The Effect of Piracy and Digital Rights Management on the Vertically Related Content Industries

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Abstract
The purpose of this paper is to investigate how digitalization affects the vertically related content industries with the threat of piracy. We construct a model of vertical relationship where an upstream [a downstream] firm is considered as a content provider [a retailer]. Three different business models are proposed depending on who has the right to implement digital rights management (DRM): a vertically-integrated entity, an upstream, and a downstream. First, we analyze how different modes of control on DRM affect the optimal prices and the level of copy protection. The results are dependent upon the different control modes of DRM and the degree of opportunistic behavior responding to increasing piracy costs. Second, we analyze the effect of two different types of piracy depending on distribution channels (non-digital versus digital). In particular, strengthening intellectual property rights protection results in a price hike for both cases, while we have opposite changes in quantities depending on the different types of piracy.

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1. Introduction

The effects of piracy on content sales and content providers’ profits have been controversial issues for economists as well as policy makers, content providers, and content retailers. With the advent of Internet and digitalization of contents, piracy is becoming a more attractive option for consumers to obtain contents illegally. This, in turn, makes the content providers and retailers come up with their own protection technologies, which are collectively termed digital rights management (DRM). Therefore, digitalization has a twofold impact on the content industries. First of all, digitalization enables consumers to have more options to obtain contents which can be used for piracy. The first option is to use traditional channels where they obtain original content through personal contacts and make an illegal copy. The second channel emerged with digitalization is to use a variety of peer-to-peer (P2P) networks. P2P networks do not host files on a central server; instead they list available files on individual PCs and directly connect to those computers, which are considered to have a more profound effect on the usage of contents. On the other hand, digitalization enables content providers and retailers to distribute their contents with better protection and control through implementing DRM.

The purpose of this paper is to investigate how digitalization of content influences consumers’ piracy behavior and firms’ optimal choice on the level of DRM and prices. Utilizing a vertical relationship, a model is developed that incorporates two different types of piracy determined by different distribution channels under the different control modes of DRM. Three different business models are proposed depending on who determines the level of DRM: a vertically integrated firm (VI), an upstream content provider (CP), and a downstream retailer (R). The results show that the optimal level of DRM and price varies depending on the different types of the control modes. The highest level of DRM is chosen by the vertically integrated firm. The next highest level is the one chosen by the downstream retailer. The lowest is the level chosen by the upstream content provider. Also, the incentive to block piracy is consistent with the order of the level of DRM. Limit pricing is adopted as the optimal response to the threat of piracy in the order of VI, R, and CP as the cost of implementing DRM decreases. The order is reversed when DRM-free regime is adopted as implementing DRM becomes costlier. It is shown that the results are dependent upon the control mode of DRM and the degree of opportunistic behavior responding to increasing piracy costs. Second, we analyze the effect of two different types of piracy depending on distribution channels. A theoretical framework is provided to show that the
effect of piracy depends crucially on the nature of distribution channels (e.g., non-digital versus digital). In particular, strengthening intellectual property rights (IPR) protection results in a price hike for both cases, while we have opposite changes in quantities depending on different types of piracy.

In this paper we incorporate two significant changes in the content industries. First, we introduce the different control modes of DRM and analyze their effect on prices and the private protection levels. Real-life examples of the different controls on DRM can be found in various content industries. The examples of the upstream control by content providers in the movie industry are Content Scrambling System (CSS) and Advanced Access Content System (AACS). CSS is a DRM system with encryption to protect DVD content from illegal copying, which is controlled by a consortium of entertainment and technology companies called the DVD Copy Control Association. AACS was introduced as a new DRM system for HD DVD and Blu-Ray Discs developed by the AACS Licensing Administrator, LLC, a consortium including some movie studios. In the music industry, Sony BMG was trying to introduce the DRM system called Extended Copy Protection (XCP) and MediaMax CD-3 software, which was designed to prevent illegal copying of music CDs.¹

One of the most popular and controversial examples of the downstream retailer’s control over DRM was Apple’s iTunes with FairPlay DRM. Apple eventually dropped its DRM from music contents in 2009 with an introduction of variable pricing.² Apple currently uses FairPlay DRM on the iBook store contents. Other major e-book retailers apply the various types of DRM to control access to copyrighted contents; Amazon uses its own DRM into Kindle e-book files, and Adobe uses Adobe Digital Editions Protection Technology, which is used by a number of retailers such as Barnes & Noble.

The effect of digitalization on the music industries has been empirically tested by Peitz and Waelbroeck (2004), Michel (2006), Liebowitz (2006) and Zentner (2006) among others. One of the main findings is the decline in the sales of recorded music. Peitz and Waelbroeck (2006) and Liebowitz (2006) provide empirical evidence of no decline in prices of recorded music, which seems like a counterintuitive observation. Theoretical research, on contrast, ¹This software was automatically installed on Windows desktop computers when customers tried to play the CDs. The software interferes with the normal way in which the Microsoft Windows operating system plays CDs, opening security holes that allow viruses to break in and causing other problems.
²http://www.nytimes.com/2009/01/07/technology/companies/07apple.html?_r=0
predicts that with the presence of piracy as a possible and maybe inferior substitute for the originals, the optimal price of monopoly should be lower. In this paper we provide a theoretical analysis to answer the above mentioned empirical findings by introducing two types of channels through which piracy can happen: non-digital channels and digital channels.

Piracy and DRM 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). In all of the above theoretical literature on piracy, the content providers [upstream] and retailers [downstream] were modeled as a single entity. Whereas this assumption may be appropriate for the software industry, it does not capture the characteristics of music and movie industries where content providers and retailers are different entities. Therefore, our paper aims at filling this gap by presenting a detailed analysis of the effect of different control modes of DRM on the level of price, piracy, and DRM. In order to emphasize explicitly the effect of different control modes of DRM, we carry out this task within a framework where upstream and downstream have access to identical DRM technology. After ruling out the technological difference in terms of DRM strategy, we are able to shed some light on the effect of the vertical relationship between the content providers and retailers on the private protection against piracy.

A theoretical approach is taken by Belleflamme and Peitz (2010), where the value of the original music can increase through piracy due to a greater willingness for consumers to pay. They also show that a piracy-free environment would decrease welfare. Peitz and Waelbroeck (2006) examine the welfare and behavior of the firm when piracy becomes a potential threat. They claim that digital piracy can weaken firms’ profits, but welfare may increase due to a larger market for the good. Khouja and Rajagopalan (2009) focus on the pricing aspect for monopolists as a result of piracy. Digitalized piracy may cause monopolists to increase their price. They claim that a price increase could result from a higher piracy rate and a greater market for the good.

Ahn and Shin (2010) suggest that there exists an optimal level of DRM in order to decrease the cost for consumers who purchase the product and not the pirated good. Copyright enforcement has several effects on the product; unproductive DRMs can be augmented through
The remainder of this paper is organized as follows. In section 2 we introduce the basic two-tier model with a non-digital distribution channel and analyze equilibrium prices and DRM under DRM-free, accommodation and limit pricing regimes under different assumptions on the control mode of DRM. In section 3 we introduce piracy through digital distribution channels in the framework of Hotelling’s linear city model to analyze the effect of digital piracy on price, the level of DRM, and profits of the content provider and the retailer. In section 4 we discuss comparative static results in detail based on the analysis conducted in the previous sections. The paper concludes with some remarks and suggestions for future research.

2. Piracy through non-digital distribution channels

Consider a two-tier market for a content invented by a monopoly content provider (upstream) with a single retailer (downstream). Consumers are heterogeneous in their value for a content such as music, movies, computer software, etc. The number of consumers is normalized to 1 and they are uniformly distributed on the unit interval $[0, 1]$. The retailer is assumed to be in charge of selling the content and located at point 0. Consumer location on the interval $x_i$ represents a consumer’s disutility towards the content. Let $v$ be the basic value each user attaches to the content, and it is assumed to be 1 for analytical simplicity. The parameter $t$ measures the degree of disutility from not consuming his/her ideal content. Each consumer is assumed to purchase at most one unit of the content. Therefore, the utility of buying an authorized content is given by

$$U(x_i) = \begin{cases} 
(v - tx_i) - p = (1 - tx_i) - p & \text{if he/she buys the content} \\
0 & \text{if he/she does not buy the content}
\end{cases}$$

where $p$ is the price of one unit of the content charged by the downstream retailer.

We now introduce the possibility of using the content through piracy without purchasing a legal product. In this case the consumer can save the price but incurs the following two costs.
First, consumers are assumed to suffer loss of valuation by $\alpha(1-tx_i)$ with $\alpha \in (0,1)$ because the consumer can be caught by the government (or the governing authority) with a probability of $\alpha$ and avoids being caught with a probability of $(1-\alpha)$. When the consumer is caught, her net utility is assumed to be zero for simplicity. This gives the pirated content a valuation of $(1-\alpha)(1-tx_i)+\alpha \cdot 0$. As such, $\alpha$ measures the intensity of public copy protection by the government. In addition, we assume that consumers also face reproduction cost ($e$) when making an illegal reproduction (Bae and Choi, 2006). The reproduction cost includes the physical cost (e.g., CDs to hold illegally copied contents) and the cost to hack the DRM system of the content. Since the physical cost is close to negligible, the reproduction cost generally means the hacking cost. In our model, the reproduction cost is determined by the level of DRM because a hacker needs to make more efforts to hack a higher DRM level. Thus, the utility of using an unauthorized copy is given by

$$U(x_i) = (1-\alpha)(1-tx_i) - e$$

Given three options to use the content, there are two marginal consumers, $x_1$ and $x_2$. We denote $x_1$ as the marginal consumer who is indifferent between buying the original and making an illegal copy. Similarly, $x_2$ is denoted as the marginal consumer who is indifferent between making an illegal copy and no use of the content. Given the definitions of the two marginal consumers, we represent them as follows:

$$(1-tx_i) - p \equiv (1-\alpha)(1-tx_i) - e \Rightarrow x_i = \frac{\alpha + e - p}{\alpha t}$$

$$(1-\alpha)(1-tx_2) - e \equiv 0 \Rightarrow x_2 = \frac{1}{t} \frac{e}{(1-\alpha)t}.$$  

With the configuration of the two marginal consumers, we restrict our attention to the parameter regions in which the piracy constraint is binding, that is,

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3 Png and Chen (1999) use a similar interpretation of $\alpha$ as the content publisher’s monitoring rate against potential copiers. On the other hand, other literature considers $\alpha$ to be a degradation rate which is a quality difference between an original content and an illegal copy (Bae and Choi, 2006; Hui and Png, 2003). In this paper, we can assume that it may be jointly determined by the level of public copy protection and quality degradation imposed by DRM. Implementing DRM may be assumed to induce quality degradation in both types of contents regardless of levels of DRM. With this assumption, $\alpha$ captures an additional increase in the copy cost proportionally each consumer’s valuation with a stronger public copy protection.
\[ x_1 \leq x_2 \Rightarrow p \geq \frac{e}{1-\alpha} \]  

When the piracy constraint is binding, the demand faced by the downstream retailer determines how the retailer responds to piracy: accommodation or limit pricing. When the retailer chooses to eliminate piracy, the limit price should be given by \( p^L = \frac{e^L}{1-\alpha} \) to eliminate the incentive to copy.\(^4\) Another option for the retailer is to charge a price \( p > p^L \) such that some consumers are better off with using the illegal content. The retailer’s demand functions under the different regimes are given by

\[
q(p,e) = \begin{cases} 
\frac{1-p}{t} & \text{when } p \leq \frac{e}{1-\alpha} \\
\frac{\alpha + e - p}{\alpha t} & \text{when } p \geq \frac{e}{1-\alpha}
\end{cases}
\]  

(4)

Notice that we can further specify the demand for the legitimate products under the accommodation regime; when the level of DRM is set equal to zero (DRM-free regime, hereafter), the demand becomes \( q(p,e=0) = \frac{\alpha - p}{\alpha t} \).

Let us now introduce the vertical structure in our model. We consider three different types of agents: the consumers, the upstream content provider and the downstream retailer. The structure of the two-stage game is slightly different depending on who has the rights to determine the level of DRM. When the upstream content provider (CP) has a control over DRM (CP regime, hereafter), the wholesale price and DRM denoted by \( (w_{cp}, e_{cp}) \) are determined by the CP at the first period. After observing the content provider’s choice, the downstream retailer (R) sets its retail price of the content. On the other hand, the content provider is only able to choose the licensing fee at the first stage in the case where the control over DRM belongs to the downstream retailer (R regime, hereafter). At the end of the second stage consumers make their usage decision under the both regimes. The timing of the two-stage game under the different regimes is summarized in table 1.

2.1. Benchmark case: vertical integration

\(^4\) Variables under the limit pricing regime are denoted by a superscript \( L \)
We now turn to the vertically integrated monopolist’s optimal choices of its price and DRM when the piracy constraint is binding:

$$p_{vi}^* \geq \frac{e_{vi}}{1-\alpha}$$  \hspace{1cm} (5)

where $p_{vi}^* \equiv \arg \max_{p_{vi}} \pi_{vi} = p_{vi} q_{vi}$ with $q_{vi} = (1 - p_{vi})/t$ is the demand function of the vertically integrated monopoly without threat of piracy. Three options are open to the monopolist: limit pricing, accommodating piracy with and without DRM. The first option for the monopolist is to set a limit price to eliminate piracy in which monopolist faces demand of $\frac{1-p}{t}$ and the only option for consumers to use the product is to buy a legitimate copy. The profit function under limit pricing becomes

$$\max_{p_{vi}^*} \pi_{vi} = p_{vi} \frac{1-p_{vi}}{t} - C(e_{vi})$$  \hspace{1cm} (6)

where we use $C(e_{j}) \overset{\text{def}}{=} \frac{c}{2} e_{j}^2 + K$ to represent a cost function to create its own copy protection (i.e., DRM) for its content under $j$ regime. Specifically, $K$ is the fixed cost of creating its copy protection, which is assumed to be 0 when the monopolist chooses her products without DRM. $c$ determines the marginal cost of copy protection, which the parameter $c$ measures the cost effectiveness of the DRM technology. We use this form of cost function in order to simplify subsequent calculation and to have interior solutions.

The second option is to accommodate piracy in which the monopolist sets a higher price and tolerates copying. In this case, the monopolist’s objective becomes:

$$\max_{p_{vi} \neq p_{vi}^*} \pi_{vi} = p_{vi} q_{vi} - C(e_{vi})$$  \hspace{1cm} (7)

with $q_{vi} = \frac{\alpha + e_{vi} - p_{vi}}{\alpha t}$. Under the accommodation regime, the monopolist has two optimal strategies: selling her product with or without DRM. The results for the vertically integrated monopolist’s profit maximization is stated in Lemma 1.

**Lemma 1.**
Lemma 1 describes the optimal level of DRM given the cost effectiveness of DRM. It shows that the monopolist chooses the highest level of DRM when \( c \) is small, but lower levels of DRM are chosen as the marginal costs of implementing DRM increase. Eventually, zero level of DRM is observed when the DRM cost becomes high. The intuition behind lemma 1 is straightforward. The optimal choice of DRM derived from comparison between the marginal revenue from reducing competition from the illegal copying by increasing private protection and the marginal cost of implementing stronger DRM. If \( c = 0 \), for example, the monopolist can charge the monopoly price such as \( p_{vi}^* = \frac{1}{2} \) as if she never has the threat of piracy. On the other hand, when \( c \) gets large, the monopoly is better-off with \( e_{vi}^* = 0 \).

2.2 Upstream control over DRM

We now introduce the vertical market structure where the upstream is assumed to control its licensing fee \( (w_{cp}) \) and DRM \( (e_{cp}) \) in the first period, while the downstream retailer is assumed to choose its retail price \( (p_{cp}) \) independently in the second period. By backward induction, we proceed with the retailer’s optimal choice of pricing in the second period. The downstream
retailer decides between accommodation and limit pricing strategies based on the realized DRM and the licensing fee. The retailer’s profits under each regime are given in the following equation.

\[
\pi_{cp} = \begin{cases} 
(p_{cp} - w_{cp}) \left( \frac{\alpha + e_{cp} - p_{cp}}{\alpha t} \right) & \text{accommodate if } \frac{e_{cp}}{1-\alpha} < p_{cp} \\
(p_{cp} - w_{cp}) \left( \frac{1- p_{cp}}{t} \right) & \text{limit pricing if } \frac{e_{cp}}{1-\alpha} \geq p_{cp}
\end{cases}
\]  

(8)

Expecting the downstream retailer’s possible choice of regimes, the upstream content provider is able to induce the downstream to choose a specific regime: making the downstream adopt accommodation by setting \( \left( w_{cp}, e_{cp} \right) \) to satisfy \( e_{cp} < \frac{(1-\alpha)(\alpha + w_{cp})}{(1+\alpha)} \) or implement limit pricing with the constraint \( e_{cp}^{L*} \geq \frac{(1-\alpha)(\alpha + w_{cp}^L)}{(1+\alpha)} \).

The optimal choice of DRM and regimes by the upstream content provider can be summarized by lemma 2.

**Lemma 2.**

1) If \( 0 \leq c \leq \hat{c}_{cp} \), where \( \hat{c}_{cp} = \frac{1}{3\alpha t(1-\alpha)} \), the content provider sets the limit price \( p_{cp}^{u*} = (1+2\alpha)/\Delta \) as her optimal choice. Other equilibrium values are

\[
e_{cp}^{u*} = \frac{(1+\alpha-2\alpha^2)/\Delta}{1+ct(1-\alpha)^2}/\Delta, \quad q_{cp}^{u*} = \frac{(1+ct(1-\alpha)^2)/\Delta}{\Delta^2 - K}, \quad w_{cp}^{u*} = \frac{(1+2\alpha(1-\alpha)^2 ct)/\Delta}{\Delta^2 - K}, \quad \pi_{cp}^{u*} = \frac{(\alpha(1+ct(1-\alpha)^2))/\Delta}{2\Delta}
\]

where \( \Delta = ct(1-\alpha)^2 + 2(1+\alpha) \).

2) If \( \hat{c}_{cp} < c \leq \hat{c}_{cp} \), where \( \hat{c}_{cp} = \frac{\alpha + 8tK}{32\alpha t^2 K} \), the optimal choice of the monopolist is to accommodate piracy and sets the price at \( p_{cp}^{d*} = \frac{3\alpha^2 ct}{4\alpha ct - 1} \) and we have \( e_{cp}^{d*} = \frac{\alpha}{4\alpha ct - 1} \), \( q_{cp}^{d*} = \frac{\alpha c}{4\alpha ct - 1}, \quad w_{cp}^{d*} = \frac{2\alpha^2 ct}{4\alpha ct - 1}, \quad \pi_{cp}^{d*} = \frac{\alpha^2 c}{2(4\alpha ct - 1)} - K \) and \( \pi_{cp}^{d*} = \frac{\alpha^3 c^2 t}{(4\alpha ct - 1)^2} \).
3) If $c > \hat{c}_{cp}$, the monopolist sets $p_{cp}^* = \frac{3\alpha}{4}$ and $w_{cp}^* = \frac{\alpha}{2}$ with $e_{cp}^* = 0$, which yields $q_{cp}^* = \frac{1}{4t}$, $
abla_{cp}^* = \frac{\alpha}{8t}$ and $
abla_{cp}^{**} = \frac{\alpha}{16t}$.

Lemma 2 shows the changes in the optimal choice of DRM technology dependent upon the effectiveness of DRM cost. As DRM technology becomes less efficient, the DRM level gets lowered, and eventually the DRM-free level is chosen. When $c \leq \hat{c}_{cp}$ the optimal choice of the upstream content provider is to implement limit price since the cost of implement DRM is low. As DRM technology becomes less efficient such as $c \geq \hat{c}_{cp}$, the upstream content provider accommodates piracy by setting a low level of DRM; Eventually DRM-free regime emerges when $c \geq \hat{c}_{cp}$. Under the CP control, the benefit of an increase in copy protection is the secondary effect to the content provider due to the lack of direct control on the retail price. Under the limit pricing regime, we can observe discrepancy in interests between the upstream content provider and the downstream retailer. As the cost effectiveness of the DRM technology decreases, it becomes costly for the upstream provider to produce the level of DRM strong enough to deter piracy. Responding to this, the upstream should lower the wholesale price which is beneficial to the downstream to increase its own profits.

2.3. Downstream control over DRM

In this section, we analyze how the downstream firm’s control over DRM changes the optimal behavior of the content provider and the retailer; the retail price ($p_r$) and the DRM ($e_r$) are determined by the downstream, while the licensing fee ($w_r$) by the upstream. Similar to the upstream control case, the downstream retailer decides whether to accommodate piracy or to

\[\frac{d\pi_{rt}^{**}}{dc} = \frac{2\alpha(1+2\alpha)(1+\alpha)^2(1+\alpha(1-\alpha)^2)}{\Delta^3} > 0.\]
implement limit pricing based on the level of the licensing fee. The retailer’s profits under two options are:

\[
\pi_r = \begin{cases} 
(p_r - w_r) \left( \frac{\alpha + e_r - p_r}{\alpha t} \right) & \text{accommodate if } \frac{e_r}{1-\alpha} < p_r \\
(p_r - w_r) \left( \frac{1 - p_r}{t} \right) & \text{limit pricing if } \frac{e_r}{1-\alpha} \geq p_r
\end{cases}
\]  

(9)

Expecting the optimal choice of the downstream in the second period, the content provider strategically sets \( \hat{w}_r > \hat{w}_r \) to make the downstream to accommodate piracy or to implement limit price when \( w_r \leq \hat{w}_r \) with \( \hat{w}_r = \frac{1-\alpha(1-\alpha)ct}{1+(1-\alpha)ct} \).

The optimal choice of price, licensing fee, DRM and profits are summarized in lemma 3.

**Lemma 3.**

1) If \( 0 \leq c \leq \hat{c}_r \), where \( \hat{c}_r = \frac{2-\alpha}{3\alpha t(1-\alpha)} \), the content provider sets the limit price

\[
p_r^{l*} = \frac{1}{1+(1-\alpha)ct}
\]

as her optimal choice. Other equilibrium values are

\[
e_r^{l*} = \frac{1-\alpha}{1+(1-\alpha)ct}, \quad q_r^{l*} = \frac{(1-\alpha)c}{1+(1-\alpha)ct}, \quad w_r^{l*} = \frac{1-\alpha(1-\alpha)ct}{1+(1-\alpha)ct},
\]

\[
\pi_r^{l*} = \frac{c(1-\alpha)^2(2\alpha ct - 1)}{2(1+(1-\alpha)ct)^2} - k, \text{ and } \pi_r^{u*} = \frac{(1-\alpha)c(1-\alpha(1-\alpha)ct)}{(1+(1-\alpha)ct)^2}.
\]

2) If \( \hat{c}_r < c \leq \hat{c}_r \), where \( \hat{c}_r = \frac{\alpha + 16tK}{32\alpha t^2K} \), the optimal choice of the monopolist is to accommodate piracy and sets the price at \( p_r^* = \frac{\alpha(3\alpha ct - 1)}{2(2\alpha ct - 1)} \) and we have \( e_r^* = \frac{\alpha}{2(2\alpha ct - 1)} \),

\[
q_r^* = \frac{\alpha c}{2(2\alpha ct - 1)}, \quad w_r^* = \frac{\alpha}{2}, \quad \pi_r^{u*} = \frac{\alpha^2 c}{4(2\alpha ct - 1)} \text{ and } \pi_r^{d*} = \frac{\alpha^2 c}{8(2\alpha ct - 1)^2} - K.
\]

3) If \( c > \hat{c}_r \), the monopolist sets \( p_r^* = \frac{3\alpha}{4} \) and \( w_r^* = \frac{\alpha}{2} \) with \( e_r^* = 0 \), which yields \( q_r^* = \frac{1}{4t} \),

\[
\pi_r^{u*} = \frac{\alpha}{8t} \text{ and } \pi_r^{d*} = \frac{\alpha}{16t}.
\]
Proposition 1 Under the accommodation regime the optimal pricing and the level of DRM across different control modes of DRM are shown as follows:

1) \( e_{vi}^* > e_r^* > e_{cp}^* \) and \( \pi_r^{us} > \pi_{cp}^{us} \left[ \pi_r^{us} < \pi_{cp}^{us} \right] \)

2) \( p_{cp}^* > p_r^* > p_{vi}^* \) with \( w_{ri}^* > w_{ri}^* = 0 \) and \( q_{vi}^* > q_r^* > q_{cp}^* \)

3) \( \hat{e}_{vi} > \hat{e}_r > \hat{e}_{cp} \) and \( \hat{e}_{vi} > \hat{e}_r > \hat{e}_{cp} \)

Proposition 1 can be understood as follows. In the two-tier model, whoever chooses to implement DRM, it is not efficient to reduce piracy compared to the choice of the vertically integrated monopoly due to the existence of opportunistic behavior. For instance, when the content provider sets a higher level of DRM, it is equivalent to an outward parallel shift in demand for the retailer. With an increased demand, there exists opportunistic behavior of the downstream retailer to respond with a price hike. The price increase, however, does not completely offset the initial demand increase with the result of increased sales. Therefore, the incentive for the content provider to provide stronger DRM is reduced. On the other hand, in the case of retailer control over DRM, we find that the optimal level of DRM chosen by the downstream retailer is higher than that by the upstream content provider. Since the upstream licensing fee is chosen before the downstream DRM, it eliminates the possible upward adjustment of the licensing fee by the content provider, which hampers the retailer’s incentive to invest in DRM. However, the level of DRM under R regime is still lower than under VI regime due to double monopolization. This phenomenon can be viewed as the downstream firm’s R&D incentive to raising the rival’s cost via increasing demand for inputs. Since the retailer’s investment in DRM to raise the copy cost is determined after the upstream firm’s choice of the licensing fee, it eliminates the negative effect of an upward adjustment of input price on R&D. As a result, the highest level of DRM is chosen by the vertically integrated firm. The next highest level is the one chosen by the downstream retailer. The lowest is the level chosen by the upstream content provider.

The optimal price across the different regimes is determined by the two opposite effects: the competition effect from piracy and the double marginalization effect. Based on the competition effect, the retailer under CP [VI] regime faces the most [least] aggressive competition since ‘the price’ of a pirated good is in the order of \( e_{vi}^* > e_r^* > e_{cp}^* \). Facing the highest
[lowest] level of competition, the retailer under CP [VI] regime has to charge the lowest price, which would result in the order of the optimal pricing such as $p^*_w > p^*_r > p^*_cp$. The double marginalization effect, on the other hand, causes the content provider to reverse the order. Since the incentive of the retailer to provide DRM under R regime is inversely related to the licensing fee\(^6\), he/she needs to charge a lower level of licensing fee compared to that under CP regime. Therefore, the effect of double marginalization is highest under CP regime; second highest under R regime and zero under VI regime [see part 2 in proposition 1]. Putting the conflicting effects together we have the dominant double marginalization effect, which yields the order of the optimal price in proposition 1.

The incentive to implement limit pricing represented by the upper boundary of $c$ shows similar intuition. Since opportunistic behavior of the downstream retailer exists under CP regime, the DRM technology should be very efficient to eliminate piracy compared to the case under R regime.

3. Piracy through digital distribution channels

We now introduce the digitalization of contents to incorporate the changes in consumer’s piracy behavior by introducing digital distribution channels such as P2P networks. Similar to Gayer and Shy (2003), we adopt Hotelling’s linear city model to incorporate consumer’s different valuation towards digitalization. The retailer is assumed to sell a traditional form of contents (i.e., CD, DVD) and locates at point 0. We assume that there exists a P2P network where consumers can obtain an illegal copy of digitalized contents and locates at point 1. Products from the retailer contain the same contents but their formats are assumed to be different. With this setting consumers view the same content with the different formats horizontally differentiated in terms of consumer preference towards the different formats, which is represented by the location of consumers. To be consistent with the model in the previous section, a consumer whose location is $x_i$ receives $(1-x_i)$ when he/she requires the non-digital

\(^6\) We can easily verify that $\frac{d e_x'}{d w_x} < 0$ from Appendix C where we have the optimal choice of DRM in the second stage such as $e_x'(w_x) = \frac{\alpha - w_x}{2\alpha \tau - 1}$. 

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format from the retailer, and the consumer gets $x_i$ with the digitalized format. Therefore, a type-$x_i$ consumer’s utility with normalization of $v$ equal to one is given by

$$U(x_i) = \begin{cases} 
(v-tx_i) - p = (1-tx_i) - p & \text{if he/she buys the traditional format} \\
(1-\alpha)(v-t(1-x_i)) - e & \text{if he/she copies the digital format}
\end{cases}$$ (10)

Given the three options to use the content, we denote $x_3$ as the marginal consumer who is indifferent between buying the original and making an illegal copy. With the definition of the marginal consumer $x_3$, we represent him/her as follows:

$$(1-tx_3) - p \equiv (1-\alpha)(1-t(1-x_3)) - e \Rightarrow x_3 = \frac{\alpha + \epsilon - \alpha t + e - p}{(2-\alpha)t}.$$

Given the configuration of the marginal consumer, we restrict our attention to the parameter regions in which the piracy constraint is binding, that is,

$$x_3 \leq 1 \Rightarrow p \geq e + \alpha - t$$ (11)

When the piracy constraint is binding, the demand faced by the downstream retailer determines how the retailer responds to piracy: accommodation or limit pricing. When the retailer chooses to eliminate piracy, the limit price is $\tilde{p}^L = \tilde{\epsilon} + \alpha - t$ which eliminates the incentive to copy.\footnote{Variables associated with piracy through digital distribution channels are denoted by a tilde.}

Another option for the retailer is to charge a price $\tilde{p} > \tilde{p}^L$ such that some consumers are better off using the illegal content. The retailer’s demand functions under the different regimes are given by

$$\tilde{q}(\tilde{p}, \tilde{\epsilon}) = \begin{cases} 
\frac{\alpha + \epsilon - \alpha t + \tilde{\epsilon} - \tilde{p}}{(2-\alpha)t} & \text{under the accommodation regime} \\
1 & \text{under the limit pricing regime}
\end{cases}$$ (12)

We consider the same two-stage game as described in the section 2 and table 1.

3.1. Benchmark case: vertically integration

We turn to the vertically integrated monopolist’s optimal choice of its price and DRM when the piracy constraint is binding, that is, $\tilde{p}_i > \tilde{e}_i + \alpha - t$. The first option for the monopolist is to accommodate piracy in which the monopolist sets a higher price and tolerates copying. In
this case, the monopolist’s objective is the same as equation (7) with \( \tilde{q}(\tilde{p}, \tilde{\epsilon}) = \frac{\alpha + t - \alpha t + \tilde{\epsilon} - \tilde{p}}{(2 - \alpha)t} \).

We derive the equilibrium for the vertically integrated monopoly results by using Kuhn-Tucker condition: when \( \tilde{c} > \hat{\tilde{c}}_v \equiv \frac{2(2 - \alpha)t}{4(2 - \alpha)Kt + ((3 - \alpha)t - \alpha)^2} \),

\[
\{\hat{p}_v^*, \hat{\epsilon}_v^*, \hat{q}_v^*, \hat{\tilde{\epsilon}}_v^*\} = \left[\frac{\alpha + t - \alpha t}{2}, 0, \frac{\alpha + t - \alpha t}{2(2 - \alpha)t}, \frac{(\alpha + t - \alpha t)^2}{4t(2 - \alpha)}\right]; \text{ When } \hat{\tilde{c}}_v = \frac{1}{(3 - \alpha)t - \alpha} \leq \tilde{c} \leq \hat{\tilde{c}}_v,
\]

\[
\{\hat{p}_v^*, \hat{\epsilon}_v^*, \hat{q}_v^*, \hat{\tilde{\epsilon}}_v^*\} = \left\{\frac{(2 - \alpha)(\alpha + t - \alpha)ct}{2(2 - \alpha)ct - 1}, \frac{\alpha + t - \alpha t}{2(2 - \alpha)ct - 1}, \frac{c(\alpha + t - \alpha t)}{2(2 - \alpha)ct - 1}, \frac{c(\alpha + t - \alpha t)^2}{2(2 - \alpha)ct - 1}\right\}.
\]

The second option for the monopolist is to eliminate piracy by setting the price sufficiently low. Since the monopolist reduces the price until the piracy constraint is binding, the limit price should satisfy the following incentive constraint to eliminate the incentive to copy. The optimal limit price that prevents the incentive to copy is given by \( \tilde{p}_v^L = \tilde{\epsilon}_v^L + \alpha - t \).

The first order condition with respect to \( \tilde{\epsilon}_v \)

\[
\frac{\partial \hat{\tilde{\epsilon}}_v^L}{\partial \tilde{\epsilon}_v} = 1 - c \tilde{\epsilon}_v^L = 0,
\]

(13)
gives us the results under limit pricing: \( \{\hat{p}_v^L, \hat{\epsilon}_v^L, \hat{q}_v^L\} = \left\{\frac{1}{c} - t + \alpha, \frac{1}{c}, \frac{1}{2c} - t + \alpha - K\right\} \). By comparing profits from each strategy, we conclude that the monopolist’s optimal choice is to limit price if \( c \leq \hat{\tilde{c}}_v = \frac{1}{(3 - \alpha)t - \alpha} \); to accommodate piracy if \( \hat{\tilde{c}}_v \leq c \leq \hat{\tilde{c}}_v \) where \( \hat{\tilde{c}}_v = \frac{2(2 - \alpha)t}{4(2 - \alpha)Kt + ((3 - \alpha)t - \alpha)^2} \); to accommodate piracy with DRM free if \( c \geq \hat{c} \).

3.2. Upstream control over DRM

We now consider the same game as the previous upstream control where the upstream still controls its licensing fee and DRM in the first period, while the downstream retailer is assumed to choose its retail price independently in the second period. The only difference is that there exists piracy through digital distribution channels. By backward induction, we proceed with the
retailer's optimal choice of pricing in the second period. The downstream retailer decides between accommodation and limit pricing strategies based on the realized DRM and the licensing fee. The retailer's profits under each regime are given in the following equation.

\[
\pi_{cp} = \left( \tilde{p}_{cp} - \tilde{w}_{cp} \right) \tilde{q}_{cp} = \begin{cases} 
\tilde{p}_{cp} - \tilde{w}_{cp} & \text{if } \tilde{p}_{cp} > \tilde{c}_{cp} + \alpha - t \\
\alpha + t - \alpha t + \tilde{c}_{cp} - \tilde{w}_{cp} & \text{if } \tilde{p}_{cp} \leq \tilde{c}_{cp} + \alpha - t
\end{cases}
\]

The first order condition with respect to \( p_{cp} \) under the accommodation regime gives us

\[
\frac{\partial \pi}{\partial p_{cp}} = \frac{1 + \tilde{c}_{cp} - \tilde{p}_{cp}}{2 - \alpha} = 0
\]

which yields \( \tilde{p}^*_{cp} = \frac{1}{2} (1 + \tilde{c}_{cp} + \tilde{w}_{cp}) \).

Comparing the profit function under two regimes, the downstream retailer's optimal prices are given by

\[
\tilde{p}^*_{cp} = \begin{cases} 
\frac{1}{2} (\alpha + t - \alpha t + \tilde{c}_{cp} + \tilde{w}_{cp}) & \text{if } \tilde{c}_{cp} < 3t - \alpha (1 + t) + \tilde{w}_{cp} \\
\tilde{c}_{cp} + \alpha - t & \text{if } \tilde{c}_{cp} \geq 3t - \alpha (1 + t) + \tilde{w}_{cp}
\end{cases}
\]

In the first stage, the upstream content provider has two options: making the downstream adopt accommodation by setting \( (w_{cp}, e_{cp}) \) to satisfy \( \tilde{c}_{cp} < 3t - \alpha (1 + t) + \tilde{w}_{cp} \) or implement the limit pricing with the constraint \( \tilde{c}_{cp} \geq 3t - \alpha (1 + t) + \tilde{w}_{cp} \). Under the accommodation regime, the CP maximizes the following profit function: \( \max_{\{w_{cp}, e_{cp}\}} \tilde{\pi}^u_{cp} = \tilde{w}_{cp} \tilde{q}_{cp} (\tilde{c}_{cp}) - C(\tilde{c}_{cp}) \). We can obtain the following solution by using Kuhn-Tucker condition:

If \( \tilde{c}_{cp} < c \leq \tilde{c}_{cp} \) where \( \tilde{c}_{cp} = \frac{1}{7t - \alpha - 3at} \) and \( \tilde{c}_{cp} = \frac{8Kt (2-\alpha) + (\alpha + t - \alpha t)^2}{32(2-\alpha)Kt^2} \), we have

\[
\{ \tilde{p}^*_{cp}, \tilde{e}^*_{cp}, \tilde{q}^*_{cp}, \tilde{w}^*_{cp} \} = \begin{pmatrix} 
\frac{3ct (2-\alpha)(\alpha + t - \alpha t)}{4(2-\alpha)ct - 1} & \alpha + t - \alpha t & c(\alpha + t - \alpha t) & 2ct (2-\alpha)(\alpha + t - \alpha t) \\
4(2-\alpha)t & 4(2-\alpha)ct - 1 & 4(2-\alpha)ct - 1 & 4(2-\alpha)ct - 1
\end{pmatrix}
\]

and
\[ \{ \tilde{\pi}_{cp}^i, \tilde{\pi}_{cp}^d \} = \left\{ \frac{c(a + t - at)^2}{2(4 - 2\alpha)(at - 1)} , \frac{c^2(t(2 - \alpha)(a + t - at)^2}{(4 - 2\alpha)at - 1} \right\}; \]

If \( c > \hat{c}_{cp} \), we have the DRM-free regime with

\[ \{ \hat{p}_{cp}^*, \hat{e}_{cp}^*, \hat{q}_{cp}^*, \hat{w}_{cp}^* \} = \left\{ \frac{3}{4} (a + t - at), 0, \frac{a + t - at}{4(1 - \alpha)t}, \frac{1}{2} (a + t - at) \right\} \text{ and} \]

\[ \{ \tilde{\pi}_{cp}^i, \tilde{\pi}_{cp}^d \} = \left\{ \frac{(a + t - at)^2}{8(2 - \alpha)t}, \frac{(a + t - at)^2}{16(2 - \alpha)t} \right\}. \]

On the other hand, the choice of the upstream is to make the downstream implement the limit pricing to maximize the following profit function:

\[ \text{Max} \hat{\pi}_{cp}^u = \tilde{w}_{cp}^L \hat{q}_{cp}^L - C \left( \hat{e}_{cp}^L \right) \text{ subject to } \hat{e}_{cp}^L \geq 3t - \alpha(1 + t) + \tilde{w}_{cp} \], which gives us

\[ \{ \tilde{p}_{cp}^*, \tilde{e}_{cp}^*, \tilde{q}_{cp}^*, \tilde{w}_{cp}^* \} = \left\{ \alpha + \frac{1}{c}, \frac{1}{c}, \frac{1}{c}, \frac{1}{c} + \alpha - (3 - \alpha)t \right\} \text{ and} \]

\[ \{ \tilde{\pi}_{cp}^i, \tilde{\pi}_{cp}^d \} = \left\{ \frac{1}{2c} + \alpha - (3 - \alpha)t - K, (2 - a)t \right\}. \]

By comparing profits under different regimes we conclude that the monopolist’s optimal choice is to limit price if \( c \leq \hat{c}_{cp} = \frac{1}{7t - \alpha - 3at} \).

### 3.3. Downstream control over DRM

We repeat the downstream control case with digital piracy. By backward induction, the downstream retailer chooses its price and DRM \( \{ \tilde{p}_r, \tilde{e}_r \} \) to maximize the following equation:

\[ \tilde{x}_r = (\tilde{p}_r - \tilde{w}_r) \tilde{q}_r - C(\tilde{q}_r) = \begin{cases} (\tilde{p}_r - \tilde{w}_r) \frac{\alpha + t - at + \tilde{e}_r - \tilde{p}_r}{(2 - \alpha)t} - C(\tilde{q}_r) & \text{accommodate if } \tilde{p}_r > \tilde{e}_r + \alpha - t \\ (\alpha + t - at + \tilde{e}_r - \tilde{w}_r) - C(\tilde{q}_r) & \text{limit pricing if } \tilde{p}_r \leq \tilde{e}_r + \alpha - t \end{cases} \]

The optimal choice of \( \{ \tilde{p}_r, \tilde{e}_r \} \) is given by
In the first stage, the upstream content provider sets $w_r$ to maximize $\tilde{\pi}_r^u = \tilde{w}_r \hat{q}_r$. By using Kuhn-Tucker condition, we have the following equilibrium values:

If $\hat{c}_r < c \leq \hat{c}_r$ where $\hat{c}_r = \frac{2}{(7-3\alpha) t - \alpha}$ and $\hat{c}_r = \frac{16Kt(2-\alpha) + (\alpha + t - \alpha)^2}{32(2-\alpha) K t^2}$, we have

$$\{\hat{p}_r^*, \hat{e}_r^*, \hat{q}_r^*, \hat{w}_r^*\} = \left\{ \frac{(\alpha + t - \alpha)(3(2-\alpha)ct - 1)}{4(2-\alpha)ct - 2}, \frac{\alpha + t - \alpha}{4(2-\alpha)ct - 2}, \frac{(\alpha + t - \alpha)c}{4(2-\alpha)ct - 2}, \frac{1}{2}(\alpha + t - \alpha) \right\} \text{ and}$$

$$\{\tilde{\pi}_r^u, \tilde{\pi}_r^{d*}\} = \left\{ \frac{(\alpha + t - \alpha)^2 c}{8(2-\alpha)ct - 4}, \frac{\alpha + t - \alpha)^2 c}{8(2-\alpha)ct - 1} \right\}.$$

If $c > \hat{c}_r$, we have the DRM-free regime with

$$\{\hat{p}_r^*, \hat{e}_r^*, \hat{q}_r^*, \hat{w}_r^*\} = \left\{ \frac{3}{4}(\alpha + t - \alpha), 0, \frac{\alpha + t - \alpha}{4(1-\alpha)t}, \frac{1}{2}(\alpha + t - \alpha) \right\} \text{ and}$$

$$\{\tilde{\pi}_r^u, \tilde{\pi}_r^{d*}\} = \left\{ \frac{(\alpha + t - \alpha)^2}{8(2-\alpha)t}, \frac{(\alpha + t - \alpha)^2}{16(2-\alpha)t} \right\}.$$

On the other hand, the choice of the upstream is to make the downstream implement the limit pricing to maximize the following profit function: $\max_{\tilde{w}_r} \tilde{\pi}_r^{UL} = \tilde{w}_r \hat{q}_r$ with

$$\tilde{w}_r \leq \alpha - (3-\alpha)t + \frac{1}{c}$$

giving us the following equilibrium values under limit pricing:

$$\{\tilde{p}_r^{UL}, \tilde{e}_r^{UL}, \tilde{q}_r^{UL}, \tilde{w}_r^{UL}\} = \left\{ \frac{1}{c} - t + \alpha, \frac{1}{c}, \frac{1}{c} + \alpha - (3-\alpha)t \right\} \text{ and}$$

$$\{\tilde{\pi}_r^{UL}, \tilde{\pi}_r^{DL}\} = \left\{ \frac{1}{c} + \alpha - (3-\alpha)t, (2-\alpha)t - \frac{1}{2c} - K \right\}.$$

By comparing profits under two different regimes-accommodation and limit pricing, we conclude that the content provider’s optimal choice is to implement limit pricing if $c \leq \hat{c}_r$. 

(17)
Proposition 2 Under the accommodation regime the impact of digital distribution channels on optimal pricing, the demand for legal contents and the level of DRM with comparison to those under the non-digital distribution channels under different control on DRM is follows:

1) $e_j^* \geq \hat{e}_j^*$

2) $p_j^* \leq \hat{p}_j^*$ with $w_j^* \leq \hat{w}_j^*$ and $q_j^* \geq \hat{q}_j^*$

3) $\hat{c}_j > \hat{c}_j$ where $j = \{vi, cp, r\}$

The intuition behind proposition 2 can be found in the different nature of the demand curves for the original content with the presence of different types of piracy. The demand curve with non-digital piracy in equation (4) is depicted in Figure 1 (a) as $D_N$ and is the kinked curve $ABC$. It implies that the higher the price of the content is, the more consumers switch to making an illegal copy. Also, a lower price reduces the incentive for consumers to turn to piracy so that the lower portion of the demand curve is the same as the old demand curve, which is denoted as $D_O$. On the other hand, the demand curve with the presence of digital piracy in equation (12) is depicted on Figure 1 (b) as $\hat{D}_N$ and is the kinked curve $EFG$. It implies that the lower the price of the content is, the harder it is to attract low-valuation consumers to switch from making an illegal copy to purchase the content. It gives less incentive for the monopoly to lower its price to compete against piracy. Also, a higher price enables the monopoly to restore his monopoly power by moving away from the threat of piracy so that the higher portion of the demand curve is the same as the old demand curve, which is denoted as $\hat{D}_O$. Comparing the shape of the two demand curves, the one with digital piracy shows unusual characteristics such as demand being more elastic in the monopoly region at higher prices than in the piracy region at lower prices. The opposite characteristics are observed with the other with non-digital piracy. Therefore, if the piracy constraint is binding and the optimal response to that is accommodation, we observe that the price is higher and the demand for the original content is lower with digital piracy than with non-digital piracy.

This may suggest a possible answer to the counterintuitive empirical observations such as observing non-decreasing prices and decrease in sales with response to digitalization in the
music industry in the United States (e.g., Liebowitz, 2006; Peitz and Waelbroeck, 2005). If we assume piracy through digital distribution channels such as P2P networks as horizontally differentiated from the non-digital content, we may observe non-decreasing prices and decline in sales as presented in proposition 2.

4. Comparative Statics
We now analyze the effect of a marginal increase in public copy protection, which is comparable to 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 on the effects associated with two different types of costs associated with piracy for the monopoly case: the constant reproduction cost and the proportional degradation rate. Since the optimal level of DRM, which corresponds to the reproduction cost, is endogenously determined by either the content provider or the retailer, we concentrate on the other measure of IPR protection, which is the public copy protection, which is represented by an increase in $\alpha$. Proposition 3 and table 2 summarize the results of the comparative statics.

**Proposition 3.** Under the accommodation regime, as expected, the retail price increases with the strengthening of IPR protection. The effects of an increase in IPR protection on the authorized usage of the content, however, depend on the types of distribution channels. Under piracy through non-digital distribution channels, a higher public protection induces less authorized usage whereas it induces more authorized usage under piracy through digital distribution channels [see table 2].

The intuition underlying this result is the following. The same increase in IPR protection induces the different results due to the different change in the demand for the original content with different types of piracy. If there is an increase in IPR protection with non-digital distribution channels, we observe a clockwise *pivot* change above the kink in demand with a “north-west” move in the kink itself that affects the *slope* of the demand curve for legal copies [see Figure 2 (a)]. Due to the proportional increase in the gross copy cost, higher valuation
consumers are more adversely affected by an increase in the detection cost. A steeper demand curve means that elasticity of consumers is lower with more market power. Thus, the monopolist is more interested in serving only the high valuation consumers. On the other hand, the same increase in IPR protection with digital distribution channels, we observe an anticlockwise pivot change below the kink in demand with a “north-west” move in the kink itself, which affects the slope of the demand for legal copies [see Figure 2 (b)]. Due to the reverse proportional increase in the gross copy cost, lower valuation consumers are more adversely affected by an increase in the detection cost. Facing a flatter demand curve but with increased demand from the low valuation consumers, the optimal response from the monopoly is to increase price but still be able to sell the content to more consumers.

5. Concluding Remarks
This paper examines how digitalization of contents influences consumers’ piracy behavior and firms’ optimal choice on the level of DRM and prices. We construct a model of vertical relationship incorporating two different types of piracy determined by different distribution channels under the different control modes of DRM. Three different business models are proposed according to the control mode of DRM which determines the right to implement DRM by vertically-integrated entity, the upstream, and the downstream. In this setup the main findings are as follows. First, we find that the optimal level of DRM and prices are determined by different types of control mode. The highest level of DRM is chosen by vertically integrated firm. The next highest level is the one chosen by the downstream retailer. The lowest is the level chosen by the upstream content provider. Also, the incentive to block piracy is consistent with the order of the level of DRM. We show that the results are dependent upon the control mode of DRM and the degree of opportunistic behavior responding to increasing piracy costs. Second, we analyze the effect of two different types of piracy depending on distribution channels. In doing so, this paper provides new insights to the literature on piracy. The introduction of horizontally differentiated digital pricy sheds light on answering some counterintuitive empirical facts in the previous literature about the impact of digitalization on prices and sales in the music industry. Through a shift from a non-digital piracy to a digital piracy, we find non-decreasing prices and decline in sales. This provides a theoretical foundation to justify the claims from the empirical literature. Third, we provide a theoretical framework to show that the effect of piracy
depends crucially on the nature of distribution channels (e.g., non-digital versus digital). In particular, strengthening IPR protection results in a price hike, while we have opposite changes in quantities depending on different types of piracy. The results in this paper thus suggest that any policy implementation of IPR protection should pay more attention to a distribution channel since the policy change will affect the two types of piracy differently.

Our approach to the effect of digitalization on the content industry with the different control modes of DRM and piracy through digital distribution channels (e.g., P2P networks) provides some insight, but there are some limitations. In our model, we analyze a simplified horizontal differentiation model with the presence of digital piracy, but we do not explicitly introduce the full-fledged model with two different types of downstream retailers in terms of the content format (e.g., one with the non-digital content and the other with the digital content) and the control of DRM. It allows us to analyze an interaction between the retailers with threats of two different types of piracy. This could be a future task of our research.
### Table 1 The timing of the game under different regimes

<table>
<thead>
<tr>
<th>The control mode of DRM</th>
<th>The vertically integrated monopoly content provider</th>
<th>The upstream monopoly content provider</th>
<th>The downstream monopoly retailer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1\textsuperscript{st} stage</td>
<td>$\left( p_{vi}, e_{vi} \right)$</td>
<td>$\left( w_{cp}, e_{cp} \right)$</td>
<td>$w_r$</td>
</tr>
<tr>
<td>2\textsuperscript{nd} stage</td>
<td>$p_{cp}$</td>
<td></td>
<td>$(p_r, e_r)$</td>
</tr>
</tbody>
</table>

### Table 2 Comparative statics under different regimes

<table>
<thead>
<tr>
<th>Accommodation</th>
<th>Piracy through non-digital channels</th>
<th>Piracy through digital channels (P2P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>An increase in $\alpha$</td>
<td>$\frac{\partial p_{vi}}{\partial \alpha} &gt; 0$ $\frac{\partial q_{vi}}{\partial \alpha} &lt; 0$ $\frac{\partial e_{vi}}{\partial \alpha} &lt; 0$</td>
<td>$\frac{\partial p_{cp}}{\partial \alpha} &gt; 0$ $\frac{\partial q_{cp}}{\partial \alpha} &lt; 0$ $\frac{\partial e_{cp}}{\partial \alpha} &lt; 0$</td>
</tr>
<tr>
<td>An increase in $c$</td>
<td>$\frac{\partial p_{vi}}{\partial c} &lt; 0$ $\frac{\partial q_{vi}}{\partial c} &lt; 0$ $\frac{\partial e_{vi}}{\partial c} &lt; 0$</td>
<td>$\frac{\partial p_{cp}}{\partial c} &lt; 0$ $\frac{\partial q_{cp}}{\partial c} &lt; 0$ $\frac{\partial e_{cp}}{\partial c} &lt; 0$</td>
</tr>
</tbody>
</table>
Figure 1 Demand curve for originals with different types of piracy

Figure 2 The Effects of an increase in $\alpha$
References


Appendix A. Proof of Lemma 1

We have the following two maximization problems for the vertically integrated monopolist:

\[
\begin{align*}
\text{Max } \pi_{vi} &= p_{vi} \left( \frac{1 - p_{vi}}{t} \right) - \frac{c}{2} e_{vi}^2 + K \quad \text{s.t. } p \leq \frac{e}{1 - \alpha} ; \\
\text{Max } \pi_{vi} &= p_{vi} \left( \frac{\alpha + e_{vi} - p_{vi}}{\alpha t} \right) - \frac{c}{2} e_{vi}^2 + K \quad \text{s.t. } p \geq \frac{e}{1 - \alpha}
\end{align*}
\]

We consider the first problem of limit pricing. It is easily verified that \( p_{vi} \left( \frac{1 - p_{vi}}{t} \right) \) is increasing when \( p_{vi} \in \left[ 0, \frac{1}{2t} \right] \). The unique solution is \( p = \frac{e}{1 - \alpha} \) with which the first order condition with respect to \( e_{vi}^c \) gives us the results under limit pricing. The first order conditions with respect to \( p_{vi} \) and \( e_{vi}^c \) for the second problem are given by

\[
\begin{align*}
\frac{\partial \pi_{vi}}{\partial p_{vi}} &= \frac{\alpha + e_{vi} - p_{vi}}{\alpha t} + p_{vi} \frac{-1}{\alpha t} = 0 \\
\frac{\partial \pi_{vi}}{\partial e_{vi}^c} &= p_{vi} \frac{1}{\alpha} - c e_{vi} \leq 0 \quad \text{with equality when } \ e_{vi} > 0
\end{align*}
\]

By using Kuhn-Tucker condition, equation (A2) has \( e_{vi}^c = 0 \) when \( c > \hat{c}_{vi} \) and \( e_{vi}^c = \frac{p_{vi}}{\alpha ct} \) when \( \hat{c}_{vi} < c \leq \hat{c}_{vi} \). Solving equation (A1) and \( e_{vi}^c = 0 \left[ e_{vi}^c = \frac{p_{vi}}{\alpha ct} \right] \) together yields the equilibrium solutions under the DRM-free case [the accommodation case].
Appendix B. Proof of Lemma 2

We have the following maximization problem for the downstream content retailer in the second period:

$$\max_{p_{cp}} \pi^{d}_{cp} = (p_{cp} - w_{cp}) \left( \frac{\alpha + e_{cp} - p_{cp}}{\alpha t} \right)$$

The first order condition with respect to $p_{cp}$ is given by

$$\frac{\partial \pi_{cp}}{\partial p_{cp}} = -\frac{p_{cp} - w_{cp}}{\alpha t} + \frac{e_{cp} - p_{cp} + \alpha}{\alpha t} = 0$$

which gives us $p_{cp}^{*} = \frac{1}{2} \left( \alpha + e_{cp} + w_{cp} \right)$ and $q_{cp} = \frac{1}{2\alpha t} \left( \alpha + e_{cp} - w_{cp} \right)$. In the first period, the upstream content provider maximizes the following problems:

$$\max_{\{e_{cp}, w_{cp}\}} \pi^{u}_{cp} = w_{cp} q_{cp} - \left( \frac{c}{2} e_{cp}^2 + K \right) \text{ s.t. } p_{cp}^{*} = \frac{1}{2} \left( \alpha + e_{cp} + w_{cp} \right) \text{ where } q_{cp} = \frac{1}{2\alpha t} \left( \alpha + e_{cp} - w_{cp} \right)$$. The optimal choices of the content provider are dependent upon parameter values.

If $0 \leq c \leq \hat{c}_{cp}$ where $\hat{c}_{cp} = \frac{1}{3\alpha t (1-\alpha)}$, the upstream content provider implements limit pricing by setting $\{e_{cp}, w_{cp}\}$ such as $p_{cp}^{*} = \frac{1}{2} \left( \alpha + e_{cp} + w_{cp} \right) \leq \frac{e_{cp}}{1-\alpha}$, which becomes $w_{cp} \leq \left( \frac{1+\alpha}{1-\alpha} \right) e_{cp} - \alpha$. It is easily verified that $w_{cp} \left( \alpha + e_{cp} - w_{cp} \right)$ is increasing when $w_{cp} \in \left[ 0, \left( \frac{1+\alpha}{1-\alpha} \right) e_{cp} - \alpha \right]$. Thus, the maximization problem becomes $\max_{e_{cp}} \pi^{u}_{cp} = w_{cp} q_{cp} - \left( \frac{c}{2} e_{cp}^2 + K \right)$ with the binding constraint,

$$w_{cp} = \left( \frac{1+\alpha}{1-\alpha} \right) e_{cp} - \alpha$$. The first order condition with respect to $e_{cp}$ is given by

$$8 \text{ We evaluate the content provider’s first order condition at } w_{cp} = \left( \frac{1+\alpha}{1-\alpha} \right) e_{cp} - \alpha, \text{ which yields }$$

$$3\alpha (1-\alpha) - e_{cp} (1-3\alpha) > 0 \text{. And, this condition should be satisfied since we assume that the piracy constraint is binding: } p_{cp}^{*} \geq e_{cp}^{\ast} \Leftrightarrow \frac{e_{cp}}{1-\alpha} \geq \frac{e_{cp}}{1-\alpha} \text{ where } w_{cp}^{\ast} = \arg \max_{w_{cp}} \pi^{u}_{cp} = w_{cp} \left( \frac{\alpha + e_{cp} - w_{cp}}{2\alpha t} \right), \text{ which, in turn, confirms that } 3\alpha (1-\alpha) - e_{cp} (1-3\alpha) > 0$$.
\[
\frac{\partial \pi_{cp}}{\partial e_{cp}} = \frac{\partial w_{cp}}{\partial e_{cp}} q_{cp} + w_{cp} \frac{\partial q_{cp}}{\partial e_{cp}} - ce_{cp} = 0
\]  

(B2)

which gives us \(e_{cp}^* = \left( 1 + \alpha - 2\alpha^2 \right) / \left( c \left(1 - \alpha \right)^2 + 2 \left(1 + \alpha \right) \right)\).

If \(c > \hat{c}_{cp}\), we can obtain the following solution by using Kuhn-Tucker condition: 

\[
w_{cp}^* = \frac{2 \alpha^2 ct}{4 \alpha ct - 1}
\]

and \(e_{cp}^* = \frac{\alpha}{4 \alpha ct - 1}\) when \(\hat{c}_{cp} < c \leq \hat{\hat{c}}_{cp}\); 

\[
w_{cp}^* = \frac{\alpha}{2}\]

and \(e_{cp}^* = 0\) when \(c > \hat{\hat{c}}_{cp}\).
Appendix C. Proof of lemma 3

By backward induction, the downstream retailer chooses its price and DRM \( \{p_r, e_r\} \) to maximize

\[
\max \pi'_r = (p_r - w_r)q_r(p_r, e_r) - C(e_r) = (p_r - w_r)\left(\frac{\alpha + e_r - p_r}{\alpha t}\right) - ce_r^2 - K \tag{C1}
\]

The first order conditions with respect to \( \{p_r, e_r\} \) gives us

\[
\begin{align*}
    p_r^*(w_r) &= \frac{\alpha^2 c t + (\alpha c t - 1) w_r}{2\alpha c t - 1}, \\
e_r^*(w_r) &= \frac{\alpha - w_r}{2\alpha c t - 1}.
\end{align*}
\]

In the first period, the CP has the following maximization problem: \( \max \pi^u_r = w_r q_r = w_r \left(\frac{\alpha - w_r}{2\alpha c t - 1}\right) \). If \( 0 \leq c \leq \hat{c}_r \), the CP has

\[
\max \pi^u_r = w_r q_r = w_r \left(\frac{\alpha - w_r}{2\alpha c t - 1}\right) \text{ s.t. } w_r \leq \frac{1 - \alpha (1 - \alpha c t)}{1 + (1 - \alpha) c t}.
\]

Since \( w_r \left(\frac{\alpha - w_r}{2\alpha c t - 1}\right) \) is creasing in \( w_r \in \left[0, \frac{1 - \alpha (1 - \alpha c t)}{1 + (1 - \alpha) c t}\right] \), we have \( w_r^* = \frac{1 - \alpha (1 - \alpha c t)}{1 + (1 - \alpha) c t} \). If \( c > \hat{c}_r \), we have

\[
w_r^* = \frac{\alpha}{2} \in \arg \max \pi^u_r = w_r \left(\frac{\alpha - w_r}{2\alpha c t - 1}\right).
\]

For the R’s profit maximization in the second period we can obtain the following solution by using Kuhn-Tucker condition: \( e_r^* = \frac{\alpha}{2(2\alpha c t - 1)} \) when \( \hat{e}_r < c \leq \hat{c}_r \); \( e_r^* = 0 \) when \( c > \hat{c}_r \).

---

9 The condition for this is \( 3\alpha (1 - \alpha c t) + \alpha - 2 > 0 \), which can be derived from evaluating the content provider’s first order condition. We evaluate the CP’s first order condition at \( w_r = \frac{1 - \alpha (1 - \alpha c t)}{1 + (1 - \alpha) c t} \). This condition should be satisfied since we assume that the piracy constraint is binding: \( p_r^* \geq \frac{e_r^*}{1 - \alpha} \iff \frac{\alpha (3\alpha c t - 1)}{2(2\alpha c t - 1)} \geq \frac{\alpha}{2(1 - \alpha)(2\alpha c t - 1)} \), which, in turn, confirms that \( 3\alpha (1 - \alpha c t) + \alpha - 2 > 0 \).