Digital Rights Management and the Pricing of Digital Products

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Abstract: As it becomes cheaper to copy and share digital content, vendors are turning to technical protections such as encryption. We argue that if protection is nevertheless imperfect, this transition will generally lower the prices of content relative to perfect legal enforcement. However, the effect on prices depends on whether the content providers use independent protection standards or a shared one, and if shared, on the governance of the system. Even if a shared system permits content providers to set their prices independently, the equilibrium prices will depend on how the vendors share the costs, and prices may be higher than with perfect legal protection. We show that demand-based cost sharing generally leads to higher prices than revenue-based cost sharing. Users, vendors and the antitrust authorities will typically have different views on what capabilities the DRM system should have. We argue that, when a DRM system is implemented as an industry standard, there is a potential for "collusion through technology."

Keywords: technical protections, DRM, antitrust, trusted systems, cost sharing

JEL Classifications: L13, L14, L15, K21, O33

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1 Introduction

As copying of digital content has become easier, content vendors have started to protect their property with technology rather than relying on legal protections. Technical protections, such as encryption and copy controls, are often lumped together with licensing privileges under the name "digital rights management (DRM)." The purpose of this paper is to explore at least one business model of how technical protections might be provided, and its effect on the pricing of entertainment products.

Technical protections have been evolving since the 1980s. Some have been industry-wide efforts such as the Serial Copy Management System for digital audio tape that was authorized by Congress. This system caused the quality of copies to degrade, so that, as with analog audio tapes, it was hard to make faithful copies of copies. The solution was inelegant at best, but in any case became obsolete due to the proliferation of other digital mediums. Other measures were introduced by vendors themselves, such as the one-installation features imposed by some distributors of computer software. One-installation features were rapidly circumvented.

As content distribution has moved to the Internet, watermark and encryption technologies have developed. A watermark, by analogy with a watermark on paper stationery, is a piece of software code embedded in a program. If illicit copies of the software circulate, the watermark can identify the original buyer or licensee of the copy that is circulating. This may or may not be useful, depending on whether the original buyer or licensee can be held liable. Encryption systems attempt to make digital content uninterpretable or inaccessible without use of a code key. The code key generally authorizes playing the content on a specific piece of hardware. For example, the movie industry has developed digital versatile disks (DVDs), which are protected by a technology called the Content Scrambling System (CSS). CSS authorizes access by matching a code embedded in disks to a code embedded in DVD players. Among other purposes, this system ensures that movies released for viewing in one region of the world cannot be viewed in another. Similarly, Apple Computer's music player, iPod, is equipped with a decryption ability called Fairplay that allows the user to download and play music from their online music store iTunes.

Two markets are implicated in technical protections: the market for players and the market for content. Since the market for players is mostly derived from the market for content, this raises questions about whether the player market can capture the value of the underlying content, and thus undermine the incentive for creation.

Market power in the player market has, in fact, raised antitrust concerns. For example, the Department of Justice Antitrust Division investigated the licensing agreements that govern the DVD and MPEG patent pools. In *VirginMega v. Apple*, the French antitrust authorities considered an antitrust claim to force the licensing of FairPlay. The DOJ issued favorable review letters on DVD and MPEG, since the patents in the pool are complements (Shapiro 2001). The French antitrust authorities also dismissed the antitrust claim against Apple. However, critics have not been assuaged, and have now taken their complaint to legislative bodies. Various national governments in Europe, including France, have proposed legislation to force interoperability.

The DVD technology and the iTunes technology differ in their relationships to the content industry. The DVD technology is largely owned by the content vendors, at least on the software side, while iTunes is owned by a hardware manufacturer. Manufacturers of DVD players must pay fees to the Motion Pictures Expert Group (MPEG) for digital video and audio algorithms called "codecs", as well as to the DVD Copy Control Association (DVD-CCA) for the Content Scramble System (CSS), and to a pool administered by Toshiba on aspects of the hardware. MPEG includes content companies, and DVD-CCA is controlled primarily by the content industry.

Disentangling the relationship between the content market and the player market is not trivial, since the demand for players is derived from the demand for content. The main harm that might arise from monopolization of the player market is that it could divert profit from creators, and thus erode the incentive to create. However, there is a natural antidote: content vendors can implement and maintain their own protection systems, either independently or through a shared protection platform. In this paper, we ask whether that solution raises new problems for competition. We explore the effect on content prices when a costly digital rights management system is owned and controlled by the content providers.

In section 2, we show that the mere fact of cost sharing has a collusive impact. If firms share cost according to their shares of total demand, a vendor can reduce its share of the cost by raising price and thus reducing demand. In fact, we show that "demand-based" cost sharing leads to higher prices than "revenue-based" cost sharing, although both put upward pressure on price.

In section 3 we introduce the idea that the level of protection is an endogenous choice, and argue that a threat of circumvention has a moderating effect on prices. We assume that the cost of protection rises with the level of protection, where the level of protection is calibrated by the cost of circumventing it. Considering only the collusive effect of cost sharing, the level of protection that maximizes the firms' joint profits may or may not be high enough to deter circumvention. If not, the firms will sell at lower prices.

In section 4, we ask whether the firms will prefer independent systems or a shared system, and whether their choice accords with efficiency. Independent systems can lead to either higher prices or lower prices, and can lead to either lower costs or higher costs. Separate systems have the advantage of being a less attractive hacking target. Therefore the vendors have less incentive to keep prices low to avoid hacking. However, a shared system has the advantage of facilitating collusion through cost sharing. These effects on prices work in opposite directions. There are also countervailing effects on costs. The costs of independent systems may be lower because the required level of protection is lower, but higher because the setup costs must be duplicated. The firms' desire to reduce costs will encourage them to make the socially efficient decision whether to share, but their desire to collude may work in the opposite direction.

In section 5 we consider the extent to which there can be "collusion through technology," in the sense that vendors can design the technological capabilities to facilitate or avoid independent pricing.

The ideas in this paper are related to an older literature of the 1980's about the feared harms of photocopying. These include, for example, the papers of Novos and Waldman (1984), and Besen and Kirby (1989), who were focused mainly on the cost and quality of copies, and how the market for copies affects the price of originals and consumer welfare more generally. In contrast, we assume that digital copies are faithful to the original, and that the cost of copying is endogenous to the level of protection, which we take as an optimizing choice of vendors. More recently, authors have focused on government interventions as a solution to digital copying. For example, Chen and Png (2003) characterize optimal fines for copying, in conjunction with subsidies and taxes, which collectively can mitigate the harms of digital copying.

We follow Conner and Rumelt (1991) in our premise that the threat of copying will cause vendors to lower their prices. (See Sundararajan (2004) for empirical evidence for the existence of DRM price effects.) We follow Belleflamme (2003) in noticing that a shared DRM system affects pricing behavior through the threat of hacking. In Belleflamme's paper, demands would be independent if the vendors had perfect legal enforcement, but demands become interdependent if hacking is a threat. We depart from these papers in assuming that the level of protection (cost of hacking) is endogenous, and in the welfare questions we address. It may be easier to deter hacking with separate DRM systems than with a shared DRM system. We therefore investigate the choice between independent and shared protections, and how it compares to what is optimal. We also investigate the effect on prices of how the shared system is governed, in particular, comparing demand-based cost sharing with revenue-based cost sharing.

2 Cost Sharing as a Collusive Device

We will make our arguments in a simple model with two sellers of substitute proprietary products. To focus on the governance of prices without getting bogged down in asymmetries between the firms, we will assume that the firms are in symmetric positions. In particular, they face demands $D_1(p_1, p_2), D_2(p_1, p_2)$, each decreasing in its own price and nondecreasing in the other firm's price. By symmetry we mean that for all (a, b), $D_1(a, b) = D_2(b, a)$. We assume that production costs are zero so that, ignoring any costs of technical protection, the firms' profits are the same as revenues:

$$R_i(p_1, p_2) = p_i D_i(p_1, p_2) \quad \text{for } i = 1, 2 \tag{1}$$

We shall assume that a symmetric equilibrium exists (the relevant conditions are included in Assumption 1 below) and will use $\left(p^M, p^M\right)$ for the symmetric equilibrium prices when the firms, respectively, maximize (1).

Suppose that the content providers deploy a technical protection system in order to avoid piracy of the product, and suppose that they share the fixed cost of the system. To isolate the pure effect of cost sharing, we first suppose that effective protection has a fixed cost. (We later relax this assumption and introduce a "no-hacking" constraint to endogenize this cost. See section 3.) We consider three ways of sharing the fixed cost:

1. according to shares of downloads (demand-based cost sharing);
2. according to shares of revenue (revenue-based cost sharing);
3. according to fixed shares.

The third of these options obviously has no effect on pricing, and will lead to the prices $\left(p^M, p^M\right)$, provided that both firms remain in the market. The main result of this section is to show that the first two cost-sharing schemes will lead to higher prices, and, further, that demand-based cost sharing is more collusive than revenue-based cost sharing, in the sense of leading to higher prices. Thus, the content vendors will be better off with a system that tracks downloads but not financial transactions.

To define the games that result from the first and second cost sharing rules, we define cost shares $\tilde{\alpha}$ and $\bar{\alpha}$ as follows for firm 1 (and symmetrically for firm 2).

$$\tilde{\alpha}_1(p_1, p_2) = \begin{cases} \frac{D_1(p_1,p_2)}{D_1(p_1,p_2)+D_2(p_1,p_2)} & \text{if} \quad D_1(p_1,p_2) + D_2(p_1,p_2) > 0 \\ 1/2 & \text{if} \quad D_1(p_1,p_2) + D_2(p_1,p_2) = 0 \end{cases} \tag{2}$$

$$\bar{\alpha}_1(p_1, p_2) = \begin{cases} \frac{R_1(p_1,p_2)}{R_1(p_1,p_2)+R_2(p_1,p_2)} & \text{if} \quad R_1(p_1,p_2) + R_2(p_1,p_2) > 0 \\ 1/2 & \text{if} \quad R_1(p_1,p_2) + R_2(p_1,p_2) = 0 \end{cases} \tag{3}$$

The demand-based cost share $\tilde{\alpha}_1$ is increasing with demand D_1 and decreasing with the other firm's demand, D_2, hence decreasing with the vendor's own price p_1. By increasing its price, the vendor reduces its cost share, which makes a high price more attractive than it otherwise would be. This suggests that with demand-based cost sharing, prices will be higher than with fixed cost shares.

The revenue-based cost share $\bar{\alpha}_1$ can be either increasing or decreasing with p_1, since R_1 can be either increasing or decreasing with p_1. Even if the cost share $\bar{\alpha}_1$ decreases with p_1 like $\tilde{\alpha}_1$, it decreases at a smaller rate – revenue decreases less quickly than demand as price rises, because the increase in price offsets the fall in demand. This suggests that there is less incentive to raise price with revenue-based cost sharing than with demand-based cost sharing, and that prices will be lower. We now show this.

We consider three different games, with payoff functions defined by the cost shares given by (1), (2), and (3), respectively. That is, we suppose that the shared cost of protection is some K, and the resulting protection prevents piracy. The profit functions in the three games are respectively

$$\begin{aligned}\tilde{\pi}_1^K(p_1,p_2) &= R_1(p_1,p_2) - \tilde{\alpha}_1(p_1,p_2)K \\ \bar{\pi}_1^K(p_1,p_2) &= R_1(p_1,p_2) - \bar{\alpha}_1(p_1,p_2)K \\ \hat{\pi}_1^K(p_1,p_2) &= R_1(p_1,p_2) - \hat{\alpha}_1 K\end{aligned} \tag{4}$$

Let $p^{\tilde{I}}(K), p^{\bar{I}}(K), p^M$ be, respectively, the symmetric equilibrium prices in the games defined by these profit functions, assuming that symmetric equilibria exist.

To compare the equilibrium prices, we need some assumptions on the profit functions. Let $\frac{\partial}{\partial p_1}\tilde{\pi}_1^K(\cdot)$ and $\frac{\partial}{\partial p_1}R_1(\cdot)$ represent partial derivatives with respect to the first argument (and analogously for the second argument, for second partial derivatives and for other functions). The following assumption is not disaggregated into separate assumptions on revenue and cost because it is more straightforward to state the assumption in the form it is used. Our objective is to ensure that there is a unique symmetric equilibrium, as that allows us to sort out the effects of cost sharing with least clutter.

Assumption 1. For the revenue and profit functions defined in (1) and (4), and every $K > 0$,

(a) The profit functions are quasiconcave in own price on domains where they are positive.[1]

(b) The own derivatives of the profit functions, such as $\frac{\partial}{\partial p_1}R_1(\cdot)$ and $\frac{\partial}{\partial p_1}\tilde{\pi}_1^K(\cdot)$, are decreasing along a price path where prices are equal. For example,

$$\frac{\partial}{\partial p_1}\tilde{\pi}_1^K(p,p) > \frac{\partial}{\partial p_1}\tilde{\pi}_1^K(p',p') \text{ if } p' > p$$

[1] But it would not be reasonable to assume that the profit functions are quasiconcave on the whole domain. Consider the profit function $\bar{\pi}_1^K$. If firm 2 is pricing so that it earns positive revenue, firm 1 can earn zero revenue and zero profits by pricing very low or very high. At intermediate prices that generate revenue, firm 1's profit may be negative because it must share the costs. But then the profit function is not quasiconcave.

The main point of Proposition 1 is that cost sharing elevates the equilibrium prices, and that demand-based cost sharing is more collusive than revenue-based cost sharing. Among the three symmetric prices compared, the lowest is p^M, namely, the price that would arise in equilibrium with fixed cost shares. Provided the supplier is not allowed to avoid the cost by supplying nothing (as assumed in the profit functions), this equilibrium price is the same for all K, and also the same as with perfect legal enforcement, since the fixed cost share does not affect the strategic incentive to change price.

Proposition 1 thus shows that cost sharing can be collusive. Since $p^{\bar{I}}(K) < p^{\tilde{I}}(K)$, demand-based cost sharing leads to higher prices than revenue-based cost sharing.

Proposition 1 (The pure effect of cost sharing on prices) *Suppose that assumption 1 holds. Given $K > 0$, let $p^{\bar{I}}(K)$, $p^{\tilde{I}}(K), p^M$ be unique symmetric equilibria of the games defined by the profit functions (4), and suppose that the vendors earn positive profits in the equilibria. Then $p^M \leq p^{\bar{I}}(K) < p^{\tilde{I}}(K)$ with strict inequality if each firm's revenue is increasing in the other firm's price. Further, $p^{\bar{I}}(\cdot), p^{\tilde{I}}(\cdot)$ are increasing.*

Proof: We first show that $p^M < p^{\bar{I}}(K)$. The first-order conditions are the following for firm 1, and symmetrically for firm 2.

$$\begin{aligned}
0 = & \frac{\partial}{\partial p_1}\bar{\pi}_1^K(p_1,p_2) \\
= & \frac{\partial}{\partial p_1}R_1(p_1,p_2) - K\frac{\partial}{\partial p_1}\bar{\alpha}_1(p_1,p_2) && (5)\\
= & \frac{\partial}{\partial p_1}R_1(p_1,p_2)\left(1-\frac{K}{R_1(p_1,p_2)+R_2(p_1,p_2)}\right) && (6)\\
& + \frac{KR_1(p_1,p_2)}{(R_1(p_1,p_2)+R_2(p_1,p_2))^2}\left(\frac{\partial}{\partial p_1}R_1(p_1,p_2)+\frac{\partial}{\partial p_1}R_2(p_1,p_2)\right)
\end{aligned}$$

Using Assumption 1(b), (p_1, p_2) cannot be an equilibrium if $p_1 = p_2 < p^M$ because $\frac{\partial}{\partial p_1}\bar{\pi}_1^K(p_1,p_2) > 0$. At $p_1 = p_2 < p^M$ it holds that $\frac{\partial}{\partial p_1}R_1(p_1,p_2) > 0$ and $\frac{\partial}{\partial p_1}R_1(p_1,p_2)+$

$\frac{\partial}{\partial p_1} R_2(p_1, p_2) > 0$. Therefore firm 1 can increase profit by increasing price. At $p_1 = p_2 = p^M$, $\frac{\partial}{\partial p_1}\bar{\pi}_1^K(p_1, p_2) = 0$ if $\frac{\partial}{\partial p_1} R_2(p_1, p_2) = 0$ (so (p^M, p^M) can be an equilibrium with revenue-based cost sharing), but $\frac{\partial}{\partial p_1}\bar{\pi}_1^K(p_1, p_2) > 0$ if $\frac{\partial}{\partial p_1} R_2(p_1, p_2) > 0$.

We now show that $p^{\bar{I}}(K) < p^{\tilde{I}}(K)$. The derivatives satisfy

$$\begin{aligned} &\frac{\partial}{\partial p_1}\bar{\pi}_1^K(p_1, p_2) \\ &= \frac{\partial}{\partial p_1}\tilde{\pi}_1^K(p_1, p_2) - \frac{K R_1(p_1, p_2)}{(R_1(p_1, p_2) + R_2(p_1, p_2))^2} \\ &\quad - \left(1 - \frac{K}{R_1(p_1, p_2) + R_2(p_1, p_2)}\right) D_1(p_1, p_2) \end{aligned} \tag{7}$$

Thus, at every symmetric price, $p_1 = p_2$, $\frac{\partial}{\partial p_1}\tilde{\pi}_1^K(p_1, p_2) > \frac{\partial}{\partial p_1}\bar{\pi}_1^K(p_1, p_2)$, and similarly for firm 2. Therefore, using Assumption 1, the only symmetric equilibrium is at higher prices.

That $p^{\bar{I}}(\cdot), p^{\tilde{I}}(\cdot)$ are increasing follows from the fact that our assumptions guarantee a unique equilibrium that is symmetric, and from $\partial\tilde{\alpha}_1(p_1, p_2)/\partial p_1 < 0$, $\partial\bar{\alpha}_1(p_1, p_2)/\partial p_1 < 0$ (similarly for firm 2) at $p_1 = p_2 > p^M$. The latter condition implies that the cross partial of firm i's profit function in its own price p_i and in K are positive.[2] Q.E.D.

3 Cost Sharing and the No-Hacking Constraint

We now assume that the cost of protection depends on the level of protection, say e. Accordingly, let $K(\cdot)$ be a positive function of e such that $K'(\cdot) > 0$, $K''(\cdot) > 0$ for $e > 0$. We calibrate e to be the cost of circumventing the system. A user will circumvent the protection system whenever the value he receives from piracy is lower than the cost of circumvention, e. The value he receives from pirating each product is the lesser of his willingness to pay or the price.[3] Users are willing to bear a higher

[2] If these conditions held globally, we could use the monotone-comparative-statics theorems of Milgrom and Roberts (1990) (Theorem 6) and Milgrom and Shannon (1994) (Theorem 13).

[3] We are assuming here that users can circumvent for personal use without detection, but that any attempt to post the circumvention tool or the illicitly received content on the internet would be

cost to circumvent a shared system than a single firm's system, because the shared system gives access to more products, namely, those of both firms.

We assume that firms using a shared system will choose strong enough protection to deter hacking by users who would otherwise be willing to purchase both products at the posted prices, as well as those who want to consume only one of the products.[4] Thus we impose the following *no-hacking constraint*:

$$p_1 + p_2 \leq e$$

With the no-hacking constraint, increasing the level of protection e increases the equilibrium prices for two reasons. First, as we showed in Proposition 1, a higher shared cost increases the equilibrium prices. Second, a higher level of e loosens the no-hacking constraint.

With shared protection, if the firms could collude to set prices, they would choose (p_1, p_2) to maximize

$$\Pi^J(p_1, p_2) = R_1(p_1, p_2) + R_2(p_1, p_2) - K(p_1 + p_2) \tag{8}$$

However, if the prices are set independently and the costs of the system are shared according to demand shares or revenue shares, the collusive prices might be impossible to reach.

We will again assume that the maximizer of (8) is symmetric, $(p_1, p_2) = \left(p^J, p^J\right)$. Let $e^J = 2p^J$. With shared cost $K\left(e^J\right)$, price competition leads to the prices p^J if and only if $p^{\bar{I}}\left(K\left(e^J\right)\right), p^{\tilde{I}}\left(K\left(e^J\right)\right) \geq p^J$. If this condition does not hold, then the firms must either waste costs of protection to achieve the collusive price p^J

detected and punished. If such postings cannot be deterred, technical protections will not work.

[4] Since some consumers only want to consume a single product, it might, in fact, be optimal to choose a lower level of protection that deters most piracy, but does not deter those consumers with a high demand for both products who would otherwise pay the posted prices. With a weaker no-hacking constraint, the required level of protection would still be an increasing function of the prices, but not necessarily equal to their sum. The key requirement for our argument is that higher prices require more protection. That would reimain true. Although we choose a simple form of the no-hacking constraint for simplicity, it should be noticed that the line of reasoning in Proposition 3 does not depend on it.

(choose a protection level higher than e^J) or sell at a lower price. In general, it will be optimal to do a little of both.

Accounting for the no-hacking constraint as well as cost sharing, the profit functions for firm 1 (symmetrically for firm 2) in games 1, 2 and 3 are the following, conditional on the level of protection e :

$$\begin{aligned}
\tilde{\pi}_1(p_1,p_2;e) &= \begin{cases} R_1(p_1,p_2) - \tilde{\alpha}_1(p_1,p_2)K(e) & \text{if} \quad p_1+p_2 \le e \\ -\,(1/2)\,K(e) & \text{if} \quad p_1+p_2 > e \end{cases} \\
\bar{\pi}_1(p_1,p_2;e) &= \begin{cases} R_1(p_1,p_2) - \bar{\alpha}_1(p_1,p_2)K(e) & \text{if} \quad p_1+p_2 \le e \\ -\,(1/2)\,K(e) & \text{if} \quad p_1+p_2 > e \end{cases} \qquad (9) \\
\hat{\pi}_1(p_1,p_2;e) &= \begin{cases} R_1(p_1,p_2) - \hat{\alpha}_1 K(e) & \text{if} \quad p_1+p_2 \le e \\ -\hat{\alpha}_1 K(e) & \text{if} \quad p_1+p_2 > e \end{cases}
\end{aligned}$$

If symmetric equilibria exist in the games defined by the three profit functions (9), the firms' equilibrium prices are respectively

$$\begin{aligned}
&\min\left\{p^{\tilde{I}}\left(K\left(e\right)\right), e/2\right\} \qquad (10) \\
&\min\left\{p^{\bar{I}}\left(K\left(e\right)\right), e/2\right\} \\
&\min\left\{p^{M}, e/2\right\}
\end{aligned}$$

We now show that whether the firms can support the collusive outcome p^J without wasting costs depends on how much of the cost is fixed, that is, independent of the level of protection. We state this result as Proposition 3, and prove it using Lemma 2. We add the following assumption about cost:

Assumption 2. The cost of protection $K(e)$ can be written $K(e) = k + \kappa(e)$ where κ is convex, positive, and increasing.

For intuition on how costs affect equilibrium prices, refer to Figure 1. Figure 1 depicts symmetric equilibrium prices $p^{\bar{I}}\left(\kappa(e)\right)$ for the game with revenue-based cost sharing. Figure 1 shows that the equilibrium price is increasing in $\kappa\left(e\right)$, hence increasing in e. (A similar diagram for demand-based cost sharing would have the

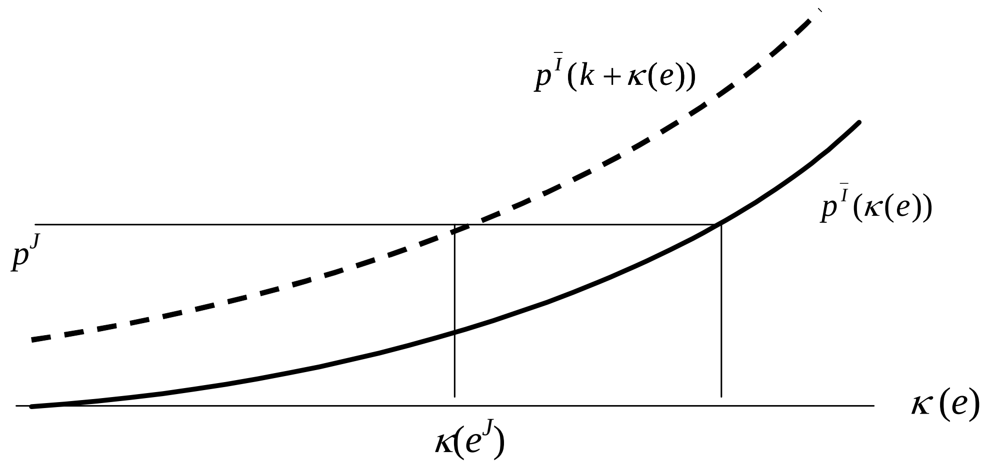

Figure 1: Equilibrium prices increase with the cost of protection

same feature.) Figure 1 also shows that $p^{\bar{I}}(k+\kappa(e)) > p^{\bar{I}}(\kappa(e))$ for $k > 0$: if the cost of protection increases, in particular, because the fixed costs increase, the symmetric equilibrium prices also increase.

A possibility not shown in figure 1 is that $p^{\bar{I}}\left(\kappa(e^J)\right) > p^J$. In that case, the equilibrium price will be p^J, according to (10). No further argument is needed to show that the firms can support the collusive price. Lemma 2 below focusses on the circumstance that $p^{\bar{I}}\left(\kappa(e^J)\right), p^{\tilde{I}}\left(\kappa(e^J)\right) < p^J$.

Part (a) of Lemma 2 says that, for high enough fixed costs, the collusive prices are an equilibrium without wasted costs. That is, if the shared costs are already high enough, the firms do not have to increase costs artificially by increasing the level of protection e in order to sustain the collusive prices.

Part (b) says that, to achieve the collusive prices without excessive protection e, the fixed costs must be even higher with revenue-based cost sharing than with demand-based cost sharing. This is for the reason explored above, that revenue-based cost sharing makes it harder to sustain high prices. Part (b) also says that if the fixed costs are lower than required to achieve the collusive prices without excessive protection, then the firms can either sustain prices below the collusive price or can sustain the collusive price with excessive protection (or, implicitly, some of each).

Part (c) suggests that demand-based cost sharing is more supportive of collusion than revenue-based cost sharing.

Lemma 2 *Suppose that assumptions 1 and 2 hold, and that there are symmetric equilibria such that* $p^M, p^{\bar{I}}\left(\kappa(e^J)\right), p^{\tilde{I}}\left(\kappa(e^J)\right) < p^J$.

(a) *There exist* $\tilde{k}, \bar{k} \in \mathbf{R}_+$, *with* $\bar{k} > \tilde{k}$, *such that*

$$p^{\tilde{I}}\left(\tilde{k} + \kappa(e^J)\right) = p^J \quad \text{and} \quad p^{\tilde{I}}\left(k + \kappa(e^J)\right) \geq p^J \text{ if } k \geq \tilde{k}$$
$$p^{\bar{I}}\left(\bar{k} + \kappa(e^J)\right) = p^J \quad \text{and} \quad p^{\bar{I}}\left(k + \kappa(e^J)\right) \geq p^J \text{ if } k \geq \bar{k}$$

(b) *Given* $\kappa(e)$, *and* $\tilde{k}$,$\bar{k}$ *defined in part(a),*

$$\text{if } k < \tilde{k}, \quad \text{then} \quad p^{\tilde{I}}\left(k + \kappa(e^J)\right) < p^J, \text{ and } p^{\tilde{I}}\left(k + \kappa(e)\right) = p^J \text{ only if } e > e^J.$$
$$\text{if } k < \bar{k}, \quad \text{then} \quad p^{\bar{I}}\left(k + \kappa(e^J)\right) < p^J, \text{ and } p^{\bar{I}}\left(k + \kappa(e)\right) = p^J \text{ only if } e > e^J.$$

(c) *If* k *satisfies* $\bar{k} > k > \tilde{k}$, *then* $p^{\bar{I}}\left(k + \kappa(e^J)\right) < p^J < p^{\tilde{I}}\left(k + \kappa(e^J)\right)$.

Proof For Lemma 2(a), we must establish that there exists $\bar{k}$ high enough that the following two conditions hold at $(p_1, p_2) = \left(p^J, p^J\right)$:

$$\frac{\partial}{\partial p_1}\bar{\pi}_1^{\bar{k}+\kappa\left(e^J\right)}\left(p_1, p_2\right) = 0 \quad \text{and} \tag{11}$$

$$\bar{\pi}_1^{\bar{k}+\kappa\left(e^j\right)}\left(p_1, p_2\right) = R_1\left(p_1, p_2\right)\left(1 - \frac{\bar{k} + \kappa(e^J)}{R_1\left(p_1, p_2\right) + R_2\left(p_1, p_2\right)}\right) > 0 \tag{12}$$

By Proposition 1, the function of k defined by $p^{\bar{I}}\left(k + \kappa\left(e^J\right)\right)$ is increasing. Since $p^{\bar{I}}\left(\kappa(e^J)\right) < p^J$, let $\bar{k}$ be high enough so that $p^{\bar{I}}\left(\bar{k} + \kappa\left(e^J\right)\right) = p^J$ as in figure 1, so that (11) holds.

From (5), since $(p_1, p_2) = \left(p^J, p^J\right)$ is an equilibrium, it holds at $(p_1, p_2) = \left(p^J, p^J\right)$ and $K = k + \kappa(e^J)$ that

$$
\begin{aligned}
0 &= \frac{\partial}{\partial p_1} R_1(p_1, p_2) - K \frac{\partial}{\partial p_1} \bar{\alpha}_1(p_1, p_2) \\
&= \frac{\partial}{\partial p_1} R_1(\cdot) - K \left[\frac{\frac{\partial}{\partial p_1} R_1(\cdot)}{R_1(\cdot) + R_2(\cdot)} - \frac{R_1(\cdot)\left[\frac{\partial}{\partial p_1} R_1(\cdot) + \frac{\partial}{\partial p_1} R_2(\cdot)\right]}{\left[R_1(\cdot) + R_2(\cdot)\right]^2} \right]
\end{aligned}
$$

hence

$$
R_1(\cdot) + R_2(\cdot) - K = -K \frac{R_1(\cdot)}{\frac{\partial}{\partial p_1} R_1(\cdot)} \frac{\frac{\partial}{\partial p_1} R_1(\cdot) + \frac{\partial}{\partial p_1} R_2(\cdot)}{R_1(\cdot) + R_2(\cdot)} \tag{13}
$$

On the other hand, p^J is defined by $\frac{\partial}{\partial p_1} R_1(\cdot) + \frac{\partial}{\partial p_1} R_2(\cdot) = K'(p_1 + p_2)$ at $(p_1, p_2) = \left(p^J, p^J\right)$, so $\frac{\partial}{\partial p_1} R_1(\cdot) + \frac{\partial}{\partial p_1} R_2(\cdot) > 0$. Remembering that $\frac{\partial}{\partial p_1} R_1(\cdot) < 0$ at $(p_1, p_2) = \left(p^J, p^J\right) > \left(p^M, p^M\right)$, the righthand side of (13) is positive, and therefore (12) holds. A similar argument applies to $\tilde{\pi}_1^{\tilde{k}+\kappa(e)}$.

Since $p^{\bar{I}}\left(k + \kappa(e^J)\right) < p^{\tilde{I}}\left(k + \kappa(e^J)\right)$ by Proposition 1, and since both prices are increasing in k, it follows that $\bar{k} > \tilde{k}$.

Lemma 2(b) follows from Lemma 2(a) and Proposition 1, as follows. By Proposition 1, $k < \tilde{k}$ implies $p^{\tilde{I}}\left(k + \kappa(e^J)\right) < p^{\tilde{I}}\left(\tilde{k} + \kappa(e^J)\right)$, hence $p^{\tilde{I}}\left(k + \kappa(e^J)\right) < p^J$. Now suppose $p^{\tilde{I}}\left(k + \kappa(e)\right) = p^J$ for some arbitrary e, and $k < \tilde{k}$. As $\kappa(e)$ is increasing in e, $p^{\tilde{I}}\left(k + \kappa(e^J)\right) < p^{\tilde{I}}\left(k + \kappa(e)\right) = p^J$ implies $e > e^J$. A similar argument applies for $p^{\bar{I}}\left(k + \kappa(e)\right)$.

2(c) follows from 2(a) and 2(b). Q.E.D.

In Proposition 3, we consider the case that the profit-maximizing prices with fixed cost shares satisfy $p^M < p^J$, since otherwise collusion should not be much of a concern. However, it can happen that the price with perfect legal enforcement or fixed cost shares, p^M, is higher than the collusive price with technical protections, p^J, since the no-hacking constraint gives an incentive to lower price. An example is in the next section.

Proposition 3 (The collusive effect of cost sharing) *Suppose that assumptions 1 and 2 hold and that* $p^M < p^J$.

(a) *Regardless of whether the vendors share costs according to revenue or demand, for high enough fixed costs of protection (high enough* k*), the equilibrium price will be the collusive price* p^J*, and* $e^J = 2p^J$.

(b) *Demand-based cost sharing supports the collusive price whenever revenue-based cost sharing does so, but not vice versa.*

(c) *The firms' equilibrium profits are higher (no lower) with demand-based cost sharing than with revenue-based cost sharing.*

Proof (a) If $p^J < p^{\bar{I}}\left(K\left(e^J\right)\right)$ or $p^J < p^{\tilde{I}}\left(K\left(e^J\right)\right)$, then the prices will be p^J, according to (10). Otherwise, the conclusion follows from Lemma 2(a).

(b) follows from Lemma 2(c).

(c) Given e, there are three cases:

$$\begin{aligned} p^J &< p^{\bar{I}}(K(e)) < p^{\tilde{I}}(K(e)) \\ p^{\bar{I}}(K(e)) &< p^J < p^{\tilde{I}}(K(e)) \\ p^{\bar{I}}(K(e)) &< p^{\tilde{I}}(K(e)) < p^J \end{aligned}$$

If the first case applies at $e = e^J$, the prices will equal p^J, according to (10). If the second case applies at $e = e^J$, demand-based cost sharing can support the collusive price according to (10), but revenue-based cost sharing cannot. If the third case applies at $e = e^J$, the collusive prices cannot be supported without waste, with either demand-based or revenue-based cost sharing. But a higher price can be supported at each e with demand-based cost sharing than with revenue-based cost sharing. Since joint profit is rising in the symmetric price for $p < p^J$, the higher price is more profitable. Q.E.D.

4 Choosing Whether to Share a System

In the previous section we introduced the idea that the level of protection is a choice variable. If the firms want to charge higher prices, they must spend more money on protection. The costliness of protection will have a moderating effect on prices. We now argue that the threat of circumvention also creates a price-moderating effect when the protection systems are independent.

A single firm's no-hacking constraint is

$$e \leq p \tag{14}$$

If $K(2p) > 2K(p)$ it is cheaper to support the prices (p, p) with separate systems, and if $K(2p) < 2K(p)$, it is cheaper to support the prices (p, p) with a shared system.

The price-moderating effect of the constraint (14) is easiest to see in the case of a single monopolist, which we consider in the Appendix.[5] To support the monopoly price, the vendor would choose a level of protection such that (14) holds as an equality at the monopoly price. There is no point in choosing protection higher than the monopoly price, and lower protection would be ineffective. But then, provided the cost of protection can be reduced by reducing its level, the vendor can save costs without having a significant impact on revenue by slightly reducing both the price and the level of protection. This can benefit both users and producers. Users benefit from the lower price, while producers may get protection that lasts longer than the statutory length of the copyright or patent. An example in the appendix shows that both users and vendors can e better off than with perfect legal enforcement.

We now show that a threat of circumvention leads to lower prices also in the context of competition: If two sellers use separate protection systems, the prices they charge in competition with each other, which we will call $\left(p^I, p^I\right)$, are lower than the monopoly prices $\left(p^M, p^M\right)$ that would arise with perfect legal enforcement.

[5] This was also noticed in the earlier debate about the pernicious effects of photocopying. See Conner and Runnelt (1991).

The firms' profit functions if they use separate systems are

$$\Pi_i^I(p_1, p_2) = R_i(p_1, p_2) - K(p_i) \quad \text{for } i = 1, 2 \tag{15}$$

where "I" stands for "independent." We have entered p_i as the argument in K, recognizing that the no-hacking constraint (14) holds for each firm. To compare prices in a systematic way, we need some additional assumptions.

Assumption 3. Given the revenue and profit functions defined above:

(a) The cross-partial derivatives of the revenue and profit functions (1) and (15) are nonnegative.

(b) The revenue and profit functions (1), (8), and (15) are quasiconcave on the domains where they are nonnegative.

(c) The own derivatives of the profit functions (1) and (15), such as $\frac{\partial}{\partial p_1} R_1(\cdot)$ and $\frac{\partial}{\partial p_1} \Pi_1^I(\cdot)$, are decreasing along a price path where prices are equal. For example,

$$\frac{\partial}{\partial p_1} \Pi_1^I(p, p) > \frac{\partial}{\partial p_1} \Pi_1^I(p', p') \text{ if } p' > p$$

Assumption 3 ensures that the symmetric equilibria are unique, since it prohibits that $\frac{\partial}{\partial p_1} \Pi_1^I(p, p) = \frac{\partial}{\partial p_1} \Pi_1^I(p', p') = 0$ for both p and p' when $p' \neq p$.

Proposition 4 (A threat of circumvention reduces prices) *Suppose that Assumption 3 holds. The symmetric prices that result from perfect legal enforcement are higher than those that result when vendors use separate DRM systems. That is,* $p^M > p^I$.

Proof We use the Corollary to Theorem 6 of Milgrom and Roberts, 1990 and Theorem 13 of Milgrom and Shannon, 1994. To show $p^M > p^I$, write

$$R_1(p_1, p_2) + tK(p_1)$$

for firm 1's profit function (symmetrically, firm 2's profit function), and let $t \in [-1, 0]$ define a class of games. Then $t = -1$ is the profit function (15) for the game with separate technical protections, and $t = 0$ is the profit function (1) for the game with perfect legal enforcement. The class of games defined by $t \in [-1, 0]$ are symmetric, (smooth) supermodular, and satisfy the single crossing property. Therefore the unique symmetric equilibrium prices of the games defined by t are increasing in t, so $p^M \geq p^I$. One can see from the derivatives that the inequality is strict. Q.E.D.

The intuition behind Proposition 4 is exactly as for single monopolists, discussed in the Appendix. Vendors find it cheaper to deter hackers by reducing the price a little rather than by choosing enough protection to support the price that would be sustainable with perfect legal enforcement.

Consumers and vendors may have conflicting interests in a shared system. If $p^J < p^I$, the shared system has a lower price and is clearly better for consumers. However the shared system is only better for the vendors if it reduces protection costs enough to outweigh the profit erosion due to lower prices. Sharing can either increase or decrease protection costs. Although sharing eliminates half the fixed costs, the need for more protection may more than offset that saving. Because the shared system is a better hacking target, it must provide a higher level of protection.

Neither the consumers nor the vendors will have a preference that aligns perfectly with efficiency. From an ex post point of view, the users care only about price, and the vendors care only about profit. From an ex ante point of view, the interests of consumers and vendors are more closely aligned, since consumers would presumably not favor price erosion so severe that it eliminates the incentive to create new products.

We now give an example to illustrate that the vendors may choose separate systems even if sharing allows them to implement the collusive price p^J, and even when sharing is more efficient than separate systems from an ex post point of view.

Example 1 Let firm 1's demand be defined as

$$D_1(p_1, p_2) = \max\{1 - p_1 + cp_2, 0\}$$

where $0 \leq p_1, p_2 \leq 1$, and $0 \leq c \leq 1$. The parameter c determines the degree of substitutability between the two products. Firm 2's demand is symmetrically defined.

Let the costs of protection be defined by

$$K(e) = k + \kappa e^2$$

so that k is a fixed cost and $2\kappa e$ is the marginal cost of increasing the cost of circumvention.

When the firms compete using separate protection systems, firm 1's best price response is $\frac{1+cp_2}{2+2\kappa}$ (symmetrically for firm 2), and the symmetric Nash equilibrium prices and per-firm profits are given by:

$$p^I = \frac{1}{2+2\kappa-c} \tag{16}$$

$$\pi^I = \frac{1+\kappa}{(2+2\kappa-c)^2} - k \tag{17}$$

As noted previously, technical protection moderates the price of content (with $\kappa > 0$), compared to perfect legal protection. The equilibrium price with perfect legal enforcement would be $p^M = \frac{1}{2-c}$, which is higher than p^I.

Suppose now that firms share a technical protection system, price as a joint monopolist, and satisfy the no-hacking constraint $e = p_1 + p_2$. The firms maximize joint profit (8). The symmetric profit-maximizing prices, quantities, and total profits are:

$$p^J = \frac{1}{2+4\kappa-2c} \tag{18}$$

$$\pi^J = \frac{2(1-c)}{(2+4\kappa-2c)^2} - k \tag{19}$$

Remark 5 *The collusive prices with a shared protection system are higher than the competitive prices with separate protection systems,* $p^J > p^I$, *if and only if* $2\kappa < c$.

This follows directly from (16) and (18). The price-moderating effect of the shared protection is increasing in κ, but the collusive effect of joint pricing is increasing in c. The latter effect dominates if $2\kappa < c$.

From the vendors' point of view, sharing a protection system may or may not reduce their protection costs. If sharing increases their costs, they may choose separate systems even if sharing would allow them to collude on price. We complete the example by illustrating that point.

Suppose, for example, that the demands for the content are independent ($c = 0$) and marginal costs for protection are positive, ($\kappa > 0$.) According to the remark, $p^I > p^J$, so consumers prefer the shared system, even with collusive pricing. The vendors' joint profits are given by (19) or (17) , respectively, when they do and do not share. Thus, assuming $c = 0$, vendors prefer a shared system if

$$\frac{1}{2(1+\kappa)} - \frac{1}{2(1+2\kappa)^2} < k \tag{20}$$

If (20) holds, vendors and consumers both prefer shared protection.

But is sharing the socially efficient option? When $c = 0$, demands are independent, and consumers' surplus in each market at price p is given by $s(p) = (1/2)(1-p)^2$. The social surplus with sharing, conditional on the products having been created in the first place, is greater than with separate systems if $2s(p^J) + \pi^J > 2s(p^I) + 2\pi^I$, which holds if

$$\frac{(1+2\kappa)^2}{4(1+\kappa)^2} - \frac{(1+4\kappa)^2}{4(1+2\kappa)^2} + \frac{1}{2(1+\kappa)} - \frac{1}{2(1+2\kappa)^2} < k \tag{21}$$

Because the difference between the first two terms of (21) is negative, (21) holds if (20) holds, but not necessarily vice versa. Thus, for a wide range of parameter values, firms will be too reluctant to share a system, relative to what is efficient from an ex post point of view.

Suppose now that $c > 0$ and $\kappa = 0$. Then $p^I < p^J$, so consumers face higher prices with sharing than with separate protections. Comparing (17) and (19), for all $k \geq 0, c > 0$, we find that $\pi^I < \frac{\pi^J}{2}$. Since the collusive prices are higher than the competitive prices, and the total costs are smaller, profits are higher with joint protection.

This example illustrates important features of the DRM problem that we have discussed above more formally. First, collusion with a shared protection system can lead to lower prices than the competitive outcome with separate protections, and can lead to either higher or lower protection costs than separate systems. Second, due to the counterintuitive possibility that the shared system may reduce prices below those that would prevail with separate systems, the vendors might forgo the opportunity to collude even if sharing reduces costs. That is, the vendors might choose separate systems even if sharing is more efficient in the sense of reducing deadweight loss and reducing the costs of protection.

If ex post efficiency were the only notion of efficiency, this would suggest that vendors are too reluctant to share, compared to the social optimum, even if sharing allows them to collude on price. But that perspective does not take account of the ex ante incentive to create new products in the first place. By making the most profitable decision, the vendors are also preserving their ex ante incentive to create new products.

5 Collusion through Technology

If the vendors share a protection system, competition between them is affected by two important aspects of the governance structure:

- whether the vendors set prices independently, and
- how they share costs.

Independence in price setting is obviously key for competition. The new wrinkle here is that the potential for independent pricing is controlled both by technology and by the governance of it, such as cost sharing.

As of the writing of this paper, vendors of entertainment products still sell their content on physical media, and set their prices independently. The technologies of DRM systems have evolved hand-in-hand with distribution systems meant to supplant physical retail channels for content. The technologies and distribution systems are tightly bound together. For example, one can imagine a future in which all content is available without charge over the internet, and it is only the right to "render" it (view it) that is priced. The DRM company then becomes the gateway to pricing, and a potential facilitator of collusion. How can this be avoided?

One possible fix is to require that the technology allows vendors to set their own prices.[6] But regulating technology seems like a heavy-handed approach. Perhaps, instead, one can depend on the vendors' incentives to "cheat" the cartel. Suppose, for example, that a DRM system decrypts and authorizes use through a call-home system, imposes a price-per-view for all content (or charges a royalty per view,) and distributes the net profit to the vendors according to some rule they agree on. If the DRM company can choose the price and is immune to cheating, it is reasonable to suppose that, acting on behalf of its vendor-owners, it would choose the profit-maximizing price and level of protection.

But the DRM cartel, like all cartels, must worry about price cutting. An obvious way for a vendor to undermine the cartel and increase its own profit at the expense of others is to offer rebates outside the DRM system, perhaps offering a "frequent user" program. Rebates implicitly reduce the price and increase demand. This would ordinarily be a capability favored by antitrust authorities, but it comes at the expense of privacy. Under the hypothesis that all content is given away for free, and only the "rendering" is sold, the vendors can only make rebates if someone, presumably the DRM subsidiary itself, keeps track of the buyers.

In yet another twist, however, if the vendors are pricing outside the DRM system, it is almost inevitable that they will share the costs according to downloads instead of revenue, since that is what the protection system tracks. We have shown

[6] Notice, for example, that iTunes does not have that capability.

that demand-based cost sharing has greater potential to support the collusive price than revenue-based cost sharing.

Short of regulating technology, it is not obvious how to ensure independent pricing.

6 Conclusions and Open Questions

Backtracking a bit, it is also not obvious in the brave new world of DRM that independence in price setting should be the goal. The main appeal of independence in price setting is that it seems to mimic the market outcome with perfect legal enforcement. But neither a shared system nor separate systems will mimic that outcome perfectly. With separate DRM systems, the vendors' prices will be lower than with perfect legal enforcement, and the vendors will also be burdened with the cost of the DRM system. Incentives to create content are correspondingly lower than with perfect legal enforcement. Sharing a system may increase the vendors' profit, but may either overreward them or underreward them. Technical protections thus change the market for creative works in fundamental ways, and the best approach may be an integrative one that rethinks the nature of copyright protection from the ground up.

As well as exploring the price consequences of sharing a DRM system, we have explored the vendors' incentive to share. A shared system may or may not be less costly than separate systems, and it may or may not lead to higher prices. Thus, from an ex post point of view, it is unclear whether sharing is more efficient. However, the vendors' decision will track profit, not efficiency. Sharing can increase profit if it facilitates high prices or reduces costs, relative to separate systems. In looking out for their profit, the vendors are preserving their incentive to create proprietary products in the first place. Thus, even if they make sharing decisions which are nonoptimal from an ex post point of view, their decisions may be optimal from an ex ante point of view.

We have explored one possible way that the market could evolve, namely, with vendors owning their own protection systems, either jointly or separately. Another possibility is that third party providers will market protection services to vendors and users, as in "two-sided markets" (Rochet and Tirole, 2003, 2004). The possibility of circumvention introduces a new variant to such markets, since a threat of circumvention creates externalities among vendors. If the other vendors charge very high prices for very attractive content, the system becomes an attractive hacking target. A vendor might therefore prefer a system with fewer vendors or lower prices. With that possibility, it is natural to think of a market populated by many competing third-party providers, each connecting vendors with users. We leave that for a future inquiry.

7 Appendix: The Price-Reducing Effect of Technical Protections

Here we show that a regime of technical protections under a threat of circumvention leads to a lower price than a regime of perfect legal enforcement. This can result in higher benefits for both users and the vendor. Users benefit through lower price, and the vendor may benefit from longer protection.

Let demand be given by by $1-p$ at price p. The consumers' surplus of buyers is then

$$s(p) = \frac{1}{2}(1-p)^2 \tag{22}$$

We assume that the marginal cost of copying is zero. Thus, if copying can be controlled, the monopoly price will be $p^* = \frac{1}{2}$, which maximizes per-period profit,

$$\pi(p) = p(1-p).$$

However, if the copies cannot be controlled, the demand curve for legitimate copies falls to zero. Technical protection measures can mitigate this problem.

Index the strength of protection by $e \in \mathbf{R}_+$, and interpret e as the cost of circumvention. Formalizing the intuition that the cost of protection increases superlinearly in the cost of circumvention, denote the cost of implementing protection level e by $K(e) > 0$, where K and K' are increasing. We shall first suppose that the cost of circumvention is the same for all users, namely, e. After the right holder has chosen the strength of protection, e, he must set a price. If $e > p^*$, then the optimal price is p^*. It is therefore wasteful to implement a protection $e > p^*$, since the proprietor does not need such strong protection in order to charge the monopoly price. If $e < p^*$, the optimal price is $p = e$, the cost of circumvention. At that price, no users will circumvent the technical protection measure in equilibrium.

Thus, for any $e \leq p^*$, the firm's profit as a function of e is $\pi(e) - K(e)$, where both π and K are increasing, and π flattens out for $e > p^*$. The profit-maximizing level of protection, say $\hat{e}$, maximizes the difference between profit and cost, and must be lower than p^*. Thus,

Remark 6 *If each user's cost of circumvention is e when the protection level is e, the profit-maximizing level of protection $\hat{e}$ satisfies $\hat{e} < p^*$, where p^* is the profit-maximizing price with perfect legal enforcement. The profit-maximizing price satisfies $\hat{p} = \hat{e} < p^*$. There is no circumvention in equilibrium.*

Thus the threat of circumvention lowers the price of content. We show in the appendix that dispersion in circumvention costs may lower it even more.

While the price and profit are lower in each period, the technical protection can continue forever, and may thus be more profitable than perfect legal enforcement, which eventually expires. This may even be true if the costs K are taken into account. Moreover, it is not obvious that the threat of circumvention increases consumer welfare, even though it reduces the per-period price. This is again because the technical protection can continue indefinitely. In fact, a technical protection system can increase both consumer welfare and the proprietor's profit, as compared with perfect legal enforcement for a limited duration. We will show this in an example, but first we make a preliminary comment on the optimal structure of rewards to creation.

For each p, let $DWL(p)$ be the lost consumers' surplus at the price p (deadweight loss). Remark 2 says that if a lower price is coupled with longer protection to just the extent that total profit is preserved, and if this has the effect of reducing the deadweight-loss-to-profit ratio, consumers are better off. This ratio test is satisfied for linear demand curves, as assumed here.

By assuming that revenue is held fixed, Remark 2 focuses on the optimal structure of rewards ex post. It allows us to consider ex post efficiency without considering the ex ante incentive to create. In the remainder of this paper, where we consider governance structures for sharing technical protections, the ex ante and ex post efficiency issues are not so easy to disentangle.

Remark 7 *Suppose a legal regime lasts T^* discounted years*[7] *with monopoly price p^*, and suppose a technical protection regime lasts $T(e)$ discounted years, $T(e) > T^*$ with price $p(e)$ that satisfies $p(e) < p^*$. Suppose that the revenue earned in both regimes is the same, $\pi(p(e))T(e) = \pi(p^*)T^*$. Then consumers are better off if and only if* [8]

$$\frac{DWL(p^*)}{\pi(p^*)} > \frac{DWL(p(e))}{\pi(p(e))} \tag{23}$$

Proof Since $p(e) < p^*$, the per-period consumers' surplus is higher, $s(p(e)) > s(p^*)$. With perfectly enforceable copyrights, total consumers surplus is

$$s(p^*)\,T^* + \left(\frac{1}{r} - T^*\right) s(0),$$

[7] The length of protection T is taken to be already discounted. If the statutory length of protection is τ, and the discount rate is r, then $T = \int_0^\tau e^{-rt}dt$. The discounted length of protection, T, cannot be larger than $\frac{1}{r}$, which corresponds to $\tau = \infty$.

[8] The ratio test for whether a simultaneous price reduction and lengthening of protection helps consumers was introduced in the antitrust context by Kaplow 1984 to evaluate the desirability of licensing practices, and in the patent design context by Tandon (1982) and many subsequent authors (see Scotchmer (2005), chapter 4) to evaluate the desirability of making patents broad or narrow. The notable feature of the ratio test is that the comparison is reduced to a static one. Even though deadweight loss lasts longer in the technical protection regime, we only have to observe that the ratio of deadweight loss to profit is reduced in each period in order to know whether in total the technical protection regime is better for consumers.

where $s(0) = \frac{1}{2}$ is the per-period consumers' surplus after the protection ends, when the product will be "sold" at the competitive price, zero. Analogously, we shall write

$$s\left(p(e)\right)T(e) + \left(\frac{1}{r} - T(e)\right)s(0)$$

for consumers' surplus with the technical protection in place. Consumers are better off with technical protection of length $T(e)$ if and only if:

$$\left[s\left(0\right) - s\left(p^*\right)\right]T^* - \left[s\left(0\right) - s\left(p(e)\right)\right]T(e) > 0 \tag{24}$$

Remark 2 follows from the observation that the consumers' surplus that is lost due to higher than competitive prices is equal to profit plus deadweight loss. Therefore,

$$s\left(0\right) - s\left(p^*\right) = \pi(p^*) + DWL(p^*)$$

$$s\left(0\right) - s\left(p(e)\right) = \pi(p(e)) + DWL(p(e))$$

Then, using $T^*\pi(p^*) = T(e)\pi(p(e))$, the inequality (24) holds if and only if (23) holds. Q.E.D.

However, this conceptual experiment is not quite the right one for comparing costless enforcement of copyrights with technical protections. Technical protections can continue forever – protection will not end at the duration $T(e)$ required for the profit equivalence. Further, technical protections are costly. Nevertheless, this line of reasoning correctly suggests that technical protections can sometimes make both creators and consumers better off. We show this with an example.

Example: As argued above, if there is no dispersion of circumvention costs, the optimal price with a technical protection is $p(e) = e$. Thus, consumers' surplus per period of time with technical protection is $s(p(e)) = \frac{1}{2}(1-e)^2$.

Social surplus is greater with technical protection than with perfect legal enforcement if

$$T^*s(p^*) + \left(\frac{1}{r} - T^*\right)s(0) \leq \frac{1}{r}s(p(e)) \tag{25}$$

Profit is greater with technical protection than with perfect legal enforcement if

$$T^* \left[p^* \left(1 - p^*\right)\right] \leq \frac{1}{r} \left[e(1-e) - K(e)\right] \tag{26}$$

Let the cost function K be given by

$$K(e) = \begin{cases} \frac{1}{80} & \text{if} \quad e \leq \frac{1}{4} \\ e^2 - \frac{1}{20} & \text{if} \quad e > \frac{1}{4} \end{cases}$$

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