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Peer-to-peer Networks and Complementary Goods: The Impact of Openness and Innovation on Profitable Piracy

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ABSTRACT – *File-sharing is often depicted as detrimental to traditional commercial activities and tends to dissuade official digital goods' producers from innovating. Meanwhile, evidence shows that producers are likely to provide complementary hardware goods that are compatible with digital goods available both offline and online. This article investigates to what extent the introduction of peer-to-peer networks has a positive impact on the level of profits reached by producers.*

Our model shows that the file-sharing activity does not crowd the official digital goods producers and hardware goods producers out of the market. Moreover, we find that there exists suitable quality-based strategies so that both types of producers benefit from the file-sharing activity. The utility that peer-to-peer networks provide to file-sharers has to be considered cautiously for commercial firms to gain positive outcomes from the file-sharing activity.

KEY WORDS: *peer-to-peer networks, piracy, complementary goods, communities*

Introduction

The emergence of the Internet as a new transactional space has deeply changed the way consumers, producers and distributors interact and has therefore led to several economic research tracks over the last decade. The development of new compression standards marks a significant step in the development of economic analyses related to the Internet, thus highlighting the transition to the 'dematerialization era' which leads to the widespreading of digital files online and to new technological adoption issues (Shapiro and Varian, 1999; Peitz and Waelbroeck, 2006a). The consumption of such digital goods is more particularly facilitated by the emergence of new electronic platforms relying on specific organizational models, namely peer-to-peer networks (Krishnan et al., 2003, 2004, 2007), as well as the increasing abilities of users to participate in productive activities (Toffler, 1980; von Hippel, 1988; von Hippel, 2005; Flowers, 2008). The increasing use of computers and the democratization of high-speed broadband help Internet users to get access to digital files, thus contributing to the increasing popularity of such file-sharing networks. As an illustration, the peer-to-peer activity nowadays represents 37% of the Internet global traffic, and gradually leads to the emergence of new networks, like FastTrack, eDonkey2K or BitTorrent which have superseded the late Napster.

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The popularity of the file-sharing activity, as far as it is widely adopted online, is in many cases perceived by commercial entities – producers and vendors – as a direct threat for their own activities which would affect their perenniality on markets they historically used to control (Bourreau and Labarthe-Piol, 2004). As such, the introduction of peer-to-peer networks would represent a convenient way for users to get access to and acquire digital goods without having to pay pecuniar fees. These considerations tend to define peer-to-peer networks as intermediaries improving the consumption of digital goods by enhancing piracy online and by altering the level of profits reached by commercial digital goods' stakeholders. In other terms, such arguments tend to state that the activity of commercial-based networks and peer-to-peer networks are substituable and that there does not exist any complementary relationship beneficial that is for both of them. As a consequence, facing the popularity of the file-sharing activity, the technological innovation efforts made by digital goods producers would appear to be vain and costly.

Yet, this point of view may have to be qualified, since recent research topics dealing with Internet activities have on the contrary revealed positive external effects between traditional and new consumption models and have proved that the emergence of new distribution channels may improve their profitability. For instance, evidence and economic analyses have shown that offline and online commercial activities are likely to be both preserved and valuated through the setting up of specific strategies for each of them (Brynjolfsson and Smith, 2000; Bakos, 2001; Curien and Moreau, 2004). Economic studies dealing with open source software research tracks have also underlined the existence of such beneficial relationships. Whereas open source software projects were previously considered as competitors by software firms, the evidence of recent hybrid software development models today exhibits new potential benefits in a framework in which open source software and commercial actors cooperate (Dahlander and Magnusson, 2005; Bonaccorsi et al., 2006; Shah, 2006).

The impact of piracy on the valuation of the traditional commercial-based activities the file-sharing activity naturally implies has yielded several major contributions, underlining the importance of network effects in the outcome of producers (Liebowitz, 1985; Besen and Kirby, 1989; Conner and Rumelt, 1991; Takeyama, 1994; King and Lampe, 2003). Focusing on digital goods (Peitz and Waelbroeck, 2005; Liebowitz, 2006), empirical studies reveal contrasted results, as some scholars exhibit a detrimental effect on commercial actors' profits (Peitz and Waelbroeck, 2004; Liebowitz, 2005; Zentner, 2006) while others on the contrary underline a beneficial one (Oberholzer and Strumpf, 2004). The piracy-related literature usually links piracy to the widespread online diffusion of digital files, thus presenting "sampling" as a way of enhancing the popularity of commercial digital goods (Bounie et al., 2005; Peitz and Waelbroeck, 2006b) as well as that of the artists concerned (Gayer and Shy, 2006; Gopal et al., 2006). Finally, some authors show that enhancing piracy and digital goods' diffusion online have to be considered with the ensuing externalities resulting from the sales of complementary goods. More particularly, even though piracy may be detrimental for digital goods' producers, the diffusion and the unauthorized consumption of digital files are likely to increase the level of profit of the producers providing the hardware products needed to use any digital goods (i.e., original or pirate ones) (Gayer and Shy, 2006). As such, piracy-related studies highlight that piracy does not necessarily represent a source of

disutility but can also be used as a strategic tool for producers to increase their surplus (Shy and Thisse, 1999; Poddar, 2005). We actually do find evidence of such complementary goods strategies through the actual provision of physical hardware terminals aiming at exploiting both original and pirate digital goods. Several well-known companies (e.g., Sony, Philips or Pioneer) offer hardware products compatible with both official and 'less official' standards, thus potentially casting on piracy to sell complementary and impossible-to-reproduce goods. One may hence think, notably on account of the current popularity of Apple and its iPod players' offer, that using piracy to enhance complementary sales is a pertinent industrial strategy.

Although the literature associating general information economics topics (e.g., dealing with network effects) with piracy ones has already led to a large number of contributions, few studies have dealt with the impact of peer-to-peer networks on the diffusion of unauthorized digital goods and its market-based consequences on traditional producers. It is generally shown that the activity of peer-to-peer networks can improve the level of sales of the products generally sold in stores under specific conditions (Gayer and Shy, 2003a; Gopal et al., 2004, Rochelandet and Le Guel, 2005). The popularity of such file-sharing networks and the increasing interest these are currently arousing nevertheless require further analyses to be carried out. Studies related to the activity of peer-to-peer networks in a managerial framework notably stress that file-sharing networks differ in their degree of openness, that is the community-based – non-financial – benefits users derive from the file-sharing activity. The acquisition of unauthorized digital goods is therefore not as easy as it is often described, since access and participation appear to be regulated by somewhat internal policies (Asvanund et al., 2001; Cunningham et al., 2004), thus impacting on the level of the goods distributed online (Domon and Yamazaki, 2004). One key issue would therefore be to take into account the organizational specificities on which file-sharing networks are based so as to see to what extent their activity may be profitable for producers.

We identify to what extent the level of openness of peer-to-peer networks may have a positive impact on the level of profits reached by traditional producers. We notably develop a model in which we consider two types of producers, each evolving in a monopoly framework: digital goods producers and hardware producers. Digital goods are available for consumption in official or pirate form. Such two types of digital goods differ in their quality, as pirate digital goods are likely to be less qualitative than official ones usually are. Customers differ in their levels of preference for quality and have three adoption strategies: official digital goods' adoption and complementary hardware purchase, pirate digital goods' adoption and complementary hardware purchase, or non-adoption.

Our results stenghten the 'beneficial complementary-based activity' hypothesis previously highlighted in the literature. In a context in which the file-sharing activity is introduced, we point out that the official digital goods firm is always able to sell their products, and that the hardware goods firm is not motivated to crowd the official digital goods producer out of the market. Moreover, the hardware goods producer intends to deter non-adoption patterns while the digital goods producer – fully or partially – serves the market. As such, the existence of peer-to-peer networks is not likely to evict commercial players from the market. Moreover, our qualitative analysis aiming at measuring the impact of the file-sharing activity on both types of commercial activities reveals positive effects. As

such, we suggest that the losses perceived by the official digital goods firm are likely to result from the setting up of inappropriate quality-based strategies according to the degree of openness that file-sharing networks may deliver. We thus underline that commercial-driven innovative efforts should cautiously be considered, according to the degree of openness file-sharing communities exhibit. Our model therefore shows that the diffusion of non-authorized digital goods may be enhance the outcomes of commercial producers, provided that firms set up appropriate strategies to gain from a so-called 'outlaw' activity (Flowers, 2008). Our findings tend to qualify the relevancy of the recent local policies that have been initiated by the Recording Industry Association of America targeting the file-sharing networks whose degree of openness is too high.

The organization of this paper is as follows. We first present the model. Second, we analyze the levels of price, quantity and profit that are obtained by the two producers when the file-sharing activity does not apply. Third, we analyze the market structures that are likely to emerge when the file-sharing activity is introduced, as well as the levels of profit that commercial players obtain from it. Fourth, we study the impact of the file-sharing activity on commercial ones and identify potential commercial opportunities. Fifth, we conclude and provide directions for further research.

The model

We first present the properties of the market we consider, as well as the nature of the goods (i.e., digital goods and hardware goods) on which we focus. We then present the demand side and the supply side that we take into account in the model.

Digital goods, hardware goods and the market

We present a market in which technological users may adopt a digital good available in two versions: official digital goods and pirate digital goods. Users have to pay a fee ($p_0 > 0$) if they adopt official digital goods while they do not have to incur any pecuniar cost if they adopt pirate digital ones. In addition, technological adopters need to purchase a hardware good so as to use the digital goods previously acquired. As such, digital goods and hardware goods appear as complementary goods. Moreover, as opposed to digital goods, which have immaterial properties that facilitate piracy and unauthorized distribution on the Internet, hardware goods provide material characteristics that disable any copying schemes.

As opposed to some studies (e.g., Gayer and Shy, 2003b), we do not restrict our analysis to the case of software and do not consider software-related compatibility network effects. We consider digital goods in the forms these are usually likely to appear on peer-to-peer networks online, such as music files, video files, text files, etc. Our model applies in an extreme framework in which peer-to-peer networks only provide pirate digital goods, in respect with the argumentation of the Majors who consider that digital goods available on file-sharing networks are unauthorized ones.

Technological adopters

We set the size of the population of potential adopters as equal to N . We describe the choices made by potential technological adopters by defining three utility functions. Due to

the heterogeneity of the users' preference, adopters differ in their intrinsic willingness to adopt or not adopt digital goods, depicted by $x \in [0;1]$. Users with a high valuation for digital goods exhibit a low value for x, while users with a low valuation for digital goods present a high value for x. Potential adopters for whom x is close to 0 acquire official digital goods and those for whom x tends to 1 do not adopt digital goods. Users for whom the value of x is intermediate adopt pirate digital goods in. Adoption choices are set by the quality provided by digital goods. In addition, we suppose that each potential user presents a level of utility which is uniformly distributed, that yields to $n_i = \delta x_i$ for adopter i.

As generally assumed (Takeyama, 1994; Shy, 1996; Shy, 2001), we state that official and pirate digital goods are vertically differentiated, i.e., $\alpha > \beta > 0$, where α (resp. β) represents the quality of the official (resp. pirate) digital goods considered. Our model applies in a framework in which the use of digital goods (whether official or pirate ones) requires the purchase of a complementary hardware good. The cost of such a hardware good is $p_h > 0$ and applies to each digital goods adopter.

We thus define three utility functions corresponding with the three adoption strategies users are given: (i) official digital goods' adoption and complementary hardware purchase, (ii) pirate digital goods' adoption and complementary hardware purchase, or (iii) non-adoption.

The utility of each adopter, according to her level of preference for digital goods, is given by:

$$\begin{cases} U_{ho} = \alpha(1-x) - p_h - p_o \\ U_{hp} = \beta(1-x) - p_h - (c_l - \gamma) \\ U_{\varnothing} = 0 \end{cases} \quad , \; x \in [0;1] \tag{1}$$

The use of peer-to-peer networks to reach pirate digital files requires learning costs ($c_l > 0$). For instance, learning costs refer to the time needed for an adopter to be able to efficiently use file-sharing access software or to distinguish relevant digital files from those that are not. Such learning costs are likely to be lowered by the thematic orientations and the scope of the monitoring policies of the file-sharing networks' moderators, aiming at regulating participation within peer-to-peer networks. As a consequence, peer-to-peer networks differ in their level of community-based dynamics, openness thus relying on the nature of the moderating policies applied within such networks. We therefore define $\gamma > 0$ as the degree of openness of the peer-to-peer network considered in our model. Here, the openness of peer-to-peer networks is likely to generate a twin-effect on the users of file-sharing networks. Firstly, it enables file-sharers to easily get access to suitable files and overcome their learning constraints related to the use of peer-to-peer networks. We particularly state that openness is likely to outweigh the learning costs required to access and efficiently use peer-to-peer networks providing pirate digital goods. Secondly, the openness of peer-to-peer networks generates both social and economic benefits from community-based interaction. As such, file-sharers may derive positive outcomes from belonging to a community whose scope is compatible with their own interests and expectations.

Producers

We consider two producers in the model. The digital goods producer provides official digital goods to potential customers and the hardware goods' producer provides physical terminals aiming at using both official and pirate digital goods. As such, hardware producers are likely to benefit from piracy and the ensuing diffusion of pirate digital goods, since complementary hardware terminals tend to be needed for digital goods' exploitation while not being duplicable at no cost. These considerations highlight a potential conflict of interest between the two types of producers that our model is aiming at estimating.

We assume that official digital goods are sold by a monopoly firm. The firm sets a price p_o^* that maximizes its profit defined by:

$$\pi_o = (n_o p_o) - K_o \qquad (2)$$

$n_o > 0$ represents the number of individuals adopting official digital goods and $K_o > 0$ the amount invested by the firm to produce official digital goods. Due to the informational nature of digital goods and their reproduction facilities, we assume that production costs do not depend on the level of production.

We also assume that hardware goods are sold by a monopoly firm. Such an assumption holds in a realistic framework in which the price convergence of complementary hardware goods is observed. This representative firm sets a price p_h^* which maximizes its profit defined by:

$$\pi_h = (n_h p_h) - (K_h + a n_h) \qquad (3)$$

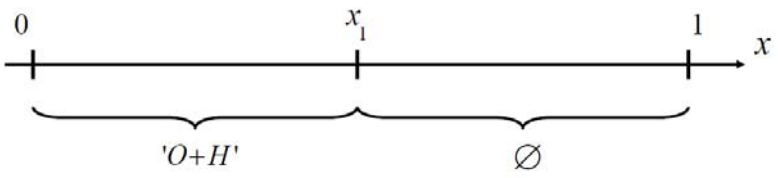
$n_h > 0$ represents the number of individuals purchasing hardware goods and $K_h > 0$ the amount invested by the firm to produce hardware goods. Besides, as hardware production relies on material production and assembling, $a > 0$ represents the cost needed by the hardware firm to produce a single quantity of hardware goods.

The next section analyzes the levels of price, quantity and profit that are obtained by both digital goods and hardware goods producers in a framework in which the file-sharing activity does not exist.

Adoption and optimal strategies when file-sharing does not apply

In a framework in which access to peer-to-peer networks is not possible, there are two categories of users: individuals that purchase both official digital and complementary goods, and individuals that do not.

Figure 1. Adoption patterns when file-sharing does not apply



The utility of each adopter in this case is given by:

$$\begin{cases} U_{ho} = \alpha(1-x) - p_h - p_o \\ U_{\varnothing} = 0 \end{cases} \quad , \; x \in [0;1] \qquad (1')$$

x_1 defines the level of intrinsic preference for digital goods for which adopters indifferently choose between technological adoption ($'O+H'$) or non-adoption ($\varnothing$); individuals exhibiting a level of x under x_1 thus adopt both the official digital good and the complementary hardware one, while others do not adopt both of them. We find that:

$$x_1 = (\alpha - p_h - p_o)/\alpha \qquad (4)$$

The official digital goods producer sets p_o which solves

$$\max_{p_o} \pi_o = (n_o p_o) - K_o = \left[\delta(\alpha - p_h - p_o)/\alpha\right] p_o - K_o \qquad (5)$$

From (5), we find that the price of the hardware goods' producer which maximizes her profit is given by:

$$p_o = (\alpha - p_h)/2 \qquad (6)$$

The hardware goods producer sets p_h that solves

$$\max_{p_h} \pi_h = (n_h p_h) - (K_h + a n_h) = \left[\delta(\alpha - p_h - p_o)/\alpha\right](p_h - a) - K_h \qquad (7)$$

From (7), we find that the price of the hardware goods' producer which maximizes her profit is given by:

$$p_h = (\alpha + a - p_o)/2 \qquad (8)$$

From (6) and (8), we find values for price equilibria in a framework in which both producers maximize their profits when the file-sharing activity does not prevail.

$$\begin{cases} p_o^* = (\alpha - a)/3 \\ p_h^* = (\alpha + 2a)/3 \end{cases} \qquad (9)$$

Assumption 1. *When the file-sharing activity does not prevail, both producers provide prices with positive levels, implying that:*

$$\alpha > a \qquad (A1)$$

This assumption stresses that digital goods producers have to provide a level of quality high enough for digital goods to be adopted. Assumption 1 implies that the price of official digital goods is always higher than the price of hardware goods when the file-sharing activity does not apply.

From (4) and (9), we find the optimal quantity of both digital goods and hardware goods sold by the two firms:

$$x_1^* = (\alpha - a)/(3\alpha) > 0 \qquad (10)$$

(10) shows that there is always a proportion of users that adopt both goods when peer-to-peer networks do not exist. Besides, as $(\alpha - a)/(3\alpha) \leq 1 \Leftrightarrow -a \leq 0 \leq 2\alpha$, we find that there is always a part of non-adopters (i.e., both hardware and digital goods non-adopters) on the market.

From (2), (9) and (10), and from (3), (9) and (10), we find the optimal levels of profits that are reached by each firm at equilibrium:

$$\begin{cases} \pi_o^* = \left(\delta(\alpha - a)^2/(9\alpha)\right) - K_o \\ \pi_h^* = \left(\delta(\alpha - a)^2/(9\alpha)\right) - K_h \end{cases} \quad (11)$$

Proposition 1. *Both digital goods and hardware goods are produced if and only if a high enough level of digital goods quality is provided by digital goods producers, i.e.,*

$$\alpha \in \left[\max\left\{ \left(2a\delta + 9K_h + \sqrt{36a\delta K_h + 81K_h^2}\right)/(2\delta); \left(2a\delta + 9K_h + \sqrt{36a\delta K_o + 81K_o^2}\right)/(2\delta) \right\}; +\infty \right[$$

Proof of proposition 1. *See Appendix*

Proposition 1 suggests that the activity of hardware goods producers are linked to that of digital goods producers.

i) there exists a level of digital goods quality that provides a positive profit for both hardware and digital goods producers;
ii) when $K_h > K_o$, there exists a level of digital goods quality that may be detrimental to the profitability of hardware producers;
iii) there exists a level of quality below which the profits of both producers are negative; such a level has to be avoided by the digital goods producer.

Proposition 1 evidences complementarities – or at least dependencies – between the activity of hardware goods producers and that of digital goods producers. We find that the level of quality chosen by the digital goods producer may, in some cases, incitate the hardware producer not to produce.

Adoption and optimal strategies when file-sharing applies

In a framework in which peer-to-peer networks are introduced, we stress the existence of several scenarii in technological adoption schemes, depending on the set of values of the parameters of the model. We first present the general case and we then analyze the five scenarii that are likely to prevail when the file-sharing activity is introduced. Primary results are eventually summarized.

Assumption 2. *When the file-sharing activity applies, the level of satisfaction reached by users whose valuation for pirate digital goods is high exceeds the cost required by the hardware producer to produce one unit of hardware good.*

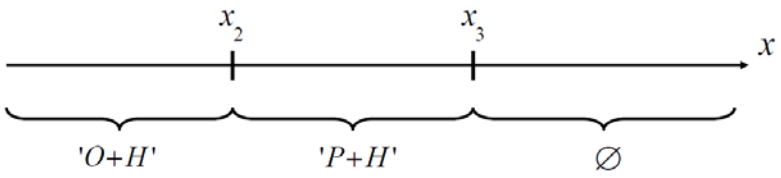
$$\beta > a \quad (A2)$$

Assumption 2 implies that adopters presenting a high level of valuation for pirate digital goods are likely to adopt complementary hardware digital goods to use such digital goods in a convenient and enjoyable way.

General case

When peer-to-peer networks are introduced and enhance the diffusion of unauthorized digital goods, there are three categories of users: individuals that purchase both official digital goods and complementary hardware goods, individuals that adopt pirate digital goods and purchase hardware goods, and individuals that do not adopt either digital goods or hardware goods.

Figure 2. Adoption patterns when file-sharing applies: General case



The utility of each adopter in the general case is given by:

$$\begin{cases} U_{ho} = \alpha(1-x) - p_h - p_o \\ U_{hp} = \beta(1-x) - p_h - (c_l - \gamma) \qquad , \; x \in [0;1] \\ U_{\varnothing} = 0 \end{cases} \tag{1}$$

x_2 defines the level of intrinsic preference for digital goods for which adopters indifferently choose between official technological adoption ('$O+H$') or pirate technological adoption ('$P+H$'). x_3 defines the level of intrinsic preference for digital goods for which adopters indifferently choose between pirate technological adoption ('$P+H$') or non-adoption ($\varnothing$). Thus, users do not purchase complementary hardware goods if their level of intrinsic preference for digital goods is above x_3. In addition, users whose level of intrinsic preference for digital goods is above x_2 do not purchase official digital goods. We find that:

$$\begin{cases} x_2 = \left[(\alpha-\beta) + (c_l - \gamma) - p_o\right] / (\alpha - \beta) \\ x_3 = \left[(\beta - p_h) - (c_l - \gamma)\right] / \beta \end{cases} \tag{12}$$

The official digital goods producer sets p_o^* which solves

$$\max_{p_o} \pi_{o,p2p} = \left[\delta\left((\alpha-\beta) + (c_l - \gamma) - p_o\right) / (\alpha - \beta)\right] p_o - K_o \tag{13}$$

From (13), we find that the price of the official digital goods' producer which maximizes her profit is given by:

$$p_o^* = \left[(\alpha-\beta) + (c_l - \gamma)\right] / 2 \tag{14}$$

The hardware goods producer sets p_h^* which solves

$$\max_{p_h} \pi_{h,p2p} = (\delta/\beta)\left((\beta - p_h) - (c_l - \gamma)\right)(p_h - a) - K_h \tag{15}$$

From (15) we find that the price of the hardware goods producer which maximizes her profit is given by:

$$p_h^* = \left[(\beta + a) - (c_l - \gamma)\right]/2 \qquad (16)$$

From (12), (14) and (16) we find the level of intrinsic preference for digital goods. We easily deduce the ensuing optimal value of the quantity of both digital goods and hardware goods sold by the two firms:

$$\begin{cases} x_2^* = \left[(\alpha - \beta) + (c_l - \gamma)\right]/\left[2(\alpha - \beta)\right] \; ; n_o^* = \delta x_2^* \\ x_3^* = \left[(\beta - a) - (c_l - \gamma)\right]/(2\beta) \; ; n_h^* = \delta x_3^* \end{cases} \qquad (17)$$

Assumption 3. *We assume that preferences for digital goods are transitive according to the type of adopters, i.e.,* $x_3^* > x_2^*$*, implying that:*

$$-(c_l - \gamma) > \left[a(\alpha - \beta)\right]/\alpha \qquad (A3)$$

Proposition 2. *Pirate digital goods' adoption requires learning costs (* c_l *) to be outweighted by the level of openness of the peer-to-peer networks (* γ *) to prevail.*

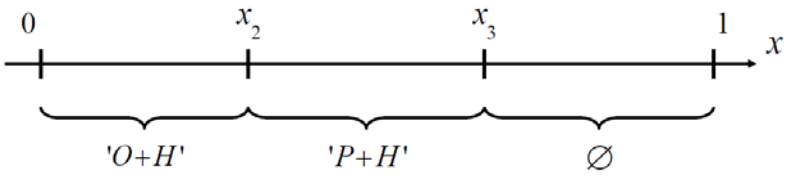
Proof of proposition 2. *From* $(A3)$ *and as* $(a/\alpha)(\alpha - \beta) \geq 0$, $-(c_l - \gamma) \geq 0 \Leftrightarrow \gamma \geq c_l$. ■

Evidence highlights the realistic nature of proposition 2, as peer-to-peer networks provide to their users with numerous services and tools aimed at stimulating interaction and mutual help, for example through the setting up of message boards, chatrooms or FAQs. The degree of openness selected by the moderators of file-sharing networks and its ensuing positive external effect all the more rapidly offsets the learning costs required by users to access relevant pirate digital goods available online.

File-sharing and technological adoption: Case 1

Case 1 refers to a situation in which the adoption of official digital goods is maintained and in which potential adopters may either adopt or not adopt digital goods, whether they are official or pirate ones.

Figure 3. Adoption patterns when file-sharing applies: Case 1



Such settings require seven conditions to be simultaneously satisfied:

$$p_o^* > 0 \Leftrightarrow (\alpha - \beta) > -(c_l - \gamma) \qquad (c1)$$

$$p_h^* > 0 \Leftrightarrow -(c_l - \gamma) > -(\beta + a) \qquad (c2)$$

$$x_3^* > x_2^* \Leftrightarrow -(c_l - \gamma) > [a(\alpha - \beta)]/\alpha \quad (c3)$$

$$x_2^* > 0 \Leftrightarrow \alpha - \beta > -(c_l - \gamma) \quad (c4)$$

$$x_3^* > 0 \Leftrightarrow -(c_l - \gamma) > a - \beta \quad (c5)$$

$$x_2^* < 1 \Leftrightarrow -(\alpha - \beta) < -(c_l - \gamma) \quad (c6)$$

$$x_3^* < 1 \Leftrightarrow -(c_l - \gamma) < \beta + a \quad (c7)$$

From $(A1),(A2),(A3),(c1),(c2),(c3),(c4),(c5),(c6)$ and $(c7)$, we find that case 1 applies when :

$$\begin{cases} -(c_l - \gamma) \in [(a/\alpha)(\alpha - \beta); \beta + a] \text{ if } \alpha - 2\beta > a \\ -(c_l - \gamma) \in [(a/\alpha)(\alpha - \beta); \alpha - \beta] \text{ if } \alpha - 2\beta < a \end{cases} \quad (18)$$

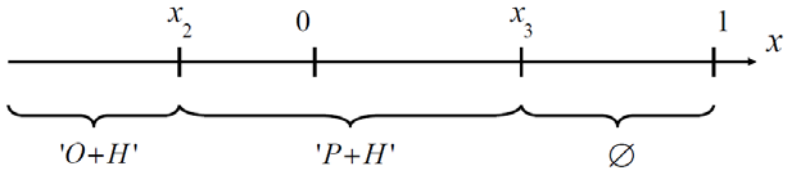
From $(13),(14),(15),(16)$ and (17), in a context in which case 1 applies, the profits obtained by both firms are:

$$\begin{cases} \pi_{o,p2p}^* = \left(\delta[(\alpha - \beta) + (c_l - \gamma)]^2 / [4(\alpha - \beta)]\right) - K_o \\ \pi_{h,p2p}^* = \left(\delta[(\beta - a) - (c_l - \gamma)]^2 / (4\beta)\right) - K_h \end{cases} \quad (19)$$

File-sharing and technological adoption: Case 2

Case 2 refers to a situation in which the firm which produces official digital goods is crowded out. In this context, official digital goods are not purchased and users adopt or do not adopt pirate digital goods.

Figure 4. Adoption patterns when file-sharing applies: Case 2



Such settings require seven conditions to be simultaneously satisfied:

$$p_o^* > 0 \Leftrightarrow (\alpha - \beta) > -(c_l - \gamma) \quad (c1)$$

$$p_h^* > 0 \Leftrightarrow -(c_l - \gamma) > -(\beta + a) \quad (c2)$$

$$x_3^* > x_2^* \Leftrightarrow -(c_l - \gamma) > [a(\alpha - \beta)]/\alpha \quad (c3)$$

$$x_2^* < 0 \Leftrightarrow \alpha - \beta < -(c_l - \gamma) \quad (c8)$$

$$x_3^* > 0 \Leftrightarrow -(c_l - \gamma) > a - \beta \quad (c5)$$

$$x_2^* < 1 \Leftrightarrow -(\alpha - \beta) < -(c_l - \gamma) \quad (c6)$$

$$x_3^* < 1 \Leftrightarrow -(c_l - \gamma) < \beta + a \quad (c7)$$

Proposition 3. *The firm which produces digital goods is never evicted from the market.*

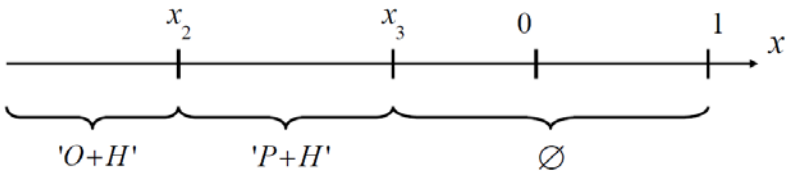
Proof of proposition 3. $(A1),(A2),(A3),(c1),(c2),(c3),(c5),(c6),(c7)$ *and* $(c8)$ *can not be simultaneously satisfied.* ■

Here, proposition 3 stresses that the file-sharing activity cannot been depicted as the key factor to explain why digital goods producers may be crowded out of the market.

File-sharing and technological adoption: Case 3

Case 3 refers to a situation in which both firms (i.e., official digital goods and hardware producers) are evicted. In this context, non-adoption patterns prevail and threaten the perenniality of the cultural goods market.

Figure 5. Adoption patterns when file-sharing applies: Case 3



Such settings require seven conditions to be simultaneously satisfied:

$$p_o^* > 0 \Leftrightarrow (\alpha - \beta) > -(c_l - \gamma) \quad (c1)$$

$$p_h^* > 0 \Leftrightarrow -(c_l - \gamma) > -(\beta + a) \quad (c2)$$

$$x_3^* > x_2^* \Leftrightarrow -(c_l - \gamma) > [a(\alpha - \beta)]/\alpha \quad (c3)$$

$$x_2^* < 0 \Leftrightarrow \alpha - \beta < -(c_l - \gamma) \quad (c8)$$

$$x_3^* < 0 \Leftrightarrow -(c_l - \gamma) < a - \beta \quad (c9)$$

$$x_2^* < 1 \Leftrightarrow -(\alpha - \beta) < -(c_l - \gamma) \quad (c6)$$

$$x_3^* < 1 \Leftrightarrow -(c_l - \gamma) < \beta + a \quad (c7)$$

Proposition 4. *Non-adoption patterns do not prevail on the cultural goods market. When file-sharing applies, there does not exist settings in which digital goods (whether they be official or pirate) are not purchased/adopted.*

Proof of proposition 4. $(A1),(A2),(A3),(c1),(c2),(c3),(c6),(c7),(c8)$ *and* $(c9)$ *cannot be simultaneously satisfied (e.g.,* $(A2)$ *and* $(c9)$ *are not compatible).* ■

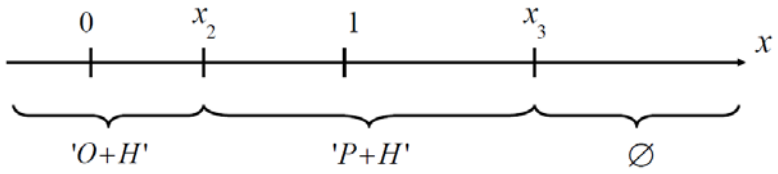
Here, proposition 4 reveals that the file-sharing activity is not likely to threaten the perenniality of the cultural goods market. At least, it suggests that there exist other key reasons to explain why the cultural goods market may vanish. Proposition 4 partially explains the actual popularity of piracy and peer-to-peer networks. Such a result also points out that productive efforts made to enhance the quality of official digital goods enable the hardware goods producer to maintain her activity. Consequently, the official digital goods

producer is not incited to evict the hardware goods producer, since such an eviction also naturally implies that of the official digital goods producer.

File-sharing and technological adoption: Case 4

Case 4 refers to a situation in which the hardware goods producer fully serves the market, while the digital goods producer is not evicted. In this case, non-adoption patterns do not apply.

Figure 6. Adoption patterns when file-sharing applies: Case 4



Such settings require seven conditions to be simultaneously satisfied:

$$p_o^* > 0 \Leftrightarrow (\alpha - \beta) > -(c_l - \gamma) \quad (c1)$$

$$p_h^* > 0 \Leftrightarrow -(c_l - \gamma) > -(\beta + a) \quad (c2)$$

$$x_3^* > x_2^* \Leftrightarrow -(c_l - \gamma) > [a(\alpha - \beta)]/\alpha \quad (c3)$$

$$x_2^* > 0 \Leftrightarrow \alpha - \beta > -(c_l - \gamma) \quad (c4)$$

$$x_3^* > 0 \Leftrightarrow -(c_l - \gamma) > a - \beta \quad (c5)$$

$$x_2^* < 1 \Leftrightarrow -(\alpha - \beta) < -(c_l - \gamma) \quad (c6)$$

$$x_3^* > 1 \Leftrightarrow -(c_l - \gamma) < \beta + a \quad (c10)$$

From $(A1), (A2), (A3), (c1), (c2), (c3), (c4), (c5), (c6)$ and $(c10)$, we find that case 4 applies when :

$$-(c_l - \gamma) \in [\beta + a; \alpha - \beta] \text{ if } \alpha - 2\beta > a \quad (20)$$

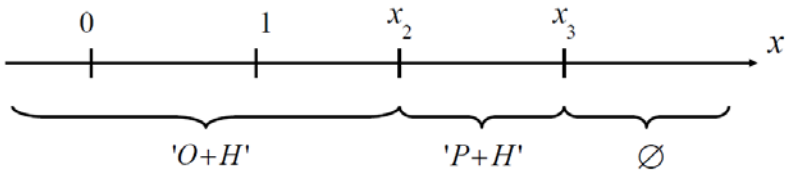
From $(13), (14), (15), (16)$ and (17), in a context in which case 4 applies, the profits obtained by both firms are:

$$\begin{cases} \pi_{o,p2p}^* = \left(\delta[(\alpha - \beta) + (c_l - \gamma)]^2 / [4(\alpha - \beta)]\right) - K_o \\ \pi_{h,p2p}^* = \left(\delta[(\beta - a) - (c_l - \gamma)]^2 / (4\beta)\right) - K_h \end{cases} \quad (19)$$

File-sharing and technological adoption: Case 5

Case 5 refers to a situation in which the market is fully served by both hardware goods and digital goods firms. This case reflects a situation in which the file-sharing activity has not a detrimental effect on the sales of both digital goods and hardware goods.

Figure 7. Adoption patterns when file-sharing applies: Case 5



Such settings require seven conditions to be simultaneously satisfied:

$$p_o^* > 0 \Leftrightarrow (\alpha - \beta) > -(c_l - \gamma) \quad (c1)$$

$$p_h^* > 0 \Leftrightarrow -(c_l - \gamma) > -(\beta + a) \quad (c2)$$

$$x_3^* > x_2^* \Leftrightarrow -(c_l - \gamma) > [a(\alpha - \beta)]/\alpha \quad (c3)$$

$$x_2^* > 0 \Leftrightarrow \alpha - \beta > -(c_l - \gamma) \quad (c4)$$

$$x_3^* > 0 \Leftrightarrow -(c_l - \gamma) > a - \beta \quad (c5)$$

$$x_2^* > 1 \Leftrightarrow -(\alpha - \beta) < -(c_l - \gamma) \quad (c11)$$

$$x_3^* > 1 \Leftrightarrow -(c_l - \gamma) < \beta + a \quad (c10)$$

Proposition 5. *The cultural goods market cannot be fully served by both digital goods and hardware goods producers.*

Proof of proposition 5. $(A1), (A2), (A3), (c1), (c2), (c3), (c4), (c5), (c10)$ *and* $(c11)$ *can not be simultaneously satisfied.* ■

As we have found in the case in which peer-to-peer networks are not introduced, we find that digital goods producers do not fully serve the market. However, proposition 5 suggests that non-adoption patterns are downplayed by patterns of pirate digital goods adoption.

Market structures

The following table (table 1) summarizes the main results we have previously found when the file-sharing activity is introduced. Moreover, we underline that two cases are likely to appear in such a framework.

Table 1. Market structures when file-sharing is introduced

Case	Details	Results
Case 1	The market is partially served by both producers No-adoption patterns partially apply	Applies when $\begin{cases} -(c_l - \gamma) \in \left[\frac{a}{\alpha}(\alpha - \beta); \beta + a\right] \text{ if } \alpha - 2\beta > a \\ -(c_l - \gamma) \in \left[\frac{a}{\alpha}(\alpha - \beta); \alpha - \beta\right] \text{ if } \alpha - 2\beta < a \end{cases}$

Case 2	The digital goods producer is crowded out The market is partially served by the hardware firm No-adoption patterns partially applies	Does not apply
Case 3	Both producers are crowded out No-adoption patterns prevail	Does not apply
Case 4	The market is fully served by the hardware firm The market is partially served by the digital firm No-adoption patterns do not apply	Applies when $-(c_l-\gamma)\in[\beta+a;\alpha-\beta]$ if $\alpha-2\beta>a$
Case 5	The market is fully served by both producers No-adoption patterns do not apply	Does not apply

As cases 2, 3 and 5 do not apply, our primary results stress that digital goods producers are always likely to sell their products. Such results reveal that the perenniality of the digital goods producer on the market can be guaranteed. The hardware goods producer is not motivated to crowd the digital goods producer out of the market so as to fully serve the market. In other words, one of the main goal of the hardware goods producer is to deter non-adoption patterns, while the digital goods producer – partially or fully – serves the market. All the ensuing adoption issues of course depend of the level of quality of digital goods provided by the digital goods firm.

Such settings reveal strong dependencies of hardware producers on digital goods' that are all the higher-leveled as most pirate digital goods are generally issued from official ones (e.g., through media copying, media ripping or miscellaneous files conversions).

Our primary results are compatible with both short term and long term perspectives, since the crowding out of official digital goods' suppliers would in the long term permanently lead to the disappearance or the strong contraction of the pirate digital goods' offer. As such, our findings primilarly suggest that the eviction of the official digital goods supplier should not to be targeted by the hardware goods' firm if it is to maintain profitability in the long run.

For cases 1 and 4, the profits of both producers are as follows:

$$\begin{cases}\pi^*_{o,p2p}=\left(\delta\left[(\alpha-\beta)+(c_l-\gamma)\right]^2/\left[4(\alpha-\beta)\right]\right)-K_o\\ \pi^*_{h,p2p}=\left(\delta\left[(\beta-a)-(c_l-\gamma)\right]^2/(4\beta)\right)-K_h\end{cases} \quad (19)$$

Lemma 1. *The profit reached by the official digital goods producer depends on both the quality gap (i.e., $\alpha-\beta$) and the degree of openness of the peer-to-peer community (i.e., $-(c_l-\gamma)$).*

More precisely, we find that the official digital goods producer reaches a positive profit in two different frameworks:

- when the degree of openness of the peer-to-peer community is high (i.e., $-(c_l-\gamma)\in\left[\left(2\delta(\alpha-\beta)+\sqrt{16\delta(\alpha-\beta)K_o}\right)/(2\delta);+\infty\right[$), whatever the quality gap is;

- both when the quality gap is high (i.e., $\alpha - \beta > \left(4K_o/\delta\right)$) and when the degree of openness of the peer-to-peer community is low (i.e., $-\left(c_l - \gamma\right) \in \left[0; \left(2\delta\left(\alpha - \beta\right) - \sqrt{16\delta\left(\alpha - \beta\right)K_o}\right) \Big/ \left(2\delta\right)\right[$).

Lemma 1 suggests that the degree of openness is critical for the digital goods' producer to get a positive profit. In a specific case, a lower degree of openness of the peer-to-peer community can generate a positive profit when the quality gap is high. This result stresses that qualitative efforts are likely to generate positive profits for the digital goods firm, by taking into account the level of its fixed costs (i.e., K_o).

Lemma 2. *The profit reached by the hardware goods producer depends on both the quality of the pirate digital goods available on file-sharing platforms (i.e., β) and the degree of openness of the peer-to-peer community (i.e., $-\left(c_l - \gamma\right)$).*

Similarly to the case of the digital goods producer, we find that the hardware goods' producer obtains a positive profit in two different frameworks:

- when the quality of the pirate digital goods is very low or very high (i.e., $\beta \in \left[0; \left(2\delta a + 4K_h - 4\sqrt{\delta a K_h + K_h^2}\right) \Big/ \left(2\delta\right)\right[\cup \left]\left(2\delta a + 4K_h + 4\sqrt{\delta a K_h + K_h^2}\right) \Big/ \left(2\delta\right); +\infty\right[$), whatever the degree of openness of the peer-to-peer community is;
- when the quality of the pirate digital goods is intermediary-leveled (i.e., $\beta \in \left]\left(2\delta a + 4K_h - 4\sqrt{\delta a K_h + K_h^2}\right) \Big/ \left(2\delta\right); \left(2\delta a + 4K_h + 4\sqrt{\delta a K_h + K_h^2}\right) \Big/ \left(2\delta\right)\right[$), and when the degree of openness of the peer-to-peer community is high (i.e., $-\left(c_l - \gamma\right) \in \left[\left(-2\delta\left(\beta - a\right) + 4\sqrt{\delta\beta K_h}\right) \Big/ \left(2\delta\right); +\infty\right[$).

Lemma 2 suggests the hardware goods producer has to consider both the quality of pirate digital goods and the degree of openness of the peer-to-peer community to get a positive profit. Moreover, the hardware goods' producer has to set its both costs (i.e., a and K_h) to reach such a valuable issue.

In this section, we have pointed out that, contrary to the conventional wisdom, the file-sharing activity does not evict the official digital goods producer and/or the hardware producer from the market. Following such a result, one key research question would be to measure the nature of the impact (i.e., positive or negative) that the introduction of peer-to-peer networks has on commercial activities (i.e., digital goods firm and hardware terminals firm). The next section is devoted to this study.

Comparative statics

In a framework in which digital goods were previously available in their official form, the file-sharing activity is likely to have an impact on the level of profits reached by the producers of official digital goods and hardware goods.

This section aims at seeing if the introduction of peer-to-peer networks in the cultural goods industrial landscape may deliver beneficial outcomes for both producers. To do so, our approach is merely qualitative, inasmuch as we identify to what extent the file-sharing activity generates gains for the firm providing official digital goods and the firm providing

hardware terminals. Qualitative results are summarized and coordination strategies are discussed.

The impact of file-sharing on the profitability of official digital goods producers

From (11) and (19), we find that the effect on the file-sharing activity on the level of profit of the producer of official digital goods is as follows:

$$\Delta\pi_o^* = \frac{\delta}{36\alpha(\alpha-\beta)}\left[9\alpha\left[(\alpha-\beta)+(c_l-\gamma)\right]^2 - 4(\alpha-\beta)(\alpha-a)^2\right] \quad (21)$$

From (21), our mathematical analysis aiming at identifying the – positive or negative – nature of the expression of $\Delta\pi_o^*$ provides the following results.

Lemma 3. *The file-sharing activity may positively or negatively influences the profitability of the official digital goods firm. The nature of such an influence depends on the qualitative effort (i.e., α) that is provided by the official digital goods firm – facing the production of pirate digital goods (i.e., β) – as well as the degree of openness of the peer-to-peer community (i.e., $-(c_l-\gamma)$).*

More precisely, we find that the introduction of peer-to-peer networks enhances the level of profit of the producer of official digital goods:

- when the digital goods firm sets a low level of quality for its official digital good (i.e., $\alpha \in \left]0;\left((324\beta-288a)+\sqrt{186624a^2-186624a\beta+104976\beta^2}\right)\Big/373248\right[$), whatever the degree of openness of the peer-to-peer community is;
- when the digital goods firm sets a high level of quality for its official digital good (i.e., $\alpha \in \left]\left((324\beta-288a)+\sqrt{186624a^2-186624a\beta+104976\beta^2}\right)\Big/373248;+\infty\right[$), and when the degree of openness of the peer-to-peer community is high (i.e., $-(c_l-\gamma) \in \left]\left(-18\alpha(\alpha-\beta)+\sqrt{144\alpha(\alpha-\beta)(\alpha-a)^2}\right)\Big/(18\alpha);+\infty\right[$).

However, we find that there exist settings in which the file-sharing activity is detrimental to that of the digital goods firm. Indeed, negative externalities are likely to appear both when the digital goods firm sets a high level of quality (i.e., α) for its product and when the degree of openness of the peer-to-peer community is low (i.e., $-(c_l-\gamma) \in \left[0;\left(-18\alpha(\alpha-\beta)+\sqrt{144\alpha(\alpha-\beta)(\alpha-a)^2}\right)\Big/(18\alpha)\right[$).

Our results show that firms producing official digital goods may benefit from the existence of peer-to-peer networks. Moreover, suitable quality-based strategies have to be set up, by taking into account the degree of openness that peer-to-peer communities may exhibit. In the case of the digital goods firm, the commercial losses the file-sharing activity may generate result from the setting up of quality-based strategies that do not cope with the level of community-based utility that file-sharers may get from peer-to-peer networks. Thus, we point out that commercial benefits may be generated from surrounded activities (e.g., the file-sharing activity) provided that appropriate strategies are delivered.

The impact of file-sharing on the profitability of hardware goods producers

From (11) and (19), we find that the effect on the file-sharing activity on the level of profit of the producer of hardware goods is as follows:

$$\Delta\pi_h^* = \pi_{h,p2p}^* - \pi_h^* = \left[\delta/(36\alpha\beta)\right]\left[9\alpha\left[(\beta - a) - (c_l - \gamma)\right]^2 - 4\beta(\alpha - a)^2\right] \quad (22)$$

From (22), our mathematical analysis aiming at identifying the – positive or negative – nature of the expression of $\Delta\pi_h^*$ provides the following results.

Lemma 4. *The file-sharing activity may positively or negatively influences the profitability of the hardware goods firm. The nature of such an influence depends on the quality of both official and pirate digital goods (i.e., α and β), as well as the degree of openness of the peer-to-peer community.*

More precisely, we find that the introduction of peer-to-peer networks enhances the level of profit of the producer of hardware goods:

- both when the quality provided by the official digital goods producer is high-leveled compared to that of pirate digital goods (i.e., $(\alpha - a)^2/\alpha > (9/4)(\beta - a)^2/\beta$) and when the degree of openness of the peer-to-peer community is high-leveled (i.e., $-(c_l - \gamma) \in \left]\left(-18\alpha(\beta - a) + \sqrt{144\alpha\beta(\alpha - a)^2}\right)/(18\alpha); +\infty\right[$);
- when the quality provided by the official digital goods producer is low-leveled compared to that of pirate digital goods (i.e., $(\beta - a)^2/\beta > (4/9)(\alpha - a)^2/\alpha$), whatever the degree of openness of the peer-to-peer community is high-leveled is.

Nevertheless, we also find that there exist settings in which the file-sharing activity is detrimental to that of the hardware goods firm. Indeed, negative externalities are likely to appear both when the quality provided by the official digital goods producer is high-leveled compared to that of pirate digital goods (i.e., $(\alpha - a)^2/\alpha > (9/4)(\beta - a)^2/\beta$) and when the degree of openness of the peer-to-peer community is low-leveled (i.e., $-(c_l - \gamma) \in \left[0; \left(-18\alpha(\beta - a) + \sqrt{144\alpha\beta(\alpha - a)^2}\right)/(18\alpha)\right[$).

Similarly to the case of the official digital goods firm, our results show that firms producing hardware goods may benefit from the file-sharing activity. We find that such beneficial outcomes depend on the levels of quality of both official and pirate digital goods, as well as the community-based benefits that peer-to-peer networks provide to their users.

Qualitative results and coordination insights

The following table (table 2) summarizes the main results we have obtained when qualitatively analyzing the impact of the file-sharing activity on the profitability of both types of producers (i.e., official digital goods firm and hardware terminals firm).

Table 2. File-sharing and commercial opportunities

	'low' degree of openness	**'high' degree of openness**
'low' official quality (compared to pirate quality)	$\Delta\pi_o^* > 0$ $\Delta\pi_h^* > 0$	$\Delta\pi_o^* > 0$ $\Delta\pi_h^* > 0$
'high' official quality (compared to pirate quality)	$\Delta\pi_o^* < 0$ $\Delta\pi_h^* < 0$	$\Delta\pi_o^* > 0$ $\Delta\pi_h^* > 0$

From table 2, we find that the strategies led by the official digital goods firm for the file-sharing activity to be beneficial for its own activity are somewhat the same that are required for the producers of hardware goods to increase their profits. From a qualitative point of view, we stress that conflicts of interest are not likely to prevail in this framework. Moreover, commercial players, whether they are digital goods producers or hardware goods producers, have similar interests *vis-a-vis* the file-sharing activity. Indeed, we find that both producers are likely to apprehend in the same way the 'official quality' (i.e., α) variable and the 'degree of openness' (i.e., $-(c_l - \gamma)$) parameter.

Discussion and further research

In this paper we have developed a model to analyze the impact of the introduction of peer-to-peer networks on commercial activities, by distinguishing official digital goods producers on the one hand and hardware goods producers on the other hand. In this framework, we have whether investigated if the diffusion of pirate digital goods is always detrimental for both producers or if it might improve the level of profit of at least one of them. When hardware goods are compatible with both official and pirate digital goods, we have shown that the degree of openness of peer-to-peer networks (i.e., the value of the switching costs required by users to access peer-to-peer networks and use pirate digital goods, as well as the benefits that file-sharers may derive from community-based interaction) has a significant impact on the variation of the level of profits obtained by producers when the file-sharing activity is introduced.

Starting from a framework in which peer-to-peer networks do not exist, we have firstly stressed that the activity of hardware goods producers are linked to that of official digital goods producers. Moreover, we have pointed out that there exist complementarities – or at least dependencies – between the activity of the hardware goods firm and the activity of the official digital goods firm. In some cases, the level of quality chosen by the producer of official digital goods may incitate the hardware goods firm not to produce.

In a framework in which the file-sharing activity exists, we have secondly stressed that several scenarii depicting technological adoption schemes and shaping ensuing market structures are likely to prevail. Yet, a deeper analysis has revealed that only two of these may occur. In particular, we have pointed out that the official digital goods firm is always able to sell their products, and that the hardware goods firm is not motivated to crowd the official digital goods producer out of the market. In other words, the hardware goods producer

intends to deter non-adoption patterns while the digital goods producer – fully or partially – serves the market. As such, contrary to somewhat common beliefs, the file-sharing activity does not appear to evict the official digital goods firm and/or the hardware goods firm from the market.

We have thirdly intended to qualitatively measure the impact of the file-sharing activity on both types of commercial activities. We have found that the file-sharing activity may positively influence the level of profits of both official digital goods and hardware goods producers. Hence, we have suggested that the losses perceived by the official digital goods firm are likely to result from the setting up of inappropriate quality-based strategies according to the degree of openness that file-sharing networks may deliver. Interestingly, we have underlined that conflicts of interest between official digital goods producers and hardware terminals producers are not likely to prevail. This result all the more stresses that the file-sharing activity may be beneficial for commercial activities, provided that firms set up suitable strategies to generate gains from such a so-called 'outlaw' activity.

Our results support the setting up of commercial strategies that are similar to those recently observed, since many producers who used to fight against piracy nowadays exploit both official and 'less official' technological standards to sell complementary material goods. As such, the diffusion of pirate digital goods has led to the setting up of new commercial strategies in which piracy is likely to be tolerated as it may enhance complementary sales. We have found that innovative strategies may be considered by official digital goods producers provided that file-sharing communities are likely to provide a high level of community-based benefits (i.e., what we have called degree of openness) to their users. Innovative strategies may be then considered, since the improvement of the quality of official digital goods over pirate ones may increase the level of profits obtained by commercial producers. Although it may seem *a priori* paradoxal, the file-sharing activity appears as a factor stimulating commercial efforts to innovate. In this context, we have pointed out that the existence of peer-to-peer communities which exhibit low degrees of openness may be detrimental to the activities of commercial players. As a consequence, the setting up of policies aiming at shutting file-sharing platforms down should be cautiously considered, since inappropriate quality-based strategies led by official digital goods firms may lead to the decrease of both producers (i.e., official digital goods firm and hardware terminals firm).

Peer-to-peer networks and commercial producers exhibit transversal relationships that reveal retroaction and interdependence between their activities. Contemporary business-models should thus take into account the existence of the wide range of digital goods available online and their diffusion through both commercial and non-commercial distribution channels, notably through peer-to-peer networks. The compatibility prevailing in both official and pirate digital goods is particularly likely to enhance the profitability of commercial producers in the media industry and to allow the setting up of new commercial strategies based upon the complementarity existing between immaterial and material goods.

The model we have presented represents – to our knowledge – one of the first attempts to understand the influence of the peer-to-peer networks on commercial activities. We have intended to consider the file-sharing networks not only as simple parallel distribution channels, but also as communities whose users derive community-based utilities from their

participation. We have taken into account these two features of the file-sharing activity to analyze technological (i.e., digital goods and hardware goods) adoption issues.

The study we have held in this part however presents three limitations that we will deal with in further contributions. First of all, we have assumed in our model that the users who adopt pirate digital goods through file-sharing platforms have the same learning constraints. One could wonder what would happen if users were heterogeneous in their learning abilities. Although our model provides results aiming at measuring the impact of the file-sharing activity on commercial ones, our findings are qualitative. Quantitative analyses would deliver stronger insights to identify the optimal strategies that official digital goods firms may set up to increase their profits. Such a quantitative approach may evidence the potential conflicts of interest between official digital goods firms and hardware terminals firms that our qualitative results are not able to reveal. By considering an oligopolistic framework in which several official digital goods producers and hardware goods' producers would evolve, it would be possible to firstly more precisely study the role of the compatibility between technological standards on commercial actors' profitability and to secondly stress the nature of the optimal industrial strategies that should be considered. Such results would enable us to estimate the relevancy of the new strategies that have been recently implemented by digital goods' producers, such as the setting up of commercial file-sharing networks whose offers are limited to the content of the catalog held by each producer, or the several merging attempts nowadays commonly observed between various digital goods producers.

We think that the file-sharing activity and its ensuing industrial economics applications open relevant fields for future research. One might investigate into these research tracks, while others – we hope – will be interested in pondering over this vast and fruitful topic.

Appendix: Proof of proposition 1

Digital goods are produced if the profit of the digital goods producer is positive, that is to say $\pi_o^* = [\delta/(9\alpha)](\alpha - a)^2 - K_o \geq 0$.

Such a conditions holds when $\alpha \in \left[\left(2a\delta + 9K_o + \sqrt{36a\delta K_o + 81K_o^2}\right)/(2\delta); +\infty\right[$.

In a similar fashion, hardware goods are produced if the profit of the hardware goods producer is positive, that is to say $\pi_h^* = [\delta/(9\alpha)](\alpha - a)^2 - K_h \geq 0$

Such a conditions holds when $\alpha \in \left[\left(2a\delta + 9K_h + \sqrt{36a\delta K_h + 81K_h^2}\right)/(2\delta); +\infty\right[$.

Therefore, both digital goods and hardware goods are produced when the quality of the digital goods is defined so that

$$\alpha \in \left[\max\left\{\left(2a\delta + 9K_h + \sqrt{36a\delta K_h + 81K_h^2}\right)/(2\delta); \left(2a\delta + 9K_o + \sqrt{36a\delta K_o + 81K_o^2}\right)/(2\delta)\right\}; +\infty\right[\text{ . } \blacksquare$$

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