

DIGITAL RIGHTS MANAGEMENT AND EXCLUSIONARY TYING

By

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ABSTRACT

Digital Rights Management is employed by firms as a way of reducing illegal copying. In this paper we investigate the idea that it can also be used as a type of exclusionary tie. In our analysis content and hardware are complementary goods, where one of the hardware sellers has the option of employing a closed Digital Rights Management system that makes legal content incompatible with rival hardware. The result is a type of exclusionary tie where the hardware producer employing Digital Rights Management gains market power in the hardware market. We also show how a hardware producer with access to DRM can achieve a similar result through licensing and high royalty fees rather than through a closed DRM system. In addition to investigating these ideas in a number of related theoretical settings, we also consider the social welfare aspects of the argument and discuss its relevance for real world hardware products such as Apple's iPod.

I. INTRODUCTION

Digital Rights Management (DRM) refers to encryption technologies used to restrict access to content such as music, movies, or software distributed frequently over the internet, so that those without proper authorization cannot access it. In the standard case the content is distributed in an encrypted form and can only be accessed using devices with the capability of unencoding the content. It has become a popular practice in content industries where the stated goal is typically that it is employed to reduce illegal copying, but its restrictive nature has been a controversial subject.¹ In this paper we theoretically investigate the idea that, in addition to DRM serving as a way of reducing illegal copying, it is sometimes used as a type of exclusionary tie used to increase market power and profitability in hardware markets.

One reason to look for motivations for the use of DRM other than a reduction of illegal copying is that there is no clear cut evidence that content providers that employ DRM have significantly increased profitability through such a reduction. For example, one possibility is that content providers' profits increase with DRM due to indirect appropriability (see Liebowitz (1985) for an early discussion of indirect appropriability). In the indirect appropriability argument the content provider increases the price of original units to reflect the prices that buyers of these units receive when he or she sells copies. If DRM decreases the supply of illegal copies, then the firm may be able to increase profits by charging a higher price for original units not subject to DRM (or alternatively, increase the price of units subject to DRM if DRM reduces copying but not to zero). However, a crucial condition for this argument to apply is that competition among sellers of copies does not drive the price of copies to zero.² Given that in many cases the price of copies of products that are DRM protected are basically zero, increased

¹ One of the legal arguments against DRM is that it restricts consumers "fair use" rights which traditional copyright laws grant. That is, under fair use users do not need the copyright holder's permission to reproduce the work under some circumstances, but circumventing a DRM system is ruled illegal under the Digital Millennium Copyright Act (Pub. L. No. 105-304 (1998), codified at 17 U.S.C. Section 1201, et. seq.).

² This point was first made by Novos and Waldman (1984) and then elaborated on in Johnson and Waldman (2005), where it is shown that if the supply of illegal copies quickly floods the market then the indirect appropriability argument does not apply. See Besen and Kirby (1989) for a related analysis.

profits through indirect appropriability does not seem to be the main reason for the use of DRM.

On the other hand, there are significant reasons for thinking that DRM is sometimes employed because it serves as a type of exclusionary tie that increases market power and profits of the hardware provider. For example, consider the case of Apple's iPod. After its introduction in 2001, the iPod quickly became the fastest selling music player in history. Its US market share among hard-drive-based portable music players exceeded 80 percent by 2004 and its online retail counterpart, the iTunes Store, accounted for more than 80 percent of US digital music sales.³ Apple's early success in this market is often claimed to be partly due to the fact that when the iPod was introduced its DRM system, known as FairPlay, was a proprietary product. That is, competing music players could not play protected content from the iTunes Store.

The logic is that a closed DRM system like the one initially employed by Apple when it introduced the iPod can serve as a type of exclusionary tie that increases the hardware seller's market power and profitability. For example, if a hardware seller employs a DRM system that it does not share with rival hardware sellers and those rivals do not have access to a competing DRM system, then it is as if legal content is tied to the hardware with DRM and users of rivals' products are forced to obtain illegal copies which can either increase the cost of using these rival systems or lower the functionality of those systems. The end result can be an increase in the market power and profitability of the hardware seller that employs DRM.

In this paper we formally investigate this argument. We begin with a simple static model with homogeneous consumers and the assumption that the firm with the DRM technology has the option of sharing the technology with its rival. We show that in a market characterized by rival hardware devices, a firm that owns a proprietary DRM technology can monopolize the hardware market by tying the protected legal content to its hardware. That is, a closed DRM system emerges in equilibrium because the hardware seller with access to DRM increases market power and profits by refusing to share its DRM system with its rival. We also show that, if the

³ These numbers are from the NPD Group, Inc. which is a leading North American market research company. For discussions of iPod's quick success see, for example, Guglielmo (2004) and Evans (2006).

government forces the DRM system to be shared, then consumer surplus increases but there is no effect on overall social welfare.

We then consider the same model but assume that the firm with the DRM technology can license its technology to the other firm. Here we find two types of equilibria. In the first type the hardware seller with DRM does not license its DRM system and the result is basically identical to the equilibrium just described for the case where sharing rather than licensing is possible. In the other equilibria the firm with the DRM system licenses its technology to the other hardware seller, where a high per unit price or royalty fee is used to achieve an outcome similar to what happens in the closed DRM equilibria. That is, consumption choices, firm profit levels, and consumer utilities are virtually the same as in the closed DRM equilibria. Also, if the government forces the DRM system to be shared, there is again no effect on overall social welfare.

We then extend the analysis to show that the social welfare conclusions change when the model is made more realistic in either of two ways. In our first extension we introduce an R&D stage at the beginning of the game where each hardware seller can invest in the development of a DRM system. The main result here is that, if the government forces DRM to be shared in this type of setting, the result can be increased social welfare by limiting investments in DRM development. However, we also point out that, if DRM increases content variety, then imposing the sharing of DRM would have an ambiguous effect on welfare. In our second extension we introduce consumer heterogeneity. Here we show that, although the basic argument remains unchanged, there is now an efficiency loss under a closed DRM system because high hardware prices lead to monopoly deadweight losses.

So in summary our basic argument is that, although the direct effect of DRM is to make copying more difficult, the motivation for the development of DRM can be either solely or at least partly the desire to reduce competition in the hardware market through a type of exclusionary tie. The analysis is thus related to models in Whinston (1990) and Carlton and Waldman (2002) where ties are used to extend or preserve market power when goods are

complementary. The difference is that in our analysis, in contrast to the analyses in those earlier papers, the tying firm does not produce the complementary product. We discuss the relationship between our paper and those earlier papers in more detail in Section II.

The outline for the paper is as follows. Section II discusses the relevant literatures. Section III sets forth our basic model. Section IV extends the analysis in two ways: i) the introduction of an R&D stage at the beginning of the game; and ii) the introduction of heterogeneous consumers. Section V relates our analysis to the iPod case and briefly discusses other real world cases concerning the use of DRM. Section VI presents concluding remarks.

II. RELATED LITERATURE

The economics literature on copyright has a long history and includes a variety of theoretical and empirical perspectives (see Peitz and Waelbroeck (2006) for a survey). From a theoretical perspective there are broadly two types of copyright protection available to owners of copyrighted goods. One is government enforced legislation, while the other consists of private actions – which are frequently technological in nature – taken by the owners themselves. Much of the early literature on the topic such as Novos and Waldman (1984) and Johnson (1985) focuses on government levels of protection and enforcement and finds that higher levels typically enhance social welfare.⁴ Recently, there has been growing attention to private copyright protection and, in particular, DRM.

Park and Scotchmer (2005) examine the effects on pricing and collusion of the use of DRM systems. They assume that content providers can deploy a DRM system and share the fixed costs of the system. They find that a shared DRM system can facilitate collusion via cost sharing, while separate systems are less vulnerable to hacking so sellers are more likely to raise prices. In our paper we focus, like in the iPod example, on a DRM system owned by a hardware seller rather than a content provider and consider whether the seller has an incentive to share the

⁴ Kim (2007) considers public copyright protection that is controlled by the copyright owner and finds that copyright protection can be used to deter potential entry.

system with a rival hardware seller.

Other papers on DRM include Sundararajan (2004) and Bergemann et al. (2005). Sundararajan focuses on DRM systems owned by a content provider and shows that the content seller chooses a lower level of DRM protection when it can price discriminate. Bergemann et al. posit that the optimal level of DRM protection trades off the user's disutility from DRM restrictions and the risk that illegal copies may circulate. They conclude that a content provider who also sells a device prefers a less stringent DRM system than one who only sells content. Note that these papers are similar to the Park and Scotchmer paper and different than ours in that the focus is mostly on DRM systems owned by content providers and there is no consideration of the possible anticompetitive effects of DRM on rival hardware producers.

Another literature relevant to our study is the extensive literature on tying and, in particular, the literature focused on the circumstances in which tying can have anticompetitive effects.⁵ The traditional Chicago School argument is that a monopolist of a primary product never has an incentive to tie in order to monopolize a complementary product because the monopolist can capture all the potential monopoly profits through the pricing of its primary product (see, e.g., Director and Levi (1956), Bowman (1957), Posner (1976), and Bork (1978)). However, a number of more recent papers including Whinston (1990), Choi and Stefanadis (2001), Carlton and Waldman (2002,2011), and Nalebuff (2004) show that the Chicago School argument that tying will not be used for anticompetitive reasons holds in a class of settings, but it is not valid in all cases. In particular, these papers show a variety of realistic settings in which tying is used to either monopolize a primary market, increase the profitability of an existing primary market monopoly, leverage its primary market monopoly into a complementary market, or preserve the primary market monopoly into the future.

The analyses most similar to ours are one of the analyses in Whinston (1990) and the analysis in Carlton and Waldman (2002) in that these analyses focus on tying used to increase

⁵ See, e.g., Carlton and Waldman (2005) and Tirole (2005) for surveys of the tying literature.

market power and profits in the tying market. Whinston (1990) considers a primary good monopolist where there is also a competitively supplied inferior substitute for the monopolist's product. Also, there is a complementary good that can be produced both by the monopolist and rivals, where there are economies of scale in the production of the complementary good. In the absence of tying, even though the competitive producers do not sell any primary units because their product is inferior, the presence of the competitively supplied inferior product reduces consumer willingness to pay for the monopolist's primary good and thus reduces monopoly profitability. Whinston shows that in this setting the monopolist may be able to increase profits by tying. This occurs when tying causes rival producers of the complementary good to exit because they cannot achieve an efficient scale of production, which in turn raises monopoly profitability because it eliminates the competitively supplied inferior product as a substitute.

Carlton and Waldman (2002) consider two related analyses where one is focused on entry costs and the other on network externalities. The entry-cost model is easier to follow, so our discussion will focus on that analysis. In that model there are two periods, a monopolist who produces primary and complementary goods, and a single rival who can enter the complementary market in either period but the primary market only in period 2. Carlton and Waldman focus on parameterizations in which in the absence of tying the rival enters the complementary market in period 1 and the primary market in period 2. Their main point is that by tying the monopolist is sometimes able to stop the rival from entering either market in either period and in this way it preserves its monopoly in the primary market into the second period. The basic logic is that tying stops the rival from selling complementary units in the first period and this can stop complementary market entry in either period because the rival is unable to sell a sufficient number of complementary units over the two periods to cover the complementary good fixed costs of entry. In turn, because consumers only have a positive value from consuming a system consisting of primary and complementary goods, in this model the rival does not enter the primary market in period 2 if it never enters the complementary market.

Our analysis is similar to these two papers in the sense that the hardware producer uses a closed DRM system as a type of tie that increases its market power and profitability in the hardware or tying market. But there are also important differences. First, in contrast to Whinston's analysis, in our main analysis the rival hardware producer offers a product of equal rather than inferior quality. Second, in contrast to the Carlton and Waldman analysis, the tying is not used to deter entry since the rival hardware producer is already present in the market. Third, and most importantly, our analysis introduces a new type of tying. In previous literature on the topic two goods produced by the same firm are physically or contractually tied together. In contrast, in our analysis the producer of one good – the hardware product – uses proprietary technology to virtually tie another firm's complementary good in order to monopolize the hardware market. Fourth, we consider this type of virtual tie in a setting where consumer copying is important. Thus, the current paper is an attempt to combine the separate literatures on tying and copying.

Finally, another related literature is the literature on systems competition and, in particular, the choice between having an open or a closed system (see, e.g., Matutes and Regibeau (1988), Kende (1998), and Church and Gandal (2000)). In the literature on systems competition firms sell systems which consist of primary or platform goods and complementary goods, where much of the focus in that literature is on compatibility choices concerning one firm's primary good and a rival's complementary good. The paper in this literature closest to our analysis is Church and Gandal (2000) where a primary good producer sometimes merges with a complementary good producer and makes the complementary good incompatible with the rival's primary product in order to increase market power and profits in the primary market. Our basic argument is similar except in our model the hardware firm does not produce and sell the complementary good in which case it can directly choose to make the good incompatible with the rival's product, but rather the firm uses DRM to achieve this incompatibility. Also, we focus on the case of a single complementary good producer while Church and Gandal allow for two complementary good producers. See the Conclusion for a discussion related to the last point.

III. MODEL AND ANALYSIS

In this section we present our argument in a basic model with homogeneous consumers and two hardware producers, where only one has access to a DRM system. In Section IV we extend the analysis both to the case where hardware producers invest in the development of DRM systems and to the case of heterogeneous consumers.

A) The Model

There are two firms ($j=A,B$) that sell hardware devices that consumers need in order to play digital content. There is a single content firm, call it firm C, that sells the content and owns its copyright. This may be due to individual artists or authors transferring their copyrights to a single firm that specializes in managing content. Both hardware devices are produced at a constant marginal cost of c while the content has a zero marginal cost of production. The content is subject to consumer piracy, where we assume that consumers can obtain illegal copies at zero marginal cost in the absence of a DRM system. That is, there are two versions of content; one we refer to as “legal content” and the other as “illegal copies.”

We assume that firm A owns a proprietary DRM technology that can encrypt digital content. Thus, in this section’s model we abstract away from the initial investment in DRM technology. When content is DRM protected it is harder for individuals to make illegal copies. Specifically, we assume that DRM protection increases a consumer’s copying cost from zero to h , $h>0$. When legal content is protected by a DRM system, firm A’s hardware is by design compatible with it. However, firm B’s hardware is compatible with protected content only if firm A shares or licenses its DRM system with or to firm B. Illegal copies, however, are not DRM protected, so both firms’ hardware are compatible with illegal copies.⁶

There are N identical consumers each of whom derives utility from consuming a system composed of hardware and content, where a consumer places zero value from consuming either

⁶ This captures the idea that most portable music players, including the iPod, are compatible with plain MP3 files which is the standard format for illegal copies.

component by itself or from a system composed of hardware and content where the two are incompatible. Let $U_i = X - e_i - p_j^H$ denote consumer i 's utility when he purchases a system consisting of firm j 's hardware and legal content that can be played on firm j 's hardware, where X is the consumer's value for reading, watching, or listening to the legal content, e_i is the consumer's expenditure on content, and p_j^H is the price of firm j 's hardware.

Illegal copies are imperfect substitutes for legal content because, for example, copies are lower quality and customer service is not available to consumers of illegal copies. To be specific, let $U_i = Y - e_i - p_j^H$ denote consumer i 's utility when he purchases a system consisting of firm j 's hardware and an illegal copy, where $Y < X$ captures that illegal copies are inferior to legal content and let $\Delta = X - Y$. We assume $Y > h + c$ which ensures both that the value of legal content exceeds the marginal cost of producing a system consisting of hardware and legal content and that the value of an illegal copy exceeds the marginal cost of producing a system consisting of hardware and an illegal copy even given DRM protection.

Let p_C denote the price of legal content. This means that when consumer i purchases legal content $e_i = p_C$. However, if instead the consumer obtains an illegal copy, $e_i = 0$ if the legal content is DRM free and $e_i = h$ if it is DRM protected. The two hardware devices are homogeneous other than the compatibility issue related to the use of DRM and firms engage in Bertrand competition when more than one firm is active. Finally, let π_j , $j = A, B$, denote firm j 's profitability and π_C denote firm C 's profitability.

The timing of the game is as follows. First, firm A has the option of adopting DRM and offering to firm C a contract that specifies that C must only sell DRM protected content and a price for that content.⁷ Second, if firm A makes such an offer, C decides whether or not to

⁷ An alternative assumption is that the contract specifies both a price for legal content and a fixed payment that C pays A for use of the DRM technology. With this assumption the equilibrium described in Proposition 1 where A does not share the DRM technology with firm B would still exist but it would not be unique. But if we made the model more realistic by assuming that consumers receive utility from multiple units of content and the marginal utility for additional content is decreasing, then even with this alternative assumption there would be a unique equilibrium similar to the equilibrium described in Proposition 1. Our approach of not allowing fixed payments from C to A and having consumers only consume either zero or one unit of content makes the analysis easier to follow.

accept it. Third, if A offers such a contract and C accepts it, then A can offer to share or license its DRM technology with or to B and if an offer is made then B either accepts or rejects the offer. Note that in the analysis that follows we start by assuming that firm A's choice is to share or not share its technology with B and we then consider the more realistic case in which it can offer a license to B. Fourth, firms set prices simultaneously subject to any contractual terms and consumers make consumption choices. Throughout the analysis we restrict attention to Subgame Perfect Nash equilibria.

B) Analysis

As indicated, we start with the assumption that firm A's choice when C accepts the contract offer is whether or not to share its DRM technology with B. Although less realistic than the licensing analysis that we consider next, in this case the basic argument is easier to follow. Consider first pricing and consumption choices as a function of the DRM choices made earlier. There are three possibilities concerning the DRM choices made in the first part of the game. First, neither hardware seller employs the DRM technology. Second, firm A employs DRM and firm C agrees to sell its product with DRM encryption, where p_C^+ denotes the contractually specified price at which firm C sells legal content. We refer to this case as firm A selling hardware with a closed DRM system. Third, both firms employ DRM and firm C agrees to sell its product with DRM, where p_C^+ is again the contractually specified price at which firm C sells legal content.⁸ We refer to this case as firm A selling hardware with an open DRM system.

Suppose neither firm employs DRM. In this case the two hardware sellers are selling identical products and there is Bertrand competition, so $p_A^H = p_B^H = c$ and $\pi_A = \pi_B = 0$. Firm C, on the other hand, faces potential competition from illegal copies which can be obtained in this case at

⁸ Another possibility is that firm A employs DRM but C sells legal content without encryption. In terms of the resulting pricing and consumption choices this case is equivalent to the first case where neither hardware seller employs DRM technology.

zero cost. This means that firm C sets its price equal to its quality advantage over illegal copies, i.e., $p_C = \Delta$, all consumers purchase legal content from C, and $\pi_C = N\Delta$.⁹

Suppose firm A sells hardware with a closed DRM system. If $p_C^+ > \Delta + h$, then consumers would obtain illegal copies rather than purchase legal content from C. In this scenario it is as if the two hardware firms are selling identical products, so we again have $p_A^H = p_B^H = c$ and $\pi_A = \pi_B = 0$. Further, since C does not sell legal content, we also have $\pi_C = 0$.¹⁰

Now suppose $p_C^+ \leq \Delta + h$. If consumer i purchases firm A's hardware and legal content, then $U_i = X - p_C^+ - p_A^H$. The other possibility is that consumer i purchases firm j 's hardware and obtains an illegal copy which yields $U_i = Y - h - p_j^H$ (consumer i will not purchase firm B's hardware and legal content because firm A sells hardware with a closed system). Given $p_C^+ \leq \Delta + h$, the consumer prefers to purchase firm A's hardware and legal content if the two firms choose equal hardware prices.¹¹ This set of parameterizations is therefore equivalent to Bertrand competition where firm A has a superior product. So $p_A^H = c + \Delta - (p_C^+ - h)$, $p_B^H = c$, and consumers purchase A's hardware and legal content from C. Also, $\pi_A = N[\Delta - (p_C^+ - h)]$, $\pi_B = 0$, and $\pi_C = Np_C^+$.

The final possibility is that firm A sells hardware with an open system. In this case the two hardware sellers are again selling identical products and there is Bertrand competition, so $p_A^H = p_B^H = c$ and $\pi_A = \pi_B = 0$. If $p_C^+ > \Delta + h$, then consumers prefer to obtain illegal copies and $\pi_C = 0$. If $p_C^+ \leq \Delta + h$, then consumers prefer legal content and $\pi_C = Np_C^+$.¹²

⁹ One might think, since consumers are indifferent between purchasing legal content and obtaining illegal copies when $p_C = \Delta$, that firm C charging $p_C = \Delta - \varepsilon$, $\varepsilon > 0$, and all consumers purchasing legal content is also consistent with Nash equilibrium behavior. But this is incorrect. Because the smallest ε , $\varepsilon > 0$, is not defined, Nash equilibrium behavior requires $p_C = \Delta$ and all consumers purchasing legal content from C.

¹⁰ One concern here is that it is not clear how consumers obtain illegal copies if firm C sells no legal content. So implicitly we are assuming there is a small number of additional consumers – at least two – who have a higher cost of obtaining illegal copies with the result that copying is not an option for these consumers. This additional assumption rationalizes the behavior above as long as $p_C^+ \leq X - c$.

¹¹ To be precise, if $p_C^+ = \Delta + h$, then given equal hardware prices consumers are indifferent between purchasing firm A's hardware and legal content and purchasing either firm's hardware and obtaining an illegal copy. In this case behavior can be consistent both with what we describe for $p_C^+ > \Delta + h$ and with what we describe for $p_C^+ \leq \Delta + h$.

¹² To be precise and similar to the discussion in footnote 11, if $p_C^+ = \Delta + h$, then consumers are indifferent between purchasing legal content and obtaining illegal copies. So π_C will be somewhere in the interval $[0, Np_C^+]$.

We now use these results to analyze the beginning of the game where DRM choices are made. From above we know that if neither firm employs DRM or there is an open DRM system (or firm A employs DRM but firm C does not encrypt its legal content), then $\pi_A = \pi_B = 0$. So firm A has an incentive to employ a closed DRM system if it can achieve strictly positive profits. From above we also know that, if firm A chooses a closed DRM system and $p_C^+ > \Delta + h$, then we again have $\pi_A = \pi_B = 0$. So our focus is on closed DRM and $p_C^+ \leq \Delta + h$.

Suppose that firm A employs a closed DRM system and chooses $p_C^+ \leq \Delta + h$. From above we know that if firm C accepts the DRM contract offer and chooses to encrypt its content, then $\pi_A = N[\Delta - (p_C^+ - h)]$ and $\pi_C = Np_C^+$. On the other hand, if firm C turns down the offer, then it is just like the no DRM case (see footnote 8) which means $\pi_A = \pi_B = 0$ and $\pi_C = N\Delta$. In other words, firm C will accept the offer as long as $p_C^+ \geq \Delta$. Clearly, firm A chooses the minimum value for p_C^+ that firm C will accept, i.e., $p_C^+ = \Delta$, because this maximizes the price that firm A charges for its hardware and thus also maximizes firm A's profit.

We state the result formally in Proposition 1. Also, formal proofs are in the Appendix.

Proposition 1: If firm A's choice is whether or not to share its technology with firm B, then there is a unique Subgame Perfect Nash equilibrium characterized by i) through vi).

- i) Firm A adopts DRM and offers its DRM system to firm C and sets $p_C^+ = \Delta$.
- ii) Firm C accepts the contract.
- iii) Firm A does not share its DRM system with firm B.
- iv) All consumers purchase hardware from A and legal content from C.
- v) $p_A^H = c + h$, $p_B^H = c$, and $p_C = p_C^+ = \Delta$.
- vi) $\pi_A = Nh$, $\pi_B = 0$, and $\pi_C = N\Delta$.

As discussed earlier, this result is related to analyses in Whinston (1990) and Carlton and Waldman (2002) on tying and Church and Gandal (2000) on systems competition. The first two papers show how a firm can increase its profits from the sale of a primary good by tying a

complementary good that it also produces, where the tie disadvantages a rival primary good producer by reducing the availability of complementary units that can be used with the rival's primary product. The third paper shows a similar result where there is no tying, but one of the primary good producers merges with a complementary good producer and then makes the complementary good incompatible with a rival's primary good.

In our analysis the primary good or hardware producer with access to DRM does not produce the complementary product and we do not consider the possibility of a merger. So the firm cannot unilaterally reduce the availability of complementary products that can be used with the rival's hardware system. Instead, the firm uses DRM to accomplish this goal, where this requires agreement by the complementary good producer because a DRM system only works when the content provider agrees to encrypt its product. So what happens in equilibrium is that the hardware producer with access to DRM, firm A, shares with the content provider, firm C, the extra profits associated with disadvantaging the rival, firm B, so that firm C also finds it (weakly) advantageous to disadvantage firm B. In other words, there is a type of tie accomplished through DRM and encryption that increases market power and profitability of the hardware seller with access to DRM, but because the tie requires the cooperation of the content provider the increased profitability must be shared with this firm.¹³

A related question of interest is how would a government policy that requires DRM systems to be shared or open affect social welfare. This issue is considered in the following corollary where we analyze the exact same game considered above except at the beginning of the game the government announces that firm A must share its DRM system with firm B. Also, in

¹³ Our argument is thus also related to Aghion and Bolton's (1987) analysis in which contracts between buyers and sellers are used to deter entry. In the Aghion and Bolton argument a buyer and seller extract rents from a potential entrant by signing a contract that specifies damages if the buyer trades with the potential entrant, where the extra profitability of the seller is shared with the buyer so that the buyer is compensated for the reduced probability of entry. In our argument a hardware producer and content provider extract surplus from consumers by signing a contract that increases market power in the hardware market, where the extra profitability of the hardware producer is shared with the content provider so that this provider is compensated for any potential loss in its profitability due to this increased market power in the hardware market.

the corollary and throughout the rest of the paper we define social welfare as the sum of firms' profits and consumers' utilities.

Corollary to Proposition 1: Suppose that at the beginning of the game considered in Proposition 1 the government announces that firm A must share its technology with firm B. The result is no change in social welfare.

The logic here is as follows. Because of the government intervention, in this case a closed DRM system is not possible, so there are multiple equilibria because $\pi_A = \pi_B = 0$ whether or not the equilibrium is no DRM (which occurs if firm A offers a contractual price to firm C that satisfies $p_C^+ < \Delta$ or $p_C^+ > \Delta + h$) or open DRM (which occurs if firm A offers a contractual price to firm C that satisfies $\Delta \leq p_C^+ \leq \Delta + h$).¹⁴ But independent of which equilibrium is realized, social welfare is exactly the same as in the equilibrium without government intervention described in Proposition 1, although consumer surplus may rise. The reason social welfare is unchanged is that with or without government intervention all consumers purchase a system consisting of one hardware unit and legal content, so the decrease in firm A's profit is exactly matched by an increase in the sum of firm C's profit and consumer surplus.¹⁵

We now consider the more realistic case where, rather than firm A having the option of sharing its DRM system with firm B, we assume that A can offer to license its technology to B. Specifically, licensing requires B to make a two-part payment to A where F is the fixed payment and s is the per unit payment or royalty fee. Proposition 2 formally considers this case.¹⁶

¹⁴ To be precise, if $p_C^+ = \Delta$, then firm C is indifferent between accepting and not accepting the contract. Similarly, if $p_C^+ = \Delta + h$, then C may or may not accept the contract because consumers are indifferent between purchasing legal content and obtaining an illegal copy when $p_C = \Delta + h$. See the proof of the Corollary to Proposition 1 in the Appendix for details.

¹⁵ Consumer surplus increases with government intervention when the intervention leads to either the no DRM equilibrium or an open DRM equilibrium where $p_C^+ < \Delta + h$.

¹⁶ For this case we make the additional assumptions that firm B does not accept contract terms which result in no hardware sales for firm B and that there are other hardware sellers each of whom has marginal cost c , but only B's product is capable of using A's DRM system. If we did not assume the existence of these other hardware sellers, then, in contrast to what we find in Proposition 2, firm A would prefer to license its DRM system over having a

Proposition 2: If firm A's choice is whether or not to license its technology to firm B, there are multiple equilibria.

- i) In some equilibria firm A does not license its DRM system to firm B, and in all respects other than the contract terms A offers to B these equilibria are equivalent to the Proposition 1 equilibrium where A has the option of sharing and employs a closed DRM system.
- ii) In the other equilibria A licenses its technology to B, where $F=0$, $s=h$, $p_C=p_C^+=\Delta$, p_A^H , $p_B^H \geq c+h$ (and at least one equals $c+h$), $\pi_A=Nh$, $\pi_B=0$, and $\pi_C=N\Delta$. Also, in every equilibrium of this type each consumer purchases hardware from either A or B (at the price $c+h$) and legal content from C.¹⁷

The logic behind the equilibria where A employs closed DRM is the same as the logic for the equilibrium described in Proposition 1. By employing closed DRM firm A is able to increase its market power in the hardware market and in this way raise its hardware price and increase profitability. As stated in the proposition, however, now there are also other equilibria in which A licenses its technology to B, where $p_C^+=\Delta$ and the equilibrium license payments are $F=0$ and $s=h$. To see why there are equilibria of this form consider what happens given this value for p_C^+ and these license fees when firms set prices to charge consumers. Because of the contract, firm C charges $p_C=p_C^+=\Delta$. To determine the hardware prices we need to know the marginal costs for hardware. B's marginal cost is $c+h$ since it is the sum of the production marginal cost and the per unit payment that B makes to A when it sells a hardware unit. In equilibrium A's marginal cost is also $c+h$ which is the sum of A's production marginal cost and the lost licensing fee equal to h that A incurs when it sells a unit because each unit A sells means one less sale for B. In turn, given Bertrand competition and a marginal cost for each hardware producer equal to $c+h$, in equilibrium p_A^H , $p_B^H \geq c+h$ (and at least one equals $c+h$). The final result is that every consumer

closed DRM system because by licensing the firm could eliminate the sale of rival hardware that plays unprotected content which, in turn, would allow the firm to increase the price of its own hardware that plays protected content.

¹⁷ There are multiple equilibria of the first type because there are multiple contract terms that A can offer to B that will be rejected, while there are multiple equilibria of the second type because p_A^H and p_B^H are not uniquely defined.

purchases hardware from either A or B and legal content from C, $p_C^+ = \Delta$, p_A^H , $p_B^H \geq c+h$ (where at least one equals $c+h$), while $\pi_A = Nh$, $\pi_B = 0$, and $\pi_C = N\Delta$.¹⁸ In other words, this second type of equilibrium is almost identical to the first except that the DRM system is open and so consumers can purchase hardware from either hardware producer.¹⁹

Note that small changes to this version of the model would eliminate this multiple equilibria result. For example, if some consumers had a slight preference for A's hardware while the others had a slight preference for B's, then the only equilibrium would be open DRM because licensing its technology would allow A to capture additional profits from the added value some consumers have for B's product. On the other hand, if there was a monitoring cost associated with A verifying B's output or if there was a positive fixed cost in addition to a marginal cost for producing hardware, then open DRM would not be an equilibrium.

We also again consider the social welfare implications of a government policy that requires DRM systems to be shared or open. We formally consider this issue in the following corollary.

Corollary to Proposition 2: Suppose that at the beginning of the game considered in Proposition 2 the government announces that firm A must share its technology with firm B. The result is no change in social welfare.

The logic for this result is basically the same as the logic for the similar result when firm A's option was to share rather than license. That is, all the equilibria in Proposition 2 have the same consumer utilities and firm profitabilities as the unique equilibrium in Proposition 1. So the same argument given above concerning why this government intervention did not affect

¹⁸ The reason only one of firms A and B needs to charge $c+h$ for its hardware is that the threat of consumers purchasing hardware from a third firm (see footnote 16) and obtaining an illegal copy means that either A or B can deviate from a price of $c+h$ without creating an incentive for the other firm to deviate.

¹⁹ That there are both licensing and no licensing equilibria in this version of the model is consistent with Apple employing closed DRM for the iPod while Microsoft employed licensing and open DRM for its "PlayForSure" DRM system.

social welfare when A's option was to share also applies here where A's option is to license its technology.

C) Two Simple Variants

In this subsection we consider two simple variants of this section's analysis. In the next section we consider more extensive changes which we label extensions. The first variant involves our assumption concerning bargaining between firms A and C. That is, by assuming that firm A makes a take-it or leave-it offer to firm C when offering to share its DRM technology, we give all the bargaining power in this exchange to firm A. As a result, firm C's profit in the unique equilibrium in Proposition 1 and all the equilibria in Proposition 2 is the same as the profit it receives in an outcome where DRM is not employed at all. If instead we assumed that each firm had positive bargaining power so that the added profits associated with DRM was shared between the firms, the main change in the equilibria would be that p_C^+ would be higher while hardware prices would be lower. That is, the outcome would still be such that prices are higher than in the absence of DRM, but instead of the higher prices being solely captured by higher hardware prices as in Propositions 1 and 2, both hardware and firm C's legal content would have higher prices.²⁰

The second variant we consider concerns the substitutability of the two hardware products. In our basic analysis we assume that in the absence of DRM protection the two products are equally attractive to the consumers. But another interesting case is what happens when consumers prefer one hardware product over the other.²¹ Suppose, for example, that consumers prefer firm A's hardware product, i.e., consumers prefer the product of the firm with access to the DRM technology.²² Consider this case and assume initially as a benchmark

²⁰ If we assumed that firm C makes a take-it or leave-it offer to firm A, then firm C would have all the bargaining power and only firm C's legal content would have a higher price.

²¹ A similar analysis would hold if consumers found the products equally attractive but one of the firms had a lower marginal cost of production.

²² If consumers preferred firm B's hardware product rather than firm A's, then A would license its technology to B and B would employ a closed DRM system.

analysis that A does not have access to a DRM system. Because consumers prefer A's hardware product, even in the absence of DRM, firm A would monopolize the hardware market where A's profit would reflect the added valuation that consumers place on A's hardware relative to B's.

Now start from the situation described above where A does not have access to a DRM system and give A such access. The result is an equilibrium similar to the one described in Proposition 1, i.e., firm A adopts a closed DRM system and all consumers purchase hardware from A and legal content from C. The question is, why does A adopt closed DRM given that it monopolizes the hardware market with or without DRM? And the answer is that, because the price that A can charge for its hardware is a function of how close a substitute B's product is for A's, firm A adopts closed DRM because in a sense closed DRM reduces the quality of B's product which allows A to raise its hardware price and increase its profitability. Note that this argument is similar to an argument of Whinston's discussed earlier in which a primary good monopolist's profits are constrained by the presence of an inferior primary product for which there are no sales in equilibrium. Whinston shows that in this setting the monopolist sometimes has an incentive to tie a complementary good because this behavior results in the inferior primary good no longer being a viable option which, in turn, increases monopoly profitability.²³

IV. EXTENSIONS

In this section we consider two extensions. First, we add an R&D stage at the beginning of the game where hardware producers can invest in the development of a DRM system.

Second, we consider a case with heterogenous consumers.²⁴

²³ Another closely related variant is that consumers prefer A's hardware product and both A and B have access to DRM, although the two firms have access to different DRM systems. If consumers are indifferent between the two DRM systems then there is no reason for A to employ closed DRM because doing so does not reduce the substitutability across the two hardware products. But if consumers prefer A's DRM system, then A will employ closed DRM because like in the variant just discussed above the behavior in a sense reduces the quality of B's product which allows A to raise its price and increase profitability. As discussed in footnote 31, we believe this variant is a good match for the iPod example.

²⁴ Kim (2009) also considers a two-period extension with upgrades that builds on the upgrade analysis in Carlton and Waldman (2011). That extension yields two main results. First, in addition to the static returns to closed DRM found in the previous section, closed DRM can also be used to deprive the hardware rival of an incentive to invest in product upgrades at a later stage which further increases the profits of the hardware seller with DRM. Second,

A) R&D Investments

In Section III's model we assumed that one firm, firm A, had access to a DRM technology, while the other firm, firm B, did not. We thus ignored the question of the incentive that hardware firms have to develop a DRM technology in the first place. This is what we focus on in this subsection. Note that in the analysis that follows to keep the argument more straightforward we assume that a hardware seller with DRM has the option of sharing its technology with the other hardware producer, but results would be quite similar if we assumed licensing rather than sharing (see footnote 26 for a discussion).

Assume everything is the same as in Section III's initial model with sharing except that at the beginning of the game each hardware seller has the option of investing in the development of a DRM technology, where r_j is the development expenditure of firm j , $j=A,B$, and $q(r_j)$ is the probability that firm j successfully develops a DRM technology. We assume $q(0)=0$, $q'(\infty)=\infty$, $q'(r)>0$ and $q''(r)<0$ for all $r>0$, $q(\infty)<1$, and investment outcomes are independent events. These assumptions ensure that in equilibrium each hardware seller chooses the same R&D expenditure which we denote r^* , where $0<r^*<\infty$. Below we describe the nature of equilibrium in this setting.

There are three possible outcomes in equilibrium. First, with probability $2q(r^*)(1-q(r^*))$ one firm develops a DRM technology and the other firm does not. In this case the rest of the equilibrium is described by Proposition 1 of Section III. That is, the outcome is a closed DRM system where the hardware seller with the DRM technology is able to increase its hardware price, but the contractually specified price for legal content is kept high enough that firm C is willing to adopt DRM and encrypt its output. Further, consumers purchase hardware from the firm with the DRM technology and legal content from firm C.

Second, with probability $(1-q(r^*))(1-q(r^*))$ neither firm develops a DRM technology. What happens in this outcome was also described in the previous section. Because the two hardware sellers are selling identical products and there is Bertrand competition, hardware prices

closed DRM can be associated with an efficiency gain because it prevents inefficient multiple investments in the upgrading of hardware products.

are at marginal cost and each hardware seller earns zero profits. Further, because DRM is not employed, illegal copies can be obtained at a zero price so the legal content provider, firm C, sets its price at the quality advantage of legal content which is Δ . Finally, each consumer purchases hardware from either firm A or firm B and purchases legal content from firm C.

Third, with probability $q(r^*)q(r^*)$ both firms develop a DRM technology. The outcome in this case is similar to the case of an open DRM system described in the previous section. Specifically, in this case the hardware sellers have in a sense identical products, so Bertrand competition requires that each firm make a contractual offer to firm C that maximizes firm C's profit which means both firms offer $p_C^+ = \Delta + h$ and firm C accepts one or both offers. Also, hardware is sold at marginal cost and $\pi_A = \pi_B = 0$.²⁵ Finally, consumers purchase legal content from firm C and hardware from a firm that allows the consumer to consume the content.

In summary, the Proposition 1 equilibrium can be thought of as part of equilibrium in a richer game where hardware sellers start the game by making expenditures on the development of a DRM technology. When only one of the firms is successful then the outcome is the Proposition 1 equilibrium, while there is also a positive probability of an outcome consistent with no DRM and a positive probability of an outcome similar to open DRM.²⁶

We can also consider how a government policy requiring DRM to be shared would affect equilibrium behavior in this enriched model. In Section III we argued that such a rule would move the equilibrium from closed DRM to either no DRM or open DRM. Here the effect is a bit different. With a rule that DRM must be shared the positive profits associated with being the only firm with DRM are eliminated. As a result, with this rule in place the equilibrium is that there is no investment in DRM so the equilibrium outcome is no DRM with probability one. This reduces the expected profits of the hardware seller and the content provider, but increases

²⁵ For this case we are assuming, similar to what we assumed in footnote 16, that there are hardware sellers other than A and B but the other hardware products are not capable of using a DRM system.

²⁶ If as in Proposition 2 of Section III a hardware seller with a DRM system has the option of licensing rather than sharing its technology with the other hardware producer, the result as in Proposition 2 would be multiple equilibria. Some of the equilibria would be equivalent to the equilibrium described in the text, while the other equilibria would be similar except that the DRM technology would sometimes be licensed rather than having a closed DRM system.

consumer welfare since prices are lower. The overall result is that the lower hardware and legal content prices are just balanced by increased consumer welfare, so social welfare rises because of the decreased expenditures on DRM development. But if we added expenditures firm C makes in developing legal content, then imposing the rule that DRM has to be shared would have an ambiguous effect on social welfare. This is because the reduced probability of a DRM system being developed would serve to reduce firm C's investments in the development of legal content.²⁷

As a final point, we could enrich the model in this subsection even further by introducing an expenditure on DRM development that the legal content provider, firm C, could make at the beginning of the game. Suppose that firm C faces the same probability of success function, $q(r)$, as do the hardware sellers. Then equilibrium would be characterized by a value r_H^* which is each hardware firm's expenditure on DRM development and a value r_C^* which is firm C's expenditure on DRM development. With probability $(1-q(r_C^*))$ firm C would be unsuccessful and the equilibrium would be along the lines of that described above. With probability $q(r_C^*)(1-q(r_H^*))^2$ only firm C would be successful and, because there would be competing hardware firms, firm C would reap all the benefits of DRM.²⁸ That is, DRM would be employed in either an open or a closed fashion, the price of legal content would be $\Delta+h$, and the hardware price would be c . With probability $q(r_C^*)q(r_H^*)^2$ all three firms would be successful. Because both hardware firms would have access to DRM and compete against each other, in this case all the benefits of DRM would again flow to firm C. Finally, with probability $2q(r_C^*)q(r_H^*)(1-q(r_H^*))$ firm C develops DRM and exactly one hardware seller develops DRM. In that case there would be multiple equilibria to the resulting subgame where any division of the surplus due to DRM across the two firms with access to DRM is possible.

²⁷ See Novos and Waldman (1984), Johnson (1985), Yoon (2002), and Bae and Choi (2006) for related analyses concerning how copying affects product quality and variety.

²⁸ Here we are assuming that when firm C is successful it can make contract offers to each hardware seller to share its DRM technology similar to the contract offers that hardware seller A makes to firm C in the basic model.

B) Heterogeneous Consumers

In this subsection we extend the analysis of Section III by introducing heterogeneous consumers, where as in the previous subsection we make the Proposition 1 assumption that DRM can be shared with a rival hardware seller rather than licensed (see footnote 30 for a discussion). To be precise, everything is the same as in Section III's initial model with sharing except for the following. Instead of consumers having identical values for consuming a system composed of hardware and legal content, we now assume a continuum of consumers of total mass N where each consumer i has a valuation x_i for consuming legal content and the x_i s in the population are uniformly distributed over the interval $(x^L, x^H]$. Also, each consumer i has a valuation y_i for consuming a system composed of hardware and an illegal copy, where $y_i = x_i - \Delta$ for all i and $x^L = c + \Delta$. Note that an important aspect of the model is that, because the lower bound for x_i is $c + \Delta$, some consumers do not purchase hardware or content (legal or illegal) when prices rise above the no DRM equilibrium prices. In other words, as opposed to what was true in Section III's analysis, if prices rise there is a standard monopoly deadweight loss.²⁹

As in the analysis of Section III, we start by deriving price and consumption choices as a function of the DRM choices made earlier. Consider first the case of no DRM. Using similar logic to that in Section III, in this case $p_A^H = p_B^H = c$ and $p_C = \Delta$. Further, because $x^L = c + \Delta$, just as was the case in the absence of DRM in Section III, all consumers purchase hardware from A or B and legal content from C.

Now consider the case of closed DRM. Using an argument similar to one in Section III, because consumers can obtain an illegal copy at a price of h , in equilibrium firm A sets $c < p_A^H \leq c + h + \Delta - p_C$. But note that only consumers for whom $x_i \geq p_A^H + p_C$ are even potential purchasers of legal content which in equilibrium means that this increase in p_A^H reduces the number of consumers who purchase a system. So in order for firm C to agree to adopt DRM,

²⁹ We further assume that, holding all the other parameters fixed, x^H is sufficiently large that there exists a DRM contract offer that A can make to C that results in strictly positive profits for A and increased profits for C. Also, assuming $x^L = c + \Delta$ is not necessary for the main qualitative results we derive but rather simplifies the analysis and discussion. The essential property is that x^L is sufficiently small and x^H is sufficiently large.

firm A must set $p_C^+ > \Delta$ because otherwise firm C will turn down the offer and the outcome will be the no DRM outcome just described.

The last possibility is open DRM. As in Section III, in this case Bertrand competition yields $p_A^H = p_B^H = c$. Further, if $p_C^+ > \Delta + h$ then consumers who purchase systems obtain illegal copies, while if $p_C^+ < \Delta + h$ then these consumers purchase legal content (if $p_C^+ = \Delta + h$, then the consumers who purchase systems are indifferent between legal and illegal content).

We can now analyze DRM choices. Just as in the model of Section III, no DRM and open DRM yield $p_A^H = c$ and $\pi_A = 0$. So firm A's equilibrium strategy is to employ a closed DRM system which, from above, means $c < p_A^H \leq c + h + \Delta - p_C$, $\Delta < p_C = p_C^+ < \Delta + h$, and only consumers for whom $x_i \geq p_A^H + p_C^+$ purchase hardware from firm A and legal content from C (and the other consumers purchase nothing). In other words, the equilibrium is similar to the Proposition 1 equilibrium except here the increased hardware and legal content prices reduce the number of consumers who purchase systems in equilibrium.

Proposition 3 formally describes the nature of equilibrium in our model with heterogeneous consumers.

Proposition 3: If firm A's choice is whether or not to share its technology with firm B, there is a unique Subgame Perfect Nash equilibrium characterized by i) through v).

- i) Firm A adopts DRM and offers its DRM system to firm C and sets $p_C^+ > \Delta$.
- ii) Firm C accepts the contract.
- iii) Firm A does not share its DRM system with firm B.
- iv) $c < p_A^H \leq c + h + \Delta - p_C^+$, $p_B^H = c$, and $\Delta < p_C^+ < \Delta + h$.
- v) Each consumer i for whom $x_i > p_A^H + p_C^+$ purchases hardware from firm A and legal content from C, while consumers for whom $x_i < p_A^H + p_C^+$ purchase neither hardware nor content.

The above proposition shows that there is an inefficiency with DRM in the heterogeneous consumer case which we did not observe with homogeneous consumers. Because $x_i > c$ for all i and legal content can be produced at zero marginal cost, the first best in this model has all consumers purchasing hardware and legal content. But in equilibrium because both firm A and firm C raise their price above marginal cost, the equilibrium is characterized by a standard deadweight loss in which fewer consumers purchase systems than is optimal.³⁰

As a final analysis in this subsection, we again consider the social welfare implications of a government policy that requires DRM systems to be shared.

Corollary to Proposition 3: Suppose that at the beginning of the game considered in Proposition 3 the government announces that firm A must share its technology with firm B. The result is multiple equilibria and in some of these equilibria social welfare is higher than in the unique equilibrium discussed in Proposition 3.

The logic here is as follows. As in the analogous analysis in Section III, there are multiple equilibria because $\pi_A = \pi_B = 0$ whether or not the equilibrium is no DRM (which occurs if firm A offers a contractual price which if accepted results in firm C earning profits less than no DRM profits) or open DRM (which occurs if firm A offers a contractual price which if accepted results in firm C earning profits greater than no DRM profits). When the realization is no DRM, social welfare rises with this government intervention because with no DRM there is no deadweight loss while with closed DRM consumers pay higher prices for hardware and legal content with the result being a deadweight loss. When the realization is open DRM the result is that social welfare may rise but it is not guaranteed to rise. That is, because $\pi_A = \pi_B = 0$

³⁰ Related to the discussion in footnote 26, if as in Proposition 2 of Section III firm A has the option of licensing rather than sharing its technology with firm B, the result as in Proposition 2 is multiple equilibria. Some of the equilibria are equivalent to the equilibrium described above, while in the other equilibria A licenses its technology to B but all these equilibria are equivalent to the closed DRM equilibrium described above in terms of firms' profit levels and consumers' utilities.

independent of firm A's behavior, A may choose a low value for p_C^+ in which case social welfare rises but it is also possible that A chooses a sufficiently high value for p_C^+ that social welfare falls. Of course, if a cost to develop DRM were incorporated into this model along the lines of the analysis in the previous subsection, then the result would be that social welfare would necessarily rise with this government intervention both because the intervention would result in the development cost being avoided and because the intervention would also eliminate the deadweight loss.

V. DISCUSSION

In this paper we have presented a model and extensions showing how a DRM system developed by a hardware seller can be used to exclude hardware rivals and in this way increase the firm's market power in the hardware market. One potential real world example of this argument is obviously Apple's iPod which for a number of years following its introduction employed the DRM system called FairPlay. In this section we discuss Apple's iPod example and then briefly mention a few other related DRM cases.

The iPod was introduced in 2001 and quickly became the fastest selling music player in history. By 2004 its US market share reached over 80 percent in the market for hard-drive-based portable music players and its online retail counterpart, the iTunes Store, also accounted for more than 80 percent of US digital music sales (see footnote 3). When the iPod was introduced it employed the DRM system called FairPlay and it did not share the system with rival hardware sellers. That is, consistent with how we modeled a closed DRM system in our theoretical analysis, rival hardware devices could not play protected content bought from the iTunes Store.

Before Apple launched the iPod the market for portable music players was small and there was no dominant firm in the market. At the time the major record labels did not sell MP3 music online because of the ease with which illegal copies could be made and, as could be seen in the Napster lawsuit, they regarded MP3 files as something to be eliminated. Thus, the major record labels at the time required encryption technology in order to increase the difficulty of

making a copy. Apple successfully persuaded the major labels to sell music using its DRM technology and then, as indicated above, did not share or license its DRM technology with rival hardware sellers.

At the time of the iPod's introduction, there were a few competitors employing competing DRM technologies but they used different strategies that with hindsight seem to have been mistakes. For example, Microsoft's Windows Media Audio format was mainly used on personal computers and it employed a subscription based pricing strategy that has not been popular with consumers. Sony's Adaptive Transform Acoustic Coding system was not subscription based but, unlike the iPod, Sony's devices did not support MP3 files which reduced their popularity. More serious challenges, like Microsoft's Zune, were introduced only after Apple dominated the market.

Given this history, it seems quite plausible that Apple's decision not to share its DRM system with rival hardware sellers helped in its quick dominance of the market as suggested by our theoretical analysis. One possibility is that, along the lines of our first analysis in Section III, by not sharing the technology Apple moved an industry that would have been quite competitive to something close to a monopoly. But another possibility – which is the one we favor – is that because of its superior design the iPod would have been quite successful even in the absence of DRM. But along the lines of one of the variants of the Section III model discussed at the end of the section, even with its superior design Apple benefitted from closed DRM because it made the rival products worse substitutes and thus allowed Apple to charge a higher price for the iPod. As discussed at the end of Section III, this argument is similar to Whinston's (1990) analysis in which a monopoly producer ties in order to eliminate an inferior substitute product which, in turn, allows the monopolist to increase its price although market share is unaffected.³¹

³¹ One might argue that this case does not match the iPod example because, as described above, a number of rival music players had their own substitute DRM systems. However, if as was arguably the case consumers preferred to purchase legal content at the iTunes Store because of its superior design, then we would argue that the variant of Section III's model described in footnote 23 closely matches the iPod example.

As a final point concerning Apple and iPod, it is important to note that in 2009 Apple changed its policy and started selling DRM-free music at the iTunes Store. Clearly, one motivation for the change was that the firm was under pressure from European antitrust regulators to change its policy. But there were also other changes in the market that could have made its DRM system for the iPod less valuable to Apple. For example, around 2007 the major record labels had changed their policy concerning MP3 files and started selling MP3 files directly to consumers through Amazon's online music store. According to our theoretical analysis, this would eliminate the return to using a DRM system because, even if DRM content was harder to copy, the presence of non-DRM legal content would mean copies could be made at low cost so there would be little return to either the record labels or to Apple to retain DRM. In other words, it is possible that Apple dropped DRM for the iPod not primarily because of consumer or antitrust complaints, but because the market had changed in a way such that much of the increased profitability associated with DRM had disappeared.

Finally, although we believe Apple's iPod is the most obvious real world example potentially consistent with our argument, it is not the only one. DRM is ubiquitous in digital content industries and we believe that in many cases part of the return to the use of DRM is increased market power of hardware sellers. An example other than Apple's iPod where we think our argument or a variant of it applies is the use of DRM in ebook readers such as Amazon's Kindle, Barnes and Noble's Nook, and Apple's iPad. In each case the firm uses a proprietary DRM system that limits the ability of purchasers of the firm's ebooks from reading the books on rival hardware devices. Although this example is different than our models because there is no dominant hardware seller in this market, we conjecture that a related model where closed DRM systems are used to increase product differentiation and therefore profits in an oligopoly hardware industry would match behavior in this industry quite well. We plan to investigate this possibility in future research.³²

³² See Carbajo, de Meza, and Seidman (1990) and Chen (1997) for analyses of tying used to increase profits in an oligopoly setting through increased product differentiation.

VI. CONCLUSION

DRM has become an important issue in today's digital economy. While previous literature on the subject has focused mostly on the use of DRM to reduce illegal copying, a number of real world examples such as Apple's iPod suggest that DRM can also be used to increase the market power of a hardware seller with a DRM system. In this paper we have considered from a theoretical perspective the extent to which DRM can be used as an exclusionary device and also asked the extent to which the government can improve welfare by requiring a hardware seller with DRM to share the system with rivals.

Our main finding is that DRM can be used as a type of exclusionary tie that increases the hardware seller's market power, although we also find that the hardware seller with DRM can typically achieve a similar outcome by licensing and using a high royalty fee. Our argument is related to analyses in Whinston (1990) and Carlton and Waldman (2002) in which a primary good producer ties a complementary product in order to increase or preserve its market power in the market for the primary or tying good. One difference, however, is that in those earlier analyses the tie was between two goods produced by the same firm, while in our analysis the hardware seller sometimes uses DRM to create a virtual tie between its hardware device and the content producer's legal content.

We also considered the social welfare and consumer welfare implications of our analysis. In our basic analysis with homogeneous consumers and one of the hardware sellers endowed with a DRM system, the use of DRM in equilibrium reduces consumer welfare because consumers pay more for hardware, but there is no effect on social welfare because the decrease in consumer welfare is exactly offset by an increase in the profits of the hardware seller with DRM. So a government rule that forces DRM to be shared has no effect on social welfare, but does increase consumer welfare.

We also considered two extensions. In the first extension where firms invest in the development of DRM, a government rule forcing DRM to be shared increases social welfare where the return is reduced expenditures on DRM development. But, as we point out, if we

enriched this model by allowing content providers to invest in the development of content, then a rule forcing DRM to be shared would have an ambiguous effect on social welfare because the reduced likelihood of the development of DRM would reduce the expected price of legal content and thus the expenditure on content development. In the second extension with heterogeneous consumers the equilibrium use of DRM reduces social welfare because it raises prices and creates a standard monopoly deadweight loss. In this analysis we also find that a government rule forcing DRM to be shared may increase social welfare by lowering prices and eliminating this deadweight loss.

Given that we identify both positive and negative social welfare effects of a hardware seller using a closed DRM system, we do not believe our analysis by itself justifies government intervention requiring DRM systems to be shared. Justifying such a rule would require evidence that in real world settings the negative effects of closed DRM that we have identified are more important than the positive effects. And with this in mind, we think that a fruitful avenue for future research would be empirical work aimed at identifying the magnitude in real world settings of the various social welfare effects we have identified of DRM systems that are not shared.

We also believe that there are other potentially fruitful avenues for future research that are theoretical. In all of our analyses we assume a single content provider but, similar to the approach taken in Church and Gandal's (2000) analysis of systems competition and merger discussed earlier, it might be worthwhile allowing for multiple content providers that sell differentiated products. We conjecture that in such an analysis DRM would still sometimes be used to increase market power in the hardware market. But allowing for multiple content providers would introduce a richer set of possible equilibrium strategies than we find in the current analysis characterized by a single content provider. Further, as mentioned briefly earlier, we believe another worthwhile theoretical extension would be to consider the use of closed DRM systems to increase product differentiation in an oligopoly hardware industry.

APPENDIX

Proof of Proposition 1: As in the informal discussion in the text, we begin by considering pricing and consumption choices as a function of DRM choices. First, suppose neither hardware seller employs DRM or one or both employ DRM but firm C does not encrypt. Then the two hardware firms sell identical products so prices equal marginal cost, i.e., $p_A^H=p_B^H=c$ and $\pi_A=\pi_B=0$. In turn, consumers can obtain an illegal copy at a price of zero, so firm C can charge $p_C=\Delta-\varepsilon$, $\varepsilon>0$, and each consumer will purchase a legal copy from C. Further, if firm C charges $p_C=\Delta$, then consumers are indifferent between purchasing legal content or an illegal copy. Since the smallest ε , $\varepsilon>0$, is not defined, the unique subgame equilibrium is that firm C charges $p_C=\Delta$, all consumers purchase legal content from C, and $\pi_C=N\Delta$.

Suppose A sells a closed DRM system. If $p_C^+>\Delta+h$, then consumers prefer to obtain an illegal copy at a price of zero which means $\pi_C=0$. Given consumers obtain illegal copies, consumers place the same value on the two hardware products, so Bertrand competition again yields $p_A^H=p_B^H=c$ and $\pi_A=\pi_B=0$.

Suppose $p_C^+<\Delta+h$. From the standpoint of consumers, in this case firm A is selling a superior product. So Bertrand competition yields $p_A^H=c+\Delta-(p_C^+-h)$, $p_B^H=c$, and consumers purchase A's hardware and legal content from C at p_C^+ . Also, $\pi_A=N[\Delta-(p_C^+-h)]$, $\pi_B=0$, and $\pi_C=Np_C^+$.

Suppose $p_C^+=\Delta+h$. From the standpoint of consumers, in this case firms A and B are selling equivalent products. So each of the two outcomes just described are possible as well as outcomes in which some consumers purchase legal content and some purchase illegal copies.

The last possibility is that both A and B employ DRM. Since the two hardware products are identical in this case, Bertrand competition yields $p_A^H=p_B^H=c$ and $\pi_A=\pi_B=0$. If $p_C^+>\Delta+h$, then consumers purchase illegal copies and $\pi_C=0$. If $p_C^+<\Delta+h$, then consumers purchase legal content and $\pi_C=Np_C^+$. If $p_C^+=\Delta+h$, all consumers purchasing legal content, all consumers

purchasing illegal copies, and some consumers purchasing each are all consistent with equilibrium. So in this case $0 \leq \pi_C \leq N(\Delta+h)$.

We now consider firm A's choices concerning DRM and p_C^+ . We have from above that if neither firm employs DRM, both employ DRM, or firm A employs DRM but firm C turns down firm A's offer to encrypt its content, then $\pi_A=0$. So firm A will choose closed DRM if firm C accepts the contract offer and choosing closed DRM yields $\pi_A>0$. Given this, consider firm A's choice of p_C^+ and firm C's choice concerning whether or not to accept the offer. From above we know $p_C^+>\Delta+h$ yields $\pi_A=0$. Suppose $p_C^+\leq\Delta+h$. If firm C turns down firm A's offer, then from above $\pi_C=N\Delta$. If firm C accepts the offer, then from above firm A chooses closed DRM and consumers purchase hardware from A at $p_A^H=c+\Delta-(p_C^+-h)$ and legal content from C at p_C^+ (this is only a possible outcome if $p_C^+=\Delta+h$). This yields $\pi_A=N[\Delta-(p_C^+-h)]$ and $\pi_C=Np_C^+$. So if $p_C^+<\Delta$, then C turns down the offer in which case $\pi_A=0$, $\pi_B=0$, and $\pi_C=N\Delta$. If $\Delta<p_C^+\leq\Delta+h$, then C accepts the offer and $\pi_C=Np_C^+>N\Delta$ (this is only a possibility when $p_C^+=\Delta+h$). If $p_C^+=\Delta$, then one possibility is firm C accepts the offer, $\pi_A=Nh$, $\pi_B=0$, and $\pi_C=N\Delta$.

From above we see that firm A can ensure itself positive profits by choosing $\Delta<p_C^+<\Delta+h$. In turn, restricting attention to these strategies it maximizes profits by choosing the smallest value for p_C^+ that satisfies $p_C^+>\Delta$. Since such a value for p_C^+ is not defined, the only Nash equilibrium is that firm A chooses $p_C^+=\Delta$, firm C accepts the offer, firm A chooses closed DRM, $\pi_A=Nh$, $\pi_B=0$, and $\pi_C=N\Delta$.

Proof of Corollary to Proposition 1: From Proposition 1 we know that, if the government does not impose sharing, then there is closed DRM, all consumers purchase hardware from A and legal content from C, $\pi_A=Nh$, $\pi_B=0$, $\pi_C=N\Delta$, and each consumer's utility equals $X-(c+h+\Delta)$. So aggregate consumer utility equals $N[X-(c+h+\Delta)]$. Social welfare is thus $N(X-c)$.

From the proof of Proposition 1 we know that, if the government imposes sharing, then independent of firm A's choice concerning p_C^+ the result is $\pi_A=0$. There are thus multiple equilibria. If $p_C^+>\Delta+h$, then C turns down the offer. The result is consumers purchase hardware

and legal content, $p_A^H = p_B^H = c$, $\pi_A = \pi_B = 0$, $\pi_C = N\Delta$, and each consumer's utility equals $X - c - \Delta$. So social welfare is again $N(X - c)$. If $p_C^+ < \Delta$, then C turns down the offer and social welfare is again $N(X - c)$. If $\Delta < p_C^+ < \Delta + h$, then C accepts the offer. The result is that consumers purchase hardware and legal content, $p_A^H = p_B^H = c$, $\pi_A = \pi_B = 0$, $\pi_C = Np_C^+$, and each consumer's utility equals $X - c - p_C^+$. So social welfare is again $N(X - c)$. If $p_C^+ = \Delta$ or $p_C^+ = \Delta + h$, then equilibrium is consistent both with C rejecting the offer and with C accepting the offer and consumers purchasing hardware and legal content. Both behaviors yield that social welfare equals $N(X - c)$.

So all the equilibria associated with a government rule that A must share its technology with B yield the same value for social welfare and this value equals the value for social welfare in the unique equilibrium in Proposition 1.

Proof of Proposition 2: The first step of the proof is to show that any equilibrium with closed DRM in the licensing game is identical in terms of firms' profits, consumption choices, consumer utility levels, p_C^+ , and output prices to the unique equilibrium described in Proposition 1. There are three conditions that are important for showing this result. Start at the point in the game in which firm A has made an offer of p_C^+ to firm C and firm C must decide whether or not to accept the offer. First, given the similarities between the sharing and licensing games, if C rejects the offer then firms' profits are independent of whether it is the sharing or licensing game. Second, suppose firm C accepts the offer and A's subsequent behavior results in closed DRM (because it does not share in the sharing game or offers contract terms that are not accepted in the licensing game). Given the similarities between the sharing and licensing games, firms' profits, consumption choices, consumer utility levels, p_C^+ , and output prices are independent of whether it is the sharing or licensing game. Third, suppose for the moment that in the licensing game, for any p_C^+ that A might offer and C would accept, firms' profits are the same whether A proceeds by offering the best contract terms from A's standpoint that B would not accept, i.e., the best closed outcome, or the best contract terms from A's standpoint that B would accept, i.e., the best open outcome.

Together these three conditions yield i) of Proposition 2. To see this start from any possible equilibrium outcome characterized by a specific value for p_C^+ that is accepted by C and then A behaves in a manner that results in closed DRM. First, we know that in the licensing game A would not have an incentive to deviate by behaving in a fashion that results in open DRM since the third condition tells us that the best deviation of this sort yields the same value for π_A . Second, firm C would have an incentive to deviate by rejecting p_C^+ in the licensing game if and only if it had an incentive to reject p_C^+ in the sharing game. Third, firm A would have an incentive to deviate by choosing a different p_C^+ in the licensing game if and only if it had an incentive to choose a different p_C^+ in the sharing game. So if the unique equilibrium in the sharing game is the closed DRM equilibrium described in Proposition 1, then there are closed DRM equilibria in the licensing game characterized by the same value for p_C^+ , from the second condition above they must be identical in terms of firms' profits, consumption choices, consumer utility levels, and output prices (there are multiple equilibria because there are multiple license terms that A can offer B that B will reject), and there are no other closed DRM equilibria in the licensing game. Further, using arguments like that in the proof of Proposition 1 it can be shown that there are no other equilibria in the licensing game in which neither hardware seller employs DRM or in which firm C does not encrypt.

The next step is to consider our supposition that in the licensing game, for any p_C^+ that A might offer and C would accept, firms' profits are the same whether A proceeds by offering the best contract terms from A's standpoint that B would not accept, i.e., the best closed outcome, or the best contract terms from A's standpoint that B would accept, i.e., the best open outcome. Using arguments like those in the proof of Proposition 1, values for p_C^+ that A might offer and C would accept must satisfy $\Delta \leq p_C^+ < \Delta + h$. From the proof of Proposition 1 we know that for any p_C^+ in this interval the closed outcome in the sharing game is such that $\pi_A = N[\Delta - (p_C^+ - h)]$, $\pi_B = 0$, and $\pi_C = Np_C^+$.

Now suppose $\Delta \leq p_C^+ < \Delta + h$, C accepts, and the game is the licensing game. We know $\pi_C = N\Delta$ since, if $\pi_C > N\Delta$, then A would leave s the same, slightly increase F, and the result would

be that C would still accept and π_A would increase. We also know that if A is choosing contract terms that maximize its profits, then all consumers purchase systems so $\pi_C = Np_C^+$. We further know that consumers always have the option of purchasing hardware without DRM at price c (see footnote 16) and obtaining an illegal copy at a cost of h . So a consumer's willingness to pay for hardware from A or B is $c + \Delta + h - p_C^+$. So A maximizes profits by choosing contract terms such that all hardware is purchased from A or B at a price $c + \Delta + h - p_C^+$.

Given this, suppose $s < \Delta + h - p_C^+$. Then competition between A and B at the pricing stage yields that p_A^H and p_B^H are strictly below $c + \Delta + h - p_C^+$. Suppose $s > \Delta + h - p_C^+$. Then competition between A and B at the pricing stage yields that only A sells hardware, so B would not accept such an offer (see footnote 16). Suppose $s = \Delta + h - p_C^+$. Then competition between A and B at the pricing stage yields $p_j^H \geq c + \Delta + h - p_C^+$, $j = A, B$, where at least one of the prices equals $c + \Delta + h - p_C^+$, all consumers purchase legal content from C at p_C^+ and hardware from either A or B at $c + \Delta + h - p_C^+$, and $\pi_A = N(\Delta + h - p_C^+)$. This proves i).

We now consider ii). Consider the licensing game. Given that we know from above that, for any p_C^+ that A might offer and C would accept, firms' profits are the same whether A chooses the best contract terms from A's perspective to offer B that are not accepted or A chooses the best contract terms from A's perspective to offer B that are accepted, for every closed DRM equilibria there are also open DRM equilibria associated with the same p_C^+ and vice versa. Thus, given i), the only open DRM equilibria are such that $p_C^+ = \Delta$. Also, given this, from above we also know that every such open equilibrium is such that $F = 0$, $s = h$, $\pi_A = Nh$, $\pi_B = 0$, $\pi_C = N\Delta$, $p_j^H \geq c + h$, $j = A, B$, where at least of the prices equals $c + h$, and consumers purchase hardware from A or B at price $c + h$ and legal content from C at price Δ . This proves ii).

Proof of Corollary to Proposition 2: From Proposition 2 we know that all the equilibria in Proposition 2 are associated with the same value for social welfare and this value equals the value for social welfare in the unique equilibrium in Proposition 1. Given this, the proof of Corollary 1 to Proposition 1 tells us that each of these equilibria is associated with a value for

social welfare equal to the value that results if the government rules that A's DRM system must be shared.

Proof of Proposition 3: We begin by considering pricing and consumption choices as a function of DRM choices. First, if neither hardware seller employs DRM or one or both employ DRM but firm C does not encrypt, then as was true in Proposition 1 Bertrand competition yields $p_A^H = p_B^H = c$ and $\pi_A = \pi_B = 0$. In turn, consumers can obtain an illegal copy at a price of zero, so firm C can charge any price that satisfies $p_C < \Delta$ and any consumer who obtains content will purchase legal content from firm C. Further, since $x^L = c + \Delta$, for any $p_C < \Delta$ all consumers purchase legal content from C. So the firm maximizes profits given $p_C < \Delta$ by choosing the highest value for p_C that satisfies the condition. Since this value is not defined, the unique subgame equilibrium is that firm C charges $p_C = \Delta$, all consumers purchase legal content from C, and $\pi_C = N\Delta$.

Second, if both A and B employ DRM and firm C encrypts, then the two firms sell identical products and Bertrand competition yields $p_A^H = p_B^H = c$ and $\pi_A = \pi_B = 0$. Further, what happens with firm C in this case is not important for the rest of the proof, so we will skip describing what happens to C in this case.

Suppose A sells a closed DRM system. If $p_C^+ > \Delta + h$, then consumers prefer to obtain illegal content at a price of zero which means $\pi_C = 0$. Given consumers obtain illegal content, consumers place the same value on the two hardware systems, so Bertrand competition again yields $p_A^H = p_B^H = c$ and $\pi_A = \pi_B = 0$.

Suppose $p_C^+ < \Delta + h$. Then Bertrand competition between A and B yields $p_B^H = c$ and $c < p_A^H \leq c + \Delta + h - p_C^+$. Further, all consumers for whom $x_i > p_A^H + p_C^+$ will purchase hardware from A and legal content from C. This yields $\pi_A = N(p_A^H - c)[(x^H - (p_A^H + p_C^+))/(x^H - x^L)]$ and $\pi_C = Np_C^+[(x^H - (p_A^H + p_C^+))/(x^H - x^L)]$.

Suppose $p_C^+ = \Delta + h$. From the standpoint of consumers, in this case firms A and B are selling equivalent products. So each of the two outcomes just described are possible as well as outcomes in which some consumers purchase legal content and some purchase illegal copies.

We now consider firm A's choice concerning DRM and p_C^+ . We have from above that if neither firm employs DRM, both firms employ DRM, or firm A employs DRM and firm C does not encrypt, then $\pi_A = 0$. So firm A will choose closed DRM if firm C accepts the contract offer and choosing closed DRM yields $\pi_A > 0$.

From above we know $p_C^+ > \Delta + h$ yields $\pi_A = 0$. Suppose firm A offers $p_C^+ < \Delta + h$. If C accepts the offer, then from above we know $c < p_A^H \leq c + \Delta + h - p_C^+$, where p_A^H maximizes $\pi_A = N(p_A^H - c)[(x^H - (p_A^H + p_C^+))/(x^H - x^L)]$ and $N[(x^H - (p_A^H + p_C^+))/(x^H - x^L)]$ is the number of hardware units A sells and the amount of legal content C sells. Taking the partial derivative of π_A with respect to p_A^H and setting it equal to zero yields after some rearranging $p_A^H = (x^H - p_C^+ + c)/2$ which, given the constraint, means $p_A^H = c + \Delta + h - p_C^+$ for x^H sufficiently large (see footnote 29). But given this and $\Delta < p_C^+ < \Delta + h$, we have that for high enough x^H the maximized value for π_A is strictly positive and $N[(x^H - (p_A^H + p_C^+))/(x^H - x^L)]$ is "close" to N . So given x^H sufficiently large, there must exist values for p_C^+ in the interval $\Delta < p_C^+ < \Delta + h$ that if offered by A result in C accepting, A choosing closed DRM, and $\pi_A > 0$.

So in equilibrium firm A offers a contract that firm C accepts and which is followed by A choosing closed DRM. We know firm A chooses $p_A^H > c$ because it is maximizing profits, while $p_C \geq \Delta$ since C could have turned down the offer and earned $N\Delta$. But if $p_A^H > c$ and $p_C \geq \Delta$, then the number of consumers who purchase systems is strictly less than N , so for firm C to accept the contract offer it must be that $p_C = p_C^+ > \Delta$.

Proof of Corollary to Proposition 3: Let n^* be the number of consumers who purchase systems in equilibrium. From Proposition 3 we know that, if the government does not impose sharing, then there is closed DRM, $\Delta < p_C^+ < \Delta + h$, $c < p_A^H \leq c + \Delta + h - p_C^+$, $\pi_A = n^*(p_A^H - c)$, $\pi_B = 0$, $\pi_C = n^*p_C^+$, and each consumer for whom $x_i > p_A^H + p_C^+$ purchases hardware from A and legal content from C and

receives utility $x_i - p_A^H - p_C^+$ (while other consumers either do not purchase systems or receive zero utility). So aggregate social welfare in this case is given by (A1).

$$(A1) \quad \int_{p_A^H + p_C^+}^{x^H} [(x_i - p_A^H - p_C^+) + (p_A^H - c) + p_C^+] N[1/(x^H - x^L)] dx_i$$

Further, (A1) can be rewritten as (A2).

$$(A2) \quad \int_{p_A^H + p_C^+}^{x^H} N(x_i - c) [1/(x^H - x^L)] dx_i$$

From the proof of Proposition 3 we know that, if the government imposes sharing, then independent of firm A's choice concerning p_C^+ the result is $\pi_A = 0$. There are thus multiple equilibria where some equilibria are characterized by no DRM and some by open DRM. If there is no DRM, then $p_A^H = p_B^H = c$, $p_C = \Delta$, $\pi_A = \pi_B = 0$, $\pi_C = N\Delta$, and each consumer i purchases hardware from a hardware seller and legal content from C and receives utility $x_i - c - \Delta$. So aggregate social welfare in this case is given by (A3).

$$(A3) \quad \int_{x^L}^{x^H} [(x_i - c - \Delta) + \Delta] N[1/(x^H - x^L)] dx_i$$

Further, (A3) can be rewritten as (A4).

$$(A4) \quad \int_{x^L}^{x^H} N(x_i - c) [1/(x^H - x^L)] dx_i$$

Given $p_A^H + p_C^+ > c + \Delta = x^L$, a comparison of (A2) and (A4) yields that social welfare is higher when the government imposes sharing and the equilibrium is no DRM.

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