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Digital piracy: Price-quality competition between legal firms and P2P network hosts

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ABSTRACT

This paper examines competition between firms that produce legal information goods and host sites that index P2P links. Specifically, we develop a simple model in which a legal firm determines price for its information good and a P2P host site decides on its investment to improve the quality and accessibility of the information goods linked to its site for free download. In the analysis, users choose between goods that are both horizontally and vertically differentiated. We show conditions under which the profitability of legal firms may or may not be negatively affected by the presence of a P2P network. In addition, we demonstrate the resilience of P2P host sites to distribute digital goods. Our approach extends earlier studies in the literature to further allow for price-quality competition between legal firms and P2P network hosts.

1. Introduction

Piracy of digital goods has become a prevalent topic in both the industrial organization and regulatory literature. The low/zero reproduction cost of digital files allows for easy exchange online, by simply transferring files between computers. More and more goods are being sold in a digital format, thus creating a strong incentive to pirate digital goods. As the internet has become ubiquitous, retailers of physical and digital goods are constantly competing with pirated copies. Anyone with the digital good (legal or illegal) and a computer can easily and costlessly create copies. A common approached for pirates is to create a specific type of online link[1] to the file which provides access through a Peer-To-Peer (P2P) network. By uploading a digital copy online, obtaining the good becomes as easy as finding the link.

Many websites exist that provide a search engine for links to specific files.[2] When the user connects via the link, they join a "swarm" which is a network that shares the desired file. It is important to note that without the host site that indexes the links, users would not be able to find anonymous sources for the desired file. Thus, host sites of P2P links provide a necessary service to create robust P2P

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[1] The magnet link pertains to a unique file (or good). By creating a magnet link, others looking for a specific good can connect to the user, and obtain pieces of the file (or good).

[2] The Pirate Bay (TPB) has become an infamous host of P2P links. Basically, they provide an index service to help users identify links to desired files (goods).

networks both in scope (i.e. size of catalog) and scale (number of suppliers and demanders of a good[3]). The larger the network, the better it can facilitate timely and anonymous transfers of digital goods. Since P2P host sites act as a central hub to find desired content, they can track access and usage of their links. This allows P2P host sites to act as gatekeepers to files that they themselves do not control. As a result, representing host sites for P2P links is necessary in order to properly identify not only competition in markets with digital goods, but also identify regulatory implications.

This paper is the first attempt to present a simple framework for analyzing the optimizing behavior of host sites of P2P network links. In the face of digital piracy, legal firms have to take into account P2P network hosts that actively manage links to illegally download P2P goods. The framework allows us to characterize explicitly, direct competition between a legal retailer that optimizes profit using price and an illegal source that optimizes profit by improving their indexing quality (in terms of enhancing both the accessibility and characteristics of the information goods linked to the site for free download).

Analyzing the economic effects of counterfeiting has a history that long predates P2P network sharing (Liebowitz, 1985; Ordover and Willig, 1978). With improvement in reproduction technology, additional research has incorporated the properties of digital goods (see, e.g., Takeyama, 1994; Varian, 2000; Chen and Png, 2003; Banerjee, 2003; Peitz and Waelbroeck, 2006a). Still, piracy research has not resulted in a consensus. Even at the firm level, research has shown piracy has an ambiguous effect on the producer's profits. Many of the discrepancies are due to the type of good (software, music, movies, etc.) and its market structure (monopoly, competitive, etc.). Nonetheless, literature has emerged to identify the effects of piracy regulation and protection on profit and welfare (see, e.g., Conner and Rumelt, 1991; Yoon, 2002; Bae and Choi, 2006; Wu and Chen, 2008; Cremer and Pestieau, 2009; Harbaugh and Khemka, 2010). Much of the counterfeit literature has implications for online piracy; however including the nuisances of P2P networks adds additional complexity.

A great deal of the research focuses on the effects piracy has on the legal distributor's market, and excludes piracy networks. More recently, economic literature has emerged discussing and identifying the unique qualities of P2P networks (Gayer and Shy, 2003; Krishna et al., 2003; Cunningham et al., 2004). However, few articles have attempted to model the user response to illegal P2P network goods in the presence of a firm producing the legal version of the good. The contribution by Casadesus-Masanell and Hervas-Drane (2010) presents digital content distribution models to compare the P2P network and client–server distribution, paying special attention to the connection between uploaders and downloaders. Another contribution by Herings et al. (2010) introduces a P2P network into a monopolistic firm's market and employ a two-stage game to capture the firm's responses. In their analysis, the authors assume that the P2P network could not influence accessibility to the user.

However, the necessary connection and communication that P2P host sites provide is often overlooked in the literature. Our approach differs in that the P2P host site is able to strategically influence the availability and quality of goods for free download, thus affecting both the users' utility from the good and their search cost. In addition, the literature about online piracy omits another critical property of online piracy: advertising. A visit to any P2P host site will require exposing oneself to various amounts of advertising, thus providing a method P2P host sites to monetize visits from users. The financial resources created by advertising allow P2P host sites to optimize their operations, thus enabling them to compete with legal retailers.

It seems that the current literature omits competition *between* a legal product firm and a P2P network host, one selecting product price and the other selecting access and quality of the good. It is the objective of this paper to fill this gap in the literature. In the analysis, users choose between a legal good and the downloaded P2P version of the good that are both horizontally and vertically differentiated. The key findings in the present paper are as follows. (i) Other things being equal, a P2P network host's investment to increase the accessibility and quality of the P2P network good is higher in the partially served market than in the fully served market. (ii) Under a fully served market, the legal firm is able to make a profit despite competition against a P2P network host. The profitability and hence the viability of the P2P network depends on elements such as legal goods value and downloading costs. (iii) As the degree of horizontal differentiation decreases for digital goods, the P2P websites' optimal level of download file quality will unambiguously increase, while their profits will decrease. In addition, lower horizontal differentiation will cause retail prices to unambiguously decrease.

Our analysis complements the recent contribution by Peitz and Waelbroeck (2006b). In examining whether the music industry necessarily suffers from free downloading, Peitz and Waelbroeck (2006b) develop an interesting model that emphasizes the role of sampling. The authors focus their analysis on the users' lack of knowledge of existing goods. In our model that stresses the role of optimizing behavior by P2P network hosts for digital goods, we consider the situations where users are familiar with the products available, and select a source of the product to maximize their utility. We find that retailers will remain profitable even when P2P network hosts are active in pursuing profit-maximizing behavior by improving the quality of the downloaded P2P goods. But the positive profitability of retailers may decrease due to competition from the P2P source.

The remainder of this paper is organized as follows. In Section 2, we lay out the analytical framework of competition between a firm that produces a legal information product and a host site that indexes P2P links for free download. Section 3 examines the case in which the market is partially served, so only a portion of consumers use the product (legal or illegal). Section 4 focuses on the analysis of competition between the firm and the P2P network host in a fully served market where consumers choose

[3] Suppliers or sources of good on a P2P network are referred to as "seeds," demanders are referred to as "nodes."

between a legal or illegal product. Concluding remarks can be found in Section 5.

2. The model

We consider a market for cultural goods[4] that can be digitalized, and are supplied by two sources, retail store and illegal downloads from P2P networks. To consumers, the legal information good has value α, and its downloaded version has value $\theta\alpha$. The P2P version may be a fully-functional product compared to legal/retail product. In this case, the value of θ is equal to 1. The downloaded good could be a compressed or lower quality version. In this case, we have $0 < \theta < 1$. We wish to examine the scenario where a P2P network host has an economic incentive to pursue optimizing behavior in improving the quality of the downloaded P2P good. That is, the P2P network host exerts costly investment by optimally determining the value of θ. The endogenous variable θ can be interpreted as a measure of vertical differentiation or *quality* measure of the P2P download good.

2.1. Users utility

Using the Hotelling spatial approach as in the literature (see, e.g., Gayer and Shy, 2003, 2006; Herings et al., 2010), we assume that there is a continuum of potential users of digital goods, indexed by x, which lies on the interval $[0,1]$. Users are ordered on the interval by their preference for each source. Users indexed close to 0 represent those with a strong preference for retail copies, which could be caused by a lack of computer proficiency or altruism. Similarly, users indexed close to 1 represent those with preference to the P2P source of the good. Although the P2P version is downloading free, its quality may be lower than that of the legal good. We wish to incorporate into the analysis both elements of horizontal and vertical differentiation.

We use τ to represent a measure of horizontal differentiation associated with the product, where users indexed close to 1 heavily discount the value of the retail good. Conversely, users indexed close to 0 heavily discount the P2P version of the good, because as x approaches 0, the value of $\tau(1-x)$ approaches τ. In addition, our model allows for the case when no horizontal differentiation is present ($\tau = 0$). Each user is assumed to obtain at most one unit of a good, and the utility of each user, x, can be defined as follows:

$$U_x = \begin{cases} \alpha - \tau x - p - \delta & \text{if retail good is purchased,} \\ \theta\alpha - \tau(1-x) - (\delta + D + A) & \text{if P2P version of good is downloaded,} \\ 0 & \text{if good is not used,} \end{cases} \tag{1}$$

where p is the retail price of the good, δ is the opportunity cost of obtaining the retail good, D represents the additional search, opportunity, and download costs of obtaining the P2P version of the product in excess of the legal retail source, and A is an additional cost related to the annoyance of viewing the advertisements during downloading. The term A will be discussed further. It is plausible to assume that $\alpha > \delta$.

To identify market size for each good we use the following notation: x_L represents the marginal user of legal information product, and x_{P2P} the marginal user of the downloaded P2P version. The interval $[0, x_L]$ represents the number of users that purchase the retail version, and the interval $[x_{P2P}, 1]$ represents the number of users obtaining the P2P downloaded good. There are two possibilities. (i) If $x_L = x_{P2P}$, the market is fully served in that all users obtain some version of the product. (ii) If $x_L < x_{P2P}$, the market partially served in that some individuals do not use either version of the product.

2.2. P2P network characteristics

In the model, we assume that the opportunity cost of obtaining a good from a P2P network is always larger than from a retail store. This is appropriate considering that most digital goods are available from retailers online. More importantly, online retailers usually have easy to navigate websites. This results in faster download times, along with higher reliability and customer service if problems occur.[5] However, whenever a user visits a P2P host site they are exposed to advertising, which provides the P2P host with an incentive to improve the access and quality of their content in order to lure more users to their website.

P2P network usage has additional constraints beyond those of a retailer. Using a P2P network requires extra computer literacy compared to a retail source. In addition, network transfer speeds are also directly influenced by the number of sources on a P2P network and the number of requests by the users.[6] Therefore the cost term associated with obtaining a good from a P2P network, D, can further be represented by

$$D = (1 - x_{P2P})C, \tag{2}$$

where C represents a generic downloading cost. It is important to note that in this equation, $(1 - x_{P2P})$ is the measures of the number of users concurrently downloading the file. Thus the download cost is the same for every user. By including a measure of the number of users, P2P download cost equation maintains the unique features of a P2P network. Additional details about download costs are provided in Appendix A.

2.3. Indexing quality of host sites

As previously mentioned, host sites for P2P links are a necessary communication hub between suppliers and

[4] Dejean (2009) describes "cultural goods" as goods that could be reproduced and are subject to copyright.

[5] Comparing a client/server network to a P2P network is difficult due to their structure, Leibnitz et al. (2007) provide an in depth analysis and discuss characteristics of both.

[6] Not only does the number of sources (seeds) impact the download speeds, but also the willingness of network participants to share while connected to the network. Cunningham et al. (2004) discusses the economics of P2P communities, and the success of sharing communities. For simplicity we assume a linear relationship between network size and download time. Additional details about the download structure of P2P networks is discussed in Appendix A.1.

demanders of digital goods. Each downloader must visit the P2P website in order to link to the desired files. By visiting the P2P website, each user is shown various advertisements, which provide revenue for the P2P website.[7]

We consider the case in which a P2P network host site finances their internet operations with income from advertisements.[8] As such, total revenue from the advertisements depends on the size (or number of users) of the P2P network host site, $(1 - x_{P2P})$. We assume that users access the site only once per download, thus a "per view" ad revenue function is used, creating a linear relationship between the number of users and ad revenue. That is, total revenue is represented by $(1 - x_{P2P})A$, where the parameter A is positive and can be interpreted as ad revenue generated per visit. As with most websites that generate revenue through showing ads, the price per advertisement is heavily influence by the major advertising companies.[9]

Websites determine the size and number of advertisements displayed on each webpage. However, the ideal number of advertisements per webpage is determined independently of the search being performed on a P2P website. Therefore, the number of advertisements would be uniform on each P2P host's webpage, thus advertisement payment would be based solely on the market price of advertisements. Since our analysis is focused on price-quality competition between legal firms and P2P networks, we assume the online advertisement revenue per visit (A) is exogenous to a P2P network host.

In order to incorporate the annoyance of viewing advertisements, the value of A is also used to reflect the amount that a user is willing to pay to not view the advertisement. This is similar to the contribution by Casadesus-Masanell and Zhu (2013), which models the annoyance from advertising quadratically in each user's utility function. Due to our focus on price-quality competition, we simplify our representation of advertising annoyance to the linear case.[10]

With income from advertisements, a P2P network host site has the financial ability to improve the accessibility and characteristics of the information goods linked to their site for free download. In addition to website layout and navigation, the P2P websites must maintain and track the catalog of files. While online distribution is incredibly efficient relative to the cost of physical distribution, it still creates a significant cost for P2P websites (Roettgers, 2009).

For model simplicity and tractability, we assume that the total investment or expenditure (E) by a P2P network host to improve the quality of files available for download is taken to be a quadratic form: $E = 1/(2\theta^2)$, where θ is a measure of file quality uploaded to the site.[11] This quadratic expenditure function implies that marginal expenditure is positive and increasing as the level of P2P download file quality, θ, increases.

The objective of the P2P host site is to choose an optimal value for θ that maximizes the following profit function:

$$\pi_{P2P} = A(1 - x_{P2P}) - \frac{1}{2}\theta^2. \tag{3}$$

The specification of the profit function in (3) allows us to examine the optimizing behavior of a P2P network host site, which is an important departure from the analyses of P2P network in the existing literature. In our analysis, we assume that the P2P host adopts a unique quality approach to competition when deciding on an optimal level of P2P file quality.

2.4. Retailers

The retailer of the legal good chooses price p to maximize its profit:

$$\Pi_L = px_L - M, \tag{4}$$

where M is the cost of producing the original information good (produced by a single monopoly firm). For analytical simplicity, we assume the reproduction/marginal cost of each good to be zero.

In order to analyze the behavior of digital piracy with P2P networks, we consider the case that the firm's variable operating profit, $\pi_L = px_L$, exceeds the sunk cost M. That is, the legal good is available in the market and can be uploaded to P2P networks. This is consistent with the observations that a great deal of goods are being sold in a digital format and that P2P networks serve as the online source for obtaining copyrighted digital goods.

We present competition between legal retailers and P2P network hosts as a two-stage game. In the first stage, the legal firm determines an optimal price p for the legal good to maximize its profit as given in (4). In the second stage, given the availability of the legal good in the market, the P2P host determines an optimal value of θ for improving the accessibility and file quality of the site that maximizes its profit as given in (3). As is standard game theory, we use backward induction to solve for the sub-game perfect Nash equilibrium in the sequential game. In the subsequent analyses, we examine the case of a partially served market (Section 3), which is followed the fully served market (Section 4).

3. Partially served market

To capture the effects of a P2P network, we first analyze the case of a segmented market where some consumers do

[7] The annual advertising revenue for The Pirate Bay, was estimated at $23.6 million (Freewebsitereport.org 2013).

[8] Many of the host sites also accept donations. Including a donation parameter would amount to scaling ad revenue by the expected "per visit donation." This would add little depth to the model, and is therefore left out.

[9] Google is considered the largest online advertising company, controlling approximately "a third of digital advertising market this year," while Google's share of online advertising revenue is even larger ($8.85 billion), projected to be "56% of the worldwide market" (Womack, 2013).

[10] Casadesus-Masanell and Zhu (2013) show business modeling innovation that would be applicable to various industries, justifying various levels of advertisements and annoyance to it. However, P2P host sites' web page show the same amount of advertising regardless of the good sought, thus a linear representation seems more practical.

[11] The expenditure function is similar to a quadratic investment function frequently adopted in the R&D investment literature. See, for example, d'Aspremont and Jacquemin (1988), Kamien et al. (1992), and Poyago-Theotoky (1996).

not use the legal information product or the P2P version. This is important for two reasons: first, we can evaluate the effects of a host site in a market that is not served by the retailer. In addition, we can compare changes to the retail market with and without a P2P version of the good.

For a partially served market, we have $x_L < x_{P2P}$ since $x_L + (1 - x_{P2P}) < 1$. By setting the utility of the retail good to be equal to zero, we identify the marginal user or the number of users that prefer purchasing the retail version, denoted as $\tilde{x}_L$. That is, solving $\alpha - \tau\tilde{x}_L - p - \delta = 0$ for $\tilde{x}_L$, we have the market size of the regal firm as follows:

$$\tilde{x}_L = \frac{\alpha - p - \delta}{\tau}. \tag{5}$$

To identifying the number of users preferring the P2P downloaded good, we solve $U_x = \theta\alpha - \tau(1 - \tilde{x}_{P2P}) - \delta - A - D = 0$ for $\tilde{x}_{P2P}$, noting that $D = (1 - \tilde{x}_{P2P})C$ according to (2). This yields

$$\tilde{x}_{P2P} = \frac{A + \tau + \delta + C - \theta\alpha}{\tau + C}. \tag{6a}$$

The market size of the P2P network host is then given as

$$1 - \tilde{x}_{P2P} = \frac{\theta\alpha - A - \delta}{\tau + C}. \tag{6b}$$

Next, we analyze the optimizing behavior of the P2P network host at the second stage of the two-stage game. Given the availability of the legal product, the P2P host decides on an optimal level of θ to improve the accessibility and download file quality of its site. Substituting $1 - \tilde{x}_{P2P}$ from (6b) into the P2P host's profit function in (3), we have

$$\pi_{P2P} = A\left(\frac{\theta\alpha - A - \delta}{\tau + C}\right) - \frac{1}{2}\theta^2. \tag{7}$$

The first-order condition (FOC) for the host is:

$$\frac{\partial\pi_{P2P}}{\partial\theta} = \frac{(A\alpha - \theta\tau - C\theta)}{\tau + C} = 0$$

and the optimal level of file quality is:

$$\theta^* = \frac{\alpha A}{\tau + C}. \tag{8}$$

The firm at the first stage of the game chooses an optimal price for the legal good to maximize its profit function in (4):

$$\Pi_L = p\tilde{x}_L - M = p\left(\frac{\alpha - p - \delta}{\tau}\right) - M. \tag{9}$$

The FOC for the firm is[12]:

$$\frac{\partial\pi_L}{\partial p} = \frac{\alpha - 2p - \delta}{\tau} = 0$$

and the equilibrium price is:

$$p^* = \frac{\alpha - \delta}{2}. \tag{10}$$

Substituting p^* from (10) into (5) and (9), we calculate the firm's market size and variable operating profit (which excludes the sunk cost M):

$$\tilde{x}_L^* = \frac{\alpha - \delta}{2\tau} > 0 \quad \text{and} \quad \pi_L^* = \frac{(\alpha - \delta)^2}{4\tau} > 0. \tag{11}$$

The equilibrium price in the partially served market is independent of the file quality level (θ) selected by the P2P host site.

Substituting θ^* from (8) into (6b) and (7), we calculate the P2P host's market size and profit[13]:

$$1 - \tilde{x}_{P2P}^* = \frac{A\alpha^2 - (A + \delta)(\tau + C)}{(\tau + C)^2}, \tag{12a}$$

$$\pi_{P2P}^* = \frac{A[A\alpha^2 - 2(A + \delta)(\tau + C)]}{2(\tau + C)^2}. \tag{12b}$$

As expected, the P2P host site's market size and profits are positively related to the value of the good. That is, $\partial(1 - \tilde{x}_{P2P}^*)/\partial\alpha > 0$ and $\partial\pi_{P2P}^*/\partial\alpha > 0$.

Some assumptions should be imposed on the parameter values in order to guarantee that the market sizes of the legal firm and the P2P network host are positive and less than one (i.e., $0 < \tilde{x}_L^* < 1$ and $0 < (1 - \tilde{x}_{P2P}^*) < 1$) and that the market is partially served (i.e., $\hat{x}_L^* < \hat{x}_{P2P}^*$). Also, the P2P host's optimal level of file quality θ^* is less than or equal to one. We show these assumptions in Appendix A.2.

By evaluating Eq. (12b), we can see that the sufficient condition for the P2P host site to have positive profits is:

$$\alpha > \sqrt{\frac{2(A + \delta)(\tau + C)}{A}}. \tag{13}$$

We thus have shown that in a partially served market where $\tilde{x}_L < \tilde{x}_{P2P}$, the price, market size, and profit of the retailer are independent of the P2P network (this also holds in the special case without a P2P network, i.e., $1 - \tilde{x}_{P2P} = 0$). Whether a P2P network host can make a profit depends on legal goods value to consumers, and other factors such as advertisements and downloading costs. The results permit us to establish

Proposition 1. *Under a partially served market, the legal firm's profits are independent of the P2P website's optimal level of download file quality whereas the profitability (and hence the viability) of the P2P website depends on the condition given in (13). Based on this condition, we see that the viability of the P2P website is likely to be higher, the greater the value of the legal good, the lower the degree of horizontal differentiation, the lower the downloading costs, and the lower the annoyance of viewing the advertisements during downloading.*

One specialized application of the partially served market is to contractual media, such as pay-per-view television. Requiring a contract/membership means price and market size will not quickly change with the appeal of content, thus in static case we can assume that price and market size are temporarily fixed. The prevailing price and market size are based on the expected appeal of future programming. In this context, we can examine the effects of an unanticipated increase in appeal (i.e. a hit show).

[12] The second-order condition for profit maximization is satisfied since $\partial^2\pi_L/\partial p^2 = -2/\tau < 0$. This implies that the interior solution is unique.

[13] The second-order condition for profit maximization is satisfied since $\partial^2\pi_{P2P}/\partial\theta^2 = -1 < 0$.

Next, we examine the change in profits for a P2P website by examining the profits from the anticipated appeal and the realized appeal. Letting α_1 represent the appeal of traditional content shown or the expected appeal, and α_2 represent the realized appeal of content, we can identify how better content affects the P2P host site in the context of contractual media (represented by $\alpha_1 < \alpha_2$).

Using the P2P host sites' file quality and market size equations, (8) and (12a), it is easy to see that both increase for the P2P website when there is an exogenous increase in α. The increase in the P2P's market size correlates with incidents reported in the news for hit shows (Stern, 2013).Using both results and (12b), we calculate the change in variable operating profit from the unexpected good with higher appeal:

$$\Delta\pi^*_{P2P} = \pi^*_{P2P,\alpha_2} - \pi^*_{P2P,\alpha_1} = \frac{A^2(\alpha_2^2 - \alpha_1^2)}{2(\tau + C)^2}.$$

The result is an unambiguous increase in profit for the P2P website. While additional profits for the P2P website may not directly affect the legal retailer in the static case, it seems reasonable to expect future contracts/memberships to be decreased in a dynamic setting thus identifying the strong incentives for pay-per-view companies to attack P2P websites (Gasior,2005).[14]

4. Fully served market

We now focus the analysis on fully served markets. By using the preference function (1), we set the utility of the retail version equal to the P2P version to identify the marginal user, denoted as $\hat{x}$. The marginal user is indifferent between the retail and the P2P versions, such that $\hat{x} = \hat{x}_L = \hat{x}_{P2P}$. Equating $\alpha - \tau\hat{x} - p - \delta$ with $\theta\alpha - \tau(1-\hat{x}) - \delta - A - D$, noting that $D = (1-\hat{x})C$ according to (2), we solve for $\hat{x}$ and hence $1-\hat{x}$ as follows:

$$\hat{x} = \frac{\alpha(1-\theta) + \tau + A + C - p}{2\tau + C} \quad \text{and}$$
$$1 - \hat{x} = \frac{\tau - \alpha(1-\theta) - A + p}{2\tau + C}, \tag{14}$$

which are the market sizes of the legal firm and the P2P network host, respectively.

As before, we begin with the second stage of the two-stage game by analyzing the optimizing behavior of the P2P network host. Substituting $1-\tilde{x}$ from (14) into the P2P host's profit function in (3), we have

$$\pi_{P2P} = A\left[\frac{\tau - \alpha(1-\theta) - A + p}{2\tau + C}\right] - \frac{1}{2}\theta^2. \tag{15}$$

The FOC for the P2P host site is[15]:

$$\frac{\partial\pi_{P2P}}{\partial\theta} = \frac{A\alpha - 4\theta\tau - 2C\theta}{2(2\tau + C)} = 0,$$

which determines the optimal level of P2P download file quality as

$$\theta^{**} = \frac{\alpha A}{4\tau + 2C}. \tag{16}$$

Eq. (16) indicates that the P2P file quality is independent of the retail price. It is easy to verify that $\partial\theta^{**}/\partial\alpha > 0$, $\partial\theta^{**}/\partial A > 0$, $\partial\theta^{**}/\partial\tau < 0$, and $\partial\theta^{**}/\partial C < 0$. The economic implications of these derivatives are straightforward. For an exogenous increase in the valuation of the legal good (α) or ad revenue per visit (A), the level of download file quality optimally chosen by the P2P network host increases. But for an exogenous increase in the degree of production differentiation (τ) to the downloading cost (C), the optimal level of download file quality decreases.

In the first stage of the game, the firm chooses an optimal price for the legal good to maximize its profit function in (4). Substituting θ^{**} from (16) and $\tilde{x}$ in (14) into the retail profit function, we have

$$\Pi_L = p\left[\frac{\alpha\left(1 - \frac{\alpha A}{4\tau+2C}\right) + \tau + A + C - p}{2\tau + C}\right] - M. \tag{17}$$

The FOC for the legal firm is[16]:

$$\frac{\partial\Pi_L}{\partial p} = \frac{\alpha\left(1 - \frac{\alpha A}{4\tau+2C}\right) - 2p + A + \tau + C}{2\tau + C} = 0.$$

Solving for the optimal retail price yields

$$p^{**} = \frac{2(2\tau + C)(\alpha + \tau + A + C) - A\alpha^2}{4(2\tau + C)}. \tag{18}$$

Some restrictions should be placed on the parameters (i) for the optimal value of P2P file quality θ^{**} to be positive but is no greater than 1, and (ii) for the equilibrium retail price to be positive. First, from θ^{**} in (16), we have the following restriction:

$$0 < \frac{A\alpha}{4\tau + 2C} \leqslant 1, \tag{19}$$

which implies that

$$A\alpha \leqslant 4\tau + 2C. \tag{20}$$

Second, from p^{**} in (18), we have the following positive price condition:

$$\left(\frac{\alpha + \tau + A + C}{A}\right)(4\tau + 2C) > \alpha^2. \tag{21}$$

These constraints in (20) and (21) will be used later on.

For the case of the fully served market, several comparative-static derivatives can be obtained by examining the optimal retail price found in (18). This yields the following:

[14] It should be noted that the attacks were attempts by HBO to "poison" specific files being shared. The attacks were ineffective in persuading users to stop downloading. In addition, many P2P networks now have methods to make this approach ineffective.

[15] The second-order condition for profit maximization is satisfied since $\partial^2\pi_{P2P}/\partial\theta^2 = -1 < 0$.

[16] The second-order condition for profit maximization is satisfied since $\partial^2\pi_L/\partial p^2 = -2/(2\tau + C) < 0$.

$$\frac{\partial p^{**}}{\partial C} = \frac{2C^2 + 8C\tau + A\alpha^2 + 8\tau^2}{4(2\tau + C)^2} > 0, \tag{22a}$$

$$\frac{\partial p^{**}}{\partial \alpha} = \frac{2\tau - A\alpha + C}{4\tau + 2C}, \tag{22b}$$

$$\frac{\partial p^{**}}{\partial A} = \frac{4\tau + 2C - \alpha^2}{8\tau + 4C}. \tag{22c}$$

As shown in (22a), when the costs of downloading the goods from a P2P network increase, other things being equal, the legal firm has an advantage in raising the equilibrium price of the retail good.

The derivatives in (22b) and (22c) indicate that the effects of value (α) and advertising revenue per visit (A) on the equilibrium retail price cannot be determined unambiguously. Further examination of Eq. (22c) under the constraints provided in (7), yields the situations where the retail price and the advertising revenue per visit are positively or negatively related, depending in part on the value of the good. We can categorize the effects based on two scenarios pertaining to the good's value:

Case 1. $\frac{\partial p^{**}}{\partial A} < 0$ when $\left(\frac{\alpha+\tau+A+C}{A}\right)(4\tau + 2C) > \alpha^2 > 2(2\tau + C)$.

The economic implication is that firms will decrease prices in response to higher advertising payments when files are very appealing.

Case 2. $\frac{\partial p^{**}}{\partial A} > 0$ when $2(2\tau + C) > \alpha^2$.

This indicates that firms will increase prices in response to higher advertising payments when files are less appealing.

4.1. Profit and market size

The equilibrium market size of the legal product is obtained by substituting p^{**} and θ^{**} into the marginal users' equation in (14). Once the marginal user is identified, calculating the profit for each firm is straightforward. Using the results from 15–18, market size and profits of each version can be calculated. For the legal firm, we calculate its market size and variable operating profits (which exclude sunk cost M) as follows:

$$\hat{x}^{**} = \frac{2(2\tau + C)(\alpha + \tau + A + C) - A\alpha^2}{4(2\tau + C)^2} \tag{23a}$$

$$\pi_L^{**} = \frac{\left[2(2\tau + C)(\alpha + \tau + A + C) - A\alpha^2\right]^2}{16(2\tau + C)^3}. \tag{23b}$$

Given the constrained condition in (20) that $A\alpha \leqslant 2\tau + C$, it is easy to verify that the numerator of $\hat{x}^{**}$ in (23a) is strictly positive.[17] This implies that $\hat{x}^{**} > 0$ and $\pi_L^{**} > 0$. Thus, the legal firm's market size and variable operating profits are always positive.

[17] Since we know the constraint that $A\alpha \leqslant 4\tau + 2C$ and that $-A\alpha^2$ is the lower threshold we can replace $A\alpha$, we have from $\hat{x}^{**}$ in Eq. (23a) that its numerator is strictly positive when the following condition holds:

$$2C^2 + 2C\alpha + 6C\tau + 2AC + 4\alpha\tau + 4\tau^2 + 4A\tau - 2\alpha(2\tau + C) > 0.$$

Rearranging this condition yields $2(2\tau + C)(A + \tau + C) > 0$, which is unambiguously positive.

As for the P2P network host's market size and profits, we have

$$1 - \hat{x}^{**} = \frac{2(2\tau + C)(C - A - \alpha + 3\tau) + A\alpha^2}{4(2\tau + C)^2}, \tag{23c}$$

$$\pi_{P2P}^{**} = \frac{A\left(4C^2 - 4C\alpha + 20C - 4AC + A\alpha^2 - 8\alpha\tau + 24\tau^2 - 8A\tau\right)}{8(2\tau + C)^2}. \tag{23d}$$

Eq. (23d) indicates that profits for the P2P network host cannot be determined unambiguously. We find the following profitable condition:

$$\pi_{P2P}^{**} > 0 \quad \text{when} \quad \frac{A\alpha^2}{4(2\tau + C)} + (3\tau + C) > (A + \alpha). \tag{24}$$

We thus have

Proposition 2. *Under a fully served market, the legal firm's variable operating profit is strictly positive despite competition against a P2P network host. The profitability and hence the viability of the P2P network depends on elements such as the legal good's value and downloading costs according the condition given in (24).*

For the remainder of the paper, we assume that the condition in (24) is satisfied.

4.2. Valuation of goods

Next, we evaluate the effects that the value of a legal good has on the market size and profit. Taking the derivatives of the profit, price, and market size functions of the retailer with respect to α yields

$$\frac{\partial \pi_L^{**}}{\partial \alpha} = \frac{(2\tau - A\alpha + C)(2C^2 + 2C\alpha + 6C\tau + 2AC + 4\alpha\tau + 4\tau^2 + 4A\tau - A\alpha^2)}{4(2\tau + C)^3}, \tag{25a}$$

$$\frac{\partial p^{**}}{\partial \alpha} = \frac{2\tau - A\alpha + C}{2(2\tau + C)}, \tag{25b}$$

$$\frac{\partial \hat{x}^{**}}{\partial \alpha} = \frac{2\tau - A\alpha + C}{2(C + 2\tau)^2}. \tag{25c}$$

Again, we see that the derivatives in (25) cannot be determined unambiguously. However, under the condition that $\tau > (A\alpha + C)/2$, we have

$$\frac{\partial p^{**}}{\partial \alpha} > 0, \quad \frac{\partial \hat{x}^{**}}{\partial \alpha} > 0, \quad \text{and} \quad \frac{\partial \pi_L^{**}}{\partial \alpha} > 0.$$

These results indicate a direct relationship between source preference, the goods' value, and their effect via price, market, and profit. Stated formally:

Proposition 3. *Under a fully served market, the price and sales of the legal information good may increase with the basic valuation parameter, α, when the degree of horizontal differentiation is sufficiently large (i.e., $\tau > (A\alpha + C)/2$).*

Since higher valuation increases both profit and market size for the legal retailer, we expect that higher valuation is detrimental for host sites. In order to identify the exact effects higher valuation has on a host site, the derivatives of the profit, quality, and market size function are taken with respect to parameter, α, which yield

$$\frac{\partial \pi^{**}_{P2P}}{\partial \alpha} = -\frac{A(4\tau - A\alpha + 2C)}{(2\tau + C)} < 0, \tag{26a}$$

$$\frac{\partial \theta^{**}}{\partial \alpha} = \frac{A}{4\tau + 2C} > 0, \tag{26b}$$

$$\frac{\partial (1 - \hat{x}^{**})}{\partial \alpha} = -\frac{(2\tau + C - A\alpha)}{2(2\tau + C)^2} < 0. \tag{26c}$$

The derivative in (26b) shows that higher valued goods require additional resources to increase the accessibility and quality necessary to compete with the retail version. Using the necessary condition established in (20), surprisingly, we see from (26a) and (26c) that both profits and market size decrease in response to better goods. Thus, we can state the following:

Proposition 4. *Under a fully served market, goods with a lower appeal require a lower level of download file quality for the P2P host site, and therefore have a lower cost. Thus, the profit of the P2P website is inversely related to the basic valuation parameter, α. (This assumes that the appeal of the good exceeds the minimum threshold to be pirated).*

The drop in profit is expected once we consider the additional cost of better goods. The derivative in (26a) shows that the catalog of files shared on P2P networks are not limited to highest valued goods, and that host sites benefit from lower valued goods.

4.3. Horizontal product differentiation

As online retailing and distribution becomes more common, the relevance of diminished product differentiation becomes paramount to understand the future market of digital goods. Online distribution is already common with movies, music, and software. Because of this, physical retail will most likely become less relevant in the near future. In addition, computer literacy is all but certain to increase which would further decrease the degree of product differentiation.

We can evaluate the retailer response to diminished product differentiation. Based on the equilibrium retail price and P2P file quality in (16) and (18), we have

$$\frac{\partial p^{**}}{\partial \tau} = \frac{(C^2 + 4C\tau + A\alpha^2 + 4\tau^2)}{2(2\tau + C)^2} > 0, \tag{27a}$$

$$\frac{\partial \theta^{**}}{\partial \tau} = \frac{-A\alpha}{(2 + C)^2} < 0. \tag{27b}$$

As shown in (27a), a positive relation exists between price and the degree of horizontal differentiation. When the degree horizontal differentiation increases (decreases), the retailer responds with higher (lower) prices. From this result, we can predict the effects from decreased horizontal differentiation:

Corollary 1. *As the degree of horizontal differentiation decreases for digital goods, the P2P websites' optimal level of file quality will unambiguously increase. That is,* $\partial \theta^{**}/\partial \tau < 0$. *In addition, lower product differentiation will cause retail prices to unambiguously decrease. That is,* $\partial P^{**}_{L}/\partial \tau > 0$.

From Corollary 1, it is easy to see that lower product differentiation will increase costs for P2P host sites, while decreasing the retail price. The net result for consumers is more accessible and higher quality goods for illegal download, and lower prices for retail goods.

Next, we evaluate the effect of diminished horizontal differentiation on market size for each type of good. Using (23a) and (24), and taking the derivative with respect to τ, we have

$$\frac{\partial \hat{x}^{**}}{\partial \tau} = \frac{2A\alpha^2 - C^2 - 4A\tau - 4\alpha\tau - 2AC\tau - 2C\alpha - 2C\tau}{2(2\tau + C)^3}, \tag{28a}$$

$$\frac{\partial (1 - \hat{x}^{**})}{\partial \tau} = \frac{C^2 + 4A\tau + 4\alpha\tau - 2A\alpha^2 + 2AC + 2C\alpha + 2C\tau}{2(2\tau + C)^3}. \tag{28b}$$

The results from (28) show that the effects of horizontal differentiation for highly valued goods are ambiguous for both markets.[18] However, we can identify a critical point to determine when each market increases in size. Setting the numerator in (28a) to zero, and solving for τ, yields:

$$\tau = \frac{A\alpha^2}{2A + 2\alpha + C} - \frac{C}{2}$$

For values of τ below (above) the critical value, the retail market expands (diminishes), and thus diminishes (expands) the P2P websites market share.

The change to the P2P websites profit resulting from a change to the level of horizontal differentiation is

$$\frac{\partial \pi^{**}_{P2P}}{\partial \tau} = \frac{A(C^2 + 4A\tau + 4\alpha\tau + 2AC + 2\alpha C + 2C\tau - A\alpha^2)}{2(2\tau + C)^3}. \tag{29}$$

In order for the derivative in (29) to be positive, the following condition must hold:

$$C^2 + 4A\tau + 4\alpha\tau + 2AC + 2\alpha C + 2C\tau - A\alpha^2 > 0.$$

Substituting the constraint $A\alpha \leqslant 4\tau + 2C$ into the above condition yields $A(2A + C)(2\tau + C)$, which is strictly positive. Thus, the P2P websites' profits will always increase with a higher level of horizontal differentiation. However, the effects of higher horizontal differentiation on profit for the retailer are ambiguous. We thus can state the following:

Proposition 5. *In the presence of digital piracy with P2P networks, how horizontal differentiation for digital goods affects the retailers' profits and market size will depend on the degree to which these goods are horizontally differentiated.*[19]

[18] This occurs with products with sufficiently high value such that: $4A^2 + 4AC + C^2 + \alpha(8A + 4C) < \alpha^2(12A - 4)$.

[19] The market, and thus profit can be determined if product differentiation is sufficiently low (i.e., if τ is such that $\tau < A$, and $\tau < (2C - 3A\alpha)/4$), if both conditions are met, then profit and market size of the retailer will increase with higher product differentiation. However, for higher product differentiation values the effects cannot be determined.

However, profits of P2P websites will unambiguously increase (decrease) with greater (less) degree of horizontal differentiation for the digital goods.

This is a significant result for legal retailers. Focusing on digital distribution will provide a method for legal retailers to diminish the incentive for P2P websites to host pirated goods. We can, with certainty, predict that decreasing horizontal differentiation will significantly erode a P2P host site's profit. However, as horizontal differentiation decreases, we cannot unambiguously determine the effects on the retailers' profit.

5. Concluding remarks

P2P networks have gained notoriety as the online source for illegally obtaining copyrighted digital goods. In this paper, we have extended earlier studies in the existing literature on digital pirating by further examining price-quality competition between firms that produce legal information goods and host sites that index P2P links. We have presented a framework in which a legal firm determines price for its information good and a P2P website decides on its investment to improve the quality and accessibility of the good linked to its site for free download. In the analysis, the costs to the P2P network host of improving index quality are financed by its income from advertisements. Such a crucial aspect of online advertising revenue for P2P network operations should not be ignored when analyzing the viability and impact of online piracy.

The analysis with this paper shows how important preference for horizontal differentiation is for retailers when P2P network hosts are actively pursuing optimizing behavior in improving the quality of the downloaded goods. With current trends pushing industry to digital distribution and the necessity of computer literacy, we show that a retailer's price diminishes, while the legal firm's profits may or may not suffer. As a result, consumers enjoy lower prices and P2P host site's profits decrease.

In the price-quality competition, we derive conditions under which the profitability of legal firms may or may not be negatively affected by the presence of a P2P network. However, market segmentation negates the effects that a P2P network has on a retailer, which maybe a viable approach with more appealing goods.

Several regulatory applications are apparent from our results to combat piracy. The two main approaches to diminish the presence of P2P networks are to: (i) decrease revenue from advertising and (ii) increase download costs for users. While the second approach is beyond the basic scope of this paper, the management of internet traffic has become an important issue. Regulation limiting P2P traffic would have a significant effect on illegal downloading, but its consequences extend far beyond piracy.

Diminishing the revenue from online advertising would significantly impact a P2P website's profit. However, online advertising has been dominated by Google, and is projected to increase its online dominance (Womack, 2013). While this may not directly result in higher revenue from displaying ads, payments for showing the ads could increases or may remain unchanged. However, additional competition would likely decrease advertising costs, by dropping the cost for companies to display their ads, and increasing demand for venues to show the ads.[20] Consequentially, the function of host sites, which has been previously omitted from the academic literature, significantly increases the resilience of P2P networks.

Our simple analysis has several implications to future studies beyond digital piracy. The price vs. quality framework of market competition developed in this paper has several applications or extensions. Communities that rely on users to construct goods and services that were previously purchased are perfect examples of competition between price and quality. In addition, financing operations through online ads is common for websites and free-to-use apps, thus providing other applications for the model described in this paper. Another consideration is to allow for multiple P2P network hosts to competing with legal firms of information goods. These are potentially interesting topics for future research.

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Appendix A

A.1. Additional details about the download structure of P2P networks

In order to capture the constraints of P2P networks, additional properties can be included into the cost term. If we denote s as the proportion of sources (or seeds) among the network population, then the generic cost term associated with obtaining a good from a P2P network, D, could also be represented by:

$$D = (1 - x)(1 - s)C,$$

where C represents the downloading cost. The term "C" has the same interpretation as σ in Herings et al. (2010). The authors indicate that the parameter σ "represents the generic cost factor of downloading, incorporating a collection of factors that may affect downloading costs, for instance, population computer literacy, the availability of broadband internet infrastructure, and most importantly, the degree of legal enforcement of intellectual property rights. Note that it is identical for every consumer and is independent of the network size" (p. 317).

An important property of a P2P network is the distinctive distribution procedure used. This builds off of Gayer and Shy's (2006) vertically differentiated model by

[20] This is another important area for additional research. Apple has expanded its online advertising which increases competition for Google. However, Google has acquired other advertising companies like AdMod, which increased its market share (Raynovich, 2013). Since Apple is also large digital good retailer, they may have unique position to benefit from any digital good being obtained legally or illegally.

including the unique sharing procedure of P2P networks. As downloaders obtain pieces of a desired file, they concurrently become suppliers of those pieces to others. A unique characteristic of P2P networks is that users with only part of a file, still share it with other downloaders. For a more elaborate description of P2P networks see Leibnitz et al. (2007) and Casadesus-Masanell and Hervas-Drane (2010). This distribution method means that file sources and connections are constantly changing. In order to model a static case, it is necessary to reduce the representation to a proportion of users supplying the file, with the remaining users demanding the file. In addition, the cost structure shows some noteworthy characteristics, specifically, the affects of increased users and/or seeds:

$$\frac{\partial D}{\partial(1-x)} = (1-s)C > 0 \quad \text{and} \quad \frac{\partial D}{\partial s} = -(1-x)C < 0.$$

We can see that as the number of network users increases, so will the cost of downloading. Also, if the proportion of sources increases, faster downloads will occur and thus lower the cost of downloading. These are properties we would expect a P2P network to have. This model assumes no or few "free-riders," many of the P2P protocols use tracking which attempts to prevent or limit access to users that try to free-ride. For issues on free riding in the analysis of P2P networks, see Casadesus-Masanell and Hervas-Drane (2010).

A.2 Restrictions on the parameter values for the partially served market

Under a partially served market, the legal firm's market size is $\hat{x}_L = (\alpha - \delta)/2\tau$. To guarantee that $\hat{x}_L > 0$ and $\hat{x}_L < 1$, the following two conditions should be satisfied: $\alpha > \delta$ and $\alpha - \delta < 2\tau$. Thus, for $0 < \hat{x}_L < 1$, the value of the legal good must be such that $\delta < \alpha < 2\tau + \delta$.

Next, the marginal user of the P2P network with optimal file quality (θ^*) located at $\hat{x}_{P2P}$ is calculated as

$$\hat{x}_{P2P} = \frac{(\tau + C)(A + C + \tau + \delta) - A\alpha^2}{(\tau + C)^2}.$$

For the value of $\hat{x}_{P2P}$ to be positive, it requires that $(\tau + C)(A + C + \tau + \delta) > A\alpha^2$ which implies that $\alpha < \sqrt{(\tau + C)(A + \tau + C + \delta)/A}$. For the positive value of $\hat{x}_{P2P}$ to be less than one, it requires that $(\tau + C)(A + C + \tau + \delta) - A\alpha^2 < (\tau + C)^2$, which implies that $\alpha > \sqrt{(\tau + C)(A + \delta)/A}$. To guarantee the viability of the P2P network site so that $0 < \hat{x}_{P2P} < 1$, the following combined condition must hold:

$$\sqrt{\frac{(C+\tau)(A+\delta)}{A}} < \alpha < \sqrt{\frac{(C+\tau)(A+C+\tau+\delta)}{A}}.$$

Finally, under a partially served market, we have the sum of the market sizes of the legal firm and the P2P network site to be less than one. That is, $\hat{x}_L + (1 - \hat{x}_{P2P}) < 1$. This implies that $\hat{x}_{P2P} - \hat{x}_L > 0$. Calculating the difference in market sizes yields the following:

$$\hat{x}_{P2P} - \hat{x}_L = \frac{(\tau + C)(A + C + \tau + \delta) - A\alpha^2}{(\tau + C)^2} - \frac{\alpha - \delta}{2\tau}.$$

Evaluating the market size difference at the critical point where $\alpha = \sqrt{(C + \tau)(A + \delta)/A}$ yields

$$\hat{x}_{P2P} - \hat{x}_L = \frac{1}{2\tau}\left(2\tau + \delta - \sqrt{\frac{(C+\tau)(A+\delta)}{A}}\right).$$

This implies that

$$\hat{x}_{P2P} > \hat{x}_L \quad \text{when } 2\tau + \delta > \sqrt{\frac{(C+\tau)(A+\delta)}{A}}.$$

As for the P2P's optimal level of file quality, $\theta^* = \alpha A/(\tau + C)$, we find that for $0 < \theta^* < 1$, the following condition must be satisfied: $\alpha < (\tau + C)/A$. It is straightforward to show that the retail price p^* is positive under the assumption that $\alpha > \delta$. The positivity of the price is also guaranteed whenever the legal firm's market size falls within the range: $0 < \hat{x}_L < 1$.

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