

Oligopolistic pricing of piratable information goods

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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 study the effects of the resulting strategic interaction by comparing the optimal choices of a multiproduct monopolist controlling all n information goods with the Nash equilibria of the pricing game played by n oligopolists.

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1 Introduction

Information can be defined very broadly as anything that can be digitized (i.e., encoded as a stream of bits), such as text, images, voice, data, audio and video (see Varian, 1998). Information is exchanged under a wide range of formats or packages (which are not necessarily digital). These formats are generically called *information goods*. Books, movies, music, magazines, databases, telephone conversations, stock quotes, web pages, news, etc. all fall into this category. Most information goods 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 be *nonexcludable*, in the sense that one person cannot exclude another person from consuming the good in question. 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

¹See, 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).

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

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 dead-weight 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 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). In his 'fixed cost model', Johnson considers a copying technology that involves an investment in costly equipment. As he 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 he is mainly concerned with the welfare implications of copying, Johnson 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; we assume, however, that the quality of copies is relatively high). 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 emphasize the effects of this interdependence, we contrast the optimal choices of a multiproduct monopolist controlling all n information goods with the Nash equilibria of the pricing game played by n oligopolists (each one controlling one good).

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 or 'accommodate' it. Our main results are the

following. First, under our assumptions, a multiproduct monopolist will never find it optimal to accommodate copying: if the consumers' average cost of copying the n goods is sufficiently high, the monopolist will be able to blockade copying; otherwise, he will choose to deter copying by setting some 'limit price'. In contrast, oligopolists might be 'forced' to accommodate copying: when the average copying cost is low enough, it is possible to have a Bertrand-Nash equilibrium in which the producers of information goods tolerate copying and make up for it by extracting a higher margin from fewer consumers of originals. Letting the average copying cost increase, we first encounter situations where neither copying accommodation nor copying deterrence is a Nash equilibrium: accommodation is undermined by incentives to undercut the other producers; deterrence is not sustainable because each producer tends to free-ride on the limit-pricing efforts of the other producers. For copying deterrence to be an equilibrium, the average cost of copying all originals must be larger than the threshold obtained in the monopoly case: strategic interaction makes it thus more difficult to eliminate copying through low enough prices. Finally, copying is blockaded over the same range of parameters in the monopoly and oligopoly cases (which is quite natural as strategic interaction disappears when the cost of copying is so high that it poses no threat on the producers of information goods).

The rest of the paper is organized as follows. In Section 2, we lay out the model. In Section 3, we derive the demand schedule for a particular original. Then, in Section 4, we analyze the pricing decisions of a multiproduct monopolist and of n oligopolists. Contrasting the two analyses, we draw our main results. We conclude and propose an agenda for future research in Section 5.

2 The model

We analyze the following model.³ 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 $[0, 1]$.

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.⁴ Therefore, in the spirit of Mussa and

³Similar models are used by Koboldt (1995) to consider commercial copying and by Yoon (2002) to analyze the market for a single information good.

⁴This assumption is common (see, e.g., Gayer and Shy, 2001a) and may be justified in

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 $0 < s_c < s_o$.

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, we assume this function is increasing and strictly concave: $C'(y) > 0 > C''(y)$. That is, we assume *increasing returns to scale in copying*. 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).⁵

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

$$U_\theta(x, y) = \theta(xs_o + ys_c) - \sum_{i \in X} p_i - C(y), \quad (1)$$

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

To make the analysis interesting and tractable, we make some further assumptions about the quality and costs of copies:

$$C(n)/n < s_c < C(1), \quad (2)$$

$$ns_c > (n - 1)s_o. \quad (3)$$

Assumption (2) simply says that no 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. $\theta ns_c > C(n)$). According to assumption (3), the quality differential between originals and copies is quite small (in particular, n copies are worth more than $n - 1$ originals for any user). Although this assumption is essentially made for technical convenience (we show below how it usefully reduces the number of cases to consider), it does not seem unrealistic, considering the development of digital technologies (which facilitate the reproduction and distribution of illicit copies of information goods).

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.

⁵In a companion paper (Belleflamme, 2002), we analyse two limiting cases of the copying technology. First, in the *variable copying cost* model, there is a constant unit cost per copy and no fixed cost. Second, in the *fixed copying cost* model, there is a positive fixed cost and no marginal cost.

We are now in a position to derive the demand function for originals. Before doing so, it is important to note that we have designed our model in such a way that copying is the only source of interdependence between the demands for the various information goods. The interdependence comes from the fact that consumers will base their decision to invest in the copying technology on the cost of this technology and on the prices of *all* originals. Otherwise, the goods are completely differentiated (which implies that a user's net utility is computed as the sum of the net utilities for the n information good). Moreover, we have implicitly assumed that consumers have a sufficient (exogenous) budget to buy all information goods if they so wish.

3 Demand function for originals

Our objectif in this section is to use the users' utility function (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 (as summarized by the function C), on the price of good i (p_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 proceed in three steps.

Step 1. Our first task is to 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 decisions to buy or to copy good i . The consumer's utility can then be rewritten as

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

For any I_x and I_y , this expression is convex in x and y . Therefore, the maximum utility 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 .

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

$$\begin{aligned} \theta s_o - p_i + \max\{(n-1)(\theta s_o - p), (n-1)\theta s_c - C(n-1), 0\} \\ \geq \max\{(n-1)(\theta s_o - p), n\theta s_c - C(n), 0\}. \end{aligned} \quad (4)$$

Proof. If consumer θ purchases original i (securing a net utility of $\theta s_o - p_i$ from that good), the highest net utility she can obtain from the other $n-1$ goods is (from Lemma 1) the maximum of $(n-1)(\theta s_o - p)$ (*purchase all other goods*), $(n-1)\theta s_c - C(n-1)$ (*copy all other goods*) and 0 (*not use any of the other goods*). This gives us the left-hand side of inequality (4). To derive the right-hand side of the inequality, we need to express the highest net utility consumer θ can obtain from all n goods if she does not purchase good i . Applying the result of Lemma 1 once more, we can fill the cells of Table 1.

Good i	Other $n-1$ goods		
	Purchased	Copied	Not used
Copied	$\theta s_c - C(1) + (n-1)(\theta s_o - p)$	$n\theta s_c - C(n)$	$\theta s_c - C(1)$
Not used	$(n-1)(\theta s_o - p)$	$(n-1)\theta s_c - C(n-1)$	0

Table 1: Net utility when good i is not purchased

Our assumption that $s_c < C(1)$ rules out the top left and top right options as candidate maximum. Furthermore, because average copying costs are assumed to decrease, the maximum cannot be the bottom middle option. We would indeed need (1) $(n-1)\theta s_c - C(n-1) > n\theta s_c - C(n) \iff C(n) - C(n-1) > \theta s_c$ and (2) $(n-1)\theta s_c - C(n-1) > 0 \iff \theta s_c > C(n-1)/(n-1)$. For inequalities (1) and (2) to be compatible, it should be that $C(n)/n > C(n-1)/(n-1)$, which violates our assumption. We are thus left with the three options appearing in the right-hand side of inequality (4). ■

The result of Lemma 2 allows us to highlight why the demands for various originals are interdependent when the copying technology exhibits increasing returns to scale. Suppose instead constant returns to scale in copying; for instance, let $C(y) = c > 0, \forall 1 \leq y \leq n$. With such copying technology, the two conditions of assumptions (2) are clearly incompatible. For copying to remain an option for some consumers, we need then to impose that $s_c > c$. Under these new assumptions, the maximum on the left-hand side of condition (4) rewrites as $\max\{(n-1)(\theta s_o - p), (n-1)(\theta s_c - c), 0\}$. As for the right-hand side, we need to adapt the data in Table 1. Doing so, we can easily show

that the highest net utility consumer θ can obtain from all n goods if she does not purchase good i is now given by the following expression: $\max\{\theta s_c - c, 0\} + \max\{(n-1)(\theta s_o - p), (n-1)(\theta s_c - c), 0\}$. As a result, the condition for consumer θ to purchase original i boils down to $\theta s_o - p_i \geq \max\{\theta s_c - c, 0\}$. The prices of the other originals are no longer relevant: the demands for different originals are independent of one another. The intuition for this result is clear: because each copy of an additional good costs the same constant amount, the “whichever use is the most profitable for the other goods” does not depend on which use is made of good i . This is no longer true, however, when the average copying cost is not constant.

Step 2. The next step consists in deriving the exact expression of condition (4) for every combination of parameters. In practice, we need to solve for and compare the maximum on both sides of the inequality. Lemma 3 collects the results of this procedure (which is a bit tedious but straightforward) and lists the specific conditions (where $AC(y)$ stands for $C(y)/y$).

Lemma 3 *The specific expression of condition (4) is as follows.*

1. For $p \leq AC(n)(s_o/s_c)$,⁶
 - (a) $\theta \geq \frac{p_i}{s_o}$ for $0 \leq \theta \leq \frac{C(n)-(n-1)p}{ns_c-(n-1)s_o}$,
 - (b) $\theta \geq \frac{p_i+(n-1)p-C(n)}{n(s_o-s_c)}$ for $\frac{C(n)-(n-1)p}{ns_c-(n-1)s_o} \leq \theta \leq 1$.
2. For $AC(n)(s_o/s_c) \leq p \leq AC(n-1)(s_o/s_c)$,
 - (a) $\theta \geq \frac{p_i}{s_o}$ for $0 \leq \theta \leq AC(n)/s_c$,
 - (b) $\theta \leq \frac{C(n)-p_i}{ns_c-s_o}$ for $AC(n)/s_c \leq \theta \leq \frac{p}{s_o}$,
 - (c) $\theta \geq \frac{p_i+(n-1)p-C(n)}{n(s_o-s_c)}$ for $\frac{p}{s_o} \leq \theta \leq 1$.
3. For $p \geq AC(n-1)(s_o/s_c)$,
 - (a) $\theta \geq \frac{p_i}{s_o}$ for $0 \leq \theta \leq AC(n)/s_c$,
 - (b) $\theta \leq \frac{C(n)-p_i}{ns_c-s_o}$ for $AC(n)/s_c \leq \theta \leq AC(n-1)/s_c$,
 - (c) $\theta \geq \frac{p_i+C(n-1)-C(n)}{s_o-s_c}$ for $AC(n-1)/s_c \leq \theta \leq \frac{p-AC(n-1)}{s_o-s_c}$,
 - (d) $\theta \geq \frac{p_i+(n-1)p-C(n)}{n(s_o-s_c)}$ for $\frac{p-AC(n-1)}{s_o-s_c} \leq \theta \leq 1$.

⁶Part (b) is possible if and only if $(n-1)p > C(n) - (ns_c - (n-1)s_o)$. Note also that Assumption (??), according to which $ns_c > (n-1)s_o$, plays its simplifying role here. Another list of conditions would obtain if we were considering instead that $ns_c < (n-1)s_o$. This would burden the analysis without giving any additional insight.

Step 3. The final step consists in considering every subcase in turn and examining for which values of p_i the specific form of condition (4) can be met in the corresponding interval. Taking case 2b as an illustration, we find easily that the condition is never met in the corresponding interval if $p_i > AC(n)(s_o/s_c)$, but is always met if $p_i < C(n) - ((ns_c - s_o)/s_o)p$. Collecting all the results of this type and comparing the various thresholds on p_i , we express, in Proposition 1, the demand schedule for original i in each of the three regimes identified above. We note $\hat{p}_i(p) \equiv n(s_o - s_c) + C(n) - (n-1)p$ the price above which the demand for original i is zero when all other originals are priced at p . Using this threshold, we can express an upper bound on the common price of all other goods: $p_j = p < \hat{p}_j(p) \iff p < s_o - s_c + AC(n)$.

Proposition 1 *Suppose $p_j = p \forall j \neq i$. Then the demand for original i , $D(p_i, p)$, takes the following form.*

Regime 1. For $0 \leq p \leq AC(n)(s_o/s_c)$, $D(p_i, p) =$

1. 0 for $p_i \geq \hat{p}_i(p)$,
2. $1 - \frac{p_i + (n-1)p - C(n)}{n(s_o - s_c)}$ for $\frac{C(n) - (n-1)p}{ns_c - (n-1)s_o} s_o \leq p_i \leq \hat{p}_i(p)$,
3. $1 - \frac{p_i}{s_o}$ for $p_i \leq \frac{C(n) - (n-1)p}{ns_c - (n-1)s_o} s_o$.

Regime 2. For $AC(n)(s_o/s_c) \leq p \leq AC(n-1)(s_o/s_c)$, $D(p_i, p) =$

1. 0 for $p_i \geq \hat{p}_i(p)$,
2. $1 - \frac{p_i + (n-1)p - C(n)}{n(s_o - s_c)}$ for $AC(n)\frac{s_o}{s_c} \leq p_i \leq \hat{p}_i(p)$,
3. $\left(1 - \frac{p_i + (n-1)p - C(n)}{n(s_o - s_c)}\right) + \left(\frac{C(n) - p_i}{ns_c - s_o} - \frac{p_i}{s_o}\right)$ for $C(n) - \frac{ns_c - s_o}{s_o} p \leq p_i \leq AC(n)\frac{s_o}{s_c}$,
4. $1 - \frac{p_i}{s_o}$ for $p_i \leq C(n) - \frac{ns_c - s_o}{s_o} p$.

Regime 3. For $AC(n-1)(s_o/s_c) \leq p \leq s_o - s_c + AC(n)$, $D(p_i, p) =$

1. 0 for $p_i \geq \hat{p}_i(p)$,
2. $1 - \frac{p_i + (n-1)p - C(n)}{n(s_o - s_c)}$ for $AC(n)\frac{s_o}{s_c} \leq p_i \leq \hat{p}_i(p)$,
3. $\left(1 - \frac{p_i + (n-1)p - C(n)}{n(s_o - s_c)}\right) + \left(\frac{C(n) - p_i}{ns_c - s_o} - \frac{p_i}{s_o}\right)$ for $p + C(n) - nAC(n-1) \leq p_i \leq AC(n)\frac{s_o}{s_c}$,
4. $\left(1 - \frac{p_i + C(n-1) - C(n)}{s_o - s_c}\right) + \left(\frac{C(n) - p_i}{ns_c - s_o} - \frac{p_i}{s_o}\right)$ for $C(n) - \frac{ns_c - s_o}{(n-1)s_c} C(n-1) \leq p_i \leq p + C(n) - nAC(n-1)$,
5. $1 - \frac{p_i}{s_o}$ for $p_i \leq C(n) - \frac{ns_c - s_o}{(n-1)s_c} C(n-1)$.

We now turn to the derivation of the equilibrium prices for the n originals.

4 Pricing game

In this section, we analyze the simultaneous price-fixing game between n producers of information goods (we assume that each producer controls one good and, without loss of generality, we set the marginal cost of production at zero). As stressed above (and as illustrated by the demand schedule derived in Proposition 1), the presence of increasing returns to scale in copying is a source of strategic interaction between the producers. To unravel the effects of this strategic interaction, we should, ideally, characterize the set of Bertrand-Nash equilibria. Unfortunately, even when restricting our analysis to symmetric equilibria, the demand schedule remains so complex that we are (or have been so far) unable to fully characterize the set of equilibria (in pure-strategies, let alone in mixed strategies).

As a result, we adopt a different strategy. First, we consider the benchmark case of a multiproduct monopolist controlling all n information goods (which is equivalent to suppose that the n independent producers form a cartel). In the absence of strategic interaction, price-setting becomes rather simple. As we show below, the optimal strategy for the multiproduct monopolist can usefully be described by using Bain (1956)'s taxonomy of an incumbent's behavior in the face of an entry threat. Unless the quality/price ratio of copies is very low (meaning that copying exerts no threat and will therefore be 'blockaded'), the producer will have to modify his behavior and decide whether to set a price for the n goods low enough to 'deter' copying, or accept to 'accommodate' copying and make up for it by extracting a higher margin from fewer consumers of originals. Second, we derive the conditions under which the same patterns of 'blockaded', 'deterred' and 'accommodated' copying appear as symmetric Nash-equilibria of the pricing game played by n independent producers. Finally, by comparing the previous results, we gain some insight about the effects of strategic interaction.

4.1 Multiproduct monopolist

A multiproduct monopolist sets a price for all n information goods to maximize the sum of the profits collected on each of the n goods. As above, we focus on symmetric price vectors.⁷ Letting q denote the common price for the n goods, it is easy to exploit the results of Proposition 1 (by setting $p_i = p = q$) and to derive the demand function the multiproduct monopolist faces for any of the n

⁷As the n goods are identical, it seems natural to suppose that they are priced the same. However, we leave it to future research to establish that this is indeed an optimal strategy for the multiproduct monopolist.

goods it controls:

$$D(q) = \begin{cases} 0 & \text{if } q \geq s_o - s_c + AC(n) \\ 1 - \frac{q - AC(n)}{s_o - s_c} & \text{if } AC(n) \frac{s_o}{s_c} \leq q \leq s_o - s_c + AC(n) \\ 1 - \frac{q}{s_o} & \text{if } q \leq AC(n) \frac{s_o}{s_c}. \end{cases}$$

By analogy with Bain (1956)'s taxonomy, we will say that the monopolist is either able to 'blockade' copying, or that he must decide whether to 'deter' copying or 'accommodate' it. Let us now define and compare these three options.

The monopolist blockades or deters copying. By setting a price sufficiently low, the monopolist can eliminate copying. The maximization program is then

$$\max_q nq(1 - (q/s_o)) \text{ s.t. } q \leq AC(n)(s_o/s_c).$$

The unconstrained profit-maximizing price and profits are easily computed as

$$q_b = s_o/2, \pi_b = ns_o/4.$$

This solution meets the constraints if and only if $AC(n) \geq s_c/2$. In this case, we can say that copying is actually *blockaded*: the monopolist safely sets the price of the n goods as if copying was not a threat. Otherwise, copying cannot be blockaded but the producer modifies his behavior to successfully *deter* copying: he chooses the highest price compatible with the constraints, i.e.,

$$q_d = AC(n)(s_o/s_c), \text{ which implies } \pi_d = ns_o AC(n) [s_c - AC(n)] / s_c^2.$$

The monopolist accommodates copying. The other option is to set a higher price and tolerate copying. The monopolist's program becomes

$$\max_q nq \left(1 - \frac{q - AC(n)}{s_o - s_c} \right) \text{ s.t. } AC(n) \frac{s_o}{s_c} \leq q \leq s_o - s_c + AC(n).$$

Here, the unconstrained profit-maximizing price is equal to

$$q_a = \frac{s_o - s_c + AC(n)}{2}.$$

This solution satisfies the constraints if and only if

$$\frac{s_o - s_c + AC(n)}{2} \geq AC(n) \frac{s_o}{s_c} \iff AC(n) \leq \frac{s_c(s_o - s_c)}{2s_o - s_c}.$$

However, assumptions (2) and (3) imply that the latter inequality cannot be met.⁸ The monopolist chooses therefore the corner solution, $q = AC(n)(s_o/s_c)$, which is equivalent to copying deterrence.

⁸From assumption (2), we have $C(n) > C(1) > s_c$, which implies that $AC(n) > s_c/n$. On the other hand, assumption (3) implies that $s_c/n > s_c(s_o - s_c)/(2s_o - s_c)$.

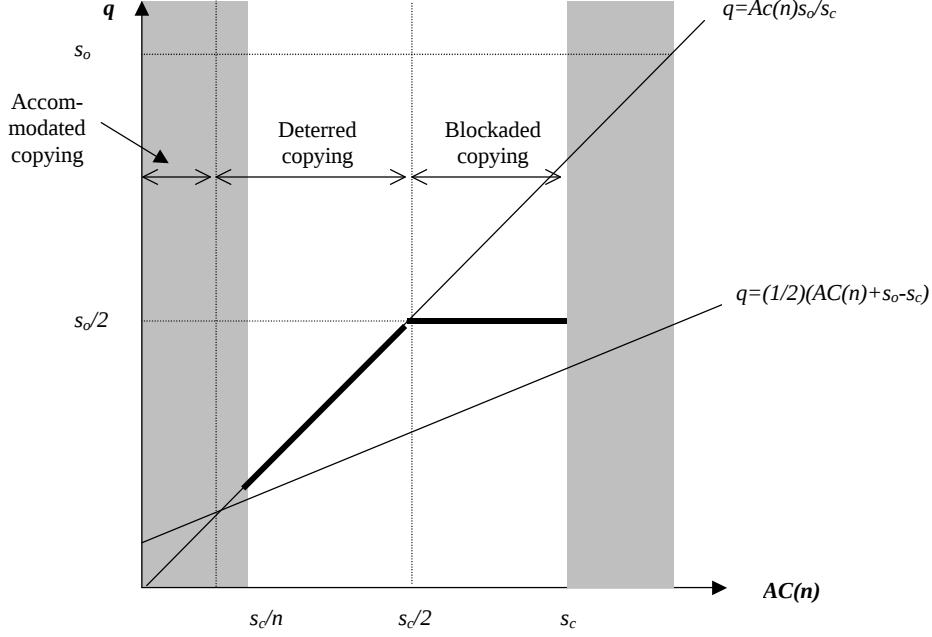


Figure 1: Multiproduct monopolist's optimal price

Blockade, deter or accommodate? Comparing the values of π_b , π_d and π_a , we observe that the multiproduct monopolist's optimal strategy depends on the relative attractiveness of copies (i.e., for a given value of s_o , on the values of $AC(n)$ and s_c), as summarized in Proposition 2 and illustrated in Figure 1. It is important to note that, under the present assumptions, the monopolist never finds it profitable to accommodate copying.⁹

Proposition 2 *The multiproduct monopolist's profit-maximizing common price for the n information goods is*

$$\left| \begin{array}{ll} q_b = \frac{s_o}{2}, & \text{for } \frac{s_c}{2} \leq AC(n) \leq s_c \quad (\text{copying is blockaded}), \\ q_d = AC(n) \frac{s_o}{s_c}, & \text{for } \frac{s_c}{n} \leq AC(n) \leq \frac{s_c}{2} \quad (\text{copying is deterred}). \end{array} \right.$$

4.2 Competing oligopolists

We are now looking for symmetric Bertrand-Nash equilibria (in pure strategies) which mirror the three patterns identified for the multiproduct monopolist. That is, we investigate under which conditions it is an equilibrium for the n

⁹In a companion paper (Belleflamme, 2002), we show that when we assume instead that $ns_c < (n-1)s_o$, the demand schedule for the multiproduct monopolist is left unchanged and there exist parameter values for which copying accommodation is the most profitable option.

independent producers of information goods to set a common price which either blockades, deters or accommodates copying.

4.2.1 Blockaded copying

As before, copying is blockaded if market conditions are such that copying exerts no threat on producers of originals even when each of them behaves as an unconstrained monopolist. Because, when there is no threat of copying, the demands for the n originals are completely independent of one another, each producer chooses p_i so as to maximize $\pi_i = p_i (1 - p_i/s_o)$. That is, each firm charges $p_b = s_o/2$. The next proposition states under which condition this behavior constitutes a Nash equilibrium.

Proposition 3 (Blockaded copying) *Each firm charging $p_b = s_o/2$, is a Bertrand-Nash equilibrium if and only if $AC(n) \geq s_c/2$.*

Proof. See the appendix. ■

A quick comparison with Proposition 2 reveals that *copying is blockaded with the same price and over the same range of parameters, be it by a multiproduct monopolist or by n oligopolists*. This is not surprising insofar as strategic interaction disappears when copying exerts no threat. In particular, copying exerts no threat on producers of information goods *when the average copying cost for n copies ($AC(n)$) is larger than the valuation of a copy for the average consumer ($s_c/2$).*

4.2.2 Deterred copying

To deter copying of its information good, producer i must find the ‘limit price’, $\bar{p}_i$, under which all consumers find the original relatively more attractive than the copy. Under increasing returns to scale in copying, this limit price clearly depends on the prices set for the other originals. Intuitively, copying should be harder to deter (in the sense that producer i will have to decrease its price further down) the higher the price set by the other producers, and conversely. Indeed, if the other producers set a relatively high price, consumers will have more incentive to invest in the copying technology and, because of increasing returns to scale, they will tend to copy good i along with the other goods, unless the price of i is considerably lower.

To formalize the intuition, we first determine producer i ’s limit price supposing that all other firms charge the same arbitrary price p . That is, we characterize the function $\bar{p}_i(p)$. We then look for a fixed point of this function, p_d , and determine under which conditions all firms charging p_d is a Bertrand-Nash equilibrium, in which copying is (collectively) deterred.

Individual limit pricing. Suppose $p_j = p \ \forall j \neq i$. We want to determine the limit price, $\bar{p}_i(p)$, under which no consumer finds it profitable to copy good i . Note that producer i is concerned only by deterring the copying of his own good. Yet, as we will see, his behavior will depend on whether consumers copy or not the other goods.

Referring to Lemma 2, let us define the net utility a user θ achieves from, respectively, buying or copying good i :

$$\begin{aligned} U_B(\theta, p_i, p) &= \theta s_o - p_i + \underbrace{\max\{(n-1)(\theta s_o - p), (n-1)\theta s_c - C(n), 0\}}_{MB} \\ U_C(\theta, p_i, p) &= \underbrace{\max\{\theta s_c - C(1) + (n-1)(\theta s_o - p), (n-1)\theta s_c - C(n)\}}_{MC} \end{aligned}$$

By comparing the exact values of MB and MC , we can express the precise form of the condition $U_B(\theta, p_i, p) \geq U_C(\theta, p_i, p)$ for all configurations of prices and parameters. For instance, if $p \leq [C(n) - C(1)] / (n-1)$, it can be shown that the condition rewrites as follows:

$$\begin{cases} \theta \leq \frac{C(1) - p_i + (n-1)p}{(n-2)s_o + s_c} & \text{for } 0 \leq \theta \leq \frac{p}{s_o} \\ \theta \geq \frac{p_i - C(1)}{s_o - s_c} & \text{for } \frac{p}{s_o} \leq \theta \leq 1. \end{cases}$$

The next step consists in deriving for which values of p_i the condition is always met in the corresponding region of parameters, and to select the lowest bound on p_i where necessary. In the above example, it can be checked that both conditions are always met if their region if $p_i \leq C(1) + p(s_o - s_c)/s_c$. Lemma 4 collects the results of this procedure for all regions of parameters and states producer i 's limit pricing behavior.

Lemma 4 *To deter copying of its good, producer i needs to set its price as follows:*

$$p_i \leq \bar{p}_i(p) = \begin{cases} f_1(p) \equiv C(1) + \frac{s_o - s_c}{s_o} p & \text{if } p \leq \frac{C(n) - C(1)}{n-1} \frac{s_o}{s_c}, \\ f_2(p) \equiv C(n) - \frac{ns_c - s_o}{s_o} p & \text{if } \frac{C(n) - C(1)}{n-1} \frac{s_o}{s_c} \leq p \leq AC(n-1) \frac{s_o}{s_c}, \\ f_3(p) \equiv C(n) - \frac{ns_c - s_o}{s_c} AC(n-1) & \text{if } p \geq AC(n-1) \frac{s_o}{s_c}. \end{cases}$$

Lemma 4 confirms our intuition. When the other goods are relatively expensive, i.e. for $p \geq AC(n-1)(s_o/s_c)$, producer i must price much lower than the other producers ($\bar{p}_i(p) < p$) in order to discourage copying of its good. On the other hand, as the other goods become cheaper, the constraint on i 's price relaxes: for $p \leq AC(n-1)(s_o/s_c)$, $\bar{p}_i(p)$ increases as p decreases and eventually becomes larger than p . Finally, for even lower values of the price of the other goods, $\bar{p}_i(p)$ evolves again in the same direction as p but remains larger than p (see Figure ??).

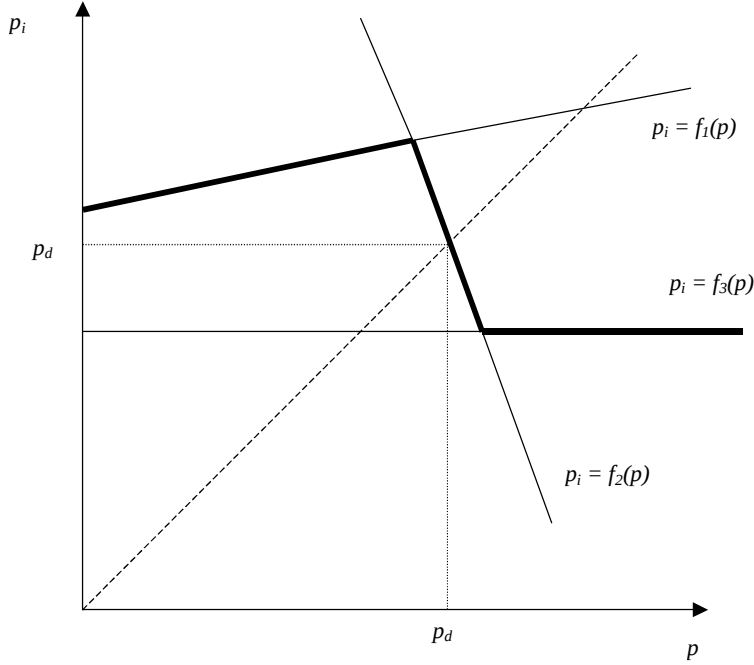


Figure 2: Individual limit pricing

Symmetric limit pricing. The previous findings illustrate how producers of information goods tend to free-ride on each other when it comes to deterring copying.¹⁰ The only situation for which no free-riding is observed is when all producers charge the *symmetric limit price* defined by $\bar{p}_i(p) = p$. Simple computations (confirmed by Figure ??) establish that the fixed point is reached in segment $f_2(p)$ and is given by

$$p = p_d \equiv AC(n)(s_o/s_c).$$

This symmetric limit price appears as a likely candidate for an equilibrium with deterred copying. We observe that a multiproduct monopolist sets exactly the same price when it is optimal for him to deter copying (see Proposition 2). However, we anticipate that, because of free-riding, oligopolists will find it optimal to set this price on a narrower range of parameters than the multiproduct monopolist does. To check this conjecture, we need to derive the conditions for a Bertrand-Nash equilibrium with all producers choosing p_d .

Applying the results of Proposition 1, we observe that the demand for orig-

¹⁰A number of authors have studied entry deterrence with several incumbents and investigate whether entry deterrence is a public good. The results they reach are ambiguous. As Applebaum and Weber (1992) summarize, precommitments by an incumbent impose both direct and indirect externalities on other incumbents. This explains why it is generally impossible to determine whether ‘investment in deterrence’ is too high, or too low relative to the collusive solution.

inal i when all other goods are priced at $p_d = AC(n)(s_o/s_c)$ is given by

$$D(p_i, p_d) = \begin{cases} 0 & \text{if } p_i \geq \hat{p}_i(p_d) \\ 1 + \frac{(ns_c - (n-1)s_o)AC(n)}{ns_c(s_o - s_c)} - \frac{p_i}{n(s_o - s_c)} & \text{if } AC(n)\frac{s_o}{s_c} \leq p_i \leq \hat{p}_i(p_d) \\ 1 - \frac{p_i}{s_o} & \text{if } p_i \leq AC(n)\frac{s_o}{s_c}. \end{cases}$$

We need to establish under which conditions producer i 's best response in this situation is to set $p_i = p_d$. The symmetric limit price is i 's best response provided that the interior solutions over segments 2 and 3 of the demand schedule are not feasible. As for the second segment, the interior solution violates the constraints if and only if

$$\begin{aligned} p_2 &\equiv \frac{n(s_o - s_c)s_c + AC(n)(ns_c - (n-1)s_o)}{2s_c} \leq AC(n)\frac{s_o}{s_c} \\ \iff AC(n) &\geq \frac{n(s_o - s_c)s_c}{(n+1)s_o - ns_c} \equiv AC_d. \end{aligned}$$

As for the third segment, the interior solution violates the constraints if and only if

$$p_3 \equiv \frac{s_o}{2} \geq AC(n)\frac{s_o}{s_c} \iff AC(n) \leq \frac{s_c}{2}.$$

We record our results in the following proposition.

Proposition 4 (Deterred copying) *Each producer charging the symmetric limit price, $p_d = AC(n)(s_o/s_c)$, is a Bertrand-Nash equilibrium if and only if $AC_d \leq AC(n) \leq s_c/2$.*

The intuition behind Proposition 4 goes as follows. Suppose the other firms charge the symmetric limit price and consider the “would-be pirates” (i.e., those users for whom $n\theta s_c > C(n)$). We want to determine how those users maximize their utility when they do not purchase product i . When the quality of copies is relatively high (as we have assumed: $ns_c > (n-1)s_o$), the would-be pirates become actual pirates if they decide not to purchase product i . To deter them to do so, producer i must therefore set a low enough price. How low this price should be depends on the average cost of copying all goods. If this cost is high ($AC(n) > s_c/2$), producer i can free-ride on the other producers' effort and safely set the monopoly price ($s_o/2$). If the average copying cost is low ($AC(n) < AC_d$), the opposite prevails: producer i must set a limit price below p_d . Finally, for intermediary average copying costs, producer i optimally deters copying by charging the same price as the other producers.

A quick comparison of Propositions 2 and 4 reveals that, *unless copies are of a very high quality, strategic interaction narrows the region of parameters where entry deterrence is the optimal conduct*. Recalling that the multiproduct

monopolist sets a price equal to p_d for $s_c/n \leq AC(n) \leq s_c/2$, it is readily verified that

$$\frac{s_c}{n} < AC_d \equiv \frac{ns_c(s_o - s_c)}{(n+1)s_o - ns_c} \iff s_c < \frac{n^2 - n - 1}{n^2 - n} s_o.$$

Viewing the multiproduct monopoly as a cartel formed by the n producers, we can say that collusion makes deterrence of copying easier (i.e., optimal for a wider range of parameters). This is another illustration of the free-riding problem described above.

4.2.3 Accommodated copying

We now look for a symmetric Bertrand-Nash equilibrium in which producers find it optimal to tolerate copying. If all originals are priced the same, users will treat all goods alike. That is, the market will be segmented as follows: low- θ users will not use any good, intermediate- θ users will copy all goods, and high- θ users will purchase all goods. We need now to determine which common price will achieve such market segmentation.

Suppose that $(n-1)$ producers charge a common price p and that producer i chooses some price p_i in the vicinity of p . To derive the demand facing firm i , we need to identify the user who is indifferent between buying or copying all goods. This user is identified by $\tilde{\theta}$ such that $\tilde{\theta}s_o - p_i + (n-1)(\tilde{\theta}s_o - p) = n\tilde{\theta}s_c - C(n)$; that is

$$\tilde{\theta} = \frac{p_i + (n-1)p - C(n)}{n(s_o - s_c)}.$$

Because all users with a larger θ than $\tilde{\theta}$ will buy all goods, the demand facing producer i (as long as p_i is not too different from p) is given by

$$D_i(p_i, p) = 1 - \frac{p_i + (n-1)p - C(n)}{n(s_o - s_c)}.$$

Maximizing $\pi_i(p_i, p) = D_i(p_i, p)p_i$ over p_i yields producer i 's reaction function:

$$R_i(p) = \frac{1}{2} (n(s_o - s_c) - (n-1)p + C(n)).$$

It is instructive to note that reaction functions are downward sloping. This means that, in the present situation, prices are *strategic substitutes* (using the terminology of Bulow *et al.*, 1985). This suggests that, when copying is accommodated, different originals are complements, whereas originals and copies are substitutes.

Our candidate for a symmetric Bertrand-Nash equilibrium with accommodated copying, p_a , must solve $p_a = R_i(p_a)$, which yields

$$p_a = \frac{n}{n+1} [s_o - s_c + AC(n)]. \quad (5)$$

A quick comparison of (5) and the results in Section 4.1 reveals that $p_a > q_a$: accommodation of copying leads the oligopolists to set a higher price than the multiproduct monopolist would set. However, it is easy to check that profits per information good are lower for the oligopolists than for the monopolist. This finding follows directly from the fact that prices are strategic substitutes under copying accommodation.

Naturally, we still need to investigate under which conditions all firms charging p_a is a Bertrand-Nash equilibrium. That is, supposing $p_j = p_a \forall j \neq i$, we want to find the conditions under which producer i 's best response is to set $p_i = p_a$ as well. Using the analysis of the multiproduct monopolist's behavior, we know that when copying accommodation dominates copying deterrence, the accommodation price must be larger than the deterrence price. Therefore, a first condition to have an equilibrium involving copying accommodation is

$$p_a \geq p_d \iff AC(n) \leq \frac{ns_c(s_o - s_c)}{(n+1)s_o - ns_c} = AC_d.$$

This confirms that copying accommodation and deterrence cannot be an equilibrium at the same time. This also tells us that the regimes of demand we need to consider are the second and third regimes of Proposition 1. Let us consider them in turn.

Regime 2 [$AC(n)(s_o/s_c) \leq p_a \leq AC(n-1)(s_o/s_c)$]. We have just shown that the first inequality is equivalent to $AC(n) \leq AC_d$. The second inequality can be rewritten as $(n+1)C(n-1)s_o - (n-1)C(n)s_c \geq n(n-1)s_c(s_o - s_c)$. If we assume that n is large, resulting in $C(n-1) \simeq C(n)$, then the latter condition is equivalent to (though a bit less stringent than)

$$AC(n) \geq \frac{(n-1)s_c(s_o - s_c)}{(n+1)s_o - (n-1)s_c} \equiv AC_a. \quad (6)$$

To examine producer i 's best response, it is worth going back to the derivation of the demand for original i in this particular regime. From Lemma 3, we know that condition (4)—which indicates when a consumer θ is better off purchasing original i —translates as follows.

- For *low* θ 's ($0 \leq \theta \leq AC(n)/s_c$), the condition is $\theta s_o - p_i \geq 0$. The issue is to prefer purchasing original i only to not consuming any information good. Letting θ_1 denote the indifferent user, users with $\theta \geq \theta_1$ purchase original i .
- For *intermediate* θ 's ($AC(n)/s_c \leq \theta \leq p_a/s_o$), the condition is $\theta s_o - p_i \geq n\theta s_c - C(n)$. Here, the issue is to prefer purchasing original i only to copying all goods. Letting θ_2 denote the indifferent user, users with $\theta \leq \theta_2$ purchase original i .

- For *high* θ 's ($p_a/s_o \leq \theta \leq 1$), the condition is $n\theta s_o - p_i - (n-1)p_a \geq n\theta s_c - C(n)$. Now, the issue is to prefer purchasing all goods to copying all goods. Letting θ_3 denote the indifferent user, users with $\theta \geq \theta_3$ purchase original i .

To build the demand schedule $D_i(p_i, p_a)$, we need to check for which prices of original i the above three “virtual” indifferent users do exist or not (that is, for which prices the various θ_k 's lie or not in their respective range). If p_i is ‘*very high*’, none of the indifferent users exist ($\theta_2 < AC(n)/s_c < \theta_1$, $\theta_3 > 1$) and there is no demand for original i (“segment 1”). For ‘*high*’ values of p_i , only θ_3 belongs to its corresponding range and $D_i(p_i, p_a) = 1 - \theta_3$ (“segment 2”). For ‘*intermediate*’ values of p_i , all three indifferent users exist and $D_i(p_i, p_a) = (1 - \theta_3) + (\theta_2 - \theta_1)$ (“segment 3”). It is important to note that in this case, the demand comes from two disjoint intervals of consumers: those who prefer purchasing all goods to copying them are now joined by users who prefer purchasing original i only to copying all or not using any goods. This means that there remain some users (between θ_2 and θ_3) who prefer copying all goods to purchasing original i (only or along with the other goods). The latter category of users disappears for ‘*low*’ values of p_i : only the first indifferent consumer exists ($\theta_1 < AC(n)/s_c$, $\theta_3 < p_a/s_o < \theta_2$) and $D_i(p_i, p_a) = 1 - \theta_1$ (“segment 4”).

If producer i chooses to maximize over the second segment of demand, the optimal price is p_a , which is feasible under the present circumstances. We denote by π_2 the corresponding level of profit. We still need to check whether π_2 is a global maximum. A few lines of tedious but straightforward algebra allow us to establish the following facts.¹¹

- The optimal price over segment 3 is feasible and yields a level of profit we denote by π_3 . We have that $\pi_2 \geq \pi_3 \iff AC(n) \geq AC_3$, with $AC_a < AC_3 < AC_d$.
- The optimal price over segment 4 is not feasible; the highest profit over segment 4 (call it π_4) is reached by setting the corner solution $p_4 = C(n) - \frac{ns_c - s_o}{s_o} p_a$. We have that $\pi_2 \geq \pi_4 \iff AC(n) \leq AC_4$, with $AC_a < AC_4 < AC_d$.
- Because $AC_4 < AC_3$, the two conditions are incompatible.

Therefore, we conclude that *choosing* $p_i = p_a$ *cannot be a best response for producer i under the conditions of the second regime of demand*. Actually, producer i always has an incentive to undercut the other producers, by moving either to segment 3 or to segment 4 of the demand schedule. The first cut allows producer i to reach those users who prefer copying all goods to purchasing them

¹¹The details of the proof are available from the author upon request.

all but not to purchasing original i only. This first cut is not profitable if the average copying cost is too high (i.e., above AC_3). A further cut allows producer i to reach all users, except for those who prefer not using any good to purchasing original i only. This further cut is not profitable if the average copying cost is too low (i.e., below AC_4). Because $AC_3 < AC_4$, one of the two cuts is necessarily profitable for producer i .

Regime 3 [$p_a \geq AC(n-1)(s_o/s_c)$]. Regime 3 applies if condition (5) is reversed, i.e., if $AC(n) \leq AC_a$. On the other hand, assumption (2) puts a lower bound on $AC(n)$: since $C(n) > C(1) > s_c$, we have that $AC(n) > s_c/n$. It is easy to check that the two bounds define an open interval provided that $s_c/s_o < (n^2 - 2n - 1)/(n-1)^2$ (which is compatible with assumption (3) for $n > 3$). Otherwise, Regime 3 of demand cannot apply when $p_j = p_a \forall j \neq i$.

If Regime 3 applies, then it is possible to repeat the previous analysis. Yet, such analysis becomes very tedious as there is one more segment to consider and one more parameter— $C(n-1)$ —to take into account. However, we are able to establish, using numerical simulations, that *a Bertrand-Nash equilibrium in which copying is accommodated might exist*. For instance, setting $n = 20$, $s_o = 1$, $s_c = 0.96$ and supposing $C(19) \simeq C(20)$, we have that $C(20)$ must be lower than 5.28 to be in Regime 3 (we also need, from Assumption 2, that $C(20) > s_c = 0.96$). It can be checked that all firms setting p_a is a Bertrand-Nash equilibrium if $C(20) > 1.16$ but not otherwise.

We summarize the previous findings in the following proposition, which partially characterizes the region of parameters in which copying accommodation is a Nash equilibrium.

Proposition 5 (Accommodated copying) *A Bertrand-Nash equilibrium in which all firms set p_a might exist. A necessary (but not sufficient) condition is $AC(n) \leq AC_a < AC_d$.*

Contrasting the results of Propositions 2 and 5, we observe a major difference between the monopoly and oligopoly cases: *whilst copying accommodation is never favoured by the multiproduct monopolist, it can emerge as the Nash equilibrium of the pricing game among oligopolists*. For such equilibrium to emerge, the average cost of copying n goods must be below some threshold (AC_a), which is itself inferior to the threshold above which copying deterrence is an equilibrium (AC_d). This means that there is a region of parameters for which no symmetric Bertrand-Nash equilibrium in pure strategies seems to exist. Further research is needed to clear this issue up.

5 Conclusion

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. To emphasize the effects of strategic interaction, we contrast the optimal choices of a multiproduct monopolist controlling all n information goods with the Nash equilibria of the pricing game played by n oligopolists (each one controlling one good). Our main results are the following. A multiproduct monopolist will never find it optimal to accommodate copying: if the consumers’ average cost of copying the n goods is sufficiently high, the monopolist will be able to blockade copying; otherwise, he will choose to deter copying by setting some ‘limit price’. In contrast, oligopolists might be ‘forced’ to accommodate copying: when the average copying cost is low enough, it is possible to have a Bertrand-Nash equilibrium in which the producers of information goods tolerate copying. Letting the average copying cost increase, we encounter next situations where neither copying accommodation nor copying deterrence is a Nash equilibrium: accommodation is undermined by incentives to undercut the other producers; deterrence is not sustainable because each producer tends to free-ride on the limit-pricing efforts of the other producers. For copying deterrence to be an equilibrium, the average cost of copying originals must be larger than the threshold obtained in the monopoly case: strategic interaction makes it thus more difficult to eliminate copying through low enough prices.

The directions for future research are threefold. First, and quite obviously, more work needs to be done to complete the characterization of Bertrand-Nash equilibria. We need not only to characterize all symmetric equilibria in pure strategies, but also to envision asymmetric equilibria and mixed strategies. It

is indeed very likely that mixed strategies cannot be dispensed with in this context: because demand functions are discontinuous, payoff functions may fail to be quasi-concave, which may lead to the non-existence of an equilibrium in pure strategies (see Dasgupta and Maskin, 1986). We must also consider the case where copies are of a relatively lower quality (i.e., when $ns_c < (n-1)s_o$).

Second, we would like to address the welfare implications of copying, by endogenizing the number of information goods supplied. In Belleflamme (2002), we perform 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, we are able 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). We would like to extend this analysis to the present setting.

Finally, the third direction for future research consists in exploiting the model to address topical issues. For instance, we could try and assess the effects of enhancing technical protective measures for information goods. A case of interest is the so-called “unrippable” CD: because the technical measure seems to decrease the quality of *both* originals and copies, it is not a priori evident that such strategy is profitable.¹²

6 Appendix

Proof of Proposition 3. (1) Suppose we have a Bertrand-Nash equilibrium with $p_i = s_o/2 \forall i \in N$. This means that producer i ’s best response to all other producers setting $s_o/2$ is to set $s_o/2$ as well. This is so provided that i ’s profit-maximising price is the interior solution to $\max_{p_i} p_i D(p_i, p)$ with $D(p_i, p) = 1 - p_i/s_o$ and $p = s_o/2$. Looking at Proposition 1, we observe that there are three configurations for which $D(p_i, p) = 1 - p_i/s_o$. We examine them in turn.

- (Regime 3/Case 5) $D(p_i, p) = 1 - p_i/s_o$ for $p \geq AC(n-1)(s_o/s_c)$ and $p_i \leq C(n) - \frac{ns_c - s_o}{(n-1)s_c} C(n-1)$. Since $p = s_o/2$, the first condition rewrites as $s_o/2 \geq AC(n-1)(s_o/s_c)$. On the other hand, since we have an interior solution, we must have (according to the second condition) that $s_o/2 \leq C(n) - AC(n-1)\frac{ns_c - s_o}{s_c}$. Joint satisfaction of the two inequalities supposes that $C(n) - AC(n-1)\frac{ns_c - s_o}{s_c} > AC(n-1)(s_o/s_c) \iff AC(n) > AC(n-1)$, which violates our assumptions about copying costs.
- (Regime 2/Case 4) $D(p_i, p) = 1 - p_i/s_o$ for $AC(n)(s_o/s_c) \leq p \leq AC(n-1)(s_o/s_c)$ and $p_i \leq C(n) - \frac{ns_c - s_o}{s_o} p$. With $p = s_o/2$, we find again an

¹²It is claimed that the technical measures that prevent (illegitimate) users from copying the CD also prevent (legitimate) users from playing the CD on the device of their choice, thereby reducing their appeal.

impossibility. On the one hand, $AC(n)(s_o/s_c) \leq p \iff AC(n) \leq s_c/2$. On the other hand, the existence of an interior solution implies that $s_o/2 \leq C(n) - \frac{ns_c - s_o}{2} \iff AC(n) \geq s_c/2$.

- (Regime 1/Case 3) $D(p_i, p) = 1 - p_i/s_o$ for $p \leq AC(n)(s_o/s_c)$ and $p_i \leq \frac{C(n) - (n-1)p}{ns_c - (n-1)s_o} s_o$. In this case, the first condition rewrites as $AC(n) \geq s_c/2$, while the existence of an interior equilibrium implies that $s_o/2 \leq \frac{C(n) - (n-1)p}{ns_c - (n-1)s_o} s_o \iff AC(n) \geq s_c/2$, which is the same condition.

We have thus demonstrated that if we have a Bertrand-Nash equilibrium with $p_i = s_o/2 \forall i \in N$, it must be that $AC(n) \geq s_c/2$.

(2) Let us now prove the reverse statement. Suppose that $AC(n) \geq s_c/2$. This is equivalent to say that $p = s_o/2 \leq AC(n)(s_o/s_c)$. Therefore, demand for original i is given by Regime 1 in Proposition 1. That is,

$$D(p_i, s_o/2) = \begin{cases} 0 & \text{for } p_i \geq \hat{p}_i(s_o/2), \\ 1 - \frac{p_i + (n-1)(s_o/2) - C(n)}{n(s_o - s_c)} & \text{for } \frac{C(n) - (n-1)(s_o/2)}{ns_c - (n-1)s_o} s_o \leq p_i \leq \hat{p}_i(s_o/2), \\ 1 - \frac{p_i}{s_o} & \text{for } p_i \leq \frac{C(n) - (n-1)(s_o/2)}{ns_c - (n-1)s_o} s_o. \end{cases}$$

We already know from the above analysis that the interior solution is feasible if producer i chooses to maximize over the third segment of demand. The corresponding profit is equal to $s_o/4$. We still need to check that no larger profit can be reached when maximizing over the second segment of demand. The unconstrained maximum is easily found as $p_2^* = (1/2)[n(s_o - s_c) - (n-1)(s_o/2) + C(n)]$. Simple computations establish that $AC(n) \geq s_c/2 \Rightarrow p_2^* < \frac{C(n) - (n-1)(s_o/2)}{ns_c - (n-1)s_o} s_o$, meaning that the interior solution is not feasible. Computing the profit at the corner solution, it is readily checked that this profit is always smaller than $s_o/4$, which completes the proof.

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