlated more significantly with open-ended technological features like file formats and connectivity ports, than by legacy disc formats or discs from other regions. We suggest conducting further research in neighbouring product categories (media as well as other devices) where consumers own complementary goods where backwards compatibility is possible. These may include Blu-ray players, video game consoles, e-readers and music players, for example.

Expanding this research into more product categories could have more general implications for business strategy, particularly in technology and innovation. Manufacturers struggle with decisions about backwards compatibility across product generations. For example, in video game consoles, manufacturer Sony included backwards compatibility on the PlayStation 2 console, allowing owners to play discs from the PlayStation 1. Sony included backwards compatibility in the PlayStation 3, but later removed the feature, likely due to cost and cybersecurity concerns[12]. Our results suggest that consumers may not be as concerned with legacy backwards compatibility as initially expected. Instead, consumers appear to value forwards interoperability: compatibility with potential and emergent complementary technologies. Consumer technology moves quickly, and obsolescence (of devices, formats and collected media) may be a reality that consumers are willing to accept for newer and more capable devices.

[12] See http://kotaku.com/5340337/sony-explain-why-the-ps3-slim-has-no-backwards-compatibility

The results of this study have applicability to innovation and intellectual property policy. If consumers value forwards interoperability and are willing to pay to access these features, there are economic welfare considerations in granting manufacturers the ability to lock out these features from products where there is demand for them. This unfulfilled demand represents a loss to society. Limiting forwards interoperability also restricts follow-on innovators and entrepreneurs from developing products which make technological improvements to legacy goods. Innovation policy here could result in a virtuous circle for new standards, in which preserving forwards interoperability promotes investment by both consumers and follow-on innovators based on the promise of future value.

Although the present study suggests that backwards compatibility is less important in the context of consumer media goods, there are other reasons why policy makers and society may find it desirable to promote backwards interoperability by limiting DRM restrictions. For example, DRM can interfere with the task of archiving and backing up collections of old media for purposes of preservation. While legacy content may not be on the minds of consumers, it may be important for cultural reasons to avoid the digital 'memory hole' caused by society's move toward digital records. Complying with copyright law is a source of costs for cultural and memory institutions dealing with collections of analog works, and research has explored the role of these costs as disincentive to cultural preservation. Future research in this sector could contribute greater precision to the potential role of DRM restrictions in the overall costs of copyright compliance.

Appendix 1:

Here, we run a brief check on the data and our experimental set-up, to ensure that two major assumptions underlying the matching technique are satisfied here.

The first requirement of using the matching method is to ensure that the Conditional Independence Assumption is satisfied. To make sure the CIA holds, we explicitly state the following: DVD players are assumed to be identical if they are similar on the following fields: Up-conversion to 1080 p, Features 1 or more USB port(s), Manufactured by a major brand, Date of introduction to the Amazon US website, used sales product condition, and used seller rating. These variables (1-6) constitute our list of covariates X, and the presence of interoperability features (measured by each of the dummies— *Is_multi_region*, *VCD_compatible*, *Xvid_compatible*, or any of these), is taken to be the treatment.

Secondly, we know that the matching estimand imposes common support which means that the estimate produced by the matching method is valid provided each covariate value has both treated and control observations. We ensure this by checking explicitly the data here:

Table A1: Fraction of Treated and control observations, for each covariate, as percentage of full sample

Xvid	**Any_Circumvention**	**Multi_region**	**VCD**
Treated: 22.5% Control: 77.5%	Treated: 42.8% Control: 57.2%	Treated: 17.5% Control: 82.5%	Treated: 16.8% Control: 83.2%

As we can see in the table above, every covariate (consisting of the variables 1-6) has non zero number of both treated and control cases, for every treatment. This ensures that the set up satisfies the requirement of common support. This validates the treatment effect computations shown in the result tables.

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