Competition over piratable goods

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May 15, 2003

Abstract

The effects of (private, small-scale) copying on the pricing behavior of producers of information goods are studied within a unified model of vertical differentiation. Although information goods are assumed to be perfectly horizontally differentiated, demands are interdependent because the copying technology exhibits increasing returns to scale. We characterize the symmetric Nash equilibria of the pricing game played by n producers of information goods. We show thereby how the producers' attitudes towards piracy are interdependent and evolve with the relative attractiveness of copies.

JEL Classification Numbers: L13, L82, L86, K11, O34.
Keywords: Information goods, piracy, copyright, pricing.

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1 Introduction

The vast majority of information goods (such as books, movies, music, magazines, databases, ...) are expensive to produce but cheap to reproduce. This combination of high fixed costs and low (often negligible) marginal costs implies that information goods are inherently *nonrival*. Moreover, because reproduction costs are also potentially very low *for anybody other* than the creator of the good, information goods might also be *nonexcludable*. The degree of excludability of an information good (and hence the creator's ability to appropriate the revenues from the production of the good) can be enhanced by legal authority–typically by the adoption of laws protecting intellectual property (IP)–or by technical means (e.g., cable broadcast are encrypted, so-called "unrippable" CDs have recently been marketed). However, complete excludability seems hard to achieve: simply specifying intellectual property laws does not ensure that they will be enforced; similarly, technical protective measures are often imperfect and can be "cracked". As a result, *illicit copying* (or piracy) cannot be completely avoided.

Over the last decade, the fast penetration of the Internet and the increased digitization of information have turned piracy of information goods (in particular music, movies and software) into a topic of intense debate. Not surprisingly, economists have recently shown a renewed interest in information goods piracy.[1] The recent contributions revive the literature on the economics of copying and copyright, which was initiated some twenty years ago.[2] The seminal papers mainly discussed the effects of photocopying and examined, among other things, how publishers can appropriate indirectly some revenues from illegitimate users (Novos and Waldman, 1984, Liebowitz, 1985, Johnson, 1985, and Besen and Kirby, 1989). The economics of (IP) protection was then addressed more generally by Landes and Posner (1989) and Besen and Raskind (1991). Both papers discuss the following trade-off between *ex ante* and *ex post* efficiency considerations. From an *ex ante* point of view, IP protection preserves the incentive to create information goods, which (as argued above) are inherently public (absent appropriate protection, creators might not be able to recoup their potentially high initial creation costs). On the other hand, IP rights encompass various potential inefficiencies from an *ex post* point of view (protection grants de facto monopoly rights, which generates the standard deadweight losses; also, by inhibiting imitation, IP rights might limit the creators' ability to borrow from, or build upon, earlier works, and thereby increase the cost of producing new ideas). A third wave of papers paid closer attention to

[1] See, e.g., Gayer and Shy (2001a,b), Duchêne and Waelbroeck (2001), Ben-Shahar and Jacob (2001), Harbaugh and Khemka (2001), Chen and Png (2001), Hui, Png and Cui (2001), and Yoon (2002).

[2] With the notable exception of Plant (1934). For a recent survey (and extension) of this literature, see Watt (2000).

software markets and introduced network effects in the analysis. Conner and Rumelt (1991), Takeyama (1994), and Shy and Thisse (1999) share the following argument: because piracy enlarges the installed base of users, it generates network effects that increase the legitimate users' willingness to pay for the software and, thereby, potentially raises the producer's profits.

Generally, the literature on the economics of copying abstracts away the strategic interaction among producers of information goods. It is often argued that the degree of horizontal differentiation between information goods (like CDs or books) is so large that one can assume that the demand for any particular good is independent of the prices of other goods. An exception is Johnson (1985): his 'fixed cost model' considers a copying technology that involves an investment in costly equipment. As the author emphasizes, "[a]n interesting feature of this model is that the demand for any particular work is affected *indirectly* by the prices of other works since they affect a consumer's decision to invest in the copying technology". However, because the focus is mainly on the welfare implications of copying, Johnson (1985) does not fully explore the effects of the strategic interaction induced by the fixed cost of copying.

The aim of the present paper is to address more systematically the strategic interaction among producers of information goods, which is induced by the existence of increasing returns to scale in the copying technology. Like a number of recent papers, we use the framework proposed by Mussa and Rosen (1978) for modelling vertical (quality) differentiation: copies are seen as lower-quality alternatives to originals (i.e., if copies and originals were priced the same, all consumers would prefer originals). Information goods are assumed to be perfectly horizontally differentiated. This does not mean, however, that the demands for different goods can be treated as independent: as in Johnson (1985), demands are interdependent because the copying technology exhibits increasing returns to scale.

To describe our results, we draw an analogy with Bain (1956)'s taxonomy of an incumbent's behavior in the face of an entry threat: we say that producers of information goods are either able to 'blockade' copying, or that they must decide whether to 'deter' copying (through limit-pricing) or 'accommodate' it. To make our analysis instructive (and more tractable), we put restrictions on the economic parameters to make sure that, at the symmetric equilibrium of the pricing game, the producers of information goods are affected by the consumers' ability to make copies. Indeed, under our assumptions, there cannot be an equilibrium where all producers behave as unconstrained local monopolists (and thus 'blockade' copying). The question is then how producers modifiy their pricing behavior in the face of copying. Our main results (see Proposition 2) show that the answer crucially depends on the properties of the copying technology: that is, on the relative importance of the average and marginal costs of copying, and on the relative quality of copies.

Regarding the latter criterion, we distinguish between 'good' and 'bad' copies, talking of good copies when n copies provide users with more gross utility than $n-1$ originals. In this case, three different attitudes can emerge at the symmetric equilibrium of the pricing game. If the copying technology exhibits important returns to scale (large average costs and small marginal costs), firms find it profitable to deter copying: they set a price for their information product which is low enough to make copying unprofitable for all users. For copying technologies with lower returns to scale, the latter option is too costly and firms prefer therefore to tolerate copying. When the marginal cost of copying is not too large, they accommodate 'reverting users' (i.e., those users who contemplate purchasing or copying all goods); for larger values of the marginal cost, firms accommodate 'copying users' (i.e., those users who would copy anyway all but one good, but who could purchase the remaining one were it priced cheaply enough). Finally, if the marginal cost of copying is low and close enough to the average cost, the copying technology exhibits weak returns to scale and a symmetric equilibrium (in pure strategies) fails to exist. The reason for such inexistence is the following. When all other firms choose to accommodate reverting users by setting a relatively high price, consumers consider that originals have become so expensive that copying (using a rather cheap technology) is preferable. As a result, any individual firm has an incentive to deviate by setting a lower price and accommodating instead the copying users.

Consider now bad copies. Although, other things being equal, copying is less attractive than in the previous case, it turns out that there is no symmetric equilibrium where firms manage to deter copying. The key to understand this seemingly paradoxical result is that, with bad copies, each firm must set a *high enough* price to deter users from reverting their purchase decision. In contrast with the case of high-quality copies, a firm's individual deterrence price *increases* with the price set by the other producers. As a result, the section of a firm's best-response function where deterrence is the optimal conduct is upward-sloping (meaning that prices become strategic substitutes) and reaches prices which are *above* the unconstrained monopoly price. Yet, our restrictions on the parameters prevent the monopoly price to be part of a symmetric equilibrium and, by the same token, so do they for any higher price. This explains why there is no symmetric deterrence equilibrium for bad copies. Two possible attitudes remain. For a sufficiently high average cost of copying, there is a symmetric equilibrium where producers tolerate copying: they accommodate reverting users for a sufficiently low marginal cost of copying, or copying users otherwise. When the average cost is close to the marginal cost, there exists no symmetric equilibrium (in pure strategies).

The rest of the paper is organized as follows. In Section 2, we lay out the model and we derive the demand schedule for a particular original. In Section

3, we characterize the symmetric equilibria of the pricing game played by n producers of originals. We conclude and propose an agenda for future research in Section 4.

2 The model

2.1 Consumers

There is a continuum of potential users who can consume from a set N of information goods (with $|N| \equiv n \geq 2$). These information goods are assumed to be perfectly (horizontally) differentiated and equally valued by the consumers. In particular, users are characterized by their valuation, θ, for any information good. We assume that θ is uniformly distributed on the interval $[\underline{\theta}, \overline{\theta}]$.

Each information good $i \in N$ is imperfectly protected and thus "piratable". As a result, consumers can obtain each information good in two different ways: they can either *buy* the legitimate product (an "original") or acquire a *copy* of the product. It is reasonable to assume that all consumers see the copy as a lower-quality alternative to the original.[3] Therefore, in the spirit of Mussa and Rosen (1978), we posit some vertical (quality) differentiation between the two variants of any information good: letting s_o and s_c denote, respectively, the quality of an original and a copy, we assume that $0 < s_c < s_o$.[4]

As for the relative cost of originals and copies, we let p_i denote the price of original i and we assume that users have access to a copying technology with the following properties. Letting $C(y)$ denote the total cost of y illicit copies (and $AC(y) = C(y)/y$ denote the average cost), we assume

Assumption 1 $C(y) > C(y-1)$ *and* $AC(y) < AC(y-1)$,

Assumption 2 $AC(n) < \overline{\theta} s_c < AC(1)$.

According to Assumption 1, the copying cost function is increasing and exhibits *increasing returns to scale in copying*.[5] The assumption for continuous number of copies would be $C'(y) > 0 > C''(y)$. In the sequel we will use the notation $C'(y)$ to denote $C(y) - C(y-1)$. Assumption 2 simply says that no

[3] This assumption is common (see, e.g., Gayer and Shy, 2001a) and may be justified in several ways. In the case of analog reproduction, copies represent poor substitutes to originals and are rather costly to distribute. Although this is no longer true for digital reproduction, originals might still provide users with a higher level of services, insofar as that they are bundled with valuable complementary products which can hardly be obtained otherwise.

[4] Similar models are used by Koboldt (1995) to consider commercial copying and by Yoon (2002) and Bae and Choi (2003) to analyze the market for a single information good.

[5] The magnitude of these increasing returns to scale will depend on the precise nature of copying: returns will be quite low if copies are acquired piecemeal on a parallel market from some large-scale pirate; returns will be much larger if copies are directly produced by the consumer himself (for instance, by burning CDs using a CD-RW drive).

consumer will invest in the copying technology if it is to copy only one original ($\theta s_c < C(1)\ \forall\theta$), but that some consumers might invest if it is to copy all n originals ($\exists\theta$ s.t. $\theta n s_c > C(n)$).

Putting these elements together (and normalizing to zero the utility from not consuming a particular information good), we can express the user's utility function. If a user indexed by θ purchases a subset $X \subseteq N$ (with $0 \leq |X| \equiv x \leq n$) of originals and acquires a number y of copies (with $0 \leq y \leq n - x$), her net utility is given by

$$U_\theta(x, y) = \theta\left(x s_o + y s_c\right) - \sum_{i\in X} p_i - C(y), \tag{1}$$

which, by the properties of $C(y)$, is strictly convex in y.

We now use expression (1) to derive the demand function for some specific original $i \in N$. As will soon become apparent, the demand for original i depends, in a rather complicated way, on the relative quality of originals and copies (s_o and s_c), on the cost of copying, on the price of good i and, because of increasing returns to scale in copying, on the prices of all other originals. To make the analysis of the pricing game tractable, we focus on symmetric Bertrand-Nash equilibria (in pure strategies). Accordingly, we derive the demand for original i under the assumption that all other originals are priced the same: $p_j = p\ \forall j \neq i$.

We first define the condition under which a typical consumer θ is better off purchasing good i (and choosing whichever use is the most profitable for the other goods) than copying or not using good i (and still choosing whichever use is the most profitable for the other goods). As a preliminary, we need to identify the "most profitable use of the other goods" when good i is either purchased or not. Because the other goods are symmetric (same price, same quality of originals and copies) and because the copying technology exhibits increasing returns to scale, the most profitable option is always to make the same use of all other goods. We demonstrate this result in the next lemma.

Lemma 1 *Suppose $p_j = p\ \forall j \neq i$. Then any consumer maximizes her utility over goods $j \neq i$ by either purchasing, copying, or not using them all.*

Proof. Let x (resp. y) denote the number of information goods other than i that consumer θ chooses to purchase (resp. copy), with $0 \leq x + y \leq n - 1$. Let I_x and $I_y \in \{0, 1\}$ be the indicator functions describing the decisions to buy or to copy good i. The consumer's utility can then be rewritten as

$$\begin{aligned} U_\theta(x, y) \quad = \quad & x\left(\theta s_o - p\right) + y\theta s_c - C(y) \\ & + I_x\left(\theta s_o - p_i\right) + I_y\left(\theta s_c - C(y+1) - C(y)\right). \end{aligned}$$

For any I_x and I_y, this expression is convex in x and y. Hence, the maximum can only be reached at corner solutions: $x = y = 0$, $x = n - 1$, or $y = n - 1$. ■

Using the previous result, we can now express the condition for consumer θ to buy an original of information good i. To ease the exposition, we introduce the following notation. Let

$$B_\theta^{-i}(p) \equiv (n-1)(\theta s_o - p) \quad \text{and} \quad P_\theta(y) \equiv y(\theta s_c - AC(y))$$

respectively be the consumer θ's utility from buying all goods but good i at price p and the consumer θ's utility from "pirating" y goods.

Lemma 2 *Facing a price vector* $\left(p_i, (p_j = p)_{j \neq i}\right)$, *a consumer of type* θ *purchases original* i *if and only if*

$$\theta s_o - p_i + \max\{B_\theta^{-i}(p), P_\theta(n-1), 0\} \geq \max\{B_\theta^{-i}(p), P_\theta(n), 0\}. \qquad (2)$$

Proof. The left-hand side of the inequality follows directly from Lemma 1. To derive the right-hand side, we express, in Table 1, the highest net utility consumer θ can obtain from all n goods if she does not purchase good i.

	Other $n-1$ goods		
Good i	Purchased	Copied	Not used
Copied	$P_\theta(1) + B_\theta^{-i}(p)$	$P_\theta(n)$	$P_\theta(1)$
Not used	$B_\theta^{-i}(p)$	$P_\theta(n-1)$	0

Table 1: Net utility when good i is not purchased

Assumption 2 ($P_\theta(1) < 0$) rules out the top left and top right options as candidate maximum. So does Assumption 1 for the bottom middle option. (For this option to be maximum, we would need (1) $P_\theta(n-1) > P_\theta(n) \iff C(n) - C(n-1) > \theta s_c$ and (2) $P_\theta(n-1) > 0 \iff \theta s_c > AC(n-1)$. But, as $AC(n) < AC(n-1)$, inequalities (1) and (2) are clearly incompatible.) We are thus left with the three options appearing in the right-hand side of inequality (2). ■

To reduce the complexity of the demand schedule, we make a final simplifying assumption by posing that *(almost) extensive copying provides a surplus for every consumer*: $P_\theta(n-1) \geq 0 \; \forall \theta \in [\underline{\theta}, \overline{\theta}]$. This is satisfied if the lowest type is such that

Assumption 3 $\underline{\theta} s_c \geq AC(n-1)$.

Under Assumption 3, no consumer ever finds it optimal to refrain from using any information good (i.e., the option 0 on both max operators is never used). So, we have that a consumer of type θ purchases original i if and only if

$$\theta s_o - p_i \geq \max\{B_\theta^{-i}(p), P_\theta(n)\} - \max\{B_\theta^{-i}(p), P_\theta(n-1)\}. \qquad (3)$$

2.2 Demand schedule for originals

Assumptions 1 and 3 imply that $P_\theta(n) \geq P_\theta(n-1)\ \forall\theta$. It follows that firm i potentially faces consumers with three different behaviors and demand functions.

"Loyal users". Users for whom $B_\theta^{-i}(p) \geq P_\theta(n)$ are such that, whatever use they make of good i, they always prefer to purchase the $(n-1)$ other goods and never find it profitable to invest in the copying technology. Therefore, firm i considers these users as loyal, as it faces no threat of copying from them. Condition (3) rewrites for loyal users as $\theta s_o - p_i \geq 0$. The 'marginal loyal user', who is identified by $\theta_\ell(p_i) = p_i/s_o$, is indifferent between purchasing original i and not using good i; in any case, he/she purchases the $n-1$ other originals. Inverting the previous relation, we define the inverse demand for loyal users as the following price function:

$$p_i^\ell(\theta) = \theta s_o.$$

"Reverting users". Users for whom $P_\theta(n) \geq B_\theta^{-i}(p) \geq P_\theta(n-1)$ change their attitude towards the $(n-1)$ other goods according to the use they make of good i. In particular, if they buy good i, they also prefer to buy the other goods, but if they do not buy good i, they prefer to copy it along with the other goods. Condition (3) rewrites for these users as $\theta s_o - p_i + B_\theta^{-i}(p) \geq P_\theta(n)$. By setting too high a price, firm i may trigger consumers to revert their decision of purchasing $n-1$ items to copying all items. The 'marginal reverting consumer' is identified by

$$\theta_r\left(p_i, p\right) = \frac{p_i + (n-1)\,p - C(n)}{n\left(s_o - s_c\right)};$$

this consumer is indifferent between purchasing and copying all n originals. The corresponding inverse demand is given by

$$p_i^r(p,\theta) = \theta s_o - \left(P_\theta(n) - B_\theta^{-i}(p)\right) = \theta n\left(s_o - s_c\right) + C\left(n\right) - \left(n-1\right)p.$$

"Copying users". Users for whom $P_\theta(n-1) \geq B_\theta^{-i}(p)$ prefer to copy the $(n-1)$ other goods whatever their decision about good i. This is so because the price p of the other originals is sufficiently high for them. For these users, Condition (3) rewrites as $\theta s_o - p_i + P_\theta(n-1) \geq P_\theta(n)$; firm i's price is not going to change the users' decision of investing in the copying technology. The 'marginal copying consumer', identified by

$$\theta_c\left(p_i\right) = \frac{p_i - C'(n)}{s_o - s_c},$$

where $C'(n)$ stands for $C(n) - C(n-1)$, is indifferent between purchasing original i (and copying all other goods) and copying all n goods. The corresponding inverse demand is given by

$$p_i^c(\theta) = \theta s_o - (P_\theta(n) - P_\theta(n-1)) = \theta(s_o - s_c) + C'(n).$$

For a given price p of the other originals, we can identify two pivotal consumers who separate the three groups.

- The *'copying/reverting' user* is indifferent between purchasing and copying the other goods:

$$B_{\theta_{cr}}^{-i}(p) = P_{\theta_{cr}}(n-1) \iff \theta_{cr}(p) \equiv \frac{p - AC(n-1)}{s_o - s_c}.$$

  As originals are valued higher than copies, consumers on the right of $\theta_{cr}(p)$ are reverting users, and consumers on the left are copying users. Moreover, $\theta_{cr}(p)$ increases with p. By definition, $p_i^c(\theta_{cr}) = p_i^r(p, \theta_{cr})$.

- The *'loyal/reverting' user* is indifferent between purchasing all goods but good i and copying all goods:

$$B_{\theta_{\ell r}}^{-i}(p) = P_{\theta_{\ell r}}(n) \iff \theta_{\ell r}(p) \equiv \frac{(n-1)p - C(n)}{(n-1)s_o - ns_c}.$$

  By definition, $p_i^\ell(\theta_{\ell r}) = p_i^r(p, \theta_{\ell r})$. Here, what consumers located on either side of $\theta_{\ell r}(p)$ prefer depends on how $(n-1)$ originals compare with n copies in terms of gross utility. We need to distinguish between two cases. We make the following definition:

Definition 2.1 *The copy technology delivers good copies if $ns_c > (n-1)s_o$ and bad copies if $ns_c \leq (n-1)s_o$.*

In the case of good copies, *high valuation consumers* (with $\theta > \theta_{\ell r}(p)$) *are reverting users*: as n copies provide all users with more utility than $(n-1)$ originals, users with higher valuations are more likely to revert to copying all items. One also observes that $\theta_{\ell r}(p)$ is a *decreasing* function of p. In the case of *"bad copies",* we have the opposite situation: *high valuation consumers are loyal users.* The bad quality of copies refrain the latter to use the copying technology. Obviously, $\theta_{\ell r}(p)$ is then an *increasing* function of p.

Other instructive results emerge from the comparison of the three price functions. First, it follows from Assumption 3 that $p_i^\ell \geq p_i^c\ \forall\theta$: not surprisingly, firm i can always charge a higher price to loyal than to copying users; moreover, because $P_\theta(n) - P_\theta(n-1)$ is an increasing function of θ, p_i^ℓ increases in θ more steeply than p_i^c. Next, p_i^r increases more steeply in θ than p_i^c because $B_\theta^{-i}(p)$ increases faster in θ than $P_\theta(n-1)$. Indeed, for a reverting consumer, the loss

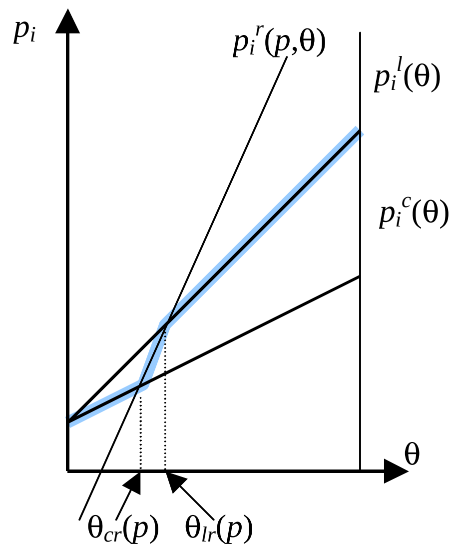


Figure 1: Inverse demand curve in the case of bad copies

associated to copying applies to all goods whereas it applies only to the last good i for the copying user. Finally, it is readily checked that p_i^ℓ increases in θ more steeply than p_i^r if and only if copies are good $(ns_c > (n-1)\, s_o)$.

Collecting the previous results, we can state that the inverse demand curve facing firm i might have up to two kinks, according to the price p of the other goods and to the relative quality of copies (either 'good' or 'bad'). What is important to note is the *existence of convex parts* in the inverse demand curve, as stated in the next lemma and illustrated in Figures 1 and 2.

Lemma 3 *Whether copies are good or bad, the inverse demand curve is (increasing and) concave in θ in the neighborhood of $\theta_{\ell r}(p)$ and, (increasing and) convex in the neighborhood of $\theta_{cr}(p)$.*

As a consequence, we anticipate that best response functions will be continuous when shifting from regime (l) to (r), but discontinuous when shifting from regime (r) to (c). The next section examines this issue in detail.

3 Pricing game

Each firm sets the price of its own original. Optimal prices depend on demand regimes. We first determine firm i's best-response function when all other originals are sold at the same price. Then, we characterize the symmetric Bertrand-Nash equilibria (in pure strategies) by looking for the fixed points of

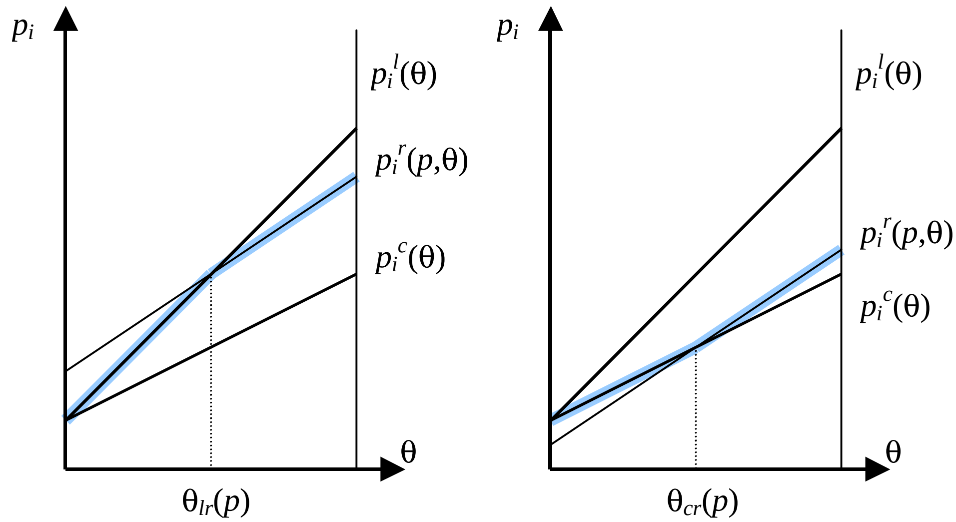


Figure 2: Inverse demand curve in the case of good copies (for different values of p)

the best-response function. For the sake of simplicity, we suppose for now that *firms' decisions never imply full market coverage.* In this case, solutions are always interior. This is so if $\underline{\theta}$ is assumed to be sufficiently small.[6]

3.1 Best-response function

As indicated in Lemma 3, the presence of convex parts in the inverse demand function implies that the best-response function is continuous when shifting from loyal to reverting users, but discontinuous when shifting from reverting to copying users. Therefore, we proceed in two steps to examine firm i's maximization program: first, we determine the optimal price when the firm decides to operate either on $p_i^\ell(\theta)$ or on $p_i^r(p,\theta)$; second, we compare the previous solution with the optimal profit the firm could achieve when it operates on $p_i^c(\theta)$.

3.1.1 Targeting loyal users or accommodating reverting users?

We first identify the choice between targeting loyal users (regime (l)) or accommodating reverting users (regime (r)). Remind that the 'loyal/reverting' user, $\theta_{\ell r}(p)$ is the user separating loyal from reverting consumers. We can therefore compute the maximal price that can be charged to this pivotal user as

[6] We conjecture that relaxing this assumption would not affect our results in any fundamental way (the only effect would be to eliminate some of the equilibrium configurations we identify). This issue necessitates, however, closer scrutiny.

$p_i^D(p) = p_i^r(p, \theta_{\ell r}(p)) = p_i^\ell(\theta_{\ell r}(p))$, or using $p_i^\ell(\theta) = \theta s_o$, we get

$$p_i^D(p) = \frac{(n-1)p - C(n)}{(n-1)s_o - ns_c} s_o.$$

The function $p_i^D(p)$ gives, for a given price p of the other originals, the price of original i that deters loyal users from becoming reverting users. The interpretation of this so-called *'reverter deterrence price'* changes as we consider good or bad copies.

- In the case of *good copies* $(ns_c > (n-1)s_o)$, firm i's consumer basis consists of reverting consumers at any price $p_i \geq p_i^D(p)$ and of loyal consumers at smaller prices. Moreover, the limit-price $p_i^D(p)$ *decreases* with p: as the other originals become more expensive, reverting becomes more profitable and consumers with low valuations are enticed to revert copying. To keep these consumers, firm i decreases its price.
- Conversely, with *bad copies* $(ns_c < (n-1)s_o)$, firm i's consumer basis consists of loyal users at any price $p_i \geq p_i^D(p)$ and of reverting consumers at smaller prices. To deter potential reversion, firm i must now set a *high enough* price, $p_i \geq p_i^D(p)$. Here, the limit-price *increases* with p. As the other originals become more expensive, the loyal consumers with the lowest valuations become reverting consumers; because the demand of these reverting consumers is rather inelastic, firm i is willing to apply a higher price.

When firm i faces only loyal and reverting consumers, it chooses the price that maximizes its profits under the loyal and reverting consumer's demand functions. In the case of good copies, it solves the following embedded maximization problem:

$$\max\{\ \max \pi_\ell(p_i) \quad \text{s.t. } p_i \leq p_i^D(p)\,; \ \ \max \pi_r(p_i, p) \quad \text{s.t. } p_i > p_i^D(p)\ \}$$

In the case of bad copies, inequalities must be reversed in the latter expression.

Given that demand functions are concave in θ (see Lemma 3), firm i continuously moves from one to the other of the three following situations according to the value of p. First, if the the price p of other goods is low enough, consumers never use the copying technology and firm i's price and marginal consumer are given by:

$$p_i^{\ell*} = \left(\overline{\theta}/2\right) s_o \text{ and } \theta_\ell^* = \overline{\theta}/2.$$

Whether copies are good or bad, it turns out that this solution is feasible as long as

$$p \leq p^f \equiv \frac{C(n)}{n-1} + \frac{(n-1)s_o - ns_c}{2(n-1)}\overline{\theta},$$

where p^f is the price of competitors for which the reverter deterrence price is equal to the optimal price charged to loyal consumers; that is $p_i^D\left(p^f\right) = p_i^{\ell *}$.

Second, when the price p of other goods is sufficiently large, firm i faces only reverting consumers. Its optimal price and marginal consumer are now equal to

$$\begin{aligned} p_i^{r*}(p) &= \frac{1}{2}\left(\overline{\theta} n\left(s_o - s_c\right) + C(n) - (n-1)p\right), \\ \theta_r^*(p) &= \frac{\overline{\theta}}{2} - \frac{C(n) - (n-1)p}{2n\left(s_o - s_c\right)}. \end{aligned}$$

This solution is feasible provided that (whether copies are good or bad)

$$p \geq p^d \equiv \frac{C(n)}{n-1} + \frac{n\left(s_o - s_c\right)\left((n-1)s_o - ns_c\right)}{(n-1)\left((n+1)s_o - ns_c\right)}\overline{\theta},$$

where p^d is the price of competitors for which the reverter deterrence price is equal to the optimal price charged to reverting consumers; that is, $p_i^D\left(p^d\right) = p_i^{r*}\left(p^d\right)$. It is readily checked that $p^d > p^f$.

Finally, when the price p of other goods takes intermediate values $p \in (p^f, p^d)$, marginal revenues are positive for any price above $p_i^D(p)$ and negative below. Hence, firm i quotes the price $p_i^D(p)$.

3.1.2 Accommodating copying users

Because of the convex section in the demand function, firm i's optimal price moves discontinuously when the price p of other goods entices firm i to swap between reverting (regime (r)) and copying users (regime (c)). Optimal prices are ruled by profit levels, which we must now compare.

We first compute the unconstrained optimal price and marginal type in regime (c) as the solution to $\max_{p_i} \pi_c(p_i) = p_i\left(\overline{\theta} - \theta_c(p_i)\right) / \left(\overline{\theta} - \underline{\theta}\right)$:

$$p_i^{c*} = \frac{1}{2}\left(\overline{\theta}\left(s_o - s_c\right) + C'(n)\right) \text{ and } \theta_c^* = \frac{\overline{\theta}}{2} - \frac{C'(n)}{2\left(s_o - s_c\right)}.$$

Second, we note that $\pi_i^{\ell *} > \pi_i^{c*}$. Indeed, the optimal profit collected under demand $p_i^\ell(\theta)$ can never be smaller than the one obtained under demand $p_i^c(\theta)$ since $p_i^\ell(\theta) > p_i^c(\theta)\ \forall \theta \in (\underline{\theta}, \overline{\theta}]$. We now have to compare π_i^{c*} with the profits under reverter deterrence, $\pi_i^D(p)$ and under reverter accommodation, $\pi_i^{r*}(p)$. Because a rise in p increases the constraint on demand for loyal consumers p_i^ℓ, the profit $\pi_i^D(p)$ must decrease in p. Also, since the demand of reverting users gets smaller when p rises, the profit $\pi_i^{r*}(p)$ must decrease in p. Hence, in any case, there exists a price p^e above which the accommodation of copying users is profitable.

Let us derive the exact value of p^e. Figure 3 illustrates the results from the previous analysis: $\pi_i^D(p)$ is the relevant profit level for $p^f < p \leq p^d$, whereas $\pi_i^{r*}(p)$ is the relevant profit level for $p > p^d$.

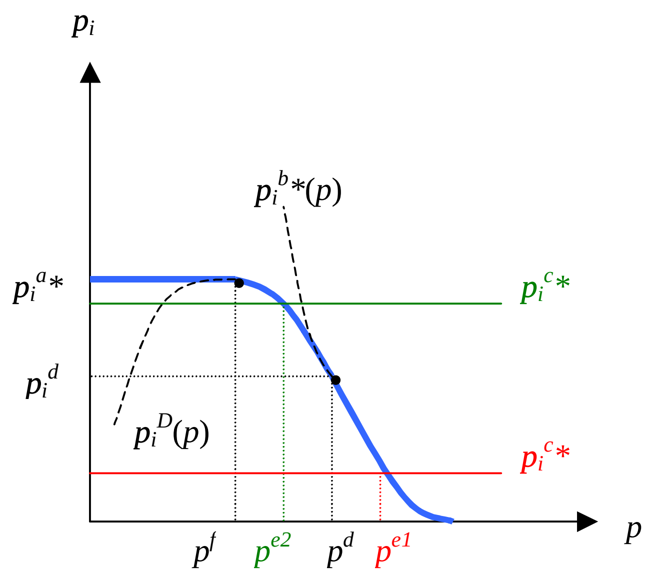


Figure 3: Comparison regimes (a) and (b) v. (c)

There are thus two possible cases according to which section of the profit function π_i^{c*} intersects. Define $\pi_i^d \equiv \pi_i^{r*}\left(p^d\right) = \pi_i^D\left(p^d\right)$. In Case 1, π_i^{c*} is lower than π_i^d and the price jump takes place at p_1^e such that $\pi_i^{r*}\left(p_1^e\right) = \pi_i^{c*}$. In Case 2, π_i^{c*} is larger than π_i^d and the price jump takes place at p_2^e such that $\pi_i^{D*}\left(p_2^e\right) = \pi_i^{c*}$. Define

$$
\begin{aligned}
C_0' &\equiv \frac{\left(ns_c - \left(n+1-2\sqrt{n}\right)s_o\right)\left(s_o - s_c\right)}{\left(n+1\right)s_o - ns_c}\overline{\theta}, \\
F\left(C'\left(n\right)\right) &\equiv \sqrt{\frac{\left(s_c(s_o-s_c)\bar{\theta}^2 - 2C'(n)(s_o-s_c)\bar{\theta} - C'(n)^2\right)\left((n-1)s_o - ns_c\right)^2}{s_o(s_o-s_c)}}.
\end{aligned}
$$

Note that $\pi_i^{\ell*} > \pi_i^{c*}$ makes sure that $F\left(\cdot\right)$ is a well-defined function of $C'\left(n\right)$.

Solving for p_1^e and p_2^e, we find

$$
\begin{aligned}
p_1^e &= p^d + \frac{\sqrt{n}}{n-1}\left[C_0' - C'\left(n\right)\right], \\
p_2^e &= p^d + \frac{1}{2\left(n-1\right)}\left[F\left(C'\left(n\right)\right) - F\left(C_0'\right)\right].
\end{aligned}
$$

Some lines of computations show that the two cases can be disentangled as stated in Lemma 4 on the basis of following two conditions:

$$
\left\{
\begin{array}{ll}
s_c/s_o > \left(n+1-2\sqrt{n}\right)/n & \text{(C1)} \\
C'(n) < C_0'. & \text{(C2)}
\end{array}
\right.
$$

Lemma 4 *Case 1 prevails if and only if both conditions (C1) and (C2) are satisfied. Case 2 prevails otherwise.*

Conditions (C1) and (C2) require that copies be attractive enough: they should have a high enough quality and and a low enough marginal cost. Under these two conditions, copies attract a sufficiently large number of users, so that the profit under accommodation (π_i^{c*}) is lower than π_i^d and Case 1 prevails. Note that because $(n+1-2\sqrt{n})/n < (n-1)/n$, condition (C1) rejects 'very bad' copies (and thus includes all good copies)

Collecting the previous results, we are now in a position to characterize firm i's best-response function (when all other firms set the same price p).

Proposition 1 *Under Assumptions 1-3, when all other producers set a common price p, the producer of information good i has the following best-response function. In Case 1,*

$$R_i^*(p) = \begin{cases} p_i^{\ell*} & \text{if} \quad 0 \leq p < p^f & \text{(reverting users are blockaded),} \\ p_i^D(p) & \text{if} \quad p^f < p \leq p^d & \text{(reverting users are deterred),} \\ p_i^{r*}(p) & \text{if} \quad p^d < p \leq p_1^e & \text{(reverting users are accommodated).} \\ p_i^{c*} & \text{if} \quad p \geq p_1^e & \text{(copying users are accommodated).} \end{cases}$$

In Case 2,

$$R_i^*(p) = \begin{cases} p_i^{\ell*} & \text{if} \quad 0 \leq p < p^f & \text{(reverting users are blockaded),} \\ p_i^D(p) & \text{if} \quad p^f < p \leq p_2^e & \text{(reverting users are deterred),} \\ p_i^{c*} & \text{if} \quad p \geq p_2^e & \text{(copying consumers are accommodated).} \end{cases}$$

In both cases, the best-response function starts with a flat section where copying is blockaded.[7] We move then continuously to a section where reverting users are deterred. Interestingly, $p_i^D(p)$ is decreasing in p if and only if copies are good. In that case, prices are strategic substitutes and reverting users are consumers with high valuation for the information goods. Each firm entices potential reverters to purchase its good by selling at a deterrence price $p_i^D(p)$ that is lower than $p_i^{\ell*}$. Such strategic price substitutability contrasts with most of the literature on price competition. It suggests that *originals become complementary products when producers face the threat of copying.* By contrast, prices are strategic complements when the quality of copies is relatively bad (i.e., if $ns_c < (n-1)s_o$). In this case, potential reverters are consumers with a low valuation θ. Each firm avoids potential reverters and focuses on loyal consumers by setting a deterrence price $p_i^D(p)$ higher than $p_i^{\ell*}$.

The next sections differ in the two cases. In Case 1, there is a continuous move to a section where reverting users are accommodated. Firm i's best response decreases with p, meaning that prices are strategic substitutes in this

[7] As noted above, this flat portion exists as long as $p^f > 0$, which is always satisfied for bad copies and is also satisfied for good copies when total copying costs are large enough.

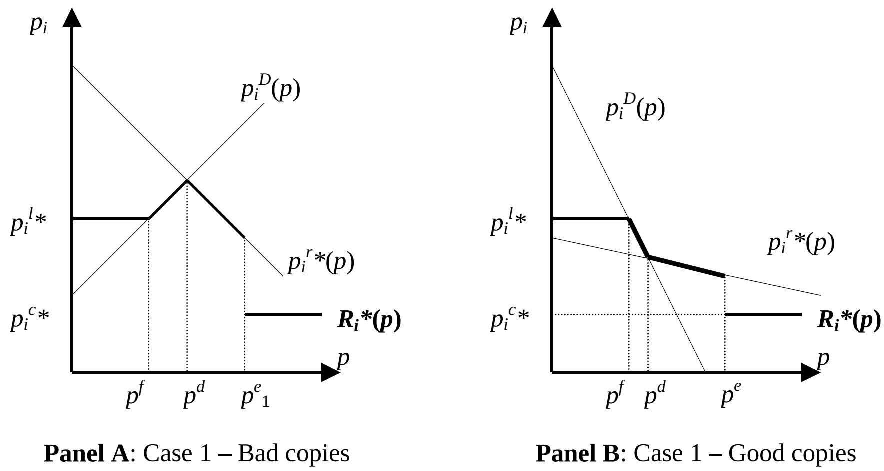


Figure 4: Best response function in Case 1

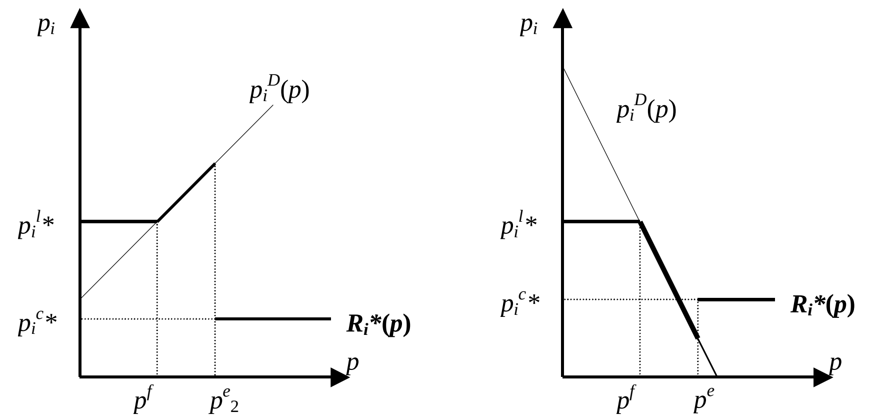
section. The threat of copying by reverting consumers makes original copies appear as complement goods irrespectively of the quality of the copying technology. Finally, there is the downward jump in the best-response function when the last, flat, section is reached (i.e., when the competitors charge a price equal to p_1^e). The reason why price jumps downward is the following. Because the reverting consumers's demand, $p_i^r(\theta)$, is steeper than the copying consumer's demand, $p_i^c(\theta)$, firms tends to charge higher prices under the former function; at equal profit levels, prices must necessarily be larger under the former inverse demand function.

In Case 2, firm i never finds it profitable to accommodate reverting users. An increase in p shifts the best-response from deterrence of reverting users to accommodation of copying users. The price jump at p_2^e can go downwards or upwards. In the case of bad copies, firm i's reverting deterrence price increases above $p_i^{\ell*}$, which reduces profits down to the profit level under copying accommodation. At that point, the best-response jumps downward to $p_i^{c*} < p_i^{\ell*}$. On the other hand, in the case of good copies, firm i's reverting deterrence price *decreases below* $p_i^{\ell*}$ down to a price that is lower than p_i^{c*}, implying that we have here an upward jump.

Figures 4 to 5 depict the best-response functions for good and bad copies in Cases 1 and 2.

3.2 Symmetric equilibria

We now examine under which conditions each of the four attitudes towards copying can emerge as a symmetric equilibrium of the pricing game. In technical



Panel A: Case 2 – Bad copies

Panel B: Case 2 – Good copies

Figure 5: Best response function in Case 2

terms, we identify the sets of parameters for which a fixed point of the best-response function is reached in each of the four portions of the function.

Blockading. Copying is blockaded when all firms quote the price $p_i^{\ell *}$. This would occur if copies were so unattractive that each firm could safely set the optimal price for loyal users, even though its competitors also set the very same high price. More formally, this would occur in Cases 1 and 2 if and only if $p^f \geq p_i^{\ell *} \iff AC(n) \geq (1/2)\,\bar{\theta} s_c$. By analogy with Bain's taxonomy, market conditions would then be such that potential entry (i.e., piracy) exerts no threat, so that incumbents (i.e., producers of originals) do not need to modify their behavior and continue to act as (local) monopolists. Note that there would be no strategic interaction in this extreme situation.

It is easy to understand, however, that our initial restrictions on the set of parameters rule out the possibility of such a 'blockading equilibrium'. In particular, Assumption 3 states that (almost) extensive copying provides a surplus for every consumer: $\underline{\theta} s_c \geq AC(n-1)$. Moreover, our focus on interior solutions implies that $\theta_\ell^* = \overline{\theta}/2 > \underline{\theta}$. It follows from the latter two inequalities that $\left(\overline{\theta}/2\right) s_c > AC(n-1)$. Because $AC(n-1) > AC(n)$, it follows that

$$AC(n) < \frac{1}{2}\bar{\theta} s_c \iff p^f < p_i^{\ell *}. \tag{4}$$

We therefore conclude that *under our assumptions on the set of parameters, copying cannot be blockaded at the symmetric equilibrium of the pricing game.*

Deterrence of reverting users. Reverting users are deterred when all firms quote the price $p_i^D(p) = p$. A symmetric equilibrium exists if the line $p_i^D(p)$

intersects with the line p within the interval $[p^f, p^d]$ in Case 1 and $[p^f, p_2^e]$ in Case 2. In the case of *bad copies*, Figures 4 and 5 reveal that for such an intersection to exist, the line p must also intersect with the section of the best-response function where copying is blockaded. However, we have just shown that blockading cannot be a symmetric equilibrium under our assumptions. Therefore, we conclude that *symmetric deterrence cannot be an equilibrium for bad copies.*

As for *good copies*, the previous argument no longer holds because prices are strategic substitutes everywhere. Indeed, the first condition for deterrence to be an equilibrium is that blockading is not an equilibrium: $p_f \leq p_i^{\ell *}$, which is always satisfied under our assumptions. The second condition depends on which case applies:

$$\text{in } \textbf{Case 1,} \quad p_i^D\left(p^d\right) \leq p^d \iff AC\left(n\right) \geq \tfrac{1}{2}\bar{\theta}s_c\left(1 - \tfrac{ns_c-(n-1)s_o}{(n+1)s_o-ns_c}\right), \quad (5)$$

$$\text{in } \textbf{Case 2,} \quad p_i^D\left(p_2^e\right) \leq p_2^e \iff AC\left(n\right) \geq \tfrac{1}{2}\bar{\theta}s_c - \tfrac{1}{2}\tfrac{s_cF(C'(n))}{ns_c-(n-1)s_o}. \quad (6)$$

It is easily checked that in each case, the lower bound on $AC\left(n\right)$ is below $\left(1/2\right)\bar{\theta}s_c$. Therefore, *there exists a non empty set of economic parameters such that symmetric deterrence occurs for good copies.*

Accommodation of reverting users. Clearly, *this type of equilibrium can only occur in Case 1.* Reverting users are accommodated when all firms quote the price $p_i^{r*}\left(p\right) = p$. Because $p_i^{r*}\left(p\right)$ is always a decreasing function, prices are strategic substitutes in this regime. Accommodation of reverting users is a symmetric equilibrium if and only if $p^d \leq p_i^D\left(p^d\right)$ and $p_1^e \geq p_i^{r*}(p_1^e)$; that is,

$$\begin{aligned} p^d &\leq p_i^D\left(p^d\right) \iff AC\left(n\right) \leq \frac{1}{2}\bar{\theta}s_c\left(1 - \frac{ns_c-\left(n-1\right)s_o}{\left(n+1\right)s_o-ns_c}\right), && (7)\\ p_1^e &\geq p_i^{r*}(p_1^e) \iff AC\left(n\right) \geq \tfrac{(n+1)\sqrt{n}-2n}{2n}\bar{\theta}\left(s_o-s_c\right) + \tfrac{(n+1)\sqrt{n}}{2n}C'\left(n\right). && (8)\end{aligned}$$

It can be checked that the latter two inequalities define an open interval under conditions (C1) and (C2) (which characterize Case 1).

Accommodation of copying users. Copying users are accommodated when firms set the price p_i^{c*}. This situation would occur if and only if p_i^{c*} is larger than p_1^e or p_2^e. In Case 1, optimal profit and price under accommodation are low. Given the low price of competitors, each individual firm has an incentive to deviate (by setting a higher price). Indeed, it can be shown analytically that $p_i^{c*} < p_1^e$ for all admissible configurations of parameters, meaning that *accommodation of copying users cannot be a symmetric equilibrium in Case 1.* On the contrary, *in Case 2, accommodation of copying users can be a symmetric equilibrium.* It is so if and only if $p_i^{c*} \geq p_2^e$, which is equivalent to

$$AC(n) \leq \frac{1}{2n}\bar{\theta}s_c + \frac{n-1}{2n}C'(n) - \frac{F(C'(n))}{2n}. \tag{9}$$

Some line of computations establish that there exist configurations of parameters for which both condition (6) and (9) are met, meaning that *deterrence of reverting users and accommodation of copying users can be simultaneous equilibria.* A quick look at Figures 4 and 5 reveals that there is no other instance of simultaneous equilibria.

Absence of a symmetric equilibrium. We first consider **Case 1**. Since reaction functions have a jump, there may exist sets of economic parameters for which no equilibrium (in pure strategies) exists. Indeed, a symmetric equilibrium may not exist because neither accommodation of reverting users nor accommodation of copying users are sustainable strategies. Indeed, suppose that firms simultaneously choose to accommodate copying users by setting the low price $p_i = p_i^{c*} < p_1^e$. Then such a low price may entice consumers not to invest in the copying technology and reverting is not a threat for firms. Some firms may set a higher price and break the symmetric equilibrium. Since the price p_i^{c*} increases with marginal costs $C'(n)$, one will expect that the existence of symmetric equilibria is less likely for small marginal costs $C'(n)$. Conversely, suppose that all firms simultaneously choose to accommodate reverting users by setting a high price $p_i > p_1^e$. Then, in some situations, consumers may consider that originals have become so expensive that copying is preferable. As a result, profits may be driven down and some firms may prefer to accommodate the copying users at the price $p_i = p_i^{c*}$, which also breaks the symmetric equilibrium.

More formally, there exists no symmetric equilibrium if and only if the reaction function does not intersect the 45° line. This occurs when (i) $p_f < p_i^{\ell*}$, (ii) $p_i^{r*}(p_1^e) > p_1^e$, and (iii) $p_1^e > p_i^{c*}$. We know from the previous analysis that conditions (i) and (iii) are always satisfied. We have also compared above $p_i^{r*}(p_1^e)$ and p_1^e, which allows to state that *a symmetric equilibrium fails to exist in Case 1 if and only if condition (8) is violated.* This is more likely to be met as the average cost of copying, $AC(n)$, is low and the marginal cost of the last copy, $C'(n)$, is large. The potential inexistence of symmetric equilibria is henceforth a natural property of copying technologies with weak increasing returns to scale.

We now study the existence of symmetric equilibria in **Case 2**. Note first that in case of good copies (see Panel A of Figure 5), the jump in the best-response function is upward, which implies that there always exists at least one fixed point, i.e., a symmetric equilibrium. In the case of bad copies (see Panel B of Figure 5), the downward jump in the best response function may compromise the existence of an equilibrium. Formally, there is no equilibrium

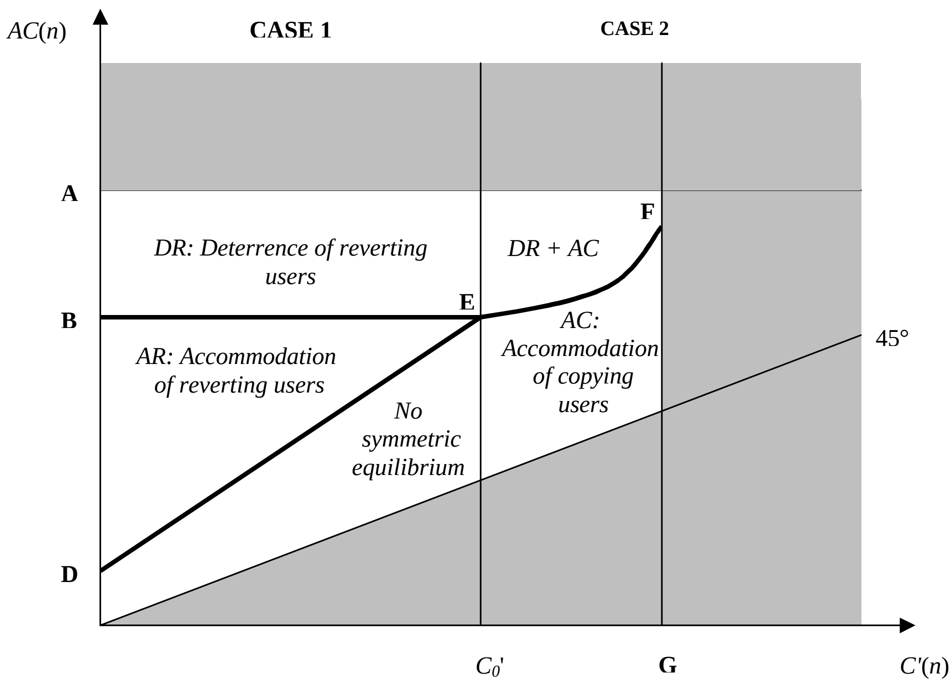


Figure 6: Characterization of symmetric equilibria for good copies.

if the condition for an equilibrium with accommodation is not met. Using our previous results, we conclude that *a symmetric equilibrium fails to exist in Case 2 if and only if copies are bad and condition (9) is violated.*

Characterization of symmetric equilibria. The next proposition collects the previous results.

Proposition 2 *Under Assumptions 1-3, the symmetric equilibrium in pure-strategies in the pricing game depends on the economic parameters as depicted in Figures 6 and 7.*

The figures read as follows:[8]

$$\begin{cases} A \equiv \frac{1}{2}\bar{\theta}s_c,\ B \equiv \frac{1}{2}\bar{\theta}s_c\left(1-\frac{ns_c-(n-1)s_o}{(n+1)s_o-ns_c}\right),\ G \equiv \left(\sqrt{s_o\left(s_o-s_c\right)}-\left(s_o-s_c\right)\right)\bar{\theta} \\ \text{segment } DE \equiv \frac{(n+1)\sqrt{n}-2n}{2n}\bar{\theta}\left(s_o-s_c\right)+\frac{(n+1)\sqrt{n}}{2n}C'\left(n\right), \\ \text{segment } EF \equiv \frac{1}{2}\bar{\theta}s_c-\frac{1}{2}\frac{s_cF(C'(n))}{ns_c-(n-1)s_o}, \end{cases}$$

[8]The case of 'very poor' copies (condition (C1) is violated) is not represented. However, the characterization of symmetric equilibria in this case is identical to what is observed in Case 2 for bad copies.

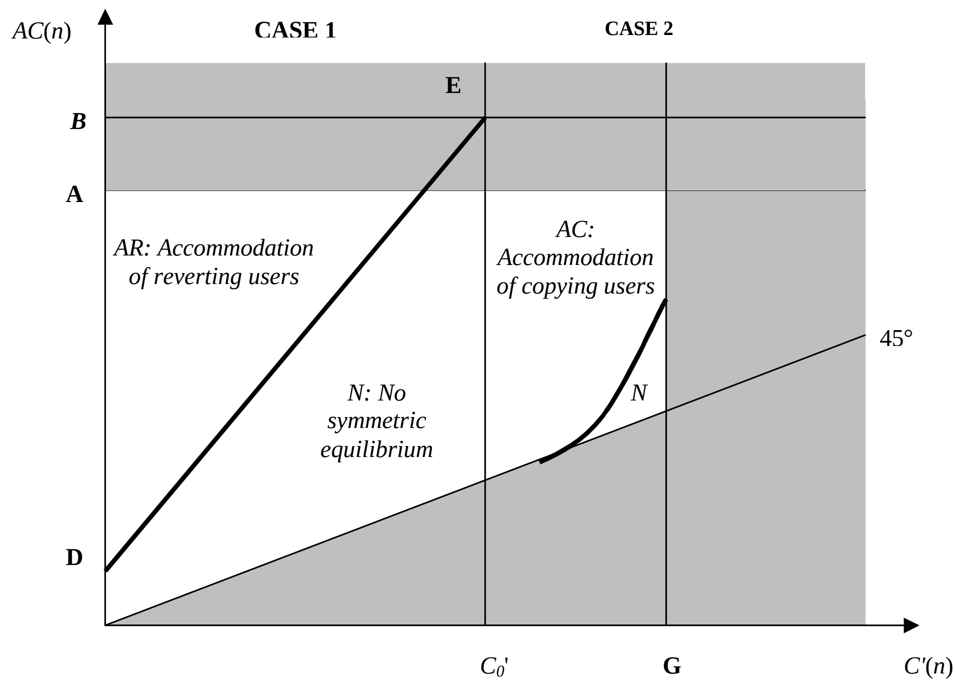


Figure 7: Characterization of symmetric equilibria for bad copies

Let us comment the results of Proposition 2. Our initial restrictions on the economic parameters make sure that, at the symmetric equilibrium of the game, the producers of information goods are affected by the consumers' ability to make copies; indeed, there cannot be an equilibrium where all producers behave as unconstrained local monopolists. The question is then how producers modifiy their pricing behavior in the face of copying. As depicted in Figures 6 and 7, the answer crucially depends on the properties of the copying technology: that is, on the relative importance of the average and marginal costs of copying ($AC(n)$ vs. $C'(n)$), and on the relative quality of copies (s_c vs. s_o).

Consider first high-quality copies. In particular, we talk of '*good copies*' when n copies provide users with more gross utility than $n-1$ originals. Another way to put it is to say that all users loose less, in terms of gross utility, when they consume copies instead of originals for all goods ($n(s_o - s_c)$) than when they refrain from consuming a single original (s_o). In this case, three different attitudes can emerge at the symmetric equilibrium. If the copying technology exhibits important returns to scale (large average costs and small marginal costs), firms find it profitable to deter copying: they set a price for their information product which is low enough to make copying unprofitable for all users. For copying technologies with lower returns to scale, the latter option is too costly and firms prefer therefore to tolerate copying. When the marginal cost of copying is not too large, they accommodate 'reverting users' (i.e., those users who contemplate purchasing or copying all goods); for larger values of the marginal cost, firms accommodate 'copying users' (i.e., those users who copy anyway all but one good, but who could purchase the remaining one were it priced cheaply enough). Finally, if the marginal cost of copying is low and close enough to the average cost, the copying technology exhibits weak returns to scale and a symmetric equilibrium fails to exist. The reason for such inexistence is the following. When all other firms choose to accommodate reverting users by setting a relatively high price, consumers consider that originals have become so expensive that copying (using a rather cheap technology) is preferable. As a result, any individual firm has an incentive to deviate by setting a lower price and accommodating instead the copying users.

Consider now copies which offer a lower quality ('*bad copies*'). Although, other things being equal, copying is less attractive than in the previous case, it turns out that there is no symmetric equilibrium where firms manage to deter copying. To understand this seemingly paradoxical result, it must be recalled that with bad copies, each firm must set a *high enough* price to deter users from reverting their purchase decision. In contrast with the case of high-quality copies, a firm's individual deterrence price *increases* with the price set by the other producers. As a result, the section of a firm's best-response function where deterrence is the optimal conduct is upward-sloping (meaning that prices become strategic substitutes) and reaches prices which are *above* the unconstrained monopoly price. Yet, our restrictions on the parameters prevent the monopoly price to be part of a symmetric equilibrium and, by the same token, so do they for any higher price. This explains why there is no symmetric deterrence equilibrium for bad copies. Two possible attitudes remain. For a sufficiently high average cost of copying, there is a symmetric equilibrium where producers tolerate copying: they accommodate reverting users for a sufficiently low marginal cost of copying, or copying users otherwise. When the average cost is close to the marginal cost, there exists no equilibrium.

4 Concluding remarks

Information goods fall in the category of *public goods with exclusion*, that is, "public goods the consumption of which by individuals can be controlled, measured and subjected to payment or other contractual limitation" (Drèze, 1980). Exclusion can be achieved through legal authority and/or technical means. However, simply specifying intellectual property laws does not ensure that they will be enforced; similarly, technical protective measures are often imperfect and can be "cracked". As a result, illicit copying (or piracy) cannot be completely avoided. It is therefore extremely important to understand how copying affects the demand for legitimate information goods and the pricing behavior of their producers. In particular, closer attention must be devoted to the strategic interaction among producers, which results from increasing returns to scale in the copying technology. The consumers' decision to invest in such technology is based, indeed, on a comparison between the cost of the copying equipment and the prices of *all* the goods that can be copied. The demand for a particular original is therefore indirectly affected by the prices of other originals.

The present paper addresses this issue within a simple, unified model of competition between originals and copies. We use the vertical differentiation framework proposed by Mussa and Rosen (1978): copies are seen as lower-quality alternatives to originals. We characterize the symmetric Nash equilibria of the pricing game played by n oligopolists (each one controlling one good). We describe how the equilibrium depends on the nature of the copying technology, which is determined by the average cost of copying all goods, the marginal cost of the last copy and the quality gap between originals and copies. Focussing on configurations of parameters which force producers to modify their pricing behavior in the face of copying, we show that at equilibrium, copying will be either deterred (through symmetric limit-pricing) or accommodated. The former attitude is observed for high-quality copies and large returns to scale in copying. The latter attitude is observed for low-quality copies and/or weaker returns to scale in copying. Interestingly, when the copying technology exhibits low returns to scale, there exists no symmetric equilibrium (in pure strategies).

The directions for future research are threefold. First and foremost, some work remains to be done to complete the characterization of symmetric equilibria: (i) we need to examine more closely corner solutions due to the bounds on the distribution of θ; (ii) we want to relax Assumption 3 and investigate how the analysis changes in the presence of low-valuation consumers who might stay out of the market; (iii) we would like to investigate the possibility of asymmetric equilibria in a simple duopoly framework; (iv) we need to characterize mixed-strategy equilibria, especially for the configurations of parameters where a pure-strategy equilibrium fails to exist.

A second direction would be to address the welfare implications of copying, by endogenizing the number of information goods supplied. Belleflamme (2002) performs such welfare analysis in the simple case where the copying technology exhibits constant returns to scale (which implies an absence of strategic interaction among producers). In particular, it is possible to balance *ex ante* and *ex post* efficiency considerations and show that copying is likely to damage welfare in the long run (unless copies are a poor alternative to originals and/or are expensive to acquire). It would be instructive to extend this analysis to the present setting.

Finally, the third direction for future research consists in exploiting the model to address topical policy issues. We would like to explore the respective impacts and merits of various protective actions against the use of copying technologies (increasing the quality of originals, damaging copies, taxing copies or the copying medium, enforcing IP rights, ...).

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