Turning Piracy into Profits: a Theoretical Investigation[*]

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Abstract

We analyze how the presence of a (private, small-scale) file-sharing community affects the profitability of producers of digital goods within a spatial duopoly model *à la* Hotelling (1929). Consumers can make the download of pirated content by joining this file-sharing network. To get access to the community, consumers have to buy and share a digital good with all the other members. We show that firms benefit from piracy in emerging markets, that is markets which are not fully covered: the activity of file-sharing, in fact, allows them to reach a larger share of customers which otherwise would not buy at all. This effect is missing in mature and widespread markets where firms prefer to be protected from piracy. This provides a rationale for the observation that in emerging countries companies are unlikely to take a firm line against piracy.

Keywords: File-Sharing Community, Piracy, Linear Spatial Model

JEL Classification Numbers: O34; L1; L86

1   Introduction

Despite many efforts by governments and media industries to stop piracy, the popularity of Internet file-sharing has increased significantly over the last decade. The diffusion of digital goods over the net has been facilitated by the emergence of more efficient storage and distribution models. Besides the centralized server-based approach (Napster, Emule), new organizational models based on peer-to-peer (P2P) networks (Direct Connect, Morpheus) have been recently developed. While in the former model communication is usually to and from a central server where files are stored, in P2P systems peer nodes simultaneously work as both *clients* and *servers* to the other nodes of the network. The resources shared within these communities are similar to club goods (Buchanan, 1965; Samuelson, 1954): they exhibit characteristics of excludability and non-rivalry, at least to some extent due to possible congestion effects (Krishnan *et al.*, 2007). In order to avoid problems of free riding, the access to these communities is generally restricted through membership rules (like the requirement of providing some minimal

quality good to the community). For instance, most P2P networks either provide incentives for uploading files or force the sharing of files which are currently downloaded.[1]

The aim of the present paper is to analyze how the presence of a (private, small-scale) file-sharing community affects the pricing behaviour of producers of digital goods and their profitability. Our analysis is based on a spatial duopoly model with two horizontally differentiated digital goods (softwares, music files, DVD movies, etc). Firms are located at the extremes of a Hotelling segment, whereas consumers are uniformly distributed along the segment. Differently from the standard linear city model, consumers can make the download of one of these two goods by joining a file-sharing community. The access to this network is restricted: consumers can join it only if they buy and share a digital good with all the community members. This initial purchase requirement is a reasonable assumption within small private communities where consumers share only files they own. There are some important file-sharing systems exhibiting these features. WASTE is a decentralized file-sharing application that enables secure communication between small trusted groups of users. It builds a virtual private network that connects a restricted group of computers, as determined by the users. WASTE networks are decentralized, which means that there is no central server that stores file data; peers must connect to each other individually. Another example is represented by Direct Connect that, differently from WASTE, is a centralized system of file-sharing: clients connect to one or more small servers (hubs) that keep track of connected users and their shared files. These hubs are often thematic and collect a restricted number of users with similar interests.

In our model there may be three different categories of agents: consumers who use only one good (buying it), consumers who use the two goods (buying the favourite good and downloading the other one), and agents that refrain from consumption. Consumers located closer to the extreme of the segment value their favourite good more than consumers located closer to the middle of the segment, regardless of whether this good is bought on the market or downloaded from the network. Moreover, the stronger is the preference for one of the two digital goods, the lower is the valuation of the other good (the second one). Thus, in our model, a consumer located closer to the extreme of the segment is less likely to join the community and make the download.

In the present paper we show that market coverage is crucial in determining firms' attitudes towards piracy. In markets which are not (yet) completely covered or, stated differently, mature, firms benefit from piracy. The intuition is that piracy may allow firms to enlarge their market shares when there are consumers still to be conquered.[2] In this scenario we have two monopolies in the market as the demands for the goods are independent. The introduction of the downloading option enlarges firms' market shares (positive *demand effect*) but it does not result in an increase in competition: firms' market power gets larger as the downloading possibility makes the goods more attractive and (at least) some consumers use both goods. On the contrary, in fully-covered markets, the activity of file-sharing is harmful to firms so that they would prefer to be protected from piracy. In this case, the positive *demand effect* is missing; we have duopolistic competition in the market, and the downloading option makes price competition tougher. Firms are unable to fully appropriate consumers' willingness to pay when pirated material is diffused over the net (*appropriability problem*). Finally, the transition from fully-served markets to partially-served markets is characterized by a market configuration that we call "covered at the limit": in this case companies quote a price that is just sufficient to cover the market by making

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[1]There is a literature studying how to improve the efficiency of goods' provision in P2P networks. Asvanund *et al.* (2003) develop a model in which access is made contingent on content made available by users to the community.

[2]There is evidence of such incentives in emerging markets where companies turned piracy to their own advantage: in the software industry, for instance, the computer giant Microsoft has recently admitted that piracy of its Windows operating system has contributed to give it huge market share (90%) in China. The interested reader is referred to "Piracy: Look for the Silver Lining", The Economist, July 19th-25th, 2008, pp. 23.

the consumer equidistant from the two firms indifferent between buying either of the two goods and refraining from consumption. In this intermediate market configuration firms do not compete. We find that also in this case companies benefit from piracy. In fact, even if firms split the market evenly, the downloading possibility increases the value of the goods for consumers and, in turn, their willingness to pay; consequently, in order to cover the market, companies may set a higher price in the presence of downloading, which gives firms the possibility to indirectly appropriate some revenue from piracy.

Our work is related to a vast theoretical literature that analyzes the consequences of piracy on firms' profitability. Some contributions point out the negative effect of piracy on firms' sales as some consumers use a free copy of the original good, instead of buying it. In a pioneering paper about the economics of copying, Johnson (1985) shows that copying can reduce social welfare in the short run, due to a reduction in the demand for the originals, as well as in the long run due to the supply elasticity of creative works. In contrast, Liebowitz (1985) highlights how a seller might indirectly appropriate some revenues from unauthorized copiers: the ability to copy increases the value that purchasers place on originals, thereby increasing their willingness to pay. In an interesting paper, Ben-Shahar and Jacob (2004) show that a monopoly may strategically promote infringement of the copyright: the monopoly sacrifices short-run profits gaining a long-run benefit in the form of reduced competition. This is a predatory pricing strategy where the incumbent, failing to enforce copyright protection, obtains the same result as lowering prices (without giving rise to antitrust complain). Other papers argue that a monopolist may benefit from piracy in the presence of network effects (Takeyama, 1994; Gayer and Shy, 2003): the main idea is that when there is no enforcement of copyright protection and network externalities are at work, an increase in the number of users makes the good more valuable, which enables a company to secure higher profits.[3] More recently, Peitz and Waelbroeck (2006b) consider the problem of a multiproduct monopolist and show that piracy in music industry can be beneficial for firms also without network externalities: starting from the observation that digital products often exhibit the characteristics of experience goods, the authors show that, introducing consumer sampling, music sales can increase thanks to downloading.

A distinguishing feature of this paper is that we focus on small-scale piracy by assuming that the access to the private file-sharing community is contingent to content uploading (sharing). Our results predict that the extent of market coverage turns out to be relevant in determining firms' attitudes towards piracy because in partially served markets the presence of these communities has a sales-enhancing effect. We thus provide another rationale for piracy to be advantageous for firms without relying on network externalities. Another important feature of our model is that it accomodates different market structures: we have, in fact, two local monopolies under partial market coverage and duopolistic competition under full market coverage. A few papers also consider strategic interaction among firms. Shy and Thisse (1999) and Peitz (2004) study how piracy influences software firms' behavior in a spatial duopoly setting with network externalities. This model differs from ours in that it does not allow consumers to use both digital goods: each user, in fact, can either buy or pirate only one of the two goods. More recently, Belleflamme and Picard (2007) contrast the strategic behaviour of a multiproduct monopolist with the behaviour of two Bertrand duopolists under the threat of piracy in a model where users are able to copy digital goods by means of copying devices. Differently from our paper, the authors use a model of vertical product differentiation to represent consumer preferences.

The rest of the paper develops as follows. Section 2 sets up the theoretical framework. In Section 3 we solve the model by individuating all the possible market configurations. In Section 4 we study how piracy affects firms' profitability. Section 5 discusses the results and concludes. The main calculations are derived in

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[3]For a complete critical review, the interested reader is referred to Peitz and Waelbroeck (2006a).

Appendix A and B.

2   The model

We develop a spatial duopoly model with heterogeneous consumers. As far as the supply side is concerned, there are two digitally-stored differentiated products, say A and B. They could be computer software packages, or alternatively, music titles, digitally-stored books, or movie titles. Such goods are produced by two different firms, A and B, that are located at the endpoints of the interval $[0, 1]$. Let p_A and p_B denote respectively the prices of products A and B, with production being costless. Goods can be obtained in two different ways. They can be purchased on conventional media. Alternatively, consumers can download the two products from a small private file-sharing community. The access to this network is restricted to consumers that buy a product and decide to share it.[4] More precisely, each consumer has three options: she can buy only one product, buy one product and download the other one, or not use any product.

As for the demand side, there is a continuum of consumers of mass 1 uniformly distributed along the interval $[0, 1]$. They differ in their valuation of the goods in such a way that types characterized by a strong preference for a good are more likely to buy this good and refrain from downloading than types with a moderate preference. These may decide to buy their favourite product and download the other one.[5] The utility of a consumer indexed by $x \in [0, 1]$ is:

$$U\left(x\right) = \begin{cases} k - x - p_A & \text{if buys } A \\ k - x - p_A + G_B(x) & \text{if buys } A \text{ and downloads } B \\ k - (1 - x) - p_B & \text{if buys } B \\ k - (1 - x) - p_B + G_A(x) & \text{if buys } B \text{ and downloads } A \\ 0 & \text{if does not use any product} \end{cases}$$

The term $k > 0$ represents the intrinsic benefit from using the first digital good. The utility of the file-sharing network's users includes an extra term, $G_i(x)$ with $i \in \{A, B\}$, which depends on the intrinsic benefit of the downloaded good, and on its cost of downloading:

$$G_B(x) \equiv \alpha k - c\left(1 - x\right), \tag{1}$$

$$G_A(x) \equiv \alpha k - cx. \tag{2}$$

The first term αk is the intrinsic benefit from using the second digital good; following Gabszewicz and Wauthy (2003), we assume that $\alpha \in (0, 1)$, so that the joint use of the goods provides an intrinsic benefit that is lower than $2k$.[6] The second term instead represents the cost of downloading, with $c \in (0, 1)$. As one can see, the cost of downloading depends on the consumer type. Such a modeling assumption allows us to capture the idea that

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[4]This modeling assumption is consistent with the observation that many file-sharing applications force users to provide some minimal content to the community. For instance, to get access to the hubs of the file-sharing system Direct Connect, one needs to share a minimum of its own files first. The very best hubs require that one shares a minimum of 100 gigabytes, albeit most of them are satisfied with 2-5 gigabytes shared. In Section 5.2 we test the robustness of our analysis by relaxing the assumption that the access to the file-sharing network is restricted only to consumers that buy a product and share it with other community members.

[5]We can think of consumers which are fool for Metallica that do not benefit also from listening to Simply Red, versus consumers characterized by a moderate preference for both bands, which may be willing to use both music files.

[6]Alternatively, we could think of α as an index of quality degradation. This is a common assumption for modeling the quality of pirated copies of digital goods.

consumers with a stronger preference for a good receive a larger benefit from downloading this good than from downloading the other good.[7]

In this scenario, a high (low) consumer type, $x \to 1$ ($x \to 0$) exhibits a strong preference for the digital good B (A) as well as a weak inclination to download the other good A (B); consumers located close to the middle of the segment exhibit a moderate preference for their favourite good and are more prone to download the second good.

It is worth observing that, in the presence of downloading, consumers do not buy both goods as downloading the second good is always a cheaper option than buying it. To ascertain this point, let us take a consumer x that buys good A and wants to use also good B. If the latter good can be either bought or downloaded, it is straightforward to verify that the second option is always preferred as: $\alpha k - (1 - x) - p_B < \alpha k - c(1 - x)$.[8]

3 Market configurations

In what follows, we solve the model and compute equilibrium candidates corresponding to each market configuration. We provide in Appendix A the parameter ranges for which each equilibrium candidate effectively yields the corresponding market outcome. The analysis is performed under the following assumption:

Assumption 1 *Consumers derive a low utility from the second digital good: $\alpha \in (0, 1/4)$.*

3.1 Fully-served market

When the market is fully covered, each consumer type $x \in [0, 1]$ purchases either good A or good B. According to how large the cost of downloading is, we can distinguish two sub-cases: (i) Absence of downloading; (ii) Coexistence of buying and downloading.

In each sub-case, for any given price pair (p_A, p_B), consumers maximize their net surplus.

3.1.1 Absence of downloading

This market configuration occurs when all consumers are willing to buy one of the two goods and no consumer benefits from downloading (Figure 1). Let $\hat{x}'$ denote the consumer type which is indifferent between using good A or good B; this is equal to:

$$\hat{x}' = \frac{1}{2} + \frac{(p_B - p_A)}{2}.$$

Consumer types $x \in [0, \hat{x}')$ buy good A, whereas consumer types $x \in (\hat{x}', 1]$ buy good B, so that the demand for good A is $D_A = \hat{x}'$ and the demand for good B is $D_B = 1 - \hat{x}'$. Firms' profits write as $\pi_A = \hat{x}' p_A$ and $\pi_B = (1 - \hat{x}') p_B$. Their maximization problems yield the following price competition equilibrium:

$$D_A = D_B = 1/2, \quad p_A = p_B = 1, \quad \pi_A = \pi_B = 1/2.$$

As we show in Appendix A1, this equilibrium candidate is the market outcome for $k \in \left(\frac{3}{2}, \frac{c}{2\alpha}\right)$, which is a non-empty interval for $c \geq 3\alpha$.

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[7]Let us take, for instance, consumer type $x = 0$; her benefit to download good B is $G_B(0) = \alpha k - c$, while her benefit to download good A is $G_A(0) = \alpha k$. Clearly, $G_B(0) < G_A(0)$. Among others, Gayer and Shy (2003) similarly model heterogeneity in the preferences for downloading. The authors motivate this heterogeneity by assuming that consumers are not equally proficient in using computers.

[8]Throughout the paper, we assume that downloading is always a feasible option for consumers. However, if piracy is not allowed, consumers might be willing to buy both goods. We discuss this issue in Section 5.1.
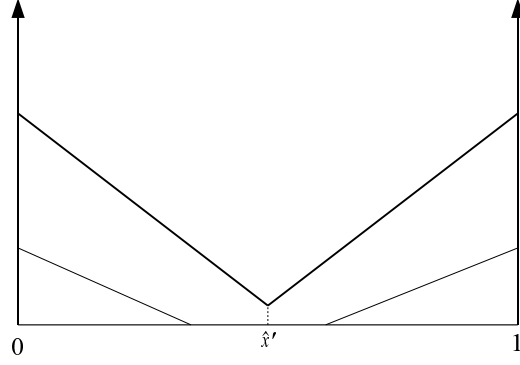
Figure 1: Absence of downloading in fully covered market: the maximal utility for each x is in bold.

3.1.2 Coexistence of buying and downloading

In this market configuration, we consider two possibilities: (a) either only some consumers benefit from downloading, whereas others decide to use only their favourite good (*partial download*); or (b) all consumers buy one good and download the other one (*full download*).

We call x_A the consumer which is indifferent between only buying product A and "buying A and downloading B". Formally, x_A solves $G_B = 0$, which gives:

$$x_A = 1 - \frac{\alpha k}{c}. \tag{3}$$

Similarly, we call x_B the consumer which is indifferent between only buying product B and "buying B and downloading A". Formally, x_B solves $G_A = 0$, that is:

$$x_B = \frac{\alpha k}{c}. \tag{4}$$

Finally, we call $\hat{x}$ the consumer that is indifferent between "buying A and downloading B" and "buying B and downloading A" i.e.,

$$\hat{x} = \frac{1}{2} + \frac{(p_B - p_A)}{2(1-c)}. \tag{5}$$

Concerning sub-case (a), x_A, $x_B \in [0,1]$ as long as $k \leq c/\alpha$. This market configuration is depicted in Figure 2(a). As for sub-case (b), $x_A < 0$, $x_B > 1$ as long as $k > c/\alpha$ (Figure 2(b)). In the first market configuration, consumer types $x \in [0, x_A)$ only buy A, consumer types $x \in (x_B, 1]$ only buy B, consumer types $x \in [x_A, \hat{x})$ buy A and download B, and consumer types $x \in [\hat{x}, x_B)$ buy B and download A. In the second market configuration, consumer types $x \in [0, \hat{x})$ buy A and download B, and consumer types $x \in [\hat{x}, 1]$ buy B and download A. Thus, regardless of whether downloading is partial or full, goods' demands are $D_A = \hat{x}$ and $D_B = 1 - \hat{x}$: these are decreasing in their own price and increasing in the rival good's price. Firms' maximization problems yield the following price competition equilibrium:

$$D_A = D_B = 1/2, \quad p_A = p_B = (1-c), \quad \pi_A = \pi_B = \frac{(1-c)}{2}.$$

As shown in Appendix A1, this equilibrium candidate is the market outcome for $k > \max\left\{\frac{c}{2\alpha}, \frac{3-c}{2(1+\alpha)}\right\}$.
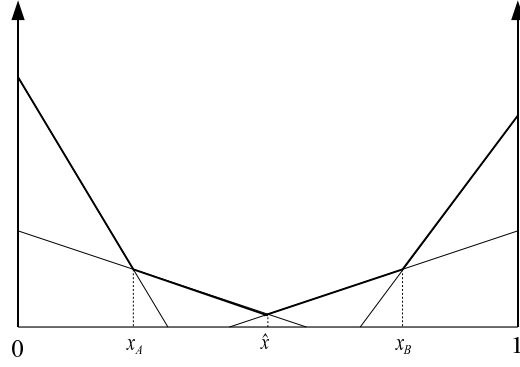
(a) Only some consumers download
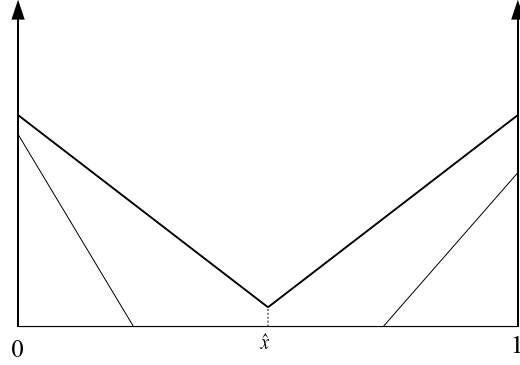
(b) All consumers download

Figure 2: Coexistence of buying and downloading in fully served market: the maximal utility for each x is in bold

3.2 Partially-served market

When the market is not covered, some consumer types $x \in [0, 1]$ prefer not using any good. As before, we can distinguish two sub-cases: (i) Absence of downloading; (ii) Coexistence of buying and downloading.

3.2.1 Absence of downloading

In this case, we observe only some consumers buying either of the two goods (Figure 3). Thus, demands are defined as:

$$D_A = x'_A = k - p_A,$$
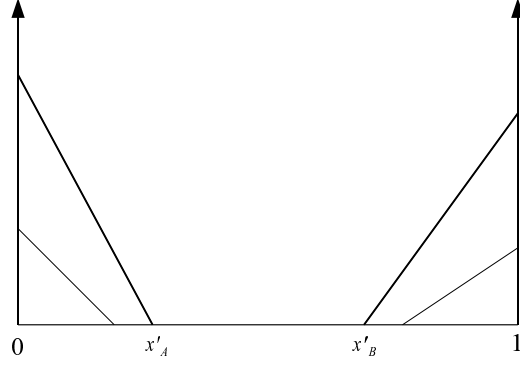$$D_B = 1 - x'_B = k - p_B.$$

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Figure 3: Absence of downloading in partially served market: the maximal utility for each x is in bold.

Firms do not interact and their maximization problems lead to:

$$D_A = D_B = \frac{k}{2}, \quad p_A = p_B = \frac{k}{2}, \quad \pi_A = \pi_B = \frac{k^2}{4}.$$

As we show in Appendix A2, this equilibrium candidate is the market outcome for $k < \min\left\{1, \frac{2c}{2\alpha+c}\right\}$.

3.2.2 Coexistence of buying and downloading

In this market configuration, we consider two possibilities about the behavior of consumers that are willing to buy: (a) either only some benefit from downloading, whereas others decide to use only their favourite good (*partial download*); or (b) all consumers buy one good and download the other one (*full download*).

The reader can easily notice that x_A and x_B are the same as in (3) and (4). For a given price pair (p_A, p_B), we call $\hat{x}_A$ the consumer that is indifferent between "buying A and downloading B" and not using any good, that is:

$$\hat{x}_A = \frac{k(1+\alpha) - c - p_A}{1 - c}. \tag{6}$$

Similarly, we call $\hat{x}_B$ the consumer that is indifferent between "buying B and downloading A" and not using any good, that is:

$$\hat{x}_B = \frac{1 - k(1+\alpha) + p_B}{1 - c}. \tag{7}$$

Concerning sub-case (a), $x_A, x_B \in [0, 1]$ as long as $k \leq c/\alpha$. This market configuration is depicted in Figure 4(a). As for sub-case (b), $x_A < 0$, $x_B > 1$ as long as $k > c/\alpha$ (Figure 4(b)). Similarly to the case of fully-served market, demands are the same both in partial and in full downloading, i.e., $D_A = \hat{x}_A$ and $D_B = 1 - \hat{x}_B$. As the market is not covered, firms are local monopolies. Firms' maximization problems yield the following price competition equilibrium:

$$D_A = D_B = \frac{k(1+\alpha) - c}{2(1-c)}, \quad p_A = p_B = \frac{k(1+\alpha) - c}{2}, \quad \pi_A = \pi_B = \frac{[k(\alpha+1) - c]^2}{4(1-c)}.$$

As before, firms realize the same level of profits under *full download* and *partial download*.

Appendix A2 shows that this equilibrium candidate is the market outcome for $k \in \left(\frac{2c}{2\alpha+c}, \frac{1}{1+\alpha}\right)$. The latter is a non-empty interval for $c < \frac{2\alpha}{1+2\alpha}$.

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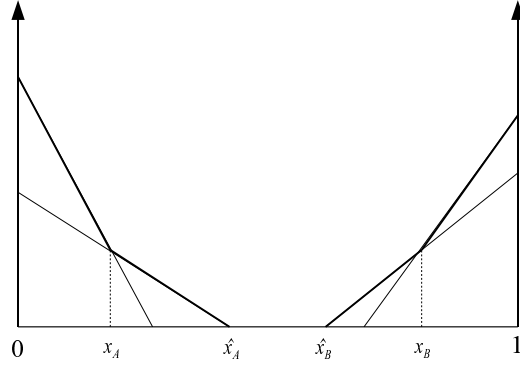
(a) Only some consumers download
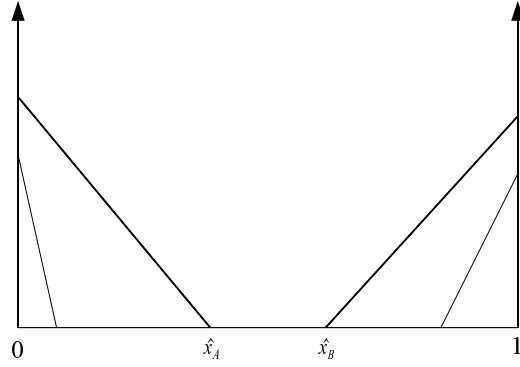
(b) All consumers willing to buy download

Figure 4: Coexistence of buying and downloading in partially served market: the maximal utility for each x is in bold.

3.3 Corner solutions

Corner solutions mark the transition from the configuration of fully-served market to that of partially-served market. This case completes the possible market configurations (see Appendix A3 for more details).

Wauthy (1996) points out the presence of corner solutions in a model of vertical differentiation. The author shows that there is a range of parameter values in which the low-quality firm chooses a price that is just sufficient to cover the market. This price makes the consumer with the lowest appreciation for quality indifferent between buying the low-quality good and refraining from consumption. Following a similar reasoning, in our model corner solutions arise when companies quote a price which makes the consumer that is equidistant from the two firms (i.e. the consumer located at $x = 1/2$) just indifferent between buying either of the two goods and not buying at all. In our framework, thus, the price that makes a market "covered at the limit" is the solution to $U(1/2) = 0$. The intuition behind the presence of these corner solutions is as follows: there is a range of parameter values for which neither the condition for fully served market nor the condition for partially served market holds. Consider, for instance, the case of absence of downloading as in the standard linear city model:
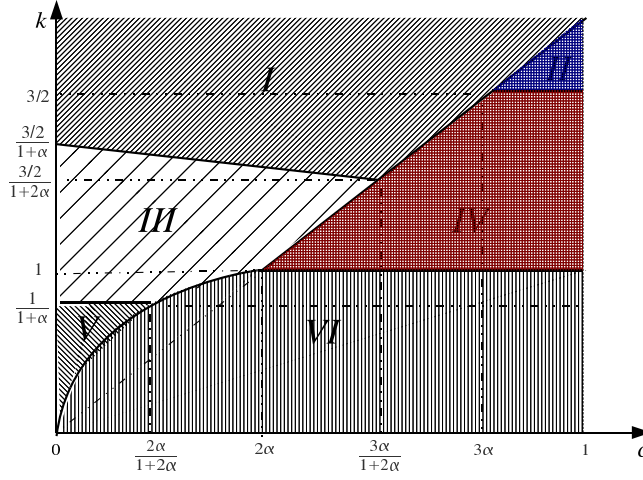
Figure 5: A graphical representation of equilibria

the equilibrium price is $p^* = 1$ when the market is fully served and $p^{**} = k/2$ when the market is partially served. The corner solution prevails when neither $k - p^* > 1/2$ nor $k - p^{**} < 1/2$ holds; substituting equilibrium prices, this occurs when $k \in (1, 3/2)$.

We now solve for the corner solutions by imposing $U(1/2) = 0$. In the absence of downloading, this occurs if and only if $p_i = k - 1/2$ for $i = A, B$; firms split the market evenly and, thus, equilibrium profits write as:

$$\pi_A = \pi_B = k/2 - 1/4.$$

This market configuration arises in the parameter region $k \in \left(1, \min\left\{\frac{c}{2\alpha}, \frac{3}{2}\right\}\right)$. In the presence of downloading, $U(1/2) = 0$ if and only if $p_i = k(1+\alpha) - (1+c)/2$ for $i = A, B$; since firms divide the market equally, equilibrium profits write as:

$$\pi_A = \pi_B = k(1+\alpha)/2 - (1+c)/4.$$

This market configuration arises in the interval $k \in \left(\max\left\{\frac{1}{1+\alpha}, \frac{2c}{2\alpha+c}, \frac{c}{2\alpha}\right\}, \frac{3-c}{2(1+\alpha)}\right)$.

3.4 Graphical representation of equilibria

We now provide a graphical representation of all market equilibria in the $(c, k)-$space (Figure 5). There are six areas corresponding to all possible market outcomes. The shaded areas I and II refer respectively to situations of coexistence of buying and downloading and absence of downloading when the market is fully served. The shaded areas III and IV refer to the two corner solutions with the market "covered at the limit", respectively in the presence of downloading and in the absence of downloading. Finally, the shaded areas V and VI refer respectively to situations of coexistence of buying and downloading and absence of downloading when the market is partially served. Appendix A4 provides a summary of market equilibria for all possible values of k and c.

It is interesting to look at the market equilibrium outcomes if downloading is not a feasible option for consumers, as in the standard linear city model. In the parameter region $k < 1$ the unique market equilibrium would be the one under partially-served market. In the interval $k \in (1, 3/2)$ the market would be "covered at the limit", while in the parameter region $k > 3/2$ the unique market equilibrium would be the one under fully-served market.
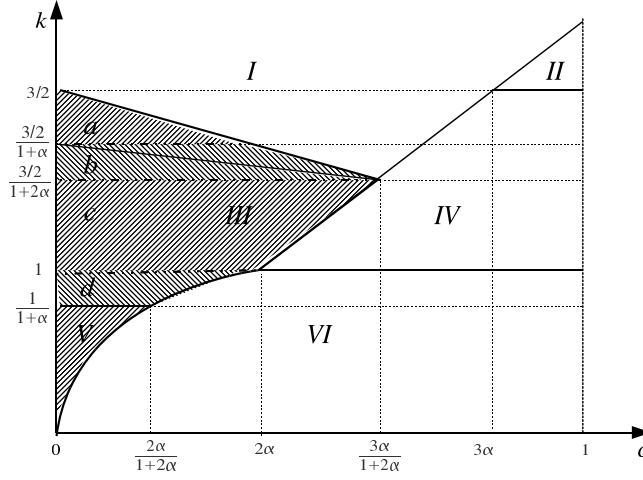
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Figure 6: Areas where firms benefit from piracy

4 Piracy and firms' profitability

We now compare firms' profits in the presence of downloading with those in the absence of downloading. To keep the notation lighter and identify exactly which market configuration we are referring to, we will add a subscript to equilibrium profits π.

Figure 6 provides a visual depiction of firms' attitude towards piracy: the shaded area of this figure corresponds to the region where firms benefit from downloading. All results are gathered in Proposition 1 and 2, for extreme values of k (either very high or very low), and for intermediate values of k, respectively.

Proposition 1 *For values of:*

(i) $k > 3/2$, the market is fully served and firms never benefit from piracy ($\pi_I - \pi_{II} < 0$);

(ii) $k < \frac{1}{1+\alpha}$, the market is partially served and firms always benefit from piracy ($\pi_V - \pi_{VI} > 0$) (area V of Figure 6).

Proof. See Appendix B1. ∎

When consumers' willingness to pay is high (i.e. $k > 3/2$), the market is fully served; firms strategically interact and split the market evenly. Comparing profits is then equivalent to comparing prices. In this case, firms are damaged from piracy as the downloading option makes price competition tougher: downloading leads to a lower price (negative *price effect*) without allowing firms to capture a higher number of consumers (the *demand effect* is nil).

When consumers' willingness to pay is low (i.e. $k < 1/(1 + \alpha)$) the market is partially served and we have two monopolies; the introduction of the downloading option enlarges firms' market shares without making competition harsher. The possibility to download makes the goods more attractive and (at least) some consumers use both goods. In this case, firms gain higher profits in the presence of piracy than otherwise.[9]

Let us now compare equilibrium profits for intermediate values of k.

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[9]Belleflamme and Picard (2007) contrast the strategic behaviour of a multiproduct monopolist with the behaviour of two

Proposition 2 *In the interval:*

(i) $k \in \left(\frac{3/2}{1+\alpha}, 3/2\right)$, *firms benefit from piracy* ($\pi_I - \pi_{IV} > 0$) *in the region* $k \in \left(\frac{3/2}{1+\alpha}, \frac{3}{2} - c\right)$ *(area* a *of Figure 6);*

(ii) $k \in \left(\frac{3/2}{1+2\alpha}, \frac{3/2}{1+\alpha}\right)$, *firms benefit from piracy* ($\pi_{III} - \pi_{IV} > 0$ *and* $\pi_I - \pi_{IV} > 0$) *in the region* $k \in \left(\frac{3/2}{1+2\alpha}, min\left\{\frac{3/2}{1+\alpha}, \frac{3}{2} - c\right\}\right)$ *(area* b*);*

(iii) $k \in \left(1, \frac{3/2}{1+2\alpha}\right)$, *firms always benefit from piracy* ($\pi_{III} - \pi_{IV} > 0$) *(area* c*);*

(iv) $k \in \left(\frac{1}{1+\alpha}, 1\right)$, *firms always benefit from piracy* ($\pi_{III} - \pi_{VI} > 0$) *(area* d*).*

Proof. See Appendix B2. ∎

It is interesting to comment these results in light of the change in the market structure occurring with the introduction of piracy in the parameter region $k \in (1/(1 + \alpha), 3/2)$. If downloading is not a feasible option for consumers, the market would be "covered at the limit" in the interval $k \in (1, 3/2)$ and partially served in the interval $k \in (1/(1 + \alpha), 1)$; therefore, equilibrium profits would be equal to π_{IV} and π_{VI}, respectively. With the introduction of piracy, the market becomes fully served for $k \in \left(max\left\{\frac{c}{2\alpha}, \frac{3-c}{2(1+\alpha)}\right\}, 3/2\right)$ and "covered at the limit" for $k \in \left(max\left\{\frac{1}{1+\alpha}, \frac{2c}{2\alpha+c}, \frac{c}{2\alpha}\right\}, \frac{3-c}{2(1+\alpha)}\right)$; firms realize profits π_I and π_{III}, respectively.

In order to assess whether firms benefit from piracy, one needs to compare equilibrium profits in the market configurations *I* and *IV*, *III* and *IV*, and *III* and *VI*.

As companies do not interact both when the market is partially served and when it is covered at the limit, in the parameter space $k \in (1/(1 + \alpha), (3/2)/(1 + 2\alpha))$ the introduction of the downloading option does not strengthen the competition in the market; however, it increases the value that consumers place on goods and, in turn, their willingness to pay. Firms always benefit from piracy because they succeed in extracting this extra surplus. In particular, for $k \in \left(\frac{1}{1+\alpha}, 1\right)$ we look at the two market configurations *III* and *VI* and find that $\pi_{III} - \pi_{VI} > 0$. Although the monopoly price of the configuration *VI* may be higher than the corresponding price of the configuration *III*, the possibility of download allows firms to serve a larger number of customers without affecting the degree of competition in the market. For $k \in \left(1, \frac{3/2}{1+2\alpha}\right)$ we look at the market configurations *III* and *IV*, where companies split the market equally and quote a price that is just sufficient to cover the market. We find that $\pi_{III} - \pi_{IV} > 0$. In this case, even though the demand effect is nil, companies may set a higher price in order to cover the market; this gives firms the possibility to indirectly appropriate some revenue from piracy.

On the contrary, for $k \in \left(\frac{3/2}{1+2\alpha}, 3/2\right)$ piracy enlarges the parameter region where the market is fully served; the change in the market structure is accompanied by an increase in the degree of competition. Also in this case the presence of piracy makes the goods more attractive for consumers. In this intermediate situation the demand effect is not at work and firms are able to set higher prices and gain from piracy provided that the cost of downloading is not too high.

Bertrand duopolists under the threat of piracy. They find that piracy may induce the monopolist to decrease prices, while the duopolists to increase prices. In our model the opposite result holds. This is due to the fact that in their model the presence of a copying device makes the two original goods complements, while in ours goods remain substitutes.

5 Final remarks

In this paper we have shown that firms' attitudes towards piracy depend on the extent of market coverage. In markets which are not fully covered, firms could benefit from piracy as it allows them to reach a larger share of customers which otherwise would not buy at all.[10] The opposite incentives arise in covered markets where firms prefer full protection from piracy. Our results are thus in line with the observation that companies operating in emerging markets are unlikely to take a firm line against piracy. By adopting a dynamic perspective, our analysis also suggests that a company becomes more willing to fight piracy at later stages of the industry development.

In what follows, we discuss the robustness of our findings with respect to two modeling assumptions. We consider, first, the possibility for consumers to buy both goods. Then, we relax the hypothesis that the access to the file-sharing community is restricted only to consumers that buy a digital good.

5.1 Consumers buying both goods

In the model, we have abstracted from the possibility for consumers to buy both goods. However, when consumers' willingness to pay is very high and downloading is not feasible, (at least) some consumers might be willing to buy both goods. In this case we would have an additional equilibrium outcome which has to be compared with the corresponding one in the presence of downloading. Here, we first analyze in which parameter space (at least) some consumers buy both goods in equilibrium and then we make the proper profit comparison.

Formally, the utility from buying both goods is

$$U_2 = k(1 + \alpha) - 1 - p_A - p_B.$$

Consumer type x chooses to buy only good A rather than good B or both A and B iff:

$$x < \bar{x}_A \equiv 1 - \alpha k + p_B.$$

Similarly, consumer type x would choose to buy only good B rather than good A or both A and B iff:

$$x > \bar{x}_B \equiv \alpha k - p_A.$$

Firms' demands would be respectively:

$$D_A = \bar{x}_B = \alpha k - p_A, \qquad D_B = 1 - \bar{x}_A = \alpha k - p_B.$$

In this scenario, even if the market is fully covered, firms do not interact strategically as the demands for the goods are independent. Thus, equilibrium prices and profits would be:

$$p_2 = \alpha k/2, \qquad \pi_2 = (\alpha k/2)^2.$$

This equilibrium outcome is possible only if $\bar{x}_A \in (0, \hat{x}')$ (and similarly $\bar{x}_B \in (\hat{x}', 1)$), which at equilibrium requires $k \geq 1/\alpha$. Looking at Figure 5, we would have a straight line $k = 1/\alpha$ (strictly higher than 3/2) above

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[10]In our model downloading may imply an increase in the sales of the first digital good (sales-enhancing effect) and a sales displacement of the second good; the latter, however, is not one-for-one. This is due to the fact that some of the consumers which download the second good would have not purchased it when downloading is not allowed. The empirical evidence for less than one-for-one displacement is provided by Rob and Waldfogel (2006, 2007) and Waldfogel (2009) who also point out a sales-stimulating effect of file-sharing when this is non-anonymous and within small groups (for details, see Varian, 2000).

which some consumers buy both goods. In the parameter region $k < 1/\alpha$ all the results contained in Section 4 still continue to hold true. Instead, in the region $k \geq 1/\alpha$, to assess whether piracy is profitable for firms, one needs to compare equilibrium profits with and without downloading, π_I and π_2 respectively. Interestingly, it is possible to show that $\pi_2 < \pi_I$, provided that the cost of downloading c is not too high; in fact, even though piracy strengthen competition in the market and reduces firms' demands, it makes the value of each good much higher, given the high level of k and the low level of c. By increasing consumers' willingness to pay, piracy is beneficial for firms as they can charge higher prices.

5.2   Agents with some endowments

In the present paper we have assumed that consumers can download a digital good only if they buy the other good and decide to share it with the other community members. This assumption may seem restrictive because in the reality agents could already be endowed with some content to upload. A legitimate question, therefore, is to check whether our results are sensitive to this modeling assumption. In order to deal with this issue, one could imagine that a fraction $s \in (0,1)$ of the population consists of agents with no endowment so that a consumer of this type has the same utility as the one specified above. The complementary share $1 - s$ consists of agents with an endowment of a good; a consumer $x \in [0,1]$ of this group has the following utility:

$$
U(x) = \begin{cases}
k - x & \text{if uses } A \\
k - x + G_B(x) & \text{if uses } A \text{ and downloads } B \\
k - (1 - x) & \text{if uses } B \\
k - (1 - x) + G_A(x) & \text{if uses } B \text{ and downloads } A
\end{cases}
$$

with $G_B(x)$ and $G_A(x)$ defined as in (1) and (2).

Since agents with some endowments never buy the second good, the consumption decisions of the fraction $1 - s$ of the population do not affect firms' profits. As for the fraction s of consumers with no endowment, the consequence of reducing s is that the market for the goods is smaller, i.e. $D_A + D_B = s < 1$. For example, in a fully served market with absence of downloading (Figure 1), demands for the two goods would be $D_A = s\hat{x}'$ and $D_B = s(1 - \hat{x}')$. One can easily ascertain that a decrease in the fraction of population with no endowment reduces equilibrium profits proportionally in each market configuration; since a change in s does not affect the profit comparison in the paper, our results continue to hold true.

Appendix A

Here, we provide the parameter ranges for which each equilibrium candidate effectively yields the corresponding market outcome.

A1 Fully-served market

Conditions for the absence of downloading. Downloading has to be unprofitable for any agent, also for $\hat{x}'$ which is the consumer type with the highest incentive to download. Moreover, we require that all consumers buy one of the two goods, including $\hat{x}'$ which is the consumer type with the lowest willingness to pay. Formally:

$$G_A(\hat{x}'), \ G_B(\hat{x}') < 0 \Leftrightarrow 2\alpha k - c + c\,|p_B - p_A| < 0,$$
$$U(\hat{x}') > 0 \Leftrightarrow k - \frac{1}{2} - \frac{p_B + p_A}{2} > 0.$$

At equilibrium, this amounts to require that $k \in \left(\frac{3}{2}, \frac{c}{2\alpha}\right)$, which is a non-empty interval for $c \geq 3\alpha$. This parameter region is depicted in the shaded area II of Figure 5.

Conditions for the coexistence of buying and downloading. In such a case, we require that downloading is profitable at least for $\hat{x}$ which is the consumer type with the highest incentive to download. Moreover, we still impose the market coverage condition. Formally:

$$G_A(\hat{x}), \ G_B(\hat{x}) > 0 \Leftrightarrow (2\alpha k - c)(1 - c) + c\,|p_B - p_A| > 0,$$
$$U(\hat{x}) > 0 \Leftrightarrow k(1 + \alpha) - \frac{1 + c}{2} - \frac{p_B + p_A}{2} > 0.$$

At equilibrium, this amounts to require that $k > \max\left\{\frac{c}{2\alpha}, \frac{3-c}{2(1+\alpha)}\right\}$. Now, if $c \geq \frac{3\alpha}{1+2\alpha}$, we have that $\frac{c}{2\alpha} \geq \frac{3-c}{2(1+\alpha)}$; therefore, downloading occurs in the parameter region $k > \frac{c}{2\alpha}$. Instead, if $c < \frac{3\alpha}{1+2\alpha}$, we get that $\frac{c}{2\alpha} < \frac{3-c}{2(1+\alpha)}$; consequently, the presence of downloading is the outcome in the interval $k > \frac{3-c}{2(1+\alpha)}$. This parameter region corresponds to the shaded area I in Figure 5.

A2 Partially-served market

Conditions for the absence of downloading. Downloading has to be unprofitable for any agent, also for x'_A and x'_B which are the consumer types with the highest incentives to download. We also require that the market is partially served. Formally:

$$G_B(x'_A) < 0, \ G_A(x'_B) < 0 \Leftarrow c > \max\left\{\frac{\alpha k}{1 - k + p_A}, \frac{\alpha k}{1 - k + p_B}\right\},$$
$$U(\hat{x}') < 0 \Leftrightarrow k - \frac{1}{2} - \frac{p_B + p_A}{2} < 0.$$

At equilibrium, these conditions require that $k < \min\left\{1, \frac{2c}{2\alpha + c}\right\}$. If $c \geq 2\alpha$, we have that $\frac{2c}{2\alpha + c} \geq 1$; thus, absence of downloading occurs in the parameter region $k < 1$. On the contrary, if $c < 2\alpha$, we get that $\frac{2c}{2\alpha + c} < 1$;

consequently, absence of downloading is the outcome in the region $k < \frac{2c}{2\alpha+c}$. In Figure 5, this parameter region is depicted by the shaded area VI.

Conditions for the coexistence of buying and downloading. Downloading has to be profitable for the consumer types x'_A and x'_B; moreover, we require that the market is not covered. Formally:

$$G_B(x'_A) > 0, \; G_A(x'_B) > 0 \Leftarrow c < \min\left\{\frac{\alpha k}{1-k+p_A}, \frac{\alpha k}{1-k+p_B}\right\},$$

$$U(\hat{x}) < 0 \Leftrightarrow k(1+\alpha) - \frac{1+c}{2} - \frac{p_B+p_A}{2} < 0.$$

At equilibrium, this requires that $k \in \left(\frac{c(2-c)}{2\alpha+c(1-\alpha)}, \frac{1}{1+\alpha}\right)$. This is a non-empty interval for $c < \frac{2\alpha}{1+\alpha}$.

It is worth observing that in the interval $k \in \left(\frac{c(2-c)}{2\alpha+c(1-\alpha)}, \min\left\{\frac{1}{1+\alpha}, \frac{2c}{2\alpha+c}\right\}\right)$ there are two candidate equilibria, that are two local maxima: either prices in the absence of downloading or prices in the presence of downloading. Since in the above interval firms realize higher profits in the absence of downloading, we select this regime as equilibrium market outcome.[11] Consequently, coexistence of buying and downloading under partially-served market occurs in the interval $k \in \left(\frac{2c}{2\alpha+c}, \frac{1}{1+\alpha}\right)$, which is a non-empty interval for $c < \frac{2\alpha}{1+2\alpha}$. This parameter region is the shaded area V that is graphically illustrated in Figure 5.

A3 Corner solutions

The model is characterized by the presence of two corner solutions, which arise when firms quote a price that is just sufficient to cover the market. Since in correspondence of these corner solutions the consumer type $x = 1/2$ is indifferent between buying either of the two goods and not buying at all, the price which makes a market "covered at the limit" is the solution to $U(1/2) = 0$. In the absence of downloading, it amounts to $p_A = p_B = k - 1/2$; this market configuration arises in the interval $k \in \left(1, \min\left\{\frac{c}{2\alpha}, \frac{3}{2}\right\}\right)$, which is the parameter region depicted by the shaded area IV in Figure 5. In the presence of downloading, instead, the equilibrium price is $p_A = p_B = k(1+\alpha) - \frac{1+c}{2}$; this market configuration arises in the parameter region $k \in \left(\max\left\{\frac{1}{1+\alpha}, \frac{2c}{2\alpha+c}, \frac{c}{2\alpha}\right\}, \frac{3-c}{2(1+\alpha)}\right)$ which is illustrated by the shaded area III in Figure 5. As one can observe, these two areas are contiguous and are separated by a straight line of equation $k = \frac{c}{2\alpha}$. In fact, downloading does not occur when:

$$G_B(1/2) < 0, \; G_A(1/2) < 0 \Leftrightarrow k < \frac{c}{2\alpha}.$$

Consequently, the areas III and IV lie respectively above and below the line $k = \frac{c}{2\alpha}$.

A4 Market equilibria for all possible values of k and c

We now summarize all the equilibrium outcomes for different levels of the parameters k and c.

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[11]In fact, profits in the absence of downloading are larger than profits in the presence of downloading in the region $k \in \left(\frac{c(1+\alpha-\sqrt{1-c})}{2\alpha+c+\alpha^2}, \frac{c(1+\alpha+\sqrt{1-c})}{2\alpha+c+\alpha^2}\right)$. After some tedious algebra, it is possible to show that this parameter region contains the interval $k \in \left(\frac{c(2-c)}{2\alpha+c(1-\alpha)}, \min\left\{\frac{1}{1+\alpha}, \frac{2c}{2\alpha+c}\right\}\right)$.

- $c \in (3\alpha, 1)$. The market outcome is fully-served market with presence of downloading for $k > \frac{c}{2\alpha}$ and absence of downloading for $k \in \left(\frac{3}{2}, \frac{c}{2\alpha}\right)$. Partially-served market with absence of downloading is instead the market outcome for $k < 1$, while presence of downloading never occurs. In the range of $k \in \left(1, \frac{3}{2}\right)$ we have a market which is "covered at the limit" with absence of downloading.

- $c \in \left(\frac{3\alpha}{1+2\alpha}, 3\alpha\right)$. The market outcome is fully-served market with presence of downloading for $k > \frac{c}{2\alpha}$, while absence of downloading never occurs: the cost of downloading is low so that in any fully-served market configuration there are always some consumers that download. Partially-served market with absence of downloading is the market outcome for $k < 1$, while presence of downloading never occurs. In the range of $k \in \left(1, \frac{c}{2\alpha}\right)$ the market is "covered at the limit" with absence of downloading.

- $c \in \left(2\alpha, \frac{3\alpha}{1+2\alpha}\right)$. The market outcome in a fully-served market is presence of downloading for $k > \frac{3-c}{2(1+\alpha)}$. Partially-served market with absence of downloading is instead the market outcome for $k < 1$, while presence of downloading never occurs. In the range of $k \in \left(1, \frac{3-c}{2(1+\alpha)}\right)$ we have a market which is "covered at the limit" with absence of downloading for $k < \frac{c}{2\alpha}$ and with presence of downloading for $k > \frac{c}{2\alpha}$.

- $c \in \left(\frac{2\alpha}{1+2\alpha}, 2\alpha\right)$. The market outcome in a fully-served market is presence of downloading for $k > \frac{3-c}{2(1+\alpha)}$. Partially-served market with absence of downloading is instead the market outcome for $k < \frac{2c}{2\alpha+c}$, while presence of downloading never occurs. In the range of $k \in \left(\frac{2c}{2\alpha+c}, \frac{3-c}{2(1+\alpha)}\right)$ the market is "covered at the limit" with presence of downloading.

- $c \in \left(0, \frac{2\alpha}{1+2\alpha}\right)$. The market outcome in a fully-served market is presence of downloading for $k > \frac{3-c}{2(1+\alpha)}$. In this range of c, the following inequality holds: $\frac{2c}{2\alpha+c} < \frac{1}{1+\alpha}$. Partially-served market with presence of downloading is then the market outcome for $k \in \left(\frac{2c}{2\alpha+c}, \frac{1}{1+\alpha}\right)$, while absence of downloading is the market outcome for $k < \frac{2c}{2\alpha+c}$. In the range of $k \in \left(\frac{1}{1+\alpha}, \frac{3-c}{2(1+\alpha)}\right)$ we have a market that is "covered at the limit" with presence of downloading.

Appendix B

In this Appendix, we provide the proofs to Proposition 1 and 2.

B1 Proof of Proposition 1

(i) For $k > 3/2$, the market is fully served and $\pi_I - \pi_{II} < 0$. This can been easily proved as $\pi_I = (1-c)/2 < \pi_{II} = 1/2$.

(ii) For $k < \frac{1}{1+\alpha}$, the market is partially served and $\pi_V - \pi_{VI} > 0$. In fact, we have that:

$$\pi_V - \pi_{VI} > 0 \Leftrightarrow c^2 + c[k^2 - 2k(1+\alpha)] + k^2\alpha(2+\alpha) > 0 \Leftrightarrow c < c_1 \cup c > c_2,$$

where $c_1 \equiv \frac{k}{2}\left[2 + 2\alpha - k - \sqrt{k^2 - 4k(1+\alpha) + 4}\right]$ and $c_2 \equiv \frac{k}{2}\left[2 + 2\alpha - k + \sqrt{k^2 - 4k(1+\alpha) + 4}\right]$. The term under square root is positive for $k < \frac{1}{1+\alpha}$, thus these two roots are real numbers with $c_2 > c_1$. After some algebra, we find that c_2 is larger than $\alpha k/(1-k)$, that is is threshold value of c beyond which both D_A and p_A are higher in the absence of downloading than in the presence of downloading. Thus, we have that c_2 is not binding. We complete the proof by showing that c_1 is also not binding. As coexistence of buying and downloading requires that $k > \frac{2c}{c+2\alpha}$, we can rewrite this inequality as $c < \frac{2\alpha k}{2-k}$. Since $c_1 > \frac{2\alpha k}{2-k}$, we conclude that $\pi_V > \pi_{VI}$.

B2 Proof of Proposition 2

As Figure 5 shows, given α, depending on k and c different market configurations arise at equilibrium.

(i) $k \in \left(\frac{3/2}{1+\alpha}, 3/2\right)$. The equilibrium outcome is fully-served market with presence of downloading for $k > \frac{c}{2\alpha}$. The market is "covered at the limit" with absence of downloading for $k < \frac{c}{2\alpha}$. Comparing firms' profits, we have:

$$\pi_I - \pi_{IV} > 0 \Leftrightarrow k < 3/2 - c.$$

Thus, firms benefit from downloading for $k \in \left(\frac{3/2}{1+\alpha}, \frac{3}{2} - c\right)$. This region is depicted in Figure 6 (shaded area a).

(ii) $k \in \left(\frac{3/2}{1+2\alpha}, \frac{3/2}{1+\alpha}\right)$. Downloading occurs for $k > \frac{c}{2\alpha}$: the market outcome is fully-served market for $k > \frac{3-c}{2(1+\alpha)}$ and a market "covered at the limit" for $k < \frac{3-c}{2(1+\alpha)}$. For $k < \frac{c}{2\alpha}$, instead, the market is "covered at the limit" with absence of downloading. Comparing profits, we get:

$$\pi_I > \pi_{IV} \Leftrightarrow k < 3/2 - c,$$
$$\pi_{III} > \pi_{IV} \Leftrightarrow k > \frac{c}{2\alpha}.$$

Therefore, firms benefit from downloading for $k \in \left(\frac{3/2}{1+2\alpha}, min\left\{\frac{3/2}{1+\alpha}, \frac{3}{2} - c\right\}\right)$. This region corresponds to the shaded area b in Figure 6.

(iii) $k \in \left(1, \frac{3/2}{1+2\alpha}\right)$. The market is "covered at the limit" with presence of downloading for $k > \frac{c}{2\alpha}$, and with absence of downloading for $k < \frac{c}{2\alpha}$. Comparing profits, we find:

$$\pi_{III} - \pi_{IV} > 0 \Leftrightarrow k > \frac{c}{2\alpha}.$$

Thus, firms benefit from downloading for $k \in \left(max \left\{ 1, \frac{c}{2\alpha} \right\}, \frac{3/2}{1+2\alpha} \right)$. This region is depicted in Figure 6 (shaded area c).

(iv) $k \in \left(\frac{1}{1+\alpha}, 1 \right)$. The market is "covered at the limit with presence of downloading" for $k > \frac{2c}{2\alpha+c}$; instead, the market is partially served with absence of downloading for $k < \frac{2c}{2\alpha+c}$. We compare profits and we get:

$$\pi_{III} - \pi_{VI} > 0 \Leftrightarrow k \in (k_1, k_2),$$

where $k_1 \equiv 1 + \alpha - \sqrt{\alpha(2+\alpha) - c}$ and $k_2 \equiv 1 + \alpha + \sqrt{\alpha(2+\alpha) - c}$. After some algebra, we find that $k_2 > 1$ while $k_1 < \frac{1}{1+\alpha}$ in the interval of interest. Therefore, firms always benefit from downloading in this region of k (shaded area d in Figure 6).

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