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Digital Rights Management and Technological Tying

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Abstract

This paper analyzes DRM-based technological tying, where the content and hardware form a system. A closed DRM system makes the legal content incompatible with a rival's hardware, whose users must then obtain illegal copies. The main finding is that the tying firm gains market power in a competitive hardware market and invests in product upgrades at a later stage. Welfare implications of the policy that requires an open DRM system are also discussed.

Keywords: digital rights management, copying, tying

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1 Introduction

Digital Rights Management (DRM) refers to encryption technologies that can restrict access to protected content distributed via the Internet or other digital media (e.g., music, movies, software) so that those without proper authentication cannot access it. It has become a popular solution for content industries in an attempt to fight consumer piracy, but its restrictive nature has been a controversial subject.[1] Given that DRM technologies have been constantly hacked, it seems that there is no clear-cut evidence that a DRM system is an effective tool for reducing consumer piracy.

For example, a DRM system can be used to increase the content firm's indirect appropriability (Liebowitz 1985). That is, a firm can indirectly charge copying consumers by increasing the initial price of the original units. If the DRM system decreases the supply of illegal copies, then the firm may be able to charge higher initial prices. However, a crucial condition for this is that competition among the sellers of copies should not drive down the price of copies to zero.[2] Given that current prices of copies are basically zero, this argument does not seem to be the main reason for the use of a DRM system.

Rather, a DRM system can be a tool for strategic tying. For example, since its inception in 2001, the iPod has become the fastest selling music player in history. Its U.S. market share reached over 80 percent among hard-drive-based portable music players by 2004, and

[1] One of the legal arguments against a DRM system is that it restricts consumers' "fair use" rights, which traditional copyright laws grant. That is, 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 current 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 elaborated in Johnson and Waldman (2005), who show that if the supply of illegal copies floods the market in a short time, then the indirect appropriability argument does not hold.

its online retail counterpart, the iTunes Store, also accounted for more than 80 percent of U.S. digital music sales.[3] Apple's success is often attributed to the exclusive nature of its proprietary DRM system, known as "FairPlay." That is, competing devices cannot play protected content bought from the iTunes Store, but only plain MP3 files.

Before Apple launched the iPod, the market for portable music players was small, and there was no dominant firm in this market. Big record labels were uncomfortable with the idea of selling MP3 music online because the majority of MP3 files were illegal copies, and, as in the Napster lawsuit, they regarded MP3 files as something that needed to be eliminated.[4] Thus, labels needed encryption technology to make sure that their legal content could not be easily copied. Apple successfully persuaded the big labels to sell their music using its DRM technology, and then Apple did not share its DRM information with its competitors.

When the iPod market took off, there were a couple of alternative DRM technologies. However, they could not seriously challenge Apple's strategy. Microsoft's Windows Media Audio format was mainly used for personal computers, and it used a subscription mechanism to control copyrights, which consumers did not like.[5] Sony's Adaptive Transform Acoustic Coding system was not subscription based, but, unlike the iPod, Sony's devices did not support MP3 files, which is one of the main reasons for Sony's failure in this market.[6] More serious challenges, like Microsoft's Zune, came only after Apple already dominated the

[3] These numbers are from the NPD Group. See, for example, Guglielmo, Connie, "Apple's Jobs Taps Teen iPod Demand to Fuel Sales, Stock Surge," *Bloomberg*, October 11, 2007; Evans, Jonny, "Apple Discusses Growing iPod Marketshare," *Macworld*, April 20, 2006.

[4] Only recently have the labels become positive about selling MP3 files through such online stores as Amazon.com, which was launched in 2007.

[5] Except for Napster and a few others, most of the online stores (e.g., AOL, Yahoo, MTV, MSN, Musicmatch) that used a subscription mechanism are now closed.

[6] Sony finally phased out its ATRAC system in 2008 and introduced a new Walkman series that supports plain MP3 files.

market.

Therefore, it seems plausible that Apple has benefited from technologically tying DRM-protected content to its hardware, making competing devices incompatible with the legal content. This strategic use of DRM systems coincides with some real world observations. For example, Apple's CEO Steve Jobs has publicly opposed licensing its FairPlay to competitors.[7] In addition, Microsoft launched its new portable music player, Zune, which like the iPod is the only portable music player that can play the protected content bought from its counterpart online store, Zune Marketplace.[8]

This paper analyzes the effects of DRM-based technological tying. When there are competing devices, or content players, as well as copyrighted content, the hardware seller who owns a DRM technology may have an incentive to make the consumer's hardware choice depend on whether the consumer would buy legal content or obtain illegal copies. By making the rival's device incompatible with DRM-protected legal content, the tying firm can force consumers to obtain illegal copies in order to use the rival's device. That is, the tying firm can effectively increase the cost of using the rival's system.

To understand the basic logic for our finding, we begin with a simple static model with homogeneous consumers. We show that, in a market of competitive hardware devices, the firm that owns a proprietary DRM technology can monopolize the market by tying the protected legal content to its hardware. That is, a closed DRM system emerges in equilibrium

[7] In an open letter on DRM, Steve Jobs (2007) argued that "if it licenses FairPlay to others, it can no longer guarantee to protect the music it licenses" because the DRM information must be shared by more companies, making it more difficult to protect the secret codes from hackers.

[8] Although Microsoft previously developed and licensed the "PlaysForSure" DRM system to alternative hardware sellers such as SanDisk and Samsung, ironically, the new Zune player is not compatible with PlaysForSure-certified content.

when the tying firm refuses to share its DRM system with the competitors. We also show that, if the government requires a closed DRM system to be opened, it can increase consumer surplus, but it would not affect overall social welfare.

We then develop two separate analyses to show that the above welfare implications can break down in the presence of consumer heterogeneity and product upgrades. In the former case, the basic intuition is the same as in the first analysis, but there is efficiency loss under a closed DRM system because high prices lead to monopoly deadweight loss. In the latter case, we find that DRM-based tying can also deprive the rival of an incentive to invest in product upgrades at a later stage. However, there can be a dynamic efficiency gain under a closed DRM system because, for example, it prevents duplicating investments in innovation.

The remainder of this paper is organized as follows. Section 2 briefly discusses the relevant literature. Section 3 lays out the basic model, and section 4 analyzes this model. Section 5 introduces heterogeneous consumers, and section 6 extends the basic model to a two-period setting where products can be upgraded. Section 7 concludes.

2 Related Literature

The economics literature on copyright issues has a long history and variety of theoretical and empirical research (see, e.g., Peitz and Waelbroeck (2006) for a survey). There are broadly two types of copyright protection available to the owners of copyrighted goods. One is government-enfored legislation, and the other is private, technological measures. Early literature (e.g., Novos and Waldman 1984, Johnson 1985) focuses on public copyright protection and finds that copyright protection generally enhances social welfare.[9] Recently, there has been growing attention to private copyright protection.

For example, 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 cost of the system. They find that a shared DRM system can facilitate collusion via cost sharing, while separate systems are less vulnerable to hacking attacks, so that sellers feel less pressure to keep prices low. In this paper, we relax one of their assumptions by considering a complementary hardware seller who owns a proprietary DRM technology and decides whether or not to share it with a rival.

Bergemann et al. (2005) 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 the content provider who also sells a device prefers a less stringent DRM system than one who only sells content. Sundararajan (2004) similarly finds that a content seller chooses a lower level of DRM protection when it can price discriminate. The current paper is different in that we consider two competing devices and focus on the tying aspect of DRM protection and its policy implications.

There is an extensive literature on tying. The traditional Chicago School argument is that a monopolist with an essential good has no incentive to tie because it can extract all the potential surplus by charging a monopoly price (e.g., Posner 1976, Bork 1978). However, a number of authors (e.g., Whinston 1990, Choi and Stefanadis 2001, Carlton and Waldman 2002) have shown plausible settings in which tying can be used by a monopolist to foreclose

[9] Kim (2007) considers public copyright protection that is controlled by the incumbent and finds that copyright protection can deter potential entry.

competition, deter potential entrants, and extend their monopoly into the future, into the complementary market, and into a newly emerging market.[10]

Most similar to our findings, Whinston (1990) shows that, when there exists an inferior substitute for the primary good, the monopolist has an incentive to tie in order to make the alternative primary good unusable, and this increases the monopolist's profit. Similarly, in this paper, the hardware firm that owns a proprietary DRM technology has an incentive to tie the legal content to its own hardware, so that the competing devices can only work with illegal copies. An important difference is that in our paper the hardware firms have identical products, whereas in Whinston's paper the tying firm has a superior primary product.

There are a couple of differences between the literature on tying and the current paper. Whereas the tying literature focuses on a firm that ties two goods of its own, in reality a firm need not own both goods in order to tie. That is, technological advancements allow a new class of tying, where a firm virtually ties another firm's good to its own good by deploying proprietary technology. This paper also addresses technological tying in the context of a digital economy, where consumer copying is an important issue. Thus, the current paper is an attempt to combine the separate literatures on tying and copying.

Finally, there are other related works on compatibility. For example, Church and Gandal (2000) show that an integrated software-hardware firm has an incentive to make its software incompatible with the competing hardware. Katz and Shapiro (1985) show that in a market with network externalities a dominant firm might prefer a technological design that is in-

[10] There is growing attention to the effects of tying on R&D incentives. Carlton and Waldman (2005b) show that the monopolist can tie in order to capture profits when products are upgraded. Gilbert and Riordan (2007) similarly find that, when tying decreases the quality of the rival's system, the monopolist can foreclose the rival and upgrade its product.

compatible with the rival's. The current paper shows that vertical integration and network externalities are not necessary for systems incompatibilities to be exploited by the firm that owns the key technology.

3 The Model

There are two firms ($j = A, B$) that sell hardware devices, which 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.[11] Both hardware devices are produced at a constant marginal cost of c, and the content is produced at zero marginal cost. The content is subject to consumer piracy in the sense 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 "illegal copies."

Suppose that firm A owns a proprietary DRM technology that can encrypt digital content. Thus, we abstract from the initial investment in DRM technology. With DRM-protected content, it is harder to make illegal copies, thus it increases the consumer's copying cost from zero to h, $h > 0$. When the 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 the protected content only if firm A shares its DRM system with firm B. Illegal copies, however, are DRM-stripped, thus they are compatible with both firms' hardware.[12]

There is a continuum of identical individuals with unit measure, who derive utility from

[11] This may be due to the environment where individual artists and authors transfer their copyrights to a single managing firm.

[12] This captures the idea that most of the portable music players including the iPod are compatible with plain MP3 files, most of which come from illegal copying.

consuming a system composed of hardware and content; that is, there is no stand-alone value when a consumer buys only one component. Let $u_j = \delta - e - p_j$ denote the consumer's utility when he chooses a system including hardware j, where δ is the value of the content, e is the cost of obtaining the content, and p_j is the price of hardware j. Consumers have a reservation utility of zero, and they buy at most one hardware device and either buy or copy the content.

The copies are imperfect substitutes for the legal content because, for example, the copies are of lower quality and customer service is not available to them. Thus, the consumer's valuation for legally purchased content is $\delta = v$, whereas the valuation for illegally obtained copies is lower; that is, $\delta = v - \Delta$, where $\Delta > 0$.[13] We assume that the consumer valuation is high enough, $v > h + \Delta + c$, to ensure interior solutions, which in particular means that DRM protection itself does not eliminate the possibility of consumer copying.

Let ρ denote the market price of the legal content. Accordingly, when a consumer buys legal content, $e = \rho$. However, when he obtains illegal copies, $e = 0$ if the legal content is DRM free, and $e = h$ if it is DRM protected.[14] The two hardware devices are homogeneous other than the (in)compatibility issue related to the use of DRM, and firms engage in Bertrand competition when more than one firm is active. When indifferent, consumers choose between hardware A and B with equal probability. Finally, let $\pi_{j=A(B)}$ and $\sigma_{j=A(B)}$ denote firm A(B)'s profit and market share, respectively.

[13] An alternative interpretation of Δ is that it represents extra time cost involved in making copies versus buying legal content.

[14] One can refine the model such that, when legal content is DRM protected, consumers can make copies of legal content at a cost of $\tilde{h}$ or simply download illegal copies at a cost of h. However, if the cost involved in making copies from DRM-protected content, $\tilde{h}$, is higher than the cost of downloading illegal copies, h, then the analysis would remain the same because consumers would choose the latter option to obtain illegal copies. Note further, if Δ represents a time cost as discussed in footnote 13, then one should interpret h and $\tilde{h}$ as the cost of copying which is in addition to Δ.

The timing of the game is as follows. In the first stage, firm A can offer to share its DRM technology with firm C if firm C sells the legal content at some $\bar{\rho}$.[15] If firm C rejects the offer, then the second stage ensues. If firm C accepts the offer, then firm A can offer to share its DRM technology with firm B, and firm B accepts or rejects the offer.[16] In the second stage, all firms set their prices simultaneously subject to any contractual terms, and consumers make their consumption choices. The solution concept throughout this paper is Subgame Perfect Nash Equilibrium.

4 Analysis

Since the model is solved backwards, we first solve for equilibrium in the second stage. Note that the consumer choices are any of the five possible options: {A,buy},{A,copy},{B,buy}, {B,copy},{Ø,Ø}, where for each pairing the first element is the hardware choice and the second element is the method of obtaining the content, and {Ø,Ø} represents abstention.[17] Since there is only one content in our model, {A,copy} and {B,copy} have identical content downloaded from the Internet illegally, and {A,buy} and {B,buy} have the same legal content that is compatible with the hardware.[18]

Note that there are three cases to consider as a result of first-stage actions: no DRM

[15] This captures the idea that Apple controls pricing on the iTunes Store, and it makes little profit from selling content on iTunes. We assume that the contract between firm A and firm C is binding, so that firm C does not breach the terms in the second stage.

[16] To be specific, firm A's offer is to license its DRM to firm B at zero royalty fee. This is, however, without loss of generality since, as we shall show, firm B would never accept any licensing agreement at a positive royalty fee because by accepting to license the DRM, firm B must engage in Bertrand competition with firm A.

[17] Note that there is no utility from buying either component alone.

[18] In a more general world, the content compatible with A and that compatible with B could be different, but in our model we abstract from that possibility.

system, a closed DRM system, and an open DRM system at the beginning of the second stage. First, if there is no DRM system, the choices are $\{\{$A,buy$\}, \{$A,copy$\}, \{$B,buy$\}, \{$B,copy$\}, \{\emptyset,\emptyset\}\}$, where both bought and copied content are of the same kind for owners of hardware A or B. Here, we show that in equilibrium firm A and firm B split the market and legal content is bought.

Second, we look at a "closed DRM system" where not all five choices are available. The choice set for the consumer is $\{\{$A,buy$\}, \{$A,copy$\}, \{$B,copy$\}, \{\emptyset,\emptyset\}\}$. That is, the choice of buying legal content for hardware B, $\{$B,buy$\}$, is not available since the legal content is not compatible with hardware B. Here, we show that in equilibrium only hardware A is purchased together with legal content; that is, $\{$A,buy$\}$ in the choice set.

Third, we look at an "open DRM system," which again allows for all five elements. The bought content for hardware A is identical to that for hardware B in this case. Here, we show that in equilibrium firm A and firm B split the market, and legal content is bought. The no DRM case can be thought of as a benchmark, and we look at the second and third cases, where it is assumed that firm A owns the DRM technology and selects to either use it for only hardware A or to use it for both hardware A and B.

We show that in the first-stage equilibrium of our basic model this leads to DRM protection compatible only with hardware A (a closed DRM system), the second case. In the above, note that in none of the three possible cases, including the equilibrium case, is there any use of illegally copied content. This is because consumers have identical copying costs. A model with heterogeneous copying costs would have illegal copies in equilibrium, however this complicates the analysis. In the next section, we consider heterogeneous consumer valuations, which yield similar intuition, but is simpler than the case of heterogeneous copying costs.

4.1 No DRM

In this case, hardware A and B are functionally identical in that both play legal content as well as illegal copies. Thus, given any price for the legal content, whether consumers buy or copy, firm A and B would engage in standard Bertrand competition, which drives their prices down to marginal cost, $p_A = p_B = c$. Firm A's and B's profits are zero, and they would have equal market shares, $\sigma_A = \sigma_B = \frac{1}{2}$.[19]

On the other hand, firm C faces competition from illegal copies, which can be obtained at zero cost. However, firm C's original content is of superior quality, so that consumers would be willing to buy the content as long as the price is not too high; that is, as long as the market price of the legal content, ρ, is less than its superior quality, Δ. Since firm C can charge $\rho = \Delta - \epsilon$ without loss of generality, all consumers buy legal content in equilibrium at $\rho = \Delta$, and firm C's profit is Δ.

4.2 Closed DRM

In this case, firm C accepts firm A's offer in the first stage, so the content price must be set by the terms of the contract, $\rho = \bar{\rho}$. That is, for the second stage, we take $\bar{\rho}$ as a given, and later when solving for the first stage we substitute the equilibrium value of $\bar{\rho}$. Since hardware B is by design incompatible with the legal content, consumers must obtain illegal copies in order to use hardware B. This means that the utility from choosing hardware B

[19] To be more specific and as mentioned earlier, when a consumer is indifferent, each individual randomizes between hardware A and B with a probability of $\frac{1}{2}$. Since there is a continuum of individuals, the actual market share equals $\frac{1}{2}$ by the law of large numbers.

is $u_B = v - \Delta - h - p_B$. On the other hand, hardware A is compatible with both legal content and illegal copies, so the consumer's utility is $u_A = v - \bar{\rho} - p_A$ if he buys, and $u_A = v - \Delta - h - p_A$ if he copies.

At the beginning of the second stage, firm A and firm B compete by setting prices, given $\rho = \bar{\rho}$. There are two cases to consider. First, suppose $\bar{\rho} < \Delta + h$. In this subcase, the utility from {A,buy} is higher than the utility from {A,copy}. Thus, consumers consider only two options: {A,buy} and {B,copy}. Since $u_A = v - \bar{\rho} - p_A > v - \Delta - h - p_B = u_B$ if $p_A = p_B$, firm B has an incentive to undercut p_A to make any sales. Given this Bertrand-like competition, $p_B = c$ in equilibrium. Then, firm A would set p_A equal (or ϵ below) to the level where consumers would be indifferent between {A,buy} and {B,copy}; that is, $p_A = \Delta + h - \bar{\rho} + c$ (as $\epsilon \to 0$).

Second, suppose $\bar{\rho} \geq \Delta + h$. In this subcase, the utility from {A,copy} is higher than the utility from {A,buy}. Thus, the relevant options for the consumers are {A,copy} and {B,copy}. This means that consumers do not buy legal content, and firm A and B would engage in standard Bertrand competition, so that $p_A = p_B = c$, and $\sigma_A = \sigma_B = \frac{1}{2}$. Intuitively, it does not matter if the DRM system is open or closed if the legal content price is set too high relative to the disadvantages of illegal copies (i.e., $\Delta + h$).

4.3 Open DRM

In this case, the content price must again be set by the terms of firm A's offer to firm C in the first stage; that is, $\rho = \bar{\rho}$. Note that under an open DRM system both hardware devices are compatible with the legal content as well as illegal copies. This means that holding the consumer's decision to buy or copy fixed, firm A and B must compete in Bertrand fashion. This would drive down the prices again to marginal cost; that is, $p_A = p_B = c$, and $\sigma_A = \sigma_B = \frac{1}{2}$. On the other hand, given $p_A = p_B = c$ and some price of legal content, $\bar{\rho}$, consumers would buy the content if $\bar{\rho} < \Delta + h$, or obtain illegal copies if $\bar{\rho} \geq \Delta + h$.

4.4 Equilibrium

Knowing the payoffs in each of the three possible subgames, which also depends on whether $\bar{\rho} < \Delta + h$ or $\bar{\rho} \geq \Delta + h$, we now solve for equilibrium in the first stage. First, suppose that firm C has accepted firm A's offer, and subsequently firm A makes an offer to firm B to share its DRM technology at no cost. Since firm B earns zero profit whether the DRM system is open or closed and whether $\bar{\rho} < \Delta + h$ or not, firm B is indifferent as to accepting or rejecting firm A's offer. However, firm A earns a strictly positive profit under a closed DRM system if $\bar{\rho} < \Delta + h$, whereas it earns zero profit under an open DRM system. Assuming a tie-breaking condition that firm B would accept firm A's offer when indifferent, for $\bar{\rho} < \Delta + h$, firm A would never offer to share its DRM technology with firm B.[20] On the other hand, if $\bar{\rho} \geq \Delta + h$, then firm A earns zero profit under both a closed and an open DRM system. Thus, for $\bar{\rho} \geq \Delta + h$, firm A would be indifferent as to sharing its DRM technology with firm B.

As discussed earlier in footnote 16, this can explain why we refer to "sharing" instead of "licensing" the DRM technology. The reason is that firm B would never accept any licensing deal that has a positive royalty fee, so the terminology is without loss of generality. Under an

[20] If we do not impose this tie-breaking rule, then there exists another equilibrium where firm A makes an offer to firm B expecting that firm B would reject it when indifferent and in fact firm B does reject the offer.

open system, firm B would earn zero profit. Thus, if firm A were to make a take-it-or-leave-it offer to firm B at a royalty fee per unit sold, then the only deal that firm B would accept is when the licensing fee is nonpositive. Clearly, firm A has no incentive to license at a cost, so the licensing if it occurs must be at zero royalty. To reduce the number of variables, we abstract from a royalty fee and use the terminology "sharing a DRM system," which can be interpreted as licensing for free.

Second, knowing that it would earn a strictly positive profit by refusing to share its DRM technology with firm B when $\bar{\rho} < \Delta + h$, firm A indeed has an incentive to make an offer to firm C conditional on firm C setting the content price at some $\bar{\rho} < \Delta + h$. Note that firm A earns zero profit under no DRM system, and, for $\bar{\rho} \geq \Delta + h$, firm A would be indifferent about making an offer to firm C because its profit would be zero in any case. On the other hand, under no DRM system, firm C is already making a positive profit, Δ. Thus, firm A must offer a content price, $\bar{\rho}$, to be greater or equal to Δ in order to have firm C accept its offer. Since firm A's profit is decreasing in $\bar{\rho}$, $\bar{\rho}$ would equal Δ, and firm C would accept firm A's offer. Since $p_A = \Delta + h - \bar{\rho} + c$ from the second-stage equilibrium under a closed DRM system, by substituting $\bar{\rho} = \Delta$, firm A's hardware price is $p_A = h + c$, and its profit is h. The following proposition characterizes the equilibrium.

Proposition 1. There is a unique Subgame Perfect Nash Equilibrium: In the first stage, firm A offers its DRM technology to firm C and sets the content price at $\bar{\rho} = \Delta$; firm C accepts the offer. Firm A does not make an offer to share its DRM technology with firm B. In the second stage, the hardware firms set their prices at $p_A = h + c$ and $p_B = c$, and the content price is $\rho = \Delta$. All consumers choose hardware A and buy the legal content.

Proof. Proof follows immediately from the above. *Q.E.D.*

This result is consistent with Whinston (1990), who shows that a monopolist may have a strategic incentive to tie in order to foreclose the rival's sales by tying its complementary good to its primary good. This is because the presence of alternative inferior substitutes constrains the monopolist's pricing and profit. In this paper, although the two hardware products are initially the same quality, the firm with access to DRM has a similar incentive to tie the legal content to its hardware by deploying a closed DRM system. The reason is that, in the absence of a tie, the rival's product is also compatible with the legal content, so that Bertrand price competition would lead to a zero profit for firm A.

However, we have not discussed yet whether this is anticompetitive conduct or an antitrust violation. The courts typically draw the line between unlawful exclusion and competition by looking at the (in)efficiency of exclusionary conduct. There have been growing concerns regarding Apple's iPod/iTunes tying, and a number of consumer groups in Europe and the U.S. have filed class action lawsuits against Apple. In response, some European countries have considered antitrust suits and government intervention that would require Apple to share its DRM technology with competitors.[21] In the next section, we analyze the model's welfare implications of such "open" policies.

[21] In 2006, the French National Assembly passed a bill that could force Apple to give its rivals access to its DRM technology. However, the Senate subsequently passed a watered-down bill that dropped key provisions on the interoperability requirements. The new French law retains some interoperability requirement, but it exempts cases when the copyright owners agree to such closed systems.

4.5 Policy Implications

The above subsection shows the possibility that a firm can become a monopolist in a homogeneous goods market by having complementary content encrypted in its proprietary DRM format and refusing to share it with competitors. In response to anticompetitive concerns, the government may consider a policy intervention to open a closed DRM system. However, regulation typically does not restrict contractual agreements, especially, the terms that firm A would require in order for firm C to use its DRM technology. This means that even if the government forces a switch to an open system the content price should still be set by the contractual terms, which do not change in equilibrium; that is, $\rho = \bar{\rho} = \Delta$.

Given this, it turns out that firm B is indifferent between requesting or not requesting firm A to disclose its DRM information because firm B's profit is zero under an open as well as a closed DRM system. Thus, even if the government intervenes by requiring firm A to share its DRM technology with any firms that ask for it, firm B may not be interested in switching to an open system. In reality, however, if hardware were horizontally differentiated, then firm B could make a strictly positive profit under an open DRM system whereas it could be eliminated under a closed DRM system. Thus, in reality, firm B might prefer to ask firm A to share its DRM technology.

However, there is another factor that might work just the opposite way. Since firm A loses all of its monopoly profit if it is forced to open its DRM system, it is realistic to expect that firm B is able to claim a part of the monopoly profit from firm A in return for not asking to share its DRM technology. That is, following government intervention, if we were to allow firm A to make a side payment to firm B on the condition that firm B does not request an open DRM system, then the policy would not lead to a switch to an open DRM system. Rather, depending on the bargaining protocol, the monopoly profit is simply redistributed between firm A and firm B.

One may also consider a stronger policy, like the bill passed by the French Assembly in 2006, where the government mandates that a DRM system must be open, so that any hardware device is compatible with the legal content. However, as it turns out, this open policy has no effect on social welfare either, when social welfare is defined as the sum of all firms' profits and the consumers' surplus. That is, social welfare under a closed and an open DRM system is the same because by switching to an open DRM system firm A's profit drops to zero, whereas the consumer surplus increases by exactly the same amount.

Proposition 2. Regardless of whether the government requires a closed DRM system to be opened unconditionally or conditionally on firm B's request, such open policies have no effect on social welfare.

Proof. In equilibrium under a closed DRM system, firm A's profit is h, firm B's profit is 0, and firm C's profit is Δ. Since $p_A = h + c$, $\rho = \Delta$ and consumers choose {A,buy}, the consumer surplus is $v - \Delta - h - c$. Thus, social welfare is $\pi_A + \pi_B + \pi_C + CS = v - c$. In equilibrium under an open DRM system, firm A's profit is 0, firm B's profit is 0, and firm C's profit is Δ. Since $p_A = p_B = c$, $\rho = \Delta$ and consumers choose either {A,buy} or {B,buy}, the consumer surplus is $v - \Delta - c$. Thus, social welfare is $\pi_A + \pi_B + \pi_C + CS = v - c$. *Q.E.D.*

To summarize our findings, firm A earns a positive profit only under a closed DRM system, whereas the consumer surplus is the lowest under a closed DRM system. The content firm is able to earn a positive profit, Δ, to the extent that the original content is of superior quality than copies. Also, firm A is able to extract monopoly profit under a closed DRM system to the extent that DRM protection increases the consumer's copying cost from zero to h. Finally, government regulation to open a closed DRM system has no effect on aggregate social welfare. However, consumers are better off under an open DRM system, whereas firm A loses all the profits it could have made with a closed DRM system.

Although intuitive, some of these results seem a little stark and may be true only in special cases. In particular, the result that social welfare is the same under a closed and an open DRM system even though firm A monopolizes the market under a closed DRM system is likely due to the nature of unit demand, where firms sell either all or nothing. Since consumers are identical, the firm is facing a horizontal demand curve. In the next section, we introduce consumer heterogeneity to identify the source of inefficiency under a closed DRM system. This also generates additional predictions that better match real world markets.

5 Heterogeneous Consumers

Consider the same model as in the previous section. The only difference is that consumers now have different valuations for the content. To be precise, instead of being a constant, consumers have valuation v_i, which is uniformly distributed on a finite interval $[c, V+c]$, where $V \geq h + 2\Delta$ to assure an interior solution. To understand what this means in our model, suppose that hardware is priced competitively and a consumer has very low valuation (i.e., $v_i = c + \epsilon$). Then he would never buy the legal content if its market price is strictly positive. He would not obtain illegal copies either because the copies have lower valuation; that is, $v_i - \Delta$. This implies that some consumers would abstain in equilibrium from buying any hardware or content.

The equilibrium is again solved by backward induction. First, without DRM protection, copying is costless, and both hardware devices are compatible with the content, legal or illegal. Thus, active consumers, who either buy or copy the content given some ρ, would choose whichever hardware sells at a lower price. This means that firms A and B would go head-to-head driving down the Bertrand prices to marginal cost, $p_A = p_B = c$. Given this, firm C's optimal price would have been $\rho = \frac{V}{2}$; however, since $\frac{V}{2} > \Delta$ by assumption, the constraint, $\rho \leq \Delta$, binds because otherwise consumers would get copies, so it can charge only $\rho = \Delta$. Note that this result is the same as in the basic model, but the difference is that now consumers with sufficiently low valuation, $v_i \in [c, c + \Delta]$, would not buy any hardware or content.

Second, under a closed DRM system, consumers who choose hardware B must also obtain illegal copies. Note that the legal content price is set by the contract at some $\bar{\rho}$ demanded by firm A, which could be a different value than the $\bar{\rho}$ in the previous section. Again, there are two cases to consider, but let us focus on the equilibrium path; that is, $\bar{\rho} \leq \Delta + h$. Since active consumers compare the utilities from the two choices, {A,buy} and {B,copy}, following the same logic as before, it is immediate that firm A monopolizes the market and sets $p_A = \Delta + h - \bar{\rho} + c > c$. However, the important difference between the two models comes from the first-stage offer. To be specific, whereas $\bar{\rho} = \Delta$ in the basic model, $\bar{\rho} > \Delta$ in this extended model.

The reason why firm A needs to offer firm C better terms for $\bar{\rho}$ in the first stage than before is because firm A monopolizes the market and sells its hardware at a higher price than marginal cost, which means more individuals would abstain from consuming at all. This in turn reduces firm C's profit for a given price. Thus, firm A cannot induce firm C to adopt its DRM technology by offering $\bar{\rho} = \Delta$ since firm C's profit would be smaller compared to that under no DRM protection. The result is that the content price must go up (i.e., $\bar{\rho} > \Delta$) under a closed DRM system when consumers have different valuation, and more consumers abstain if $v_i \in [c, c + \Delta + h]$.

Third, under an open DRM system, hardware prices are again driven down to marginal cost, $p_A = p_B = c$. On the equilibrium path, firm A would have made an offer to firm C on terms that $\bar{\rho} > \Delta$, but an open DRM system is not on the equilibrium path. Suppose instead that the government would require an open DRM system. If this regulation is expected *ex ante*, then firm A has no incentive to make an offer to firm C on terms that $\bar{\rho} > \Delta$, so $\bar{\rho}$ would equal Δ. However, if the regulation is unexpected and *ex post*, then $\bar{\rho}$ would be higher than Δ following the intervention without any renegotiation. Note that firm A's profit is zero under an open DRM system regardless of the content price. Thus, $\bar{\rho}$ would remain above Δ even if we were to allow renegotiation since firm A has no incentive to renegotiate the terms with firm C.

Therefore, if the regulation is expected and $\bar{\rho} = \Delta$ under an open DRM system, then the equilibrium is basically the same as that under no DRM system. Since both content and hardware are competitively priced under no DRM system (i.e., $p_A = p_B = c$, $\rho = \Delta$), the effect of expected regulation would be to eliminate the deadweight loss and increase social welfare. Even if the regulation is unexpected so that $\bar{\rho}$ remains what it used to be under a closed DRM system, it can be shown that social welfare still increases by switching to an open DRM system. The reason is that, even though the content price is still above the competitive level, hardware prices are driven down to the competitive level, which means fewer consumers abstain under an open DRM system than under a closed one.

Proposition 3. Suppose that v_i is uniformly distributed on $[c, V+c]$ and $V \geq h + 2\Delta$.

(a) In the unique equilibrium, the content price is $\rho = \bar{\rho} = \frac{\Delta(V-\Delta)}{V-h-\Delta} > \Delta$, and a closed DRM system emerges. Consumers in $v_i \in [c, c+\Delta+h]$ abstain, and all active consumers choose hardware A and buy the legal content.

(b) If the government mandates a switch to an open DRM system, either expectedly or unexpectedly, social welfare increases. Consumers in $v_i \in [c, c+\bar{\rho}]$ abstain, where $\bar{\rho} \leq \Delta + h$, and active consumers choose hardware A or B with equal probability and buy the legal content.

Proof. Since $\rho = \Delta$ due to copying constraints, firm C's profit under no DRM system is $\Delta(\frac{V-\Delta}{V})$. Since firm A can make a positive profit only under a closed DRM system, it has an incentive to have firm C adopt its DRM technology. To do so, firm A must offer $\bar{\rho}$ such that it would yield at least as large a profit for firm C under a closed DRM system as under no DRM system. Under a closed DRM system, $p_A = \Delta + h - \bar{\rho} + c$, and $p_B = c$ if $\bar{\rho} \leq \Delta + h$. Consumers choose {A,buy} as long as $u_A = v_i - \bar{\rho} - p_A = v_i - \Delta - h - c \geq 0$, i.e., $v_i \geq \Delta + h + c$. Thus, firm C's profit would be $\bar{\rho}(\frac{V-(\Delta+h)}{V})$ under a closed DRM system. By setting $\bar{\rho}(\frac{V-(\Delta+h)}{V}) = \Delta(\frac{V-\Delta}{V})$, firm A's offer must be $\bar{\rho} = \frac{\Delta(V-\Delta)}{V-h-\Delta}$. Also, $p_A = \Delta + h - \bar{\rho} + c > c$ because $\bar{\rho} = \frac{\Delta(V-\Delta)}{V-h-\Delta} \leq \Delta + h$ if and only if $h \geq V - 2\Delta$, which is satisfied by assumption. Since the welfare analysis is trivial if $\bar{\rho} = \Delta$ under an open DRM system, in the following, we consider the case where $\bar{\rho} = \frac{\Delta(V-\Delta)}{V-h-\Delta}$ after switching to an open DRM system, i.e., the case of *ex post* regulation.

Under an open DRM system, firm A's and firm B's profits are zero, and firm C's profit is $\bar{\rho}(\frac{V-\bar{\rho}}{V})$; consumers' surplus is $\int_{c+\bar{\rho}}^{c+V}(v_i - \bar{\rho} - c)\frac{1}{V}dv_i$. Under a closed DRM system, firm A's profit is $(p_A - c)(\frac{V-(\Delta+h)}{V})$, firm B's profit is zero, and firm C's profit is $\bar{\rho}(\frac{V-(\Delta+h)}{V})$; consumers' surplus is $\int_{c+\Delta+h}^{c+V}(v_i - \Delta - h - c)\frac{1}{V}dv_i$. Social welfare under an open DRM system (SW_O) is $\bar{\rho}(\frac{V-\bar{\rho}}{V}) - (\bar{\rho}+c)(\frac{V-\bar{\rho}}{V}) + \frac{1}{2V}[(c+V)^2 - (c+\bar{\rho})^2]$. Social welfare under a closed DRM system (SW_C) is $(\Delta+h-\bar{\rho})(\frac{V-(\Delta+h)}{V}) + \bar{\rho}(\frac{V-(\Delta+h)}{V}) - (\Delta+h+c)(\frac{V-(\Delta+h)}{V}) + \frac{1}{2V}[(c+V)^2 - (c+\Delta+h)^2]$. That is, $SW_O = -c(\frac{V-\bar{\rho}}{V}) + \frac{1}{2V}[(c+V)^2 - (c+\bar{\rho})^2]$ and $SW_C = -c(\frac{V-(\Delta+h)}{V}) + \frac{1}{2V}[(c+V)^2 - (c+\Delta+h)^2]$. $SW_O - SW_C = -c(\frac{\Delta+h-\bar{\rho}}{V}) + \frac{1}{2V}[(c+\Delta+h)^2 - (c+\bar{\rho})^2] = -c(\frac{\Delta+h-\bar{\rho}}{V}) + (2c+\Delta+h+\bar{\rho})(\frac{\Delta+h-\bar{\rho}}{2V}) = (\frac{\Delta+h+\bar{\rho}}{2})(\frac{\Delta+h-\bar{\rho}}{V})$. Since $\bar{\rho} \leq \Delta + h$, $SW_O \geq SW_C$. *Q.E.D.*

The above proposition shows that there is a source of inefficiency under a closed DRM system when we allow consumers to have different valuations. This inefficiency arises because legal content as well as hardware devices are priced above the competitive level under a closed DRM system. This welfare result is intuitive because with heterogeneous consumers the demand curve firm A is facing would be downward sloping, not horizontal as in the basic model. This means that there is a monopoly deadweight loss under a closed DRM system. Thus, social welfare increases by switching to an open DRM system.[22]

Another implication from the above findings is that there could be a conflict of interest between the content firm and the compatible device seller. That is, whereas firm A prefers to keep its DRM system closed by refusing to share it with firm B, firm C might actually

[22] This welfare implication is in line with a strand of literature on patents (e.g., Tandon 1982), where compulsory licensing can be welfare enhancing under some circumstances.

prefer an open DRM, especially when it is achieved through *ex post* government regulation, because it can sell the content at a profit to a larger population of consumers including those who have previously abstained from consumption.[23] That is, firm A initially has to guarantee a higher content price (i.e., $\bar{\rho} > \Delta$) to build a closed DRM system, but later firm C has an incentive to demand an open DRM system to increase its own profit.

This seems consistent with some real world observations. For example, Warner Music CEO Edgar Bronfman criticized Apple's refusal to share its DRM technology with competing device sellers, and the Recording Industry Association of America urged Apple to open its DRM system to competitors.[24] Similarly, in the growing market for electronic publishing, anticircumvention measures are effectively tying a publisher's encrypted e-book formats to a particular e-book reader. The result being that there are some efforts by the Open eBook Forum to develop an e-book format using an encryption technology with only open standards.

One final comment concerns the idea that DRM-based tying can be anticompetitive conduct. Antitrust authorities should be cautious because it may be difficult to prove that this tying arrangement is actually damaging social welfare.[25] While the analysis in this section shows a case where this is a theoretical possibility, we have not considered potential efficiency gains associated with a closed DRM system. As U.S. courts acknowledge in the Microsoft

[23] However, if the regulation is perfectly foreseen at the beginning of the game, then firm C would not have an *ex ante* preference for an open DRM system over a closed one. This is because if a DRM system must be open, firm A has no reason to initially offer its system to firm C on terms $\bar{\rho} > \Delta$, so that $\bar{\rho}$ must equal Δ, in which case firm C would make the same profits both under a closed and an open DRM system.

[24] See, for example, Berlind, David, "Jobs Drowning in His Own Kupertino Kool-Aid," *ZDNet*, February 8, 2007; Dignan, Larry, "The Jobs' DRM Fallout Is Mixed," *ZDNet*, February 9, 2007; Farrell, Nick, "RIAA Slams Steve Jobs," *Inquirer*, April 12, 2007.

[25] *Per se* condemnation of tying requires some sort of coercion by the seller. However, Apple did not explicitly force iTunes users to buy an iPod. Thus, this type of virtual tying is likely to fall under the rule of reason approach. For more antitrust discussion of tying in general, see Tirole (2005), Carlton and Waldman (2005a), and Nalebuff (2005).

cases, considerable weight should be given to plausible efficiencies of the tie. Moreover, a DRM system serves another purpose of promoting compliance with the copyright law, which complicates the matter.

In fact, European regulators and U.S. agencies have had divergent views on Apple's business model. In particular, some U.S. officials backed Apple on the basis of intellectual property rights. For example, Assistant Attorney General Thomas Barnett criticized European regulators by saying that their antitrust pursuit "provides a useful illustration of how an attack on intellectual property rights can threaten dynamic innovation."[26] In the next section, we consider welfare implications of an open policy on the firms' dynamic R&D incentives.

6 Product Upgrades

6.1 The Model

In this section, we extend the basic model into a two-period setting, which is based on Carlton and Waldman (2005b), where at the beginning of the second period the two hardware firms can invest to upgrade their product's quality. The difference is that in Carlton and Waldman (2005b) the tying firm is a monopolist in the primary market, whereas in our model the tying firm is not a monopolist when there is no DRM protection or the DRM technology is shared by the two hardware firms. Another difference is that in their paper the alternative producer's

[26] In March 2008, the U.S. Federal Trade Commission issued a staff report that says, "the challenge for the FTC, then, is not to ensure that products are interoperable, but rather to ensure that consumers are provided sufficient information prior to purchase so that they understand any inherent limitations on the use of the products they buy."

complementary product is higher quality, whereas in our model they are the same quality.

The upgraded hardware is identical to the original except for the extra quality improvement (e.g., product design, additional features, and larger memory). In particular, an upgraded product can also play DRM-protected content as long as its previous version could. To illustrate what this means in our model, suppose that a closed DRM system is in place. Then, an individual who bought the legal content in the first period would prefer to buy an upgraded product from firm A rather than from firm B, all other things being equal. This is because, if the consumer switches to firm B's upgraded product, he incurs an additional cost to obtain illegal copies.

To be more precise, suppose that at the beginning of the second period each firm has the option of investing a fixed amount R, $R > 0$, to produce at a marginal cost of c an upgraded product whose quality is higher than the previous version by $\lambda > 0$. An investment is socially desirable when the benefits from innovation are larger than the costs; that is, $\lambda q > R + cq$, where q is the quantity sold. In particular, we assume $\lambda > R + c$, which ensures that each firm's investment is efficient when all consumers purchase the firm's upgrade in the second period (i.e., $q = 1$). Firms sell their upgrades by setting a price $\hat{p}_{j=A,B}$, and they engage in Bertrand competition when more than one firm is active. Following Fudenberg and Tirole (1998), we allow firms to charge different prices to their previous customers and to new customers.[27]

A consumer's utility from buying an upgrade from firm j in the second period is $\hat{u}_j = \delta - e - \hat{p}_j + \lambda$, where δ and e are the same as in the basic model. That is, δ is the value of the

[27] To be precise, firm j's price for firm A's and B's previous customers are $\hat{p}_{j|\sigma_A}$ and $\hat{p}_{j|\sigma_B}$, respectively. By a slight abuse of notation, we use $\hat{p}_j$ when they are equal.

content, e is the cost of obtaining the content, where $e = 0$ if one uses the content obtained in the first period. The consumer's valuation for legally purchased content is $\delta = v$, whereas the valuation for illegally obtained copies is lower; that is, $\delta = v - \Delta$. We assume that v is again a constant. As before, let ρ denote the market price of the legal content, so that when a consumer buys legal content, $e = \rho$, but when he obtains illegal copies, $e = 0$ if the legal content is DRM free, and $e = h$ if it is DRM protected.

The hardware and the content purchased in the first period are durable goods, so that the utility from continuing to use them becomes the new reservation utility in the second period. That is, consumers do not have to purchase new hardware and content again, and they buy at most one upgraded hardware product. Thus, the reservation utility of those who own legal content and hardware to play it on is v, whereas it is $v - \Delta$ for those who own illegal copies and hardware. This means that firm A and B are effectively selling their quality improvement, λ, associated with the upgrades in the second period subject to any switching costs.

To keep the analysis simple, we assume that there are no new customers, content, or entry of new firms in the second period, and firms cannot price below marginal cost in the first period.[28] In addition, we restrict attention to a parameterization, $\Delta + h > R$, to reduce the number of cases that need to be considered. This means that, when both firms are active under a closed DRM system, firm A can invest in the second period and earn a positive second-period profit if its first-period market share is large enough. As we shall show, $\Delta + h$ are the switching costs in the model, so the interpretation is that the investment

[28] Even if we allow first-period prices to be below marginal cost or negative, this does not change the following analysis significantly. See Appendix A for this extension.

cost is smaller than the switching costs.[29] Finally, we assume no discounting between the two periods by either firms or consumers.

6.2 Analysis

Two results follow from this extended model given our assumptions. One is that there is a unique equilibrium in which a closed DRM system emerges in the first period, and only firm A invests and sells an upgraded product in the second period. The other is that, if the government mandates an open DRM system in the first period, then social welfare may decrease in the second period. For example, consumer surplus can increase under an open DRM system when both firms invest, but Bertrand competition would make producers incur negative profits, where the profit decrease is as large or larger than the increase in consumer surplus. Thus, social welfare in the second period is at least as high under a closed DRM system as under an open one, and this illustrates a case of dynamic efficiency gain associated with a closed DRM system.

We begin with a preliminary result concerning what happens in the second period when firm A's and B's first-period market shares are given as σ_A and σ_B. First, suppose that both firms invest under either no or open DRM protection. Since firms can price discriminate depending on whether a consumer purchased firm A's or firm B's hardware in the first period, we refer to these two submarkets as firm j's turfs. In firm A's turf, a consumer who previously bought legal content receives a utility of $v-e-\hat{p}_A+\lambda$ if he buys firm A's upgrade, and $v-e-\hat{p}_B+\lambda$ if he buys firm B's upgrade. Similarly, a consumer who bought illegal

[29] That is, $\Delta + h$ are the switching costs because those who own legal content and firm A's hardware in the first period must obtain illegal copies to switch to firm B's upgraded hardware in the second period.

copies in the first period compares utilities, $v - \Delta - e - \hat{p}_A + \lambda$ and $v - \Delta - e - \hat{p}_B + \lambda$, from buying an upgrade from each firm.

Since there is no reason to buy the legal content again, $e = 0$ for those who have legal content. On the other hand, those who have illegal copies may choose to buy the legal content to improve the quality of the content if the market price, ρ, falls below Δ in the second period. However, in equilibrium, ρ does not fall below Δ because in the first period firm C can have all consumers buy the legal content at $\rho = \Delta$, so it does not earn more profit by lowering the price in the second period.[30] Thus, Bertrand competition leads second-period prices to equal c (i.e., $\hat{p}_A = \hat{p}_B = c$). Exactly the same logic applies to the nature of competition in firm B's turf since firms are symmetric under no or an open DRM system.

Next, suppose that both firms invest under a closed DRM system. In firm A's turf (σ_A), consumers may have either legal content or illegal copies. Let us focus on the case where they own legal content. If they switch to firm B's upgrade, then they must incur switching costs, which are defined as $\Delta + h$, in the sense that the quality of copies are lower than the legal content by Δ and it costs h to obtain a copy. Thus, firm A can capture this submarket at a profit; that is, $\hat{p}_{A|\sigma_A} = \Delta + h + c > c = \hat{p}_{B|\sigma_A}$. On the other hand, in firm B's turf (σ_B), all consumers have illegal copies since the original device B is not compatible with legal content. However, both upgrades A and B are compatible with illegal copies, so that Bertrand competition leads to $\hat{p}_{A|\sigma_B} = \hat{p}_{B|\sigma_B} = c$ in firm B's turf.

The equilibrium in the second period can be found by looking at the payoff matrices constructed from above. Under a closed DRM system, if both firms invest, then firm B

[30] This feature is due to identical consumer valuation, v, in this model. With heterogeneous valuations, the Coase Conjecture might apply, but we abstract from this issue here.

cannot make any profit because its price is driven down to marginal cost in both submarkets. However, firm A can make a positive profit from selling to its previous customers (i.e., $\pi_A = \sigma_A(\Delta + h) - R$) if its first-period market share is high enough (i.e., $\sigma_A \rightarrow 1$). The payoffs when only one firm invests, or no firm invests, are relatively straightforward, and so are the payoff matrices under no or open DRM protection. For example, a single innovating firm under an open DRM system can sell its upgrade at $\hat{p}_j = \lambda$ in both submarkets and extract all consumer surplus.

The result is that under a closed DRM system investing is a dominant strategy for firm A, and, given this, firm B would not invest because it would only incur a net loss of $-R$ when both firms invest and compete. However, under no or an open DRM system, firm B might invest and capture the whole market in the second period. To be more specific, since firm A and firm B are symmetric in this case, an innovating firm can be either firm, which becomes a monopolist as long as the other firm does not invest. If they both invest, they both suffer a net loss of $-R$. That is, following no or open DRM protection, the second period game has multiple equilibria.

Proposition 4. Taking σ_A and σ_B as given, second-period equilibrium behavior is characterized as follows:

(a) Under a closed DRM system, there is a unique equilibrium in which only firm A invests and sells its upgrade at $\hat{p}_A = \lambda$ to all consumers if its first-period market share is above a certain threshold, $\bar{\sigma} = \frac{R}{\Delta+h} < 1$, and those who obtain illegal copies in the first period would buy the legal content if $\rho < \Delta$.

(b) Under an open DRM system, there are two pure strategy equilibria where either firm

A or firm B alone invests and sells its upgrade at $\hat{p}_{j=A,B} = \lambda$ to all consumers. There is also a mixed strategy equilibrium where firm A and firm B randomize their investment decisions with strictly positive probabilities.

Proof. See Appendix B. *Q.E.D.*

The above proposition shows that the switching costs (i.e., $\Delta + h$) are crucial for the equilibrium characterization under a closed DRM system. That is, firm B cannot profitably invest because firm A's first-period customers must also obtain illegal copies if they switch to firm B's upgraded product. This can discourage firm B from investing as long as the switching cost is larger than the investment cost; that is, $\Delta + h > R$. On the other hand, under an open DRM system, each firm earns a negative profit of $-R$ when they both invest, and when only one firm invests the innovating firm captures the whole market. This means that there are two asymmetric pure strategy Nash equilibrium, in which either firm may invest alone.

We now consider what happens in the first period when this second-period behavior is taken into account. In the second period equilibrium, under a closed DRM system, firm A would earn a positive profit of $\lambda - c - R$ because firm A alone invests and sells to the whole market. However, under an open DRM system, the best firm A can do is to earn the same amount of profit, $\lambda - c - R$, in only one of the three possible equilibria. Thus, an open DRM system is a weakly dominated regime for firm A in terms of second-period profit. Since firm A earns strictly higher first-period profit under a closed DRM system, there is no reason for firm A to prefer an open DRM system rather than a closed one in this extended model.

This result is similar to Carlton and Waldman (2005b), who show that in the presence of durable goods tying can be a profitable strategy more generally than is suggested by the previous literature. More specifically, when consumers are in the market for more than one period and there are upgrades for the complementary good, the monopolist may tie in order to capture the profit from the upgrade market, and adding consumer switching costs leads to an even stronger motivation for tying. By the same logic, in our setting, firm A forecloses firm B's investment by using DRM-based tying in the first period. However, there is a subtle difference between the two papers regarding welfare implications.

In this paper, the government intervention that mandates an open DRM system in the first period has a negative effect on social welfare in the second period. For example, in a mixed strategy equilibrium it would be socially wasteful if both firms happen to invest in upgrades of the same quality. Even when firm B invests alone under an open DRM system, regulation would not increase social welfare but only changes which firm becomes the monopolist in the second period. However, if firm B produced a superior upgraded product, then, similar to Carlton and Waldman (2005b), social welfare could increase under an open DRM system when only firm B invests and sells a higher quality product.

If we focus on the symmetric mixed strategy equilibrium, then we find that social welfare unambiguously decreases by switching to an open DRM system in both an *ex ante* and *ex post* sense. *Ex post*, any of the four strategy profiles can be the final outcome; that is, $\{R, R\}, \{R, 0\}, \{0, R\}, \{0, 0\}$.[31] If $\{R, R\}$ is chosen, then one firm's investment is wasted because it merely duplicates the other firm's investment. If $\{0, 0\}$ is chosen, then social welfare is again less than its full potential because innovation itself is socially desirable; that

[31] For each pairing the first(second) element denotes firm A(B)'s choice of investing (R) or not investing (0).

is, $\lambda > R+c$. Only when $\{R, 0\}$ or $\{0, R\}$ is the result that social welfare remains the same.

Ex ante, before the firms make their investment decisions, the effect of an open policy on second-period social welfare is also negative. By definition, each firm invests with the same probability, which in equilibrium is given by, $\phi_A = \phi_B = \frac{\lambda-c-R}{\lambda-c} \in (0,1)$. For social welfare to stay the same under an open DRM system, the mixing probabilities should be either $(\phi_A, \phi_B) = (0,1)$ or $(\phi_A, \phi_B) = (1,0)$, so that only one firm invests. However, this cannot happen in equilibrium because the mixing probabilities are the same (i.e., $\phi_A = \phi_B$), which means that the expected social welfare is strictly lower under an open DRM system than under a closed one.

Proposition 5. Suppose each of firm A and firm B can invest R and sell an upgraded product in the second stage. Assume $\lambda > R + c$ and $\Delta + h > R$.

(a) There is a unique Subgame Perfect Nash Equilibrium in which a closed DRM system emerges in the first period, firm A captures the entire first-period market, and then firm A invests and sells its upgraded product to all consumers in the second period.

(b) If the government mandates an open DRM system in the first period, it weakly decreases social welfare in the second period. Further, focusing on symmetric mixed strategy equilibrium, it strictly decreases expected social welfare.

Proof. It is straightforward to show that the second-period equilibrium with no DRM protection is the same as the equilibrium under an open DRM system. Moreover, the equilibrium under an open DRM system does not depend on the first-period market shares, σ_A and σ_B. Thus, as long as $\sigma_A > \bar{\sigma}$, firm A's second-period payoff under a closed system, $\lambda - c - R$, is at least as large as that under an open or no DRM system in any equilibrium of the subgame. That is, the most firm A can earn in the second period under an open or no DRM system is the same as what it can always gain under a closed DRM system.

Note that firm A's profit is the largest with a closed DRM system in the first period, in which case firm A monopolizes the first-period market (i.e., $\sigma_A = 1$). Also, note that firm C would accept the offer from firm A on terms $\bar{\rho} = \Delta$ because by doing so it can sell the legal content to all consumers, which is a durable good. Thus, the equilibrium description in the first period is exactly the same as in proposition 1, and in the second period firm A alone invests and sells its upgrade to all consumers. The proof of the second result on social welfare is as explained in the text. *Q.E.D.*

The above proposition shows a case for dynamic efficiency gains from keeping a closed DRM system in place. This means that, even though the closed DRM system may have a negative effect on social welfare in the first period due to the deadweight loss it creates, DRM-based tying can be beneficial in the second period by avoiding coordination failure between the two firms in a mixed strategy equilibrium. That is, a closed DRM system basically makes the tying firm the next period's innovating firm. However, an open policy can have a positive effect on social welfare in the second period if firm B were to produce a higher quality upgrade, and the equilibrium is chosen such that only firm B invests. Therefore, overall welfare implications are ambiguous.

7 Conclusion

DRM-based tying has become an important issue in today's digital economy. While the literature has focused on traditional tying arrangements, technological tying wherein a firm ties another firm's good to its own good using its key technology has not received much attention. In this paper, we investigate whether DRM-based tying has the effect of gaining market power and whether the government can increase social welfare by requiring an open DRM system. Although exemplified by Apple's iPod/iTunes tying, such a tying strategy can emerge in other markets too. For example, Apple seems to be extending its DRM-based tying into the smartphone market, where Apple sells DRM-protected applications for its iPhone, which are incompatible with competing phones.

In line with the previous literature on tying, we find that the hardware firm that owns DRM technology has an incentive to tie the legal content to its hardware based on its DRM technology. This increases the tying firm's profits above the competitive level because users of the rival's hardware must obtain illegal copies, which is costly when the content is DRM-protected. This could explain how Apple's iPod became dominant in the portable music player market. We also find that in a static setting such tying may have a negative effect on social welfare due to deadweight losses, but in a dynamic setting social welfare can be higher under a closed DRM system even though it appears to turn a possible duopoly into a monopoly.

More work needs to be done before using antitrust to attack this type of technology-based tying. For example, DRM-based tying is effectuated by both product design and contractual arrangement, which makes it difficult to apply standard arguments in the antitrust literature such as those concerning exclusive dealing. Although this paper shows that there are considerable private incentives to tie, it also shows that a closed DRM system has ambiguous welfare implications even in this simplified model. In particular, in terms of the continuing policy debate, one must consider the dynamic tradeoff between foreclosing a possibly more efficient rival against duplicating investments that produce similar innovation.

8 Appendix A

In section 6.1, we made the assumption that a firm cannot stay in the market if it incurs a negative profit in the first period. Basically, this means that firms cannot price below marginal cost in the first period. Here we show that relaxing this assumption by allowing prices to be below marginal cost or negative does not meaningfully change the results in section 6.2. First of all, firm C has no incentive to price the legal content below marginal cost, which is zero, because everyone would buy the legal content at a negative price and the content is a durable good. Instead, if firm C sets $\rho = \epsilon > 0$, it can sell the legal content to all consumers at a positive profit.

Next, consider the hardware firms. Under no or an open DRM system, firm A and firm B have no incentive to incur a negative profit in the first period because the second-period profits do not depend on the first-period market shares. Under a closed DRM system, firm B may have an incentive to expand its first-period market share by pricing below marginal cost. If indeed firm B were to capture the first-period market ($\sigma_B = 1$), then the second-period payoff matrix is the same as that under no or an open DRM system since it is only firm A's first-period customers who bear potential switching costs. Thus, there are three equilibria as in proposition 4.

If $\{0, R\}$ is the equilibrium assuming that $\sigma_B = 1$, then firm B has an incentive to price below marginal cost as long as the second-period profit is at least as large as the first-period loss, that is, $\lambda - c - R \geq c - p_B$. This means that in equilibrium $p_B = 2c + R - \lambda$, which could be a negative or positive number. By Bertrand competition, however, firm A can still capture the first-period market by setting $p_A = h + p_B$, that is, $p_A = h + 2c + R - \lambda$ in equilibrium. Firm A has an incentive to do so because at that price its overall profit would be positive (i.e., $\lambda - c - R > c - p_A$), whereas its profit would be zero if firm A does not undercut firm B's prices.

If $\{R, 0\}$ is the equilibrium in the second period assuming that $\sigma_B = 1$, then firm B has no incentive to price below marginal cost in the first period because its second-period profit is zero. The case of mixed-strategy equilibrium is similar. The expected second-period profits of firm A and firm B are both zero, that is, $E\pi_j = \phi_j(-R) + (1 - \phi_j)(\lambda - c - R) = -(\frac{\lambda - c - R}{\lambda - c})R + (\frac{R}{\lambda - c})(\lambda - c - R) = 0$. This is intuitive because the expected payoff must be the same as the payoff from not investing, which is zero; otherwise, firms would prefer a pure strategy. This implies that firm A and firm B have no incentive to price below marginal cost in the first period.

9 Appendix B

Proof of Proposition 4. Let $\{\{R, R\}, \{R, 0\}, \{0, R\}, \{0, 0\}\}$ denote the set of pure strategy profiles of firm A and firm B in the second period, where R means investment and 0 means no investment.

(a) First, suppose that a closed DRM system is in place at the beginning of the second period. There are two possible types of firm A's turf (σ_A), wherein all consumers in this submarket own legal content, or illegal copies. On the other hand, there is only one type of firm B's turf (σ_B), wherein all consumers in this submarket own illegal copies.

(i) Suppose both firms invest. If consumers in σ_A own legal content, then their reservation utility is v, and the utilities from buying firm A's and firm B's upgrades are $v + \lambda - \hat{p}_{A|\sigma_A}$ and $v - \Delta + \lambda - h - \hat{p}_{B|\sigma_A}$, respectively. Since the two firms compete in Bertrand fashion, firm A captures this submarket at $\hat{p}_{A|\sigma_A} = \Delta + h + c$. If consumers in σ_A own illegal copies, then the reservation utility is $v - \Delta$, and the utilities from buying firm A's and firm B's upgrades are $v - \Delta + \lambda - \hat{p}_{A|\sigma_A}$ and $v - \Delta + \lambda - \hat{p}_{B|\sigma_A}$, respectively. Thus, hardware prices are driven down to $\hat{p}_{A|\sigma_A} = \hat{p}_{B|\sigma_A} = c$. Consider firm B's turf. Consumers in σ_B have a reservation utility of $v - \Delta$, and the utilities from buying firm A's and firm B's upgrades are $v - \Delta + \lambda - \hat{p}_{A|\sigma_B}$ and $v - \Delta + \lambda - \hat{p}_{B|\sigma_B}$, respectively. Thus, hardware prices are driven down to $\hat{p}_{A|\sigma_B} = \hat{p}_{B|\sigma_B} = c$.

(ii) Suppose only firm A invests. Then, firm A would capture A's turf as long as $v + \lambda - \hat{p}_A > v$ if the consumers own legal content, and as long as $v - \Delta + \lambda - \hat{p}_A > v - \Delta$ if they own illegal copies. Both cases lead to $\hat{p}_A = \lambda$. For the same reason, firm A would capture B's turf too at $\hat{p}_A = \lambda$.

(iii) Suppose only firm B invests. Then, firm B would capture A's turf as long as $v - \Delta + \lambda - h - \hat{p}_B > v$ if the consumers own legal content, and as long as $v - \Delta + \lambda - \hat{p}_B > v - \Delta$ if they own illegal copies. Thus, $\hat{p}_{B|\sigma_A} = \max\{c, \lambda - \Delta - h\}$ in the first case, and $\hat{p}_{B|\sigma_A} = \lambda$ in the second case. Firm B would capture B's turf if $v - \Delta + \lambda - \hat{p}_B > v - \Delta$, so that $\hat{p}_{B|\sigma_B} = \lambda$.

To summarize, when both firms invest under a closed DRM system, firm A's profit is $\sigma_A(\Delta + h) - R$, and firm B's profit is $-R$. If only firm A invests, its profit is $\lambda - c - R > 0$. Since firm A earns zero profit if it does not invest, investing is a dominant strategy for firm A if $\sigma_A > \frac{R}{\Delta+h}$. In this case, if firm A's dominated strategy is eliminated, then firm B chooses not to invest in equilibrium because its payoff when both firms invest is $-R$, whereas it can earn a zero profit by not investing.

(b) Second, suppose that either no or an open DRM system is in place at the beginning of the second period. There are two possible types of firm A's turf (σ_A), wherein all consumers in this submarket own legal content, or illegal copies. There are also two possible types of firm B's turf (σ_B), which are the same as in firm A's turf.

(i) Suppose both firms invest. If consumers in $\sigma_{j=A,B}$ own legal content, then the reservation utility is v, and the utilities from buying firm A's and firm B's upgrades are $v+\lambda-\hat{p}_A$ and $v+\lambda-\hat{p}_B$, respectively. Thus, hardware prices are driven down to $\hat{p}_A = \hat{p}_B = c$. If consumers in $\sigma_{j=A,B}$ own illegal copies, then the reservation utility is $v-\Delta$, and the utilities from buying firm A's and firm B's upgrades are $v-\Delta+\lambda-\hat{p}_A$ and $v-\Delta+\lambda-\hat{p}_B$, respectively. Thus, hardware prices are driven down to $\hat{p}_A = \hat{p}_B = c$.

(ii) Suppose only one firm, $j = A(B)$, invests. Then, firm j would capture A's turf as long as $v+\lambda-\hat{p}_j > v$ if the consumers own legal content, and it would also capture A's turf as long as $v-\Delta+\lambda-\hat{p}_j > v-\Delta$ if they own illegal copies. Both cases lead to $\hat{p}_{j=A(B)} = \lambda$. For the same reason, firm j would capture B's turf at $\hat{p}_{j=A(B)} = \lambda$.

To summarize, firm A's and firm B's payoffs under no or an open DRM protection are $-R$ and $-R$ when both firms invest. The payoffs from $\{0, 0\}$ are of course $(0, 0)$. If only one firm invests, then it earns a positive profit of $\lambda - c - R$. Then, it is straightforward to show that $\{R, 0\}$ and $\{0, R\}$ are the two pure strategy equilibria, and there is a mixed strategy equilibrium where each firm chooses to invest R with probability $\phi = \phi_A = \phi_B = \frac{\lambda-c-R}{\lambda-c} \in (0, 1)$ and not to invest with probability $1-\phi$. *Q.E.D.*

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