Strategic Piracy Management for Digital Products

By

Sang Hoo Bae* and Pilsik Choi**

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Abstract

The purpose of this paper is to investigate how different types of strategic interactions between two firms affect their optimal pricing and private copy protection levels of digital products. In our model, the firms do not directly interact with each other in terms of prices, but they become interdependent through private copy protection levels. Our analysis shows that 1) stronger public copy protection leads to lower private copy protection and more piracy when the firms regard their private copy protection levels as "strategic substitutes," but higher private copy protection and less piracy when they treat their private copy protection levels as "strategic complements" and 2) more compatibility between private copy protection systems leads to lower private copy protection and more piracy. We also discuss public policy issues regarding these findings.

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*Sang Hoo Bae (Corresponding Author)
Department of Economics, Clark University
Worcester, MA 01610-1477
E-mail: sbae@clarku.edu

**Pilsik Choi
Graduate School of Management, Clark University
Worcester, MA 01610-1477
E-mail: pchoi@clarku.edu

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1. Introduction

In the last decade or so, there has been a surge in consumers' usage of the Internet and digital products, such as CDs, DVDs, iPods, downloadable software, e-books, and the like. Since digitalization and the Internet make (illegal) copying easier, content providers have used protection technologies to protect their digital products from illegal copying. These protection technologies, such as encryption and copy controls, are collectively termed "digital rights management" (DRM) (Park and Scotchmer 2005). Consumers, however, have financial incentives to acquire digital products through illegal copying, and recent advances in technologies have made this process easier. Facing this threat of piracy, content providers have ratcheted up their protection, which irk honest consumers because high level of DRM restricts usage of digital products that consumers acquire legally (Wingfield and Smith 2007). As such, piracy and copy protection have been controversial issues for content vendors of digital products and consumers alike.

Piracy and copy protection have been topics of intense debate in the industries (e.g., music, movie, and software industries) that are affected by actual and potential loss due to piracy. The most intense debate has occurred in the music industry, which has been affected by piracy more than any other industries. In a recent online essay, Steve Jobs, CEO of Apple, contends that the major music companies should consider allowing content distributors to sell songs without DRM software (Jobs 2007). He argues that the current DRM system does not prevent piracy effectively and abandoning DRM would spur growth in the overall music industry. While it is not clear whether the major music companies will follow his recommendation, his essay clearly shows how controversial and significant piracy and associated DRM have become in the music industry.

The movie industry has been affected greatly by piracy as well. According to a study conducted by LEK Consulting, in 2005 the worldwide movie industry lost \$18.2 billion as a result of piracy and U.S. movie studios lost about \$6.1 billion to piracy worldwide (McBride and Fowler 2006). Sixty-two percent of the \$6.1 billion losses in the U.S. resulted from piracy of hard goods, such as DVDs, and 38% from Internet piracy, which has increased rapidly in recent years. Major U.S. movie studios take measures to deal with losses due to piracy by embedding copy-protection software on their DVD products, and by lobbying the U.S. government to pressure governments in piracy-rampant countries to crack down on piracy more aggressively (King 2007).

Piracy and copy protection have also drawn substantial attention from academia. Early research on piracy focused on photocopying and addressed the issue of how publishers can appropriate some of their lost revenues from copied products (e.g., Liebowitz 1985). Later research turned to copyright issues and examined how copyright protection affects the level of piracy, pricing, development incentives, and social welfare (e.g., Bae and Choi 2006; Besen and Raskind 1991). Most of this research, however, focuses on monopoly cases, and only a handful of studies address duopoly cases (Belleflamme and Picard 2007; Johnson 1985; Park and Scotchmer 2005). Given the observation that only a small number of large companies dominate the industries with digital products, analysis of duopoly is more realistic than that of monopoly. Even, those studies which consider duopoly, do not adequately reflect the reality of the industries. Belleflamme and Picard (2007) and Park and Scotchmer (2005) model duopoly settings focusing only on pricing, rather than addressing both copy protection levels and pricing for digital goods providers. Since copy protection is one of the central issues in piracy, it makes more sense to treat copy protection level as a decision variable, rather than a parameter. And, Johnson (1985) analyzes information goods producers who are price-takers, while digital goods producers are price-setters in reality.

This paper addresses all of the issues mentioned above. We formulate a duopoly model where firms sell perfectly differentiated products in the presence of end-user piracy. One innovative approach in this study is that we introduce the endogenous choice of private copy protection, which induces three different types of strategic interactions between firms. Within this framework, we analyze optimal private copy protection levels as well as optimal pricing schemes. To the best of our knowledge, this paper is one of the few studies that address both optimal private copy protection levels and pricing as decision variables in a duopoly setting.

The purpose of this paper is to investigate how different types of strategic interactions between two firms affect their optimal pricing and private copy protection levels of digital products. Specifically, utilizing Hotelling's linear city model with two sellers[1] (or content providers) at the ends, this paper develops a model that identifies three different types of strategic interactions (i.e., the strategic substitute (SS), strategic complement (SC), and no strategic interaction (NSI)

[1] In this paper, we use content providers, sellers, and firms interchangeably. We define these concepts broadly to include companies that produce digital products (e.g., music companies and movie studios), online and offline retailers, and rental stores. Also, we do not differentiate "producers" of digital products from "sellers" of digital products.

regimes) between the firms and analyzes how the firms compete in the market and how they cope with pirated products preferred by some consumers. In the model, the equilibrium prices and copy protection levels are dependent upon the two parameters: public copy protection (imposed by the government) and the degree of compatibility of private copy protection systems (imposed by the firms). The results show that when dual piracy become less attractive as compatibility between copy protection systems decreases, firms focus on high-valuation consumers and do not interact with each other, which we term "no strategic interaction regime." At the intermediate degree of compatibility, the dual piracy becomes a common substitute for both information goods. Firms respond with focusing on intermediate-valuation consumers as well. As a result, this common substitute makes firms' copy protection become strategic complement, which we term "strategic complement regime." At the high degree of compatibility, we observe another regime termed "strategic substitute regime." Under this regime, the firms also target the low valuation-consumers who buy one legitimate digital product and use one pirated product. The firms regard their private copy protection levels as "strategic substitutes"[2] since more consumers are willing to switch to dual piracy when the other firm raises its copy protection level.

Using this framework, we compare optimal prices and copy protection levels of two duopolists to those of a multiproduct monopoly. At the high degree of compatibility, the duopolists consider private copy protection as strategic substitute and set higher levels of copy protection. On the other hand, the monopolist has an incentive to decrease its copy protection because it realizes that decreasing copy protection for one good increases demand for the other good. As a result, we obtain the following interesting result: the multiproduct monopoly actually sets lower prices and private protection levels, which improves welfare.

Our analysis reveals that when the firms consider their private copy protection levels as strategic substitutes, the effects of stronger public copy protection result in lower levels of private copy protection and more piracy among consumers. But, when the firms treat their private copy protection levels as strategic complements, stronger public copy protection leads to higher levels of private copy protection and less piracy. This provides an important policy implication that policymakers should be aware that, in some situations, a stronger policy on public copy protection might not be successful in reducing piracy among consumers. Also, a higher degree of private copy protection compatibility results in lower levels of private copy

[2] For strategic complements and substitutes, see Bulow et al. (1985).

protection and more piracy, whether the firms regard their private copy protection levels as strategic substitutes or complements. This result suggests that policymakers should not enforce a higher level of compatibility among private copy protection systems when their goal is to curb the spread of piracy.

The remainder of this paper is organized as follows: In Section 2, we develop models with different types of strategic interactions and derive equilibrium solutions in each type. In the next section, we discuss results of comparative static analysis in detail based on the results of the previous section. The paper concludes with some remarks and several areas for future research.

2. Model

A. Overview of the Model

The model in this paper is based on Hotelling's linear city model. The number of consumers is normalized to 1, and they are uniformly distributed on the unit interval [0,1]. Firm 1 is located at point 0, and firm 2 is located at point 1. Firm 1 sells a digital product, product 1, and firm 2 sells another digital product, product 2 to consumers. These digital products are horizontally differentiated perfectly, so they are not substitutes for each other. The two products are assumed to contain quite different contents, so that if a consumer likes to consume one product, then the consumer does not like to consume the other product in general. In other words, the firms have local monopoly power over consumers nearby. Those consumers in the middle of the market do not value the two products enough to buy a legitimate copy of any of the products. Hence, the market is "not covered" with legitimate copies of the two products. Two example products might be rap music and classical music. In general, consumers who are fans of rap music do not enjoy classical music as much as they enjoy rap music, and vice versa. And, consumers who love country music would not buy rap or classical music because they do not value those types of music enough.

The two products are "piratable," i.e., they are imperfectly protected. Therefore, there are always some consumers who want to and are able to make illegal copies of the products, depending on their valuation (or their maximum willingness to pay) of the products, prices, and protection levels.

In the model, consumers are not required to purchase one or two products uniformly. Based on their valuation of the products, prices, and availability of illegal copies, consumers may decide to (1) buy one legitimate product and obtain one illegal copy of the other product, (2) purchase only one legitimate product, (3) obtain only one illegal copy of a product, or (4) obtain copies of the two products. Consumers receive the same amount of valuation (i.e., $v > 0$) from consuming product 1 or 2. The valuation (v) is the utility from consuming either (legitimate) product 1 or 2 within the usage that the companies permit and is assumed the same across consumers. Also, consumers suffer disutility from choosing a variant that differs from their ideal. This disutility is determined by t, which captures how much displeased a consumer is because her ideal product is not offered, and the consumer's location (x_i). Specifically, depending upon their location in the interval, consumers incur disutility of tx_i when they acquire a legitimate or illegal copy of product 1 and disutility of $t(1-x_i)$ when they acquire product 2. Hence, a consumer' location (x_i) represents how much the products are horizontally differentiated from her vantage point (i.e., musical preference).

Consumers value differently a legitimate copy and an illegal copy of product 1 or 2, and this is captured by α, where $0 < \alpha < 1$. When a consumer located at x_i purchases a legitimate copy of product 1, the consumer's net utility is $v - tx_i$. In the case of an illegal copy, however, the consumer's net utility becomes $(1-\alpha)(v - tx_i)$. Thus, α measures the degree of quality degradation of illegal copies (Bae and Choi 2006). In this setup, x_i determines how much the legitimate products and their copies are vertically differentiated.

In addition to quality degradation cost, consumers also face reproduction cost (e) when making an illegal reproduction (Yoon 2002). The reproduction cost includes the physical cost (e.g., CDs to hold illegally copied songs) and the hacking cost to hack the private copy protection system of a digital product. Since the physical cost is currently close to negligible, the reproduction cost generally means the hacking cost. In our model, the reproduction cost is determined by the sellers of the digital goods. The rationale is that if a seller sets a high level of private copy protection for its product, the reproduction cost will also high because a hacker needs to make more efforts to hack the private copy protection system.[3] We assume that there is

[3] A typical private copy protection system is DRM, which is an encryption program to control access to or usage of digital content. DRM used in downloaded songs for instance has different methods to restrict access or usage. They can limit the number of times a song can be played, limit the number of computers to store songs, decide to make it

a synergy effect in hacking digital products. That is, if a hacker succeeds in hacking one digital product, then the hacker can hack the other product with a lower reproduction cost than that for the first product. This synergy effect is captured by β, where $\frac{1}{2} \leq \beta \leq 1$. More formally, β measures the compatibility of private copy protection systems between the digital products in terms of hacking technology.

The two firms compete in a two-stage game. In the first stage, each firm decides the optimal protection level for its digital product. Then in the second stage, each firm chooses the price that maximizes its profits, given the protection levels set by the two firms in the first stage. Like most sequential games, we derive equilibrium outcomes by solving backward.

Let $u(x_i;(A_1, A_2))$ denote the gross utility for consumer i who is located at x_i with choices of acquiring product 1 and 2. A_1 is consumer i's choice of acquiring product 1 with $A = \{B, C, O\}$ where B, C, and O are abbreviations of buy, copy and no use, respectively. Let p_1 denote the price for a legitimate copy of product 1 and e_1 denote the reproduction cost of product 1. Then, we can derive the gross utilities for all combinations of consumption choices of product 1 and 2, which are shown in Table 1.

Insert Table 1 about here.

B. Demand Functions

Without loss of generality, we fix v and t to 1 for simplicity in the remainder of the paper. To calculate the demand for product 1 (focusing on the vicinity of firm 1), we need to know how many consumers would buy a legal copy of product 1 in each regime, which will determine the demand for product 1. For such consumers, their net utility must satisfy the following condition:

$$(1 - x_i - p_1) + \max\{(1-\alpha)x_i - e_2, 0\} \geq \max\{u(x_i;(C,C)), u(x_i;(C,O))\} \tag{1}$$

Depending on the location of consumers, expression (1) can take three different forms.

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iPod compatible, and whether or not it can be burned to CD. We assume here that the more complex control in private copy protection, the more costly to hack into the copy protection system.

1) No strategic interaction (NSI) regime

For high-valuation users whose location is close to firm 1, *(C,O)* is preferred to *(C,C)* even with the synergy effect of hacking technology since they have strong preference in product 1 but not in product 2, which leads to $\beta(e_1+e_2)-e_1 \ge (1-\alpha)x_i$. Then, expression (1) becomes

$$(1-x_i-p_1) \ge (1-\alpha)(1-x_i)-e_1 \Leftrightarrow \frac{\alpha+e_1-p_1}{\alpha} \ge x_i .$$

The maximum price they are willing to pay for product 1 equals

$$p_1^{NSI}(x_i)=\alpha(1-x_i)+e_1, \tag{2}$$

which shows that the price they are willing to pay is equal to the two types of copy cost: the difference in quality of a copy and an original, and the cost of hacking private copy protection of product 1.

2) Strategic complement (SC) regime

As the location of consumers is further away from firm 1, the synergy effect makes the option of *(C,C)* more attractive than *(C,O)*. However, these consumers prefer (B,O) to (B,C) since making a copy of only one product is not desirable without the synergy effect. Therefore, for intermediate valuation consumers such as $\beta(e_1+e_2)-e_1 \le (1-\alpha)x_i \le e_2$, the expression (1) becomes

$$(1-x_i-p_1) \ge (1-\alpha)-\beta(e_1+e_2) \Leftrightarrow \alpha+\beta(e_1+e_2)-p_1 \ge x_i . \tag{3}$$

Therefore, their maximum price is given by $p_1^{SC}(x_i)=\alpha-x_i+\beta(e_1+e_2)$.

3) Strategic substitute (SS) regime

Finally, for low valuation consumers who are furthest away from firm 1 such that $(1-\alpha)x_i \le e_2$ expression (1) can be rewritten as

$$(1-x_i-p_1)+((1-\alpha)x_i-e_2) \ge (1-\alpha)-\beta(e_1+e_2) \Leftrightarrow \frac{\alpha+\beta(e_1+e_2)-e_2-p_1}{\alpha} \ge x_i . \tag{4}$$

For these consumers who prefers (B,C) to (B,O) even without the synergy effects making a copy of one content is preferred to no use. Their maximum price is thus equal to $p_1^{SS}(x_i)=\alpha-\alpha x_i-e_2+\beta(e_1+e_2)$.

Putting the three price functions together we can derive a twice-kinked demand function for product 1. Depending on the relative magnitude of (e_1, e_2) the demand function is concave in x_i in the neighborhood of $\frac{\beta(e_1+e_2)-e_1}{1-\alpha}$ and convex in x_i in the neighborhood of $\frac{e_2}{1-\alpha}$. Combining the demands for product 1 in the above three regimes, we have the following aggregate demand function with three segments and two kinks (in the order of the SS regime, the SC regime, and the NSI regime):

$$q_1(p_1,e_1,e_2)=\begin{cases}\frac{1}{\alpha}\left[\alpha+\beta e_1-(1-\beta)e_2-p_1\right] & \text{if } p_1<\Gamma_1\\ \alpha+\beta(e_1+e_2)-p_1 & \text{if } \Gamma_1\le p_1\le\Gamma_2\\ \frac{1}{\alpha}\left[\alpha+e_1-p_1\right] & \text{if } p_1>\Gamma_2\end{cases} \tag{5}$$

where $\Gamma_1=\alpha+\beta(e_1+e_2)-\frac{1}{1-\alpha}e_2$ and $\Gamma_2=\alpha-\frac{\alpha\beta}{1-\alpha}(e_1+e_2)+\frac{1}{1-\alpha}e_1$[4]. Γ_1 and Γ_2 are derived from the corresponding prices at the two kinks. Figure 1 illustrates the above kinked demand function.

Insert Figure 1 about here.

C. Equilibrium Prices, Protection Levels, and Profits

Firm 1 has the following profit function to maximize in each regime:

$$\pi_1^R=p_1^R q_1^R-\left[K+\frac{m}{2}\left\{e_1^R\right\}^2\right], \text{ where } R=\{SS,SC,NSI\}. \tag{6}$$

The terms in the brackets represent the cost structure of firm 1 to create its own copy protection (e.g., DRM) for its product. Specifically, K is the fixed cost of creating its copy protection, and m determines the marginal cost of copy protection.

[4] Since we have $\frac{1}{2}\le\beta\le 1$, we know that $\Gamma_1\le\Gamma_2$.

The two firms in this model compete in a two-stage game, where they set their private copy protection levels in the first stage and then choose their prices in the second stage, given the private copy protection levels set in the first stage. As most sequential games are solved backward, we first examine the second-stage competition and then return to the first-stage competition.

The Second Stage

In the second stage, both firms simultaneously choose the optimal prices that maximize their profits, taking the private copy protection levels for product 1 and product 2 as given. Since the two firms employ the identical price-setting mechanism, we focus only on firm 1 in this stage. Given the price-wise linear and convex-kinked demand function, the optimal prices are expected to be discourteous when the shift of regime from SC to SS occurs.

When e_1 is large enough firm 1 is is able to attract some low valuation consumer by charging the following price:

$$p_1^{SS*} \equiv \arg\max\, p_1\left(\frac{1}{\alpha}\left[\alpha+\beta e_1-(1-\beta)e_2-p_1\right]\right)=\frac{1}{2}\left(\beta\left(e_1+e_2\right)-e_2+\alpha\right).$$

In the above equilibrium prices, we include additional profit constraint, denoted as $\hat{e}_1^{SS}$, since we have the convex kink in the demand function, we need to compare profit level in order to determine the condition for the regime shift from SS to SC. We have

$$\pi_1^{SS*}\left(p_1^{SS*}\right)>\pi_1^{SC*}\left(p_1^{SC*}\right)\Leftrightarrow e_1>\hat{e}_1^{SS}\equiv\left(\frac{1}{\left(1-\sqrt{\alpha}\right)\beta}-1\right)e_2-\frac{\alpha}{\beta}.$$

For $e_1 \le \hat{e}_1^{SS}$ some intermediate valuation consumers are now attracted to make dual copy of contents (C, C). Firm 1 can either accommodate or implement limit price to deter dual copy. When e_1 is large enough firm 1 sets

$$p_1^{SC*} \equiv \arg\max\, p_1\left(\alpha+\beta(e_1+e_2)-p_1\right)=\frac{1}{2}\left[\beta(e_1+e_2)+\alpha\right].$$

Otherwise it implement limit pricing by setting $p_1=\Gamma_2$. The shift from accommodation to limit pricing takes place if $p_1^{SC*}=\Gamma_2 \Leftrightarrow \hat{e}_1^{SC}\equiv\dfrac{(1+\alpha)\beta e_2-\alpha(1-\alpha)}{2-\alpha\beta-\beta}<\hat{e}_1^{SS}$. When e_1 gets smaller, even high valuation consumers prefer to make a copy of product 1. Facing this threat the optimal price equals

$$p_1^{NSI*} \equiv \arg\max\, p_1\left(\frac{1}{\alpha}\left[\alpha + e_1 - p_1\right]\right) = \frac{1}{2}\left(\alpha + e_1\right).$$

Using (5) $p_1^{NSI*} \geq \Gamma_2 \Leftrightarrow e_1 \leq \hat{e}_1^{NSI} \equiv \dfrac{2\alpha\beta e_2 - \alpha(1-\alpha)}{1-\alpha-2\alpha\beta}$.

As a result, we have the following equilibrium prices (in the order of the SS regime, the SC regime, the limit pricing regime, and the NSI regime) for the second stage:

$$p_1^*(e_1,e_2) = \begin{cases} p_1^{SS*} & \text{if } \hat{e}_1^{SS} < e_1 \\ p_1^{SC*} & \text{if } \hat{e}_1^{SC} \leq e_1 \leq \hat{e}_1^{SS} \\ \Gamma_2 & \text{if } \hat{e}_1^{NSI} \leq e_1 \leq \hat{e}_1^{SC} \\ p_1^{NSI*} & \text{if } e_1 \leq \hat{e}_1^{NSI} \end{cases} \tag{7}$$

One notable fact regarding the above equilibrium prices is that they are not functions of firm 2's prices in any of the regimes. Similarly, the equilibrium prices of firm 2 are not functions of firm 1's prices in all regimes. This means that the two firms do not compete directly with each other in prices in the second stage. Their actual competition takes place in the first stage.

The First Stage

In the first stage, firms determine their optimal private copy protection levels that maximize their profits simultaneously. As in the second stage, because both firms use the same copy protection mechanism, we focus only on the results for firm 1 in this stage. In order to derive the reaction function for the private copy protection level of firm 1 in each regime, we plug the equilibrium price in expression (7) into equation (6) and differentiate equation (6) with respect to its private copy protection level (i.e., e_1). Solving the FOC for e_1 yields the following reaction function for firm 1 (in the order of the SS regime, the SC regime, the limit pricing regime, and the NSI regime):

$$e_1^*(e_2)=\begin{cases} e_1^{SS*}(e_2)=\dfrac{\alpha\beta-\beta(1-\beta)e_2}{2\alpha m-\beta^2} & \text{if } \hat{e}_2^{SS}\geq e_2 \\ e_1^{SC*}(e_2)=\dfrac{\beta^2 e_2+\alpha\beta}{2m-\beta^2} & \text{if } \hat{e}_2^{SC}\geq e_2\geq \hat{e}_2^{SS} \; ^5 \\ \hat{e}_1^{NSI} & \text{if } \hat{e}_2^{NSI}\geq e_2\geq \hat{e}_2^{SC} \\ e_1^{NSI*}(e_2)=\dfrac{\alpha}{2\alpha m-1} & \text{if } e_2\geq \hat{e}_2^{NSI} \end{cases} \tag{8}$$

We can derive the reaction function for firm 2 with the same procedure although it is not shown here. Since the reaction function for firm 1 is a function of firm 2's private copy protection (and vice versa), the optimal private copy protection levels set by the two firms are strategically related. In the SS regime, the slopes of the reaction functions for firm 1 and firm 2 are negative. Hence, with the following stability and convergence condition

$$2\alpha m-\beta>0, \tag{9}$$

the optimal private copy protection levels set by the firms are strategic substitutes. In the SC regime, however, the slopes of the reaction functions for firm 1 and firm 2 are positive. Therefore, the optimal private copy protection levels for firm 1 and firm 2 are strategic complements, given the following two conditions for stability and convergence:

$$m>\beta^2 \ . \tag{10}$$

One intuitive explanation for the firms' strategic interaction in the SS regime is that when firm 2 increases its protection level (i.e., e_2), the demand for product 2 increases because some consumers who consume (C,C) switch to (C,B) due to an increase in reproduction cost for product 2. But, the increase in firm 2's protection level has a negative impact on the demand for

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[5] The boundary of each regime is calculated from equation (7). From $e_1^{NSI*}(e_2)\leq \hat{e}_1^{NSI}$ we derive $e_2\geq \dfrac{\alpha(1+m(1-\alpha-\beta))}{(2\alpha m-1)\beta}\equiv \hat{e}_1^{NSI}$. The upper boundary under SC regime is derived from $e_1^{SC*}(e_2)\geq \hat{e}_1^{SC}\Leftrightarrow e_2\leq \dfrac{\alpha((1-a)m+\beta(1-\beta))}{(m(1+\alpha)-\beta)\beta}\equiv \hat{e}_2^{SC}$.

The transition from the SC regime to the SS regime is required to compare profits between two regimes due to the existence of the convex kink:

$$\pi_1^{SS*}\left(e_1^{SS*}(e_2)\right)>\pi_1^{SC*}\left(e_1^{SC*}(e_2)\right)\Leftrightarrow e_2<\hat{e}_2^{SS}\equiv \frac{\alpha\beta^2-2m(\alpha-(1-\alpha)\alpha\beta)+\sqrt{\alpha^2\left(4\alpha m^2-2m(1+\alpha)\beta^2+\beta^4\right)}}{2m\left(\beta\left(2-(1-\alpha)\beta\right)-1\right)\beta^2-2\beta^3} .$$

product 1 (negative demand-shift effect). The reason is that consumers who consume (B,C) don't value product 2 enough to buy a legitimate copy of product 2 facing the increased protection level for product 2. In order to reduce the overall cost of consuming both products and increase the gross utility, some of the consumers who consume (B,C) obtain an illegal copy of product 1, instead of buying a legal copy of product 1. Hence, some consumers in that segment switch to (C,C), which results in a decrease in the demand for product 1. To boost its demand, firm 1 needs to reduce its price, which gives consumers less incentive to pirate product 1. With this lowered piracy level, firm 1 can reduce its protection level to reduce its cost and thus increase its profit.[6]

A real-life example of the SS regime can be found in the music business. While most of the major music companies attempt to increase their DRM requests to online sellers, such as Apple and Amazon.com, to curb music piracy, EMI Group has recently decided to license its music to online sellers without copy protection (Smith and Vara 2007). EMI Group's decision is the opposite of the DRM policy adopted by its major competitor, Universal Music Group, which is greatly concerned about online piracy. EMI Group's strategic behavior in this example can be explained by the above intuition. Another example is in the download movie business. Paramount, a major movie studio, has refused to make its movies available on Apple's iTunes due to piracy concerns, although iPod and iTunes are very popular among consumers. It is unlikely that Paramount would agree to license their movies to Apple, until Apple makes its sharing rules on downloaded movies stricter and put more protection for their movies (Grover 2007). Contrary to this position, however, Walt Disney, another major movie studio, has agreed to license its movies to Apple and made its movies available on iTunes. Clearly, Disney has a different strategic mindset on Apple's DRM that is the opposite of the viewpoint of its major competitor. The above intuition provides a good rationale for Walt Disney's decision on offering its movies to Apple.

The intuition behind the firms' strategic interaction in the SC regime is as follows. If firm 2 increases its protection level (i.e., e_2), the demand for product 2 increases because some

[6] Taking the partial derivative of equation (7) and (8) with respect to e_2 in the case of the SS regime yields $\frac{\partial p_1^*(e_1,e_2)}{\partial e_2} = -\frac{1}{2}(1-\beta) < 0$ and $\frac{de_1^*(e_2)}{de_2} = -\frac{\beta(1-\beta)}{2\alpha m-\beta^2} < 0$ respectively.

consumers who consume (C,C) and strongly prefer product 2 switch to (O,B) facing an increase in the reproduction cost for product 2. In this case, however, the increase in firm 2's protection level has a positive impact on the demand for product 1 (positive demand-shift effect). With the increased protection level for product 2, consumers who consume (C,C) and strongly prefer product 1 switch to (B,O) because the increase in reproduction cost for product 2 is too much for them. Instead, they purchase a legitimate copy of product 1 and opt not to consume product 2 (legitimate or illegal), which results in an increase in the demand for product 1. Since its demand is increased, firm 1 can increase its price. At the same time, firm 1 needs to increase its protection level to reduce the increased piracy incentive for its product due to the price increase.[7]

This strategic nature of the SC regime can be illustrated by decisions made by companies that sell music or movies through the Internet. In 2006, CinemaNow announced that it would allow consumers to burn copies of some movies onto a DVD that can be watched on a television, which means less restricted copy protection (McBride 2006). Responding to CinemaNow's move, Movielink, a competing movie download service, attempted to strike a similar deal with movie studios. Another real-life example is a recent announcement by Amazon.com. that its music-download service would only sell music that comes without copy protection (Smith and Vara 2007). This announcement was made as Apple was preparing to offer music without copy protection on its iTunes. Essentially, Amazon.com followed suit and reduced its private copy protection when its major rival, Apple, planned to reduce its private copy protection. These two examples illustrate the strategic nature of the SC regime.

Now, we derive optimal private copy protection levels, which is the ultimate objective in the first stage. Since the reaction functions are discontinuous and kinked twice, we may not be able to have pure-strategy equilibria. But, to avoid excessive complications that would hinder us from deriving meaningful results, we rather restrict our attention to symmetric pure-strategy equilibria. We can calculate specific optimal private copy protection levels for both firms by solving the reaction functions of firm 1 and firm 2 for e_1 and e_2 simultaneously in each regime.

[7] Taking the partial derivative of equation (7) and (8) with respect to e_2 in the case of the SC regime yields $\frac{\partial p_1^*(e_1,e_2)}{\partial e_2}=\frac{\beta}{2}>0$ and $\frac{de_1^*(e_2)}{de_2}=\frac{\beta^2}{2m-\beta^2}>0$ respectively.

The following proposition summarizes the optimal private copy protection levels determined by firm 1 in the three regimes:

Proposition 1: *If condition (9) is satisfied in the SS regime and condition (10) in the SC regime, the optimal private copy protection levels chosen by firm 1 are (in the order of the SS, SC, limit pricing, and NSI regimes)*

$$e_1^* = \begin{cases} \left\{e_1^{SS*}, p_1^{SS*}\right\} = \left\{\dfrac{\alpha\beta}{2\alpha m+\beta-2\beta^2}, \dfrac{\alpha^2 m}{2\alpha m+\beta-2\beta^2}\right\} & \text{if } \hat{\beta}^{SS} \geq \beta \\ \left\{e_1^{SC*}, p_1^{SC*}\right\} = \left\{\dfrac{\alpha\beta}{2\left(m-\beta^2\right)}, \dfrac{\alpha m}{2\left(m-\beta^2\right)}\right\} & \text{if } \hat{\beta}^{SC} \geq \beta \geq \hat{\beta}^{SS} \\ \left\{\hat{e}_2^{SC}, \Gamma_2\right\} = \left\{\dfrac{\alpha\left((1-a)m+\beta(1-\beta)\right)}{\left(m(1+\alpha)-\beta\right)\beta}, \Gamma_2\right\} & \text{if } \hat{\beta}^{NSI} \geq \beta \geq \hat{\beta}^{SC} \\ \left\{e_1^{NSI*}, p_1^{NSI*}\right\} = \left\{\dfrac{\alpha^2 m}{2\alpha m-1}, \dfrac{\alpha^2 m}{2\alpha m-1}\right\} & \text{if } \beta \geq \hat{\beta}^{NSI} \end{cases} .^{8} \qquad (11)$$

<u>Comparison with Multiproduct Monopoly Case</u>

We now consider the optimal pricing and protection of a multiproduct monopoly. Since the demand function (5) is independent with respect to the price of the other product and thus the monopoly adopts the identical equilibrium prices as in equation (7), it is meaningful to compare the optimal protection level in the first stage. Further, in order to simplify the boundary condi-

[8] The boundary of each regime is calculated from equation (8). From $e_2 \geq \hat{e}_2^{NSI}$ we derive $\beta \geq \dfrac{1+m(1-\alpha)}{2} \equiv \hat{\beta}^{NSI}$. The upper boundary under the SC regime is derived from $\hat{e}_2^{SC} \geq e_2^* \Leftrightarrow \beta \leq \min\left\{\sqrt{2m}, \dfrac{1}{4}\left(1+\sqrt{1+8m(1-\alpha)}\right)\right\} \equiv \hat{\beta}^{SC}$. The lower boundary under the SC regime is derived from $e_2^{SC*} \leq \hat{e}_2^{SS} \Leftrightarrow \beta \geq \hat{\beta}^{SC}$, where $\hat{\beta}^{SC}$ is a solution of $\dfrac{\alpha\beta}{2\left(m-\beta^2\right)} = \dfrac{\alpha\beta^2 - 2m\left(\alpha-(1-\alpha)\alpha\beta\right)+\sqrt{\alpha^2\left(4\alpha m^2-2m(1+\alpha)\beta^2+\beta^4\right)}}{2m\left(\beta\left(2-(1-\alpha)\beta\right)-1\right)\beta^2-2\beta^3}$. The transition from the SC regime to SS regime happens where $e_2^{SS*} \geq \hat{e}_2^{SS} \Leftrightarrow \beta \leq \hat{\beta}^{SS}$ where $\hat{\beta}^{SS}$ solves $\dfrac{\alpha\beta}{2\alpha m+\beta-2\beta^2} = \dfrac{\alpha\beta^2 - 2m\left(\alpha-(1-\alpha)\alpha\beta\right)+\sqrt{\alpha^2\left(4\alpha m^2-2m(1+\alpha)\beta^2+\beta^4\right)}}{2m\left(\beta\left(2-(1-\alpha)\beta\right)-1\right)\beta^2-2\beta^3}$. Since $\hat{e}_2^{SS}$ is an increasing function in β.

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tions across the different market structures, namely a multiproduct monopoly versus a duopoly, we consider a situation where the both firms are merged into a multiproduct monopoly and set its protection level to maximize its joint profits denoted as

$$\pi_m^R = \pi_1^R + \pi_2^R . \tag{12}$$

We, first of all, observe that the optimal protection under the NSI regime is the same across the different market structures due to no strategic interaction. As long as the strategic interaction exists, the monopoly reacts differently according to the strategic nature of private protection. For instance, under the SC regime the dual piracy makes both product common substitutes. To internalizing this positive externality, the monopoly chooses a higher level of protection and thus increases its price such as $\left\{e_m^{SC*}, p_m^{SC*}\right\} = \left\{\dfrac{\alpha\beta}{m-2\beta^2}, \dfrac{\alpha m}{2\left(m-2\beta^2\right)}\right\}$ by maximizing its profit function (12) with demand functions specified in equation (7) under the SC regime. On the other hand, as the protection systems become similar the monopoly now faces the SS regime where it deliberately decreases its protection and price in order to internalize the negative demand-push externality. With the similar derivation used in the SS regime we have $\left\{e_m^{SS*}, p_m^{SS*}\right\} = \left\{\dfrac{\alpha(2\beta-1)}{2\alpha m-(1-2\beta)^2}, \dfrac{\alpha^2 m}{2\alpha m-(1-2\beta)^2}\right\}$. As a result, we have a situation where more competition ends up with a higher price and protection as compatibility increases. Comparing the welfare performances of two market structures in a short-run perspective we find counterintuitive results; competition in fact reduces welfare since the higher price decreases not only the legal usage but also the surplus of consumers who purchase it. Moreover, the higher protection also reduces the usage of pirated good. Proposition 2 summarizes the comparison between two market structures.

Proposition 2: *With the presence of strategic interactions, the multiproduct monopoly sets different levels of price and copy protection, compared to those of two-product duopoly. With a higher degree of compatibility of private copy protection systems, the monopoly increases welfare by setting lower prices with more usage of legal products, which results from less private copy protection.*

The similar findings are also observed in Belleflamme and Picard (2007) where strategic interactions with respect to pricing is considered under a two-product duopoly with the increasing cost of copying technology. They propose that genuinely independent products become complements in some price range due to piracy where the monopoly also sets its price lower to internalize the positive externality because of the so-called "Cournot effect". In our paper, in contrast, the complementarities stems from the strategic nature of private copy protection while the products are still independent at any level of price.

3. Comparative Static Analysis

We now analyze the effects of a marginal increase in public copy protection, which is comparable to Intellectual Property Rights (IPR) protection. As with previous studies in the literature (e.g., Bae and Choi 2006; Novos and Waldman 1984), we model the increase in IPR protection as an increase in the cost of piracy, which makes the option of piracy less attractive. For example, Bae and Choi (2006) provide the generalized results of the effects associated with two different types of costs associated with piracy for the case of monopoly: constant reproduction cost and proportional degradation rate. Since the optimal level of private copy protection, which corresponds to the reproduction cost, is endogenously determined by content providers, we concentrate on the other measure of IPR protection, which is the public copy protection. Unlike previous literature, in this model we have composite effects which can be written as

$$\frac{dp_1^{R*}}{d\alpha} = \frac{\partial p_1^{R*}}{\partial \alpha} + \frac{\partial p_1^{R*}}{\partial e_1}\frac{de_1^{R*}}{d\alpha} \text{ and } \frac{dq_1^{R*}}{d\alpha} = \frac{\partial q_1^{R*}}{\partial \alpha} + \frac{\partial q_1^{R*}}{\partial e_1}\frac{de_1^{R*}}{d\alpha}. \tag{13}$$

The first term shows the usual direct effect, the indirect effect in the second term comes from the fact that an increase in public copy protection changes the optimal level of private copy protection level, thus affecting the optimal price and quantity in each regime. Therefore, the total effect of α on $\left(p^{R*}, q^{R*}\right)$ is the sum of these two effects.

The signs of $\partial p_1^{R*}/\partial \alpha$, $\partial p_1^{R*}/\partial e_1$, $\partial q_1^{R*}/\partial \alpha$, and $\partial q_1^{R*}/\partial e_1$ are determined by how these changes affect demand for legal products under different regimes. An increase in public copy protection under the SC regime and the level of private copy protection has the same directional impact in the copy cost across consumers, which is equivalent to an outward parallel shift in demand for the original goods. Facing higher demand, content providers respond with the price increase but this is not enough to offset the initial demand increase: $\frac{\partial p_1^{SC*}}{\partial a} = \frac{1}{2} > 0$, $\frac{\partial q_1^{SC*}}{\partial \alpha} = \frac{1}{2} > 0$, $\frac{\partial p_1^{R*}}{\partial e_1} > 0$ and $\frac{\partial q_1^{R*}}{\partial e_1} > 0$.[9] On the other hand, stricter public copy protection implies a pivot change in demand that affects the slope of the demand curve for legal copies under the SS and NSI regimes. Due to a proportional increase in the copy cost, higher valuation consumers are more adversely affected by an increase in public copy protection, which reduces it's the demand elasticity. The content providers are more interested in serving only the high valuation consumers, which means $\frac{\partial p_1^{NSI*}}{\partial \alpha} = \frac{1}{2} > 0$ and $\frac{\partial q_1^{NSI*}}{\partial \alpha} = -\frac{e_1^{NSI}}{2\alpha^2} < 0$.[10]

We now calculate the effect of an increase in public copy protection on the optimal private copy protection level under each regime. It is shown that the effect can have different implications depending on which regime the content providers are operating under and the strategic nature of private copy protection systems. Let $e_1^{R*} = R_1(\alpha, e_2^{R*})$ and $e_2^{R*} = R_2(\alpha, e_1^{R*})$ be the optimal choices of private copy protection under regime R, where $R = \{SS, SC\}$. We differentiate the equilibrium condition $e_1^{R*} = R_1(\alpha, R_2(\alpha, e_1^{R*}))$ with respect to α to set

$\frac{de_1^{R*}}{d\alpha} = \frac{\partial e_1^{R*}}{\partial \alpha} + \frac{\partial R_1}{\partial e_2}\frac{\partial R_2}{\partial e_1}\frac{de_1^{R*}}{d\alpha} + \frac{\partial R_1}{\partial e_2}\frac{dR_2}{d\alpha}$, which yields

$$\frac{de_1^{R*}}{d\alpha} = \frac{1}{\left(1 - \partial R_1/\partial e_2 \cdot \partial R_2/\partial e_1\right)}\left[\frac{\partial e_1^{R*}}{\partial \alpha} + \frac{\partial R_1}{\partial e_2}\frac{dR_2}{d\alpha}\right]. \tag{14}$$

The denominator is always positive to ensure the stability of the equilibrium. Therefore, the effect of α on e_1^{R*} is shown to depend on three factors: 1) the direct effect of α on e_1^{R*} $\left[\partial e_1^{R*}/\partial \alpha\right]$, 2) the slope of the reaction function $\left[\partial R_1/\partial e_2\right]$and 3) firm 2's response to an increase in α $\left[dR_2/d\alpha\right]$. Since the first and the third effects are symmetric, we only concentrate on the third effect for analytical convenience.

To illustrate how a higher level of public copy protection affects the level of private copy protection in the equilibrium, we first look at the changes in reaction function curves.

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9 Simple comparative statics exercise of taking the partial derivative of the optimal price and demand in the second period with respect to α and e respectively confirms the results.

10 Another possible outcome under the SS regime if $e_2 - \beta(e_1 + e_2) > 0$ would be a rightward shift in demand with a steeper slope where the effect of higher α on price and quantity are similar to those under the SC regime.

Under the SS regime, we have shown that $\partial R_1/\partial e_2 < 0$, and the sign of $dR_2/d\alpha$ depends on the level of e_1. If $e_1 > \frac{\beta^2}{2m(1-\beta)}$, we have $\frac{dR_2}{d\alpha} > 0$. Otherwise, $\frac{dR_2}{d\alpha} < 0$. These effects are shown as the counter-clockwise rotation of firm 1's reaction curve around $e_1 = \frac{\beta^2}{2m(1-\beta)} (> e_1^{SS*})$. The new equilibrium point moves to the "south-west", which implies that the higher public copy protection rate induces the optimal private copy protection to decrease. Under the SC regime, in contrast, we have a situation of strategic complements: an anticipated increase in firm 2's copy protection level causes firm 1 to raise its protection [i.e., $\partial R_1/\partial e_2 > 0$]. A higher public copy protection rate makes both firms more "soft", leading them to choose a higher level of private copy protection given any choice of their rivals [i.e., $dR_2/d\alpha > 0$], which make the new reaction curves shift outward.[11] Therefore, with a higher public copy protection rate under the SC regime, we observe a higher level of private copy protection which moves to the "north-east". Under other regimes, there is no strategic interaction between content providers, which means $\partial e_1^{R*}/\partial e_2^{R*} = 0$. Proposition 3 and Table 2 summarize the results of the comparative statics.

Insert Table 2 about here.

Proposition 3: *The effects of an increase in the public copy protection rate on the optimal level of private copy protection, price, and the authorized usage crucially depend on the demand structure and the strategic nature of private copy protection levels under different regimes.*

Proof. See Appendix A.

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[11] The derivation of $\frac{dR_2}{d\alpha}$ comes from differentiating the reaction function of firm 1 with respect to α, which yields $\frac{\beta}{(2\alpha m-\beta^2)^2}\left[2(1-\beta)me_1-\beta^2\right]$ under the SS regime and $\frac{\beta}{2m-\beta^2}$ under the SC regime.

The intuition underlying this result is the following. Facing less threat from dual piracy with an increase in the public copy protection rate, the direct effect $\left[\partial e_1/\partial\alpha < 0\right]$ under the SS regime results in a reduction in firm 1's private copy protection level because the content providers are only interested in serving high valuation consumers with pivot change in demand. This direct effect is, however, lessened by strategic interaction between firms due to the strategic nature of private copy protection levels. Using the terminology of Fudenberg and Tirole (1984) we can explain the strategic effect as follows: when firm 2 regards firm 1's private copy protection level as a strategic substitute $\left[\partial R_2/\partial e_1 < 0\right]$ and an increase in the public copy protection rate makes it "soft" $\left[dR_2/d\alpha < 0\right]$, the appropriate strategy for firm 2 would be that of " stay lean and hungry" if firm 2 were able to control the level of public copy protection.[12] That is, firm 2 wants to have a lower level of α in order to commit to being more aggressive without considering the direct effects. Firm 1 then decides on a less aggressive level of private copy protection. As a result, an increase in public copy protection via a higher level of α exerts two opposite effects on the optimal level of private copy protection, in which the net effect is a lower level of private copy protection.

On the other hand, an outward-parallel shift of demand with an increase in the public copy protection rate under the SC regime makes the content providers respond with a higher level of private copy protection which expands the demand further. This effect is further augmented by the strategic effect with strategic complements. We can again explain the strategic effect with the terminology of Fudenberg and Tirole (1984). When firm 2 regards firm 1's private copy protection level as a strategic complement $\left[\partial R_2/\partial e_1 > 0\right]$ and an increase in public copy protection makes it "soft" $\left[dR_2/d\alpha > 0\right]$, the appropriate strategy for firm 2 would be that of "fat cat" if firm 2 were able to control the level of public copy protection. That is, firm 2 wants to have a higher level of α in order to commit to being less aggressive. Firm 1 then replies with a higher level of private copy protection. Under the SC regime, therefore, a change in the public copy protection rate leads to the same-direction direct and strategic effects on the optimal level of private copy protection.

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[12] To be consistent with the direct effect we examine firm 2's strategic incentive.

We also determine the total effect of a higher level of α on firm 2's profits by taking the total derivative of π_2^R, where *R={SS, SC},* with respect to α, which yields

$$\frac{d\pi_2^R}{d\alpha} = \frac{\partial \pi_2^R}{\partial \alpha} + \frac{\partial \pi_2^R}{\partial e_1^R}\frac{de_1^R}{d\alpha}. \tag{15}$$

The first term in the right-hand side of equation (15) is the direct effect on firm 2's profit from a higher α; the second term is the strategic effect as the equilibrium response of firm 1 to the change in α. Firm 2 always prefers a higher level of public copy protection since we have both positive direct and strategic effects under both regimes while the nature of strategic interaction across regimes is different; $\frac{\partial \pi_2^{SS}}{\partial e_1^{SS}} < 0$, $\frac{\partial \pi_2^{SC}}{\partial e_1^{SC}} > 0$, $\frac{de_1^{SS}}{d\alpha} < 0$, and $\frac{de_1^{SC}}{d\alpha} > 0$.

Public Policy Consideration

Since rampant piracy can negatively affect digital goods companies' profits and the country's reputation in the global economy, most national governments are concerned about piracy and attempt to control the level of piracy inside their boundaries (McCary 2007). For these governments, the key question is how much public copy protection they should enforce. In other words, they are concerned about whether they should increase or decrease their current public copy protection level. When making a decision, governments should take into account whether digital goods companies are exercising appropriate levels of their own copy protection since the private sector, along with the government, should play an important role in combating piracy. If the overall level of private copy protection by the private sector is deemed insufficient, the government can induce a higher level of private copy protection by adjusting its public copy protection level. Based on the results from Proposition 3 and the proof, increasing public copy protection may produce different outcomes, depending on competition types among digital goods companies. In the SS and NSI regimes, an increase in public copy protection leads companies to "reduce" their private copy protection levels. In the SC regime, however, when the government enforces stricter public copy protection, companies follow suit and "increase" their private copy protection. Hence, the government should first have a good understanding of the nature of competition in the private sector and then choose a public copy protection policy best suited for the particular competition type among digital goods companies.

In terms of effects of public copy protection on piracy level, we suggest that the government should exercise caution because its policy can produce opposite effects, depending on competition types among digital goods companies. Proposition 3 and the proof reveal that, in the SS and NSI regimes, an increase in public copy protection causes demands for legitimate digital goods to decrease as lower private copy protection and higher prices, both induced by the increase in public copy protection, provide more incentives for consumers to switch to pirated products from legitimate ones. In the SC regime, however, an increase in public copy protection leads to higher demands for legitimate digital goods because the effects of higher private copy protection and higher prices, again both induced by the increase in public copy protection, offset each other and the direct effect of the public copy protection increase boosts overall demands of legitimate products. Since pirated goods along with legitimate ones render the market covered in our model, these results suggest that if the government enforces a stricter public copy protection policy, it would increase piracy in the SS and NSI regimes while it would decrease piracy in the SC regime. Therefore, when the objective is to discourage piracy, if the government legislates for stronger public copy protection in an attempt to reduce piracy, it can achieve the objective only in the SC regime. In the SS and NSI regimes, the government should do the opposite, i.e., a weaker public copy protection policy, to discourage piracy among consumers.

Another interesting comparative statics exercise is how less compatible private copy protection systems affect the optimal level of private copy protection, price, and quantity. Since the derivation of these effects is the simple reiteration of that of an increase in public copy protection rate, we only show the results in Proposition 4 and Table 2.

Proposition 4: *An increase in the compatibility of private copy protection systems has positive effects on the optimal level of private copy protection, price and the authorized usage across regimes but its magnitude crucially depends on the strategic nature of private copy protection levels under different regimes.*

Proof. See Appendix B.

With a lower degree of the compatibility (i.e., higher β) of private copy protection systems in term of hacking technology, all consumers face the same increase in dual copy cost, which is equivalent to an overall demand increase for firms. Hence the firms benefit from higher demand by increasing their optimal levels of private copy protection, inducing even higher price, yet increasing sales at the same time under both the SS and SC regimes. This direct effect is, however, either augmented or lessened depending on the nature of strategic interaction between firms.

Public Policy Consideration

In 2006, France passed a controversial law that would require sellers of digital-music players (including Apple's iPod) and online music services (including Apple's iTunes) in France to make their technical standards available to other companies, so that their music tracks and players could become "interoperable" by making their private copy protection systems more compatible (Hesseldahl 2006). And, other European countries took notice of this and might consider similar laws for their consumers (Carlin 2007). The heart of the issue was whether such laws would lead to "state-sponsored piracy." Apple argued that when state-sponsored piracy occurs, legal music sales would decrease substantially because consumers would have legal alternatives to piracy, rather than buying legitimate music products (Hesseldahl 2006).

Relying on Proposition 4 and the proof, we can provide some suggestions regarding this issue. The results show that more compatibility (i.e., lower β) between private copy protection systems would cause digital-goods companies to lower their private copy protection levels and would lead to lower prices and less demands for the digital products. Unlike the conventional negative relationship between price and demand, the results indicate that when more compatibility is enforced by the government, the demands for legitimate products would decrease even though prices for the products are reduced as well (i.e., a positive relationship between price and demand). This suggests that more compatibility might encourage some consumers to obtain (free) pirated products, instead of buying legal products at cheaper prices, as they take advantage of weakened private copy protection. As a result, more consumers would opt to obtain pirated products, and piracy would spread more widely when such a policy is in place. Our results clearly support the "state-sponsored piracy" argument. Therefore, we suggest that governments should not enforce a higher level of compatibility among private copy protection systems when reducing piracy is their top priority.

4. Conclusion

This paper examines how different types of strategic interactions between two digital-goods firms influence their decisions on optimal private copy protection levels and optimal prices. For this purpose, we first developed a model that includes three types of strategic interactions (i.e., the SS, SC, and NSI regimes) between the firms and allows consumers to obtain pirated products, depending on their valuation. Then, we derived the optimal private copy protection levels, prices, and demands for the legitimate products under each of the strategic interaction types. Our analysis offers the following insights. First, stronger public copy protection would lead to lower private copy protection and more piracy among consumers in the SS and NSI regimes, but higher private copy protection and less piracy in the SC regime. Second, more compatibility between private copy protection systems would lead to lower private copy protection and more piracy. Third, when private copy protection systems are highly compatible, the monopoly would choose lower private copy protection levels and lower prices than those set by two firms in a duopoly setting.

This paper provides new, important insights to the literature on piracy. Most of the past studies on piracy examine monopoly situations, and only a small number of studies deal with duopoly cases (e.g., Johnson 1985; Park and Scotchmer 2005). Those studies examining duopoly settings mainly focus on prices of information goods, rather than addressing private copy protection of information goods. This paper incorporates private copy protection as well as prices of digital goods as key decision variables in a duopoly setting and shows that when a competitor changes its private copy protection level, a firm adjusts its private copy protection level in the opposite direction under the SS regime and in the same direction under the SC regime. This paper suggests that policymakers' decision on public copy protection may generate opposite results in firms' decisions on private copy protection levels, depending on whether the firms consider their private protection levels as strategic substitutes or strategic complements. Eventually, the policymakers' decision would affect overall consumers' welfare in the industry because consumers' welfare is influenced by firms' private copy protection levels. This paper also reveals that, in situations where firms are *independent* of each other in the price-setting game, they become *interdependent* with each other through private copy protection competition when a significant portion of consumers prefer pirated goods.

This paper provides opportunities for future research. One possible direction would be modeling a situation where the two firms can cooperate or collude with each other, which is in line with the work by Park and Scotchmer (2005). In the current paper, the two content providers set their optimal private copy protection levels competitively. But, how would the results from this paper change if the content providers develop and own the *same* copy protection system *jointly*? Would this situation offer a better approach in dealing with piracy? Would consumers be better off in this situation? Would the overall industry be better off? These are important and interesting research questions that need to be addressed in the area of piracy and copy protection. Another direction would be to include content producers and content sellers as separate players in a model. In the current paper, firms produce *and* sell digital goods to consumers. In reality, however, content producers are not usually content sellers. Music companies and movie studios produce contents, but usually are not engaged in selling their products directly to consumers. They make their products available to consumers through online and offline retailers. The following would be a key research question for this direction: How would this setup change the optimal levels of private copy protection and prices for digital goods? Research in this direction will be a meaningful extension of this paper.

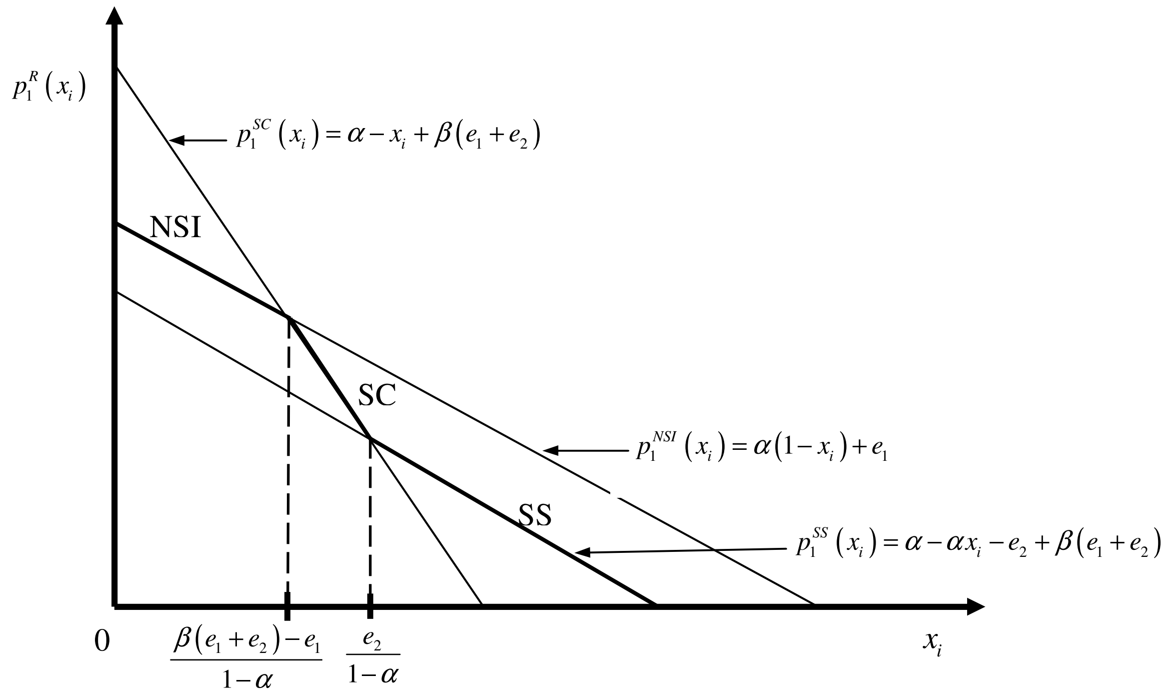
Table 1 Gross Utilities of Consumer i with Various Options of Acquiring Product 1 and 2

2 \ 1	**B**	**C**	**O**
B	N.A.	$(1-\alpha)(v-t\,x_i)-e_1+v-t(1-x_i)-p_2$	$v-t(1-x_i)-p_2$
C	$v-t\,x_i-p_1+(1-\alpha)(v-t(1-x_i))-e_2$	$(1-\alpha)(2v-t)-\beta(e_1+e_2)$	$(1-\alpha)(v-t\,(1-x_i))-e_2$
O	$v-t\,x_i-p_1$	$(1-\alpha)(v-t\,x_i)-e_1$	0

Table 2 Summary of Comparative Statics

	e^{R*}	p^{R*}	q^{R*}
Strategic substitute	$\frac{de^{SS*}}{d\alpha}\leq 0$, $\frac{de^{SS*}}{d\beta}\geq 0$	$\frac{dp^{SS*}}{d\alpha}\lesseqgtr 0$, $\frac{dp^{SS*}}{d\beta}\geq 0$	$\frac{dq^{SS*}}{d\alpha}\leq 0$, $\frac{dq^{SS*}}{d\beta}\geq 0$
Strategic complement	$\frac{de^{SC*}}{d\alpha}\geq 0$, $\frac{de^{SC*}}{d\beta}\geq 0$	$\frac{dp^{SC*}}{d\alpha}\geq 0$, $\frac{dp^{SC*}}{d\beta}\geq 0$	$\frac{dq^{SC*}}{d\alpha}\geq 0$, $\frac{dq^{SC*}}{d\beta}\geq 0$
No strategic interaction	$\frac{de^{NSI*}}{d\alpha}\leq 0$	$\frac{dp^{NSI*}}{d\alpha}\lesseqgtr 0$	$\frac{dq^{NSI*}}{d\alpha}\leq 0$

Figure 1 Aggregate Demand Function



Appendix A. Proof of Proposition 3

Calculation of the optimal level of private copy protection with respect to α under different regimes yields

$$\frac{de_1^{SS*}}{d\alpha} = \frac{1}{\left(1-\partial R_1/\partial e_2 \cdot \partial R_2/\partial e_1\right)}\left[\underbrace{\frac{\partial e_1^{SS*}}{\partial \alpha}}_{(-)} + \underbrace{\frac{\partial R_1}{\partial e_2}}_{(-)}\underbrace{\frac{dR_2}{d\alpha}}_{(-)}\right] = -\frac{(2\beta-1)\beta^2}{(2\alpha m+\beta-2\beta^2)^2} \le 0,$$

$$\frac{de_1^{SC*}}{d\alpha} = \frac{1}{\left(1-\partial R_1/\partial e_2 \cdot \partial R_2/\partial e_1\right)}\left[\underbrace{\frac{\partial e_1^{SC*}}{\partial \alpha}}_{(+)} + \underbrace{\frac{\partial R_1}{\partial e_2}}_{(+)}\underbrace{\frac{dR_2}{d\alpha}}_{(+)}\right] = \frac{m}{2(m-\beta^2)} \ge 0, \text{ and}$$

$$\frac{de_1^{NSI*}}{d\alpha} = -\frac{1}{(2\alpha m-1)^2} \le 0.$$

We now are ready to determine the effect of α on the equilibrium price and quantity under different regimes.

$$\frac{\partial p_1^{SS*}}{\partial \alpha} = \underbrace{\frac{\partial p_1^{SS*}}{\partial \alpha}}_{(+)} + \underbrace{\frac{\partial p_1^{SS*}}{\partial e}}_{(+)}\underbrace{\frac{de_1^{SS*}}{d\alpha}}_{(-)} = \frac{2\alpha m\left(\alpha m+\beta-2\beta^2\right)}{(2\alpha m+\beta-2\beta^2)^2} \ge 0,$$

$$\frac{\partial p_1^{SC*}}{\partial \alpha} = \underbrace{\frac{\partial p_1^{SC*}}{\partial \alpha}}_{(+)} + \underbrace{\frac{\partial p_1^{SC*}}{\partial e}}_{(+)}\underbrace{\frac{de_1^{SC*}}{d\alpha}}_{(+)} = \frac{m}{2(m-\beta^2)} \ge 0,$$

$$\frac{\partial p_1^{NSI*}}{\partial \alpha} = \underbrace{\frac{\partial p_1^{NSI*}}{\partial \alpha}}_{(+)} + \underbrace{\frac{\partial p_1^{NSI*}}{\partial e}}_{(+)}\underbrace{\frac{de_1^{NSI*}}{d\alpha}}_{(-)} = \frac{2\alpha m(\alpha m-1)}{(2\alpha m-1)^2} \ge 0,$$

$$\frac{\partial q_1^{NSI*}}{\partial \alpha} = \underbrace{\frac{\partial q_1^{NSI*}}{\partial \alpha}}_{(-)} + \underbrace{\frac{\partial q_1^{NSI*}}{\partial e}}_{(+)}\underbrace{\frac{de_1^{NSI*}}{d\alpha}}_{(-)} = -\frac{m}{(2\alpha m-1)^2} \le 0,$$

$$\frac{\partial q_1^{SS*}}{\partial \alpha} = \underbrace{\frac{\partial q_1^{SS*}}{\partial \alpha}}_{(-)} + \underbrace{\frac{\partial q_1^{SS*}}{\partial e}}_{(+)}\underbrace{\frac{de_1^{SS*}}{d\alpha}}_{(-)} = \frac{(1-2\beta)\beta m}{(2\alpha m+\beta-2\beta^2)^2} \le 0, \text{ and}$$

$$\frac{\partial q_1^{SC*}}{\partial \alpha} = \underbrace{\frac{\partial q_1^{SC*}}{\partial \alpha}}_{(+)} + \underbrace{\frac{\partial q_1^{SC*}}{\partial e}}_{(+)}\underbrace{\frac{de_1^{SC*}}{d\alpha}}_{(+)} = \frac{m}{2(m-\beta^2)} \ge 0.$$

Q.E.D.

Appendix B. Proof of Proposition 4

Calculation of the optimal level of private copy protection with respect to β under different regimes yields

$$\frac{de_1^{SS*}}{d\beta} = \frac{1}{\left(1 - \partial R_1/\partial e_2 \cdot \partial R_2/\partial e_1\right)} \left[\underbrace{\frac{\partial e_1^{SS*}}{\partial \beta}}_{(+)} + \underbrace{\frac{\partial R_1}{\partial e_2}}_{(-)} \underbrace{\frac{dR_2}{d\beta}}_{(+)} \right] = \frac{\alpha m\left(\beta^2 + \alpha m\right)}{(2\alpha m + \beta - 2\beta^2)^2} \geq 0,$$

$$\frac{de_1^{SC*}}{d\beta} = \frac{1}{\left(1 - \partial R_1/\partial e_2 \cdot \partial R_2/\partial e_1\right)} \left[\underbrace{\frac{\partial e_1^{SC*}}{\partial \beta}}_{(+)} + \underbrace{\frac{\partial R_1}{\partial e_2}}_{(+)} \underbrace{\frac{dR_2}{d\beta}}_{(+)} \right] = \frac{\alpha(m + \beta^2)}{2(m - \beta^2)^2} \geq 0.$$

We now are ready to determine the effect of β on the equilibrium price and quantity under different regimes.

$$\frac{\partial p_1^{SS*}}{\partial \beta} = \underbrace{\frac{\partial p_1^{SS*}}{\partial \beta}}_{(+)} + \underbrace{\frac{\partial p_1^{SS*}}{\partial e}}_{(+)} \underbrace{\frac{de_1^{SS*}}{d\beta}}_{(+)} = \frac{\alpha^2 m\left(4\beta - 1\right)}{(2\alpha m + \beta - 2\beta^2)^2} \geq 0,$$

$$\frac{\partial p_1^{SC*}}{\partial \beta} = \underbrace{\frac{\partial p_1^{SC*}}{\partial \beta}}_{(+)} + \underbrace{\frac{\partial p_1^{SC*}}{\partial e}}_{(+)} \underbrace{\frac{de_1^{SC*}}{d\beta}}_{(+)} = \frac{\alpha\beta m t}{(m - \beta^2)^2} \geq 0,$$

$$\frac{\partial q_1^{SS*}}{\partial \beta} = \underbrace{\frac{\partial q_1^{SS*}}{\partial \beta}}_{(+)} + \underbrace{\frac{\partial q_1^{SS*}}{\partial e}}_{(+)} \underbrace{\frac{de_1^{SS*}}{d\beta}}_{(+)} = \frac{\alpha m\left(4\beta - 1\right)}{(2\alpha m + \beta - 2\beta^2)^2} \geq 0, \text{ and}$$

$$\frac{\partial q_1^{SC*}}{\partial \beta} = \underbrace{\frac{\partial q_1^{SC*}}{\partial \beta}}_{(+)} + \underbrace{\frac{\partial q_1^{SC*}}{\partial e}}_{(+)} \underbrace{\frac{de_1^{SC*}}{d\beta}}_{(+)} = \frac{\alpha\beta m}{(m - \beta^2)^2} \geq 0.$$

Q.E.D.

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