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PIRACY ACCOMMODATION AND THE OPTIMAL TIMING OF ROYALTY PAYMENTS

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ABSTRACT. This paper generalizes the two-period model of Watt (2000) who demonstrates the possibility of optimal accommodation of a pirate when the royalty rate applying to a creation is uniform and second-period Cournot competition applies. Admitting nonlinear contracts with period-specific royalty rates that leave total payments unchanged, simulation analysis shows that a producer of originals does better to increase the royalty rate in period 1 and decrease the rate to a negative level in period 2, thereby more than offsetting the usual cost advantage available to a pirate. Watt's illustrative examples regarding piracy accommodation (but not piracy exclusion) are overturned when a nonlinear contract is chosen optimally, although accommodation remains optimal in some other cases. Further, where exclusion is impossible under uniform royalties, cases exist where exclusion is feasible under nonlinear royalties. Even so, accommodation may be a preferable strategy.

1. INTRODUCTION

The notion of indirect appropriability as advanced and applied by Liebowitz (1981, 1985) emphasizes that the ability to copy enhances the willingness to pay for originals since the demand for originals reflects copiers' demand for an input in addition to consumers' demand for an output (for which copies are a substitute). This important insight has been widely developed in the theoretical literature and frequently used to provide insight into the circumstances under which copying may prove beneficial to the producer of originals, limiting the relevance of legislative copyright protection and possibly even harming copyright owners if such protection were enforced. In his contribution to a recent symposium, however, Liebowitz (2005) considers that this literature has perhaps oversold the applicability of the concept, and bemoans the general lack of empirical studies necessary to give credence to the robustness of indirect appropriability. Thus, although Liebowitz (1985) established positive effects of pirating on the profitability of producers of originals in the case of photocopying academic journals, he is clearly unconvinced of the generality of such a result in other contexts, particular in cases involving digital technologies such as file-sharing.[1]

While Liebowitz's point is well taken, the present article makes little contribution to the empirical debate regarding indirect appropriability. Instead, it generalizes

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I would like to thank Amy Johnson for programming assistance and the editor for some suggestions relating to the topic of this article. Any errors are mine.

[1]For theoretical arguments suggesting the widespread importance of indirect appropriability in the context of competitive markets that could make copyright law largely otiose, see, in particular, Boldrin and Levine (2002, 2004, 2005), and for more skeptical views, Klein, Lerner and Murphy (2004), Liebowitz (2002, 2003, 2005), and Johnson and Waldman (2005).

the theoretical model of Watt (2000) in order to test for the robustness of indirect appropriability to the choice of the structure of royalty payments made by a producer of originals to a creator. The essential elements of Watt's model are as follows. There exists a sole producer of an original delivery good (hereafter "producer") possessing monopoly power in an initial period and facing the threat of entry by a sole pirate (which makes no royalty payments) in a subsequent period. Originals and copies are assumed to be perfect substitutes, with a continuum of consumers each demanding one unit of the good and satisfying first period linear inverse demand $p_1 = 1 - bx$, where $0 \leq p_1 \leq 1$.[2] In the second period, consumers (whose time preference is zero) discount their willingness to pay by a positive fraction k, reflecting the reduced durability of a product for which consumption is delayed until period 2. Period 2 inverse demand is defined by $p_2 = k(1 - bx)$, where $0 \leq p_2 \leq k$, and if period 1 sales are positive, the relevant period 2 demand is residual demand. The pirate must purchase a unit of the delivery good in period 1 for use as a template for copying, and can only sell copies to consumers in period 2. If the pirate enters, Cournot competition occurs in period 2, while if the pirate elects not to enter, the producer maintains the monopoly over both periods. Other than the fixed cost of the pirate's purchasing of a unit to serve as the copying template, all other fixed costs are assumed to be zero and both firms face the same constant marginal production cost c. No copyright protection is assumed to be available. Nevertheless, Watt establishes the possibility that indirect appropriability may be sufficiently important for the producer of originals to welcome so-called unauthorized copying by a pirate, and provides some simulation results illustrating this outcome.

In Watt's analysis, the producer pays a royalty to a creator that is proportional to sales volume, the royalty rate λ being independent of the period in which sales are made. An important implication is that while the producer's two-part marginal cost is $c + \lambda$, the pirate's marginal cost is only c, since the pirate avoids royalty payments. If the pirate enters in period 2, the producer faces a cost disadvantage, and, whatever the size of the market in this period, the producer's Cournot equilibrium output share is smaller than that of the pirate while the producer's profit share in period 2 is smaller still. In the present article, Watt's model is generalized so that a time-invariant value of the royalty rate λ is a special case. More generally, we have $\lambda_1 \neq \lambda_2$, and compare these circumstances to Watt's benchmarks where $\lambda_1 = \lambda_2 = \lambda$.

While Watt's model emphasizes the importance of strategic first-period price-setting by the producer, decoupling the royalty rate across time adds an additional strategic dimension to the producer's decisions. For example, it permits consideration of the "level playing field" case where the producer and the pirate potentially compete with identical marginal costs in the second period, so that whatever is the size of this market, output and profit shares will be equal if the pirate enters. To make comparisons meaningful, however, λ_1 and λ_2 are set so as to generate the

[2] The assumption that originals and copies are perfect substitutes is one of the few nudges in the direction of favouring the relevance of indirect appropriability in Watt's model. For example, Besen and Kirby (1989) show that imperfect of substitution along with unlimited copying potential does not permit indirect appropriation in their model since competition among purchasers of originals drives their price down to marginal cost. Similar results are shown by Johnson and Waldman (2005) even when only limited copying is possible. Lower quality copies constrain the prices of originals and low consumer valuation of imperfect copies can in turn prevent profitable indirect appropriation; see Takeyama (1997), Belleflame (2003), and Johnson and Waldman (2005).

same royalty income as would a given time-invariant λ, thus leaving the creator indifferent to the producer's choice of royalty structure. An implication is that if royalties are paid only in period 1, the producer must face a correspondingly higher royalty rate in period 1 in order to compensate the creator for the loss of royalty income in period 2. In turn, this raises marginal cost in period 1, reducing sales in this period and shifting some demand into period 2 where the producer can now compete on more favourable terms. There is no guarantee, however, that a feasible iso-royalty income value of λ_1 exists in these circumstances, or, more generally, where $\lambda_2 \neq 0$. Where feasible iso-royalty income values of λ_1 and λ_2 exist, however, the interesting possibility arises that it may pay the producer to raise the period 1 royalty rate and lower the period 2 royalty rate sufficiently for λ_2 to become negative, in which case the creator agrees to subsidize production in the second period in order for the producer to overturn the pirate's usual cost advantage.

Finally, the analysis permits testing of the robustness of Watt's important result that for a range of parameter values, the producer may be able to design a period 1 pricing strategy that would exclude a pirate from entry, but such a strategy need not be optimal and that it is in the producer's interest to accommodate entry by the pirate. In these circumstances, if the pirate were excluded as a result of the introduction of copyright law, the producer of originals would lose profits by the pirate's enforced removal. Here, economic theory is seen by Watt as a foe rather than a friend of copyright law, although producers might elect not to enforce their rights against infringers depending on how damages are awarded by the courts. And while the optimality of piracy accommodation may not be applicable for much of the relevant parameter space, the result is significant given the assumption that network externalities are absent, and the producer has neither the means of selling to groups of consumers nor of determining the identity of the pirate when first-period sales are made, ruling out the practice of price discrimination.[3]

2. A Generalized Model of Copyright Piracy

This section sets out the model of the paper. It spells out the working needed for the simulations that follow. However, little is lost for non-technical readers by skipping this section entirely and going directly to the numerical simulations in the next section.

2.1. **The theoretical model.** The analytical development follows closely the procedure outlined in Watt (2000, Chapter 2.4). To set the stage, consider first single period behaviour of a monopoly producer facing inverse linear demand $p = \alpha - \beta x$

[3]Besen and Kirby (1989) and Bakos, Brynjolfsson, and Lichtman (1999) demonstrate related, but different, conditions under which sharing in teams of consumers permits the possibility that copying can help profitability; see Johnson and Waldman (2005) for further discussion. In Liebowitz (1985), producer gains from indirect appropriability are significant because libraries, representing consumer groups, have higher willingness to pay than individual subscribers to journals and can be identified as such, so that a necessary condition for price discrimination is present. Further, in his contribution to a recent symposium on indirect appropriability, Watt (2005) also emphasizes the importance of price discrimination in supporting the relevance of indirect appropriation. Novos and Waldman (1984), however, emphasize the difficulties in identifying pirates, while Johnson (1985) assumes that indirect appropriability is impossible so that producers are always harmed by piracy. In this context, Watt's results are important in that indirect appropriability can be profitable even when price discrimination is impossible.

and marginal cost δ. At any price p sales will be

$$x(p) = \frac{\alpha - p}{\beta} \tag{1}$$

Profits are

$$\pi(p) = \left(\frac{\alpha - p}{\beta}\right)(p - \delta) \tag{2}$$

The first order condition to maximize profits with respect to the choice of the price is

$$\pi'(p) = \left(\frac{\alpha - p}{\beta}\right) - \left(\frac{p - \delta}{\beta}\right) = \frac{1}{\beta}(\alpha - 2p + \delta) = 0 \tag{3}$$

whence

$$p^* = \frac{\alpha + \delta}{2} \tag{4}$$

The second-order condition is satisfied since $\pi''(p) = -\frac{2}{\beta} < 0$.

Substitution from (4) into (2) yields the equilibrium value of profits as

$$\pi(p^*) = \frac{(\alpha - \delta)^2}{4\beta} \tag{5}$$

Now consider the monopolist producer who supplies originals over two periods in the absence of threat of entry by the pirate. If the monopolist sells a positive amount in period 1, consumers buying in period 1 will not participate in period 2 so the second-period residual inverse demand curve is

$$p_2 = k(1 - bx_1 - bx) = k(p_1 - bx) \tag{6}$$

In Watt, the royalty rate λ is time-invariant, but here we distinguish the royalty rates λ_1 and λ_2 by periods. Optimal second-period profits can then be expressed in terms of the period 1 price as follows. Substituting

$$\alpha = kp_1 \qquad \beta = kb \qquad \delta = c + \lambda \ \ \text{(distinguishing } \lambda \text{ by period)}$$

into (5) yields:

$$\pi_2(p_1) = \frac{(kp_1 - c - \lambda_2)^2}{4kb} \tag{7}$$

Total profits for the two periods are:

$$\pi(p_1) = \pi_1 + \pi_2 = \left(\frac{1 - p_1}{b}\right)(p_1 - c - \lambda_1) + \frac{(kp_1 - c - \lambda_2)^2}{4kb} \tag{8}$$

The first-order condition to maximize profits over both periods with respect to the choice of the period 1 price is

$$\pi'(p_1) = \frac{2(1 + \lambda_1) - \lambda_2 + c - (4 - k)p_1}{2b} = 0$$

whence

$$p_1^* = \frac{2(1 + \lambda_1) - \lambda_2 + c}{4 - k} \tag{9}$$

The second-order condition is satisfied since $\pi''(p_1) = -\frac{4-k}{2b} < 0$.

To find the optimal price for period 2, substitute $\alpha = kp_1^*$ and $\delta = c + \lambda_1$ into (4), while optimal period 2 profits are obtained by substituting from (9) for p_1^* in (7).

Now let there be a threat of entry by the pirate, who may purchase one unit of the original in period 1 and compete under Cournot quantity competition in period 2. Again, consider the equilibrium under fairly general generic conditions, and consider the special cases *seriatim*. Begin with period 2 assuming that both producers are in the market. The profits of producer i are

$$\pi^i(x^i) = x^i(\alpha - \beta x^i - \beta x^j - \delta^i) \tag{10}$$

For producer i, the first-order condition to maximize profits with respect to own-quantity, given the quantity of the rival x^j, is

$$\frac{\partial \pi^i(x^i)}{\partial x^i} = \left(\alpha - \beta x^j - \delta^i\right) - 2\beta x^i = 0$$

whence

$$x^{i*} = \frac{\alpha - \beta x^j - \delta^i}{2\beta} \tag{11}$$

Similarly, the optimal strategy for producer j is

$$x^{j*} = \frac{\alpha - \beta x^i - \delta^j}{2\beta} \tag{12}$$

The solution to the pair of simultaneous linear equations (11) and (12) is

$$x^{i*} = \frac{\alpha + \delta^j - 2\delta^i}{3\beta} \tag{13}$$

$$x^{j*} = \frac{\alpha + \delta^i - 2\delta^j}{3\beta} \tag{14}$$

Total output in equilibrium is

$$x^* = x^{i*} + x^{j*} = \frac{2\alpha - \delta^i - \delta^j}{3\beta} \tag{15}$$

The equilibrium profits of producers i and j are, respectively,

$$\pi^i(x^{i*}) = x^{i*}(\alpha - \beta x^* - \delta^i) = \frac{1}{9\beta}\left(\alpha + \delta^j - 2\delta^i\right)^2 \tag{16}$$

$$\pi^j(x^{j*}) = x^{j*}(\alpha - \beta x^* - \delta^j) = \frac{1}{9\beta}\left(\alpha + \delta^i - 2\delta^j\right)^2 \tag{17}$$

Since piracy (and Cournot competition) occurs only in the second period, the relevant substitutions (assuming i produces originals and j produces pirated copies) are

$$\alpha = kp_1 \qquad \beta = kb \qquad \delta^i = c + \lambda_2 \qquad \delta^j = c$$

Assuming entry by the pirate, the second period equilibrium output strategies become

$$x_2^{o*} = \frac{kp_1 - c - 2\lambda_2}{3kb} \tag{18}$$

$$x_2^{p*} = \frac{kp_1 - c + \lambda_2}{3kb} \tag{19}$$

The second-period profits of each producer are given by

$$\pi_2^o(x_2^{o*}) = \frac{1}{9kb}\left(kp_1 - c - 2\lambda_2\right)^2 \tag{20}$$

$$\pi^j(x^{j*}) = \frac{1}{9kb}\left(kp_1 - c + \lambda_2\right)^2 \tag{21}$$

The optimal first period pricing strategy of the producer of originals when facing a pirate in the second period can now be obtained. In period 1, the producer of originals will sell to consumers according to their period 1 demand function, sell one unit to the pirate, and will receive period 1 profits of

$$\widehat{\pi}_1^o(\widehat{p}_1) = \left(\frac{1-\widehat{p}_1+b}{b}\right)(\widehat{p}_1 - c - \lambda_1) \tag{22}$$

which, together with (20) gives total profits of

$$\widehat{\pi}^o = \left(\frac{1-\widehat{p}_1+b}{b}\right)(\widehat{p}_1 - c - \lambda_1) + \frac{1}{9kb}\left(kp_1 - c - 2\lambda_2\right)^2 \tag{23}$$

The first-order condition to maximize profits over both periods with respect to the choice of the period 1 price is

$$\widehat{\pi}^{o\prime}(\widehat{p}_1) = \left(\frac{1}{9kb}\right)(9 + 9b + 7c + 9\lambda_1 - 4\lambda_2 - (18-2k)\widehat{p}_1) = 0 \tag{24}$$

Solving (24) for $\widehat{p}_1$ yields the optimal first period pricing strategy for the producer of originals facing entry by a pirate in period 2:

$$\widehat{p}_1^*(\lambda) = \frac{9 + 9b + 7c + 9\lambda_1 - 4\lambda_2}{18-2k} \tag{25}$$

Turning to the optimal strategy for the pirate, note that the pirate's total profits must be non-negative to induce entry. First-period profits are negative, equal to the negative of the price of the original that must be acquired in order to manufacture copies. Second-period profits must therefore be positive, and at least as great as the first period price. Using p to denote a general first period price, the condition (using (21), and assuming that if profits are zero the pirate will not enter) is that

$$p < \left(\frac{1}{9kb}\right)(kp - c + \lambda_2)^2 \tag{26}$$

or that

$$f(p) \equiv k^2p^2 + k\left(2\lambda_2 - 2c - 9b\right)p + \left(\lambda_2 - c\right)^2 > 0 \tag{27}$$

The second derivative of (27) is $2k^2 > 0$ so that $f(p)$ is a convex function. Denoting the expression $(2\lambda_2 - 2c - 9b)$ by ω, the roots of (27) are given by

$$(r_1, r_2) = \frac{-k\omega \pm \sqrt{(k\omega)^2 - 4k^2\left(\lambda_2 - c\right)^2}}{2k^2} \tag{28}$$

Assuming the existence of a pair of real roots in (28), the implication is that the pirate will enter if the first period price is at least as great as r_2 or is below r_1. A similar result is obtained by Watt, who reasons that if the first-period price is price is low, the original is inexpensive to acquire and consequently causes few inroads into a pirate's first period profits. But since the original is inexpensive in period 1, many consumers will join the pirate in its purchase, reducing the demand for the pirate's product when the pirate enters in period 2. On the other hand, if the price is high, while the pirate's first period profits will be negative and large in absolute magnitude, a high first period price for the original also chases away many consumers who will emerge when the pirate's product is marketed in period 2. The latter effect is clearly favourable to high period 2 profits for the pirate. Where real roots of (27) do not exist, however, $f(p) > 0$ for all p and the producer has no discretion over the choice of first-period price that might, but need not, exclude the pirate; the pirate always enters in these circumstances.

Turning now to the iso-royalty income constraint, where $\lambda_1 = \lambda_2 = \lambda$, and denoting the expression $\frac{9+9b+7c+5\lambda}{18-2k}$ by μ, the producer's royalty payments over the two periods are

$$R(\lambda) = \lambda\left(\frac{1-\mu+b}{b} + \frac{k\mu - c - 2\lambda}{3kb}\right) \tag{29}$$

Where $\lambda_1 \neq \lambda_2$, denoting the expression $\frac{9+9b+7c+9\lambda_1-4\lambda_2}{18-2k}$ by ν, the producer's corresponding royalty payments over the two periods are

$$R(\lambda_1,\lambda_2) = \lambda_1\left(\frac{1-\nu+b}{b}\right) + \lambda_2\left(\frac{k\nu - c - 2\lambda_2}{3kb}\right) \tag{30}$$

The iso-royalty income constraint is satisfied by equating (29) and (30). Denoting the expression $\frac{1}{18-2k}$ by θ and the expression $(9+9b+7c)\theta$ by ψ, after some manipulation the iso-royalty income constraint can be shown to satisfy the following condition:

$$\begin{aligned}&3k\left[(1+b)(\lambda-\lambda_1) - \psi\left(\tfrac{2}{3}\lambda - \lambda_1 + \tfrac{1}{3}\lambda_2\right) + \theta\left(9\lambda_1^2 - \tfrac{10}{3}\lambda^2 - 7\lambda_1\lambda_2 + \tfrac{4}{3}\lambda_2^2\right)\right]\\ &-(\lambda-\lambda_2)c - 2\left(\lambda^2-\lambda_2^2\right) = 0\end{aligned} \tag{31}$$

Clearly, (31) is an implicit function in λ, λ_1, and λ_2. Taking λ as given, and taking λ_2 (or, alternatively, λ_1) as given, (31) may be solved explicitly for the corresponding values of λ_1 (or, alternatively, λ_2) satisfying the iso-royalty income constraint. For example, taking λ and λ_2 as given, the solution for λ_1 is given by the roots of the following quadratic:

$$g(\lambda_1;\lambda,\lambda_2) = a(g)\lambda_1^2 + b(g)\lambda_1 + c(g) = 0 \tag{32}$$

where

$$\begin{aligned}a(g) &= 27k\theta,\quad b(g) = 3k(\psi - 1 - b - 7\theta\lambda_2),\ \text{and}\\ c(g) &= 3k\left[(1+b)\lambda - \psi\left(\tfrac{2}{3}\lambda + \tfrac{1}{3}\lambda_2\right) + \theta\left(\tfrac{4}{3}\lambda_2^2 - \tfrac{10}{3}\lambda^2\right)\right]\\ &\quad -(\lambda-\lambda_2)c - 2\left(\lambda^2-\lambda_2^2\right)\end{aligned}$$

Real roots in (32) may not exist, in which case it is not possible to find values of λ_1 that satisfy the iso-royalty income constraint for the selected values of λ and λ_2.

2.2. **Simulation Methods.** In this subsection, the simulation methods are presented and discussed. The model was programmed in STATA 9, which was also used to carry out the simulation exercises. The programme first sets benchmark values for the parameter set $\{c, k, b, \lambda\}$ and given λ and λ_2, tests whether there exists any λ_1 satisfying the iso-royalty income constraint, i.e., checks the existence of real roots to (32). Where a pair of distinct real roots exist, the root yielding the higher profits for the producer is subsequently chosen for further analysis once the following steps are carried out for each root. First, conditions for pirate entry are found by finding the roots of $f(p) = 0$ from (27), and, given the existence of real roots, the solutions for p_1^* and corresponding monopoly profits in each period are found. The programme then examines the case of duopoly with pirate entry in period 2, and calculates the values of the endogenous variables of the system as functions of both roots. Then, the root (r_1 or r_2) that maximizes profits under the monopoly regime is identified and denoted by r (with corresponding total profits

$\pi(r)$), along with the root that maximizes profits under the duopoly regime which is denoted by $\widehat{r}$ (with corresponding total profits $\widehat{\pi}^o(\widehat{r})$). The following four cases are then considered, with the following checks carried out.

(1) If $r_1 < p_1^* < r_2$ and either $r_1 > \widehat{p}_1^*$ or $r_2 < \widehat{p}_1^*$. If so, $p^*(1)$ is given by the monopoly price, p_1^*, if $\pi(p_1^*) > \widehat{\pi}^o(\widehat{p}_1^*)$ or by $\widehat{p}_1^*$ if $\pi(p_1^*) < \widehat{\pi}^o(\widehat{p}_1^*)$.
(2) If $r_1 < p_1^* < r_2$ and $r_1 < \widehat{p}_1^* < r_2$. If so, $p^*(2)$ is given by the monopoly price, p_1^*, if $\pi(p_1^*) > \widehat{\pi}^o(\widehat{r})$ or by $\widehat{r}$ if $\pi(p_1^*) < \widehat{\pi}^o(\widehat{r})$.
(3) If either $r_1 > p_1^*$ or if $p_1^* > r_2$ and if either $r_1 > \widehat{p}_1^*$ or if $\widehat{p}_1^* > r_2$. If so, $p^*(3)$ is defined as r if $\pi(r) > \widehat{\pi}^o(\widehat{p}_1^*)$ or by $\widehat{p}_1^*$ if $\pi(r) < \widehat{\pi}^o(\widehat{p}_1^*)$.
(4) If either $r_1 > p_1^*$ or if $p_1^* > r_2$ and if $r_1 < \widehat{p}_1^* < r_2$. If so, $p^*(4)$ is given by r if $\pi(r) > \widehat{\pi}^o(\widehat{r})$ or by $\widehat{r}$ if $\pi(r) < \widehat{\pi}^o(\widehat{r})$.

The programme then checks that non-uniform royalty rate pricing restrictions are satisfied,[4] and, if so, generates the maximum of the exclusion profit and the accommodation profit for the producer, and displays the optimal pricing and exclusion/accommodation strategies consistent with this profit maximum.

In the simulation exercises, initial values of λ_2 are typically set equal to the value of λ chosen for the particular experiment, forcing equality between λ_1 and λ_2 and thus reproducing the results obtainable under Watt's assumption of a royalty rate proportional to total sales over the two periods. Holding λ constant and varying λ_2, and where the iso-royalty income constraint is satisfied, the more profitable value of λ_1 is calculated. Newton-Raphson search permits a mapping from feasible values of the royalty rates for each period into aggregate producer profits $\pi(\lambda_1, \lambda_2)\,\big|_{\lambda,\ R(\lambda)=R(\lambda_1,\lambda_2)}$ over the two periods.[5] In all experiments considered, a unique global maximum was identified.

3. Simulation Results

In order to facilitate the comprehension of the following discussion, it is worthwhile to remind the reader of the notation that is used. It is the following:

(1) λ_1; royalty percentage of sales in the first period.
(2) λ_2; royalty percentage of sales in the second period.
(3) r_1; minimum first period price that deters entry of pirate.
(4) r_2; maximum first period price that deters entry of pirate.
(5) p_1^*; optimal first period price assuming no threat of piracy exists.
(6) $\widehat{p}_1^*$; optimal first period price assuming a pirate has entered.
(7) $\pi(p_1^*)$; profits of seller of originals assuming no threat of piracy exists.
(8) p_m^*; optimal price that excludes pirate (will be either p_1^* or r_2, which ever is smaller).[6]

[4] These restrictions, which correspond to those of the case of a uniform royalty rate as derived by Watt (2000, p. 51), are as follows. For the case where the monopoly is maintained, $p_1^* \geq 0 \Rightarrow 2(1+\lambda_1) - \lambda_2 + c \geq 0$; $p_1^* \leq 1 \Rightarrow 2\lambda_1 - \lambda_2 + k + c \leq 0$. For the case where the pirate enters and Cournot competition occurs in period 2, $\widehat{p}_1^* \geq 0 \Rightarrow \lambda_1 - (4/9)\lambda_2 + 1 + b + (7/9)c \geq 0$; $\widehat{p}_1^* \leq 1 \Rightarrow \lambda_1 - 1 + (2/9)k + b + (7/9)c - (4/9)\lambda_2 \leq 0$; $\widehat{p}_2^* \geq 0 \Rightarrow \widehat{p}_1^* \geq \frac{b(k\widehat{p}_1^* - c - 2\lambda_2)}{3kb}$; $\widehat{p}_2^* \leq k\widehat{p}_1^* \Rightarrow \frac{k[2(1+\lambda_1)-\lambda_2+c]}{4-k} \geq 0$.

[5] Discontinuities in this profit function occur if and when the optimal strategy switches between accommodation and exclusion.

[6] Actually, theoretically, p_m^* could also work out to be r_1. However, for all of the simulations in the present paper, in no case is r_1 relevant for pricing purposes.

(9) $\pi(p_m^*)$; maximum profits of seller of originals assuming that it has excluded the pirate.
(10) $\widehat{p}_c^*$; optimal price that accommodates the pirate (will be either $\widehat{p}_1^*$ or r_2, which ever is greater).[7]
(11) $\widehat{\pi}^o(\widehat{p}_c^*)$; maximum profits of seller of originals assuming that pirate is accommodated.
(12) p^*; optimal first period price (will be either p_m^*, or $\widehat{p}_c^*$, which ever gives greater profits).
(13) p_2; second period price.
(14) $\frac{\widehat{\pi}_2}{\widehat{\pi}}$; ratio of second period total industry profits to total industry profits over both periods.
(15) $\frac{\widehat{\pi}_2^o}{\widehat{\pi}_2}$; ratio of second period profits of seller of originals to total industry profits in second period.
(16) $\frac{\widehat{\pi}_1^o}{\widehat{\pi}^o(\widehat{p}_c^*)}$; ratio of first period profits of seller of originals to total profits over both periods of seller of originals.

The first results to be discussed, shown in Table 1, compare some combinations of λ_1 and λ_2 satisfying the iso-royalty income constraint for values of $\lambda = 0.05,\ c = 0.1,\ k = 0.5$, and $b = 0.02$. These parameter values correspond to Watt's scenario 1 in his Table 2.1, p. 52.

Table 1: Simulation 1 [$c = 0.1,\ k = 0.5,\ b = 0.02$]

Scenario	1	1.1	1.2	1.3	1*
λ_1 λ_2	0.05 0.05	0.0505 0.04	0.0517 0.03	0.0601 0.0	0.0804 -0.0352
r_1	0.0185	0.0250	0.0323	0.0897	0.0902
r_2	0.5415	0.5750	0.6077	0.8090	0.8106
p_1^*	0.6143	0.6174	0.6210	0.6556	0.6560
$\widehat{p}_1^*$	0.5959	0.5985	0.6015	0.6317	0.6320
$\pi(p_1^*)$	9.5714	9.6431	9.7069	9.8491	9.9123
p_m^*	r_2	r_2	r_2	p_1^*	p_1^*
$\pi(p_m^*)$	9.3399	9.5641	9.6992	9.8491	9.9123
$\widehat{p}_c^*$	$\widehat{p}_1^*$	$\widehat{p}_1^*$	r_2	r_2	r_2
$\widehat{\pi}^o(\widehat{p}_c^*)$	9.5619	9.5994	9.6294	9.3064	8.1663
optimal strategy	$p^* = \widehat{p}_1^*$ accommodate	$p^* = \widehat{p}_1^*$ accommodate	$p^* = r_2$ exclude	$p^* = p_1^*$ exclude	$p^* = p_1^*$ exclude
p_2	0.1827	0.1798	0.2169	0.2086	0.1964
$\frac{\widehat{\pi}_2}{\widehat{\pi}}$	0.0770	0.0776	0.0818	0.1405	0.2649
$\frac{\widehat{\pi}_2^o}{\widehat{\pi}_2}$	0.1350	0.1990	0.2745	0.5000	0.6593
$\frac{\widehat{\pi}_1^o}{\widehat{\pi}^o(\widehat{p}_c^*)}$	0.9889	0.9835	0.9761	0.9244	0.8079

Scenario 1 in Table 1 replicates Watt's results, showing that with a uniform royalty rate of 5 percent along with the other specified parameter values, the optimal policy for the producer of originals is to set a first-period price at a level that induces

[7] Again, theoretically, $\widehat{p}_c^*$ could also work out to be r_1, but for all of the simulations in the present paper, in no case is r_1 relevant for pricing purposes.

entry by the pirate and, by implication, reject setting a *lower* first-period monopoly price for which the pirate would elect not to purchase the delivery good from the producer and so would not enter the market in period 2. The relatively high price of the good encourages entry by leaving a sufficient level of residual demand to make entry profitable for the pirate.[8] Accommodation of the pirate is more profitable than exclusion at the relatively low monopoly price because the small size of the second-period market (particularly when shared with the producer) makes entry unprofitable even though the cost of purchasing the delivery good is smaller under feasible monopoly pricing. This significant result illustrates indirect appropriability in action even when it is impossible to determine the pirate's identity *a priori*.

In addition to replicating Watt's solution values for prices and profits for this simulation, Table 1 further explores the characteristics of this particular accommodation equilibrium by investigating equilibrium profit shares in the final three rows. The first of these, $\frac{\widehat{\pi}_2}{\widehat{\pi}}$, shows the share of period 2 industry profits in industry profits over both periods as a small 7.70 percent. The second, $\frac{\widehat{\pi}_2^o}{\widehat{\pi}}$, shows the producer's share of period 2 industry profits as a relatively small 13.50 percent, reflecting the producer's marginal cost disadvantage ($c + \lambda = 0.15$ versus $c = 0.10$ for the pirate) when the producer and the pirate compete in period 2. This illustrates the well-known result that even small differences in marginal cost lead to relatively large differences in output and profits among Cournot competitors. The final row, $\frac{\widehat{\pi}_1^o}{\widehat{\pi}^o(\widehat{p}_c^*)}$, shows that the share of the producer's first-period profits in its profits over both periods is nearly 99 percent. Evidently, this accommodation equilibrium involves setting a sufficiently high price in period 1 that leaves a sufficiently large market in period 2 to induce entry by the pirate, which receives the vast majority of profits earned in period 2. Nevertheless, the pirate's profits are only 6.67 percent of industry profits over the two periods, so that the producer of originals captures the vast bulk of its total gains in period 1. And by charging the (lower) best monopoly price and excluding the pirate, the producer would face a miniscule second-period market under this parameter set.

A question arises, however, as to the robustness of this result when the producer may be able to take strategic advantage of a more flexible royalty structure than is assumed by Watt. Scenario 1.1 in Table 1 illustrates the outcome when there is a 0.0005 (1 percent) increase in the royalty rate applying to period 1 sales along with a compensating reduction of 0.01 (20 percent) in the royalty rate applying to period 2 sales in order to maintain constant the creator's royalty income. This minor change in the royalty structure leaves unchanged the decision to accommodate the pirate, and involves a small increase in the optimal period 1 price, expanding the market in period 2. *Ceteris paribus*, this is desirable for the producer since its marginal cost falls in period 2 and it increases its shares of output and profits in this period. The producer's share of period 2 profits increases from 13.50 percent to 19.90 percent, although the reduction in the optimal second-period price helps to explain the very small increase in the share of period 2 industry profits in total profits for both firms over the two periods. The change in royalty structure, however, is profitable for the producer, whose profits over both periods increase by 3.75 percent.

[8] Note that in both Watt's simulation results and in the present article, optimal second-period prices lie below first-period prices, consistent with many optimal price trajectories found in the more general framework of Nascimento and Vanhonacker (1988).

Scenario 1.2 in Table 1 considers a further reduction in the period 2 royalty rate (to 3 percent) along with a compensating increase in λ_1 to 5.17 percent. Again, this relatively minor further change is profitable for the producer. For example, the producer would gain additional profits of 0.07 (0.7 percent) over the outcome in scenario 1.1 if the pirate continues to be accommodated. The producer, however, does better still by setting an optimal monopoly price in period 2 and excluding the pirate.[9] The optimal monopoly price is equal to the root $r_2 = 0.6077$, and which exceeds the corresponding optimal accommodation price $\widehat{p}_1^* = 0.6015$ in this instance, illustrating the point that the optimal monopoly first-period price may, but need not, be less than the corresponding optimal accommodation price.

Scenario 1.3 in Table 1 illustrates the special case whereby the producer of originals designs a royalty structure such that if the pirate entered, the two firms would compete on a level playing field regarding production costs in period 2, and would accordingly share the period 2 market equally. Here, $\lambda_2 = 0$ and λ_1 increases to slightly more than 6 percent in order to maintain royalty income constant. In this case, compared to a uniform 5 percent royalty rate, the change in royalty structure is an inferior policy if the producer continues to accommodate the pirate, but the producer does better than in any of the aforementioned scenarios by excluding the pirate, retaining its monopoly, and charging a first-period price $p_m^* = p_1^* = 0.6556$. Its profits of 9.8491 are some 3 percent higher than in the scenario 1 accommodation equilibrium.

The final scenario 1* shown in Table 1, however, describes the optimal royalty structure relative to a uniform royalty rate $\lambda = 0.05$. Here, λ_1 increases to 8 percent in order to maintain royalty income constant, while λ_2 falls to -3.47 percent, implying that the producer's second-period marginal cost is 0.0653 compared to the pirate's 0.1. Again, the optimal policy is to maintain the monopoly and exclude the pirate, and the producer would do considerably worse relative to the benchmark of scenario 1 if it instead adopted its best accommodation price in period 1. Its best monopoly price $p_m^* = p_1^* = 0.6560$, and its profits increase by 3.50 percent over the benchmark. Notably, its optimal monopoly first-period price is much smaller than when it elects to compete under equal terms with a pirate (given entry), so that the second-period market is much smaller as a result. But since its production costs in period 2 are subsidized by the creator, and given that the pirate is excluded, this small market is highly profitable. It is little wonder that the pirate stays out even though the delivery good is not priced too much higher than in the accommodation equilibrium; the second-period market is small and the pirate faces a significant cost disadvantage. On the other hand, the producer would be most unwise to adopt this royalty structure and set its first-period price at the optimal level that accommodates the pirate. The producer's profits over both periods would be nearly 15 percent less than if it maintained a time-invariant royalty rate of 5 percent in these circumstances.

For the parameter set under consideration, these simulations suggest that increasing the royalty rate in period 1 and reducing the royalty rate in period 2 initially raises profits while maintaining accommodation of the pirate as an optimal policy. The results also suggest, however, that the producer of originals does even better by making further similar directional changes in the royalty rates to the point

[9]The unique switch point from an accommodation to an exclusion equilibrium occurs at $\lambda_1 = 0.0508$ and $\lambda_2 = 0.0374$.

where the second-period royalty rate is negative so that the actually subsidizes the second-period production of the producer and for which exclusion of the pirate is optimal.

Two final points regarding this benchmark simulation may also be noted. First, it is possible to obtain iso-royalty income equilibria in which royalty rates in both periods exceed the benchmark uniform rate of 5 percent and where it is optimal to continue to accommodate the pirate. An example is $\lambda_1 = 0.05738$ and $\lambda_2 = 0.10$. The producer's profits with these royalty structures, however, are smaller than with the uniform royalty rate of 5 percent and consequently will never be adopted. It is always more profitable for the producer to reduce λ_2 in response to an increase in λ_1, given royalty income is held constant, and the producer's profits decrease monotonically for increases in λ_1 in excess of 0.08. Secondly, for values of λ_1 less than 0.05 (other than arbitrarily close to 0.05), no values of λ_2 exist that satisfy the iso-royalty income constraint.

To consider the robustness of the general results emerging from the analysis of Watt's scenario 1, first consider the results from the analysis of Watt's three remaining scenarios as illustrated in Table 2. Here, scenarios 2, 3, and 4 replicate Watt's results for the parameter sets chosen, while scenarios 2*, 3*, and 4* describe the corresponding optimal royalty structures when royalty rates differ over time.

Table 2: Simulations 2-4 [$c = 0.1,\ k = 0.5$]

Scenario	2	2*	3	3*	4	4*
λ_1	0.05	0.0807	0.05	0.0811	0.01	0.0364
λ_2	0.05	-0.0356	0.05	-0.0361	0.01	-0.0469
b	0.025	0.025	0.03	0.03	0.016	0.016
r_1	0.0158	0.0807	0.0138	0.0733	0.0546	0.1132
r_2	0.6342	0.9117	0.7262	1.0111	0.5934	0.7623
p_1^*	0.6143	0.6563	0.6143	0.6567	0.6029	0.6342
$\widehat{p_1^*}$	0.5985	0.6349	0.6012	0.6379	0.5820	0.6094
$\pi(p_1^*)$	7.6571	7.9297	6.3810	6.6080	13.3786	13.5583
p_m^*	p_1^*	p_1^*	p_1^*	p_1^*	r_2	p_1^*
$\pi(p_m^*)$	7.6571	7.9297	6.3810	6.6080	13.3737	13.5583
$\widehat{p_c^*}$	r_2	r_2	r_2	r_2	r_2	r_2
$\widehat{\pi}^o(\widehat{p_c^*})$	7.6908	4.9341	6.0318	2.2135	13.2015	11.8769
optimal strategy	$p^* = r_2$ accommodate	$p^* = p_1^*$ exclude	$p^* = p_1^*$ exclude	$p^* = p_1^*$ exclude	$p^* = r_2$ exclude	$p^* = p_1^*$ exclude
p_2	0.1890	0.1963	0.2286	0.1962	0.2234	0.1851

Table 2 shows first that a *ceteris paribus* increase in the demand parameter b from 0.02 to 0.025 leaves the general nature of the results from the first simulation unchanged.[10] The piracy accommodation result in Watt's scenario 2 is again overturned in scenario 2*, and the most profitable strategy again involves an increase in the first-period royalty rate accompanied by a negative royalty rate in

[10]With $b = 0.025$ rather than 0.02, the benchmark profit shares are also much the same, with second-period duopoly profits increasing to a little over 9 percent of industry profits over the two periods, and the producer's share of the duopoly profits increasing to 16.12 percent. In the first period when the monopoly is held, the producer also continues to capture over 90 percent of total industry profits over the two periods.

period 2. With λ_1 and λ_2 set at their optimal values of 0.0807 and -0.0356, respectively, the producer's profits are 13.52 percent greater than with a uniform royalty rate $\lambda = 0.05$, and are a substantial 60.71 percent greater than if the producer had instead chosen to accommodate the pirate by setting a first-period price $\widehat{p}_c^* = r_2 = 0.9117$. The intuition is that in the latter case, even though a high return is obtained when a unit of the delivery good is sold to the pirate, there is a significant opportunity cost in that sales to most consumers are thereby delayed. The resulting second period market is very substantial and in spite of the considerable advantage gained by sharing it with a pirate over which the producer has a significant cost advantage, the combination of having to share this market along with the 50 percent discount applied to the valuation of the less-durable product by the bulk of consumers makes such a situation relatively unprofitable. Thus, the producer retains the monopoly and excludes the pirate, adopting a first-period price $p_1^* = 0.6563$ that is only about 72 percent of the best accommodation price.

Watt's scenario 3 involves a *ceteris paribus* increase in b from 0.02 to 0.03, in which case the producer's optimal strategy with a uniform royalty rate $\lambda = 0.05$ is to exclude rather than accommodate the pirate. An interesting question is, given that the accommodation results are overturned by the introduction of optimally-selected time-dependent royalty rates, whether the producer's optimal strategy of excluding the pirate might be overturned when variable royalty rates are considered. Scenario 3*, however, shows that while it again pays the producer to switch from a uniform royalty structure to one for which the first-period royalty rate is increased and the second-period royalty rate becomes negative, the policy of excluding the pirate and charging a first-period monopoly-maintaining price of is unchanged, although the level of this price is greater in order to take advantage of a larger second-period market under the more favourable cost conditions. In this case, when the royalty rates are adjusted to $\lambda_1 = 0.0811$ and $\lambda_2 = -0.0361$, it is not feasible to optimally accommodate the pirate since $\widehat{p}_c^* = r_2 = 1.0111$, exceeding the value for which first-period demand becomes negative.

Finally, Watt's scenario 4 substantially reduces the uniform royalty rate from 0.05 to 0.01, and sets the demand parameter b at 0.016, the smallest value chosen for his simulations. As with scenario 3, it is both feasible and profitable to exclude the pirate.[11] Scenario 4*, however, shows that the producer again does better by increasing the first-period royalty rate (from 0.01 to 0.0364) and selecting a negative royalty rate (of -0.0469 rather than 0.01) in period 2. In this case, the optimal strategy now involves setting a first-period price equal to p_1^* rather than r_2.

In sum, in the scenarios examined by Watt where the producer of originals was able to set a monopoly price and exclude entry by a pirate but where it was not always profitable to do so, the accommodation equilibria are rejected in favour of exclusion when optimal time-variant royalty rates are selected. On the other hand, in the scenarios where exclusion was both possible and profitable, setting optimal time-variant royalty rates did not upset the exclusion property (although different equilibrium values for the endogenous variables were obtained). Further, optimal time-variant royalty rates are uniformly characterized by an increase in the royalty rate applying to the period for which there is no threat of piracy along with a

[11]Notably, for parameter sets for which exclusion of the pirate is both feasible and optimal under uniform royalty rates, no cases were found for which it pays the producer to switch to accommodate entry by the pirate when λ_1 and λ_2 are both optimally chosen.

reduction (to negative levels) of the royalty rate applying in period 2 whether or not the pirate is accommodated or excluded. Thus, the producer, instead of facing a cost disadvantage *vis a vis* a pirate entering in period 2, strategically chooses a royalty structure that leaves the creator indifferent to a uniform royalty rate and provides a cost advantage over a pirate that is a potential entrant in the second period. This cost advantage is sufficient in the cases examined to deter entry while raising the producer's profits. Notably, in all of Watt's examples, optimal nonlinear royalty contracts produced exclusion prices that did not require limit pricing, a result characteristic of only one of the four examples when uniform royalty rates were assumed.

It is not possible to consider the full generality of these results, but an attempt was made to at least try to upset them.[12] First, a search was carried out to discover whether there existed cases where an existing optimal accommodation policy with a given uniform royalty rate survived the introduction of optimally-set time-variant royalty rates. Such cases were found, but only after intensive and wide-ranging search. One such case is generated by the following parameter set: $c = 0.1$; $k = 0.65$; $b = 0.01$. With a uniform royalty rate $\lambda = 0.05$, it pays the producer of originals to charge the best accommodating period 1 price and share the second-period market with the pirate, generating profits of 19.0672 for the producer over the two periods. In this example, the share of period 2 producer profits in aggregate profits over firms and time is higher at 12.39 percent than in previous cases of accommodation equilibrium reported, while the producer's profits in period 1 are a lower 87.62 percent. As with simulations 1 and 2, however, the producer does better to increase the royalty rate in period 1 and reduce it in period 2, and does best to set $\lambda_1 = 0.0726$ and $\lambda_2 = -0.0137$, continuing to accommodate the pirate and making profits of 19.321, a 1.33 percent increase over the uniform royalty rate benchmark. Profits decrease monotonically for increases in λ_1 accompanied by constant royalty income reductions in λ_2 thereafter, although profits continue to exceed those in the benchmark until λ_1 increases to somewhat more than 10 percent. When λ_1 reaches 0.1675 and λ_2 is simultaneously reduced to -0.0954, the system switches to an exclusion equilibrium initially, although feasible piracy accommodation equilibria re-emerge and are maintained when λ_1 is raised to about 20 percent or higher, until feasible solutions cannot be found for λ_1 in excess of approximately 50 percent (and which require an absolute magnitude for λ_2 that would imply negative marginal costs for the producer in period 2 once λ_1 exceeds about 40 percent). Although these reswitching outcomes are interesting, none will be chosen if the accommodating royalty rates are chosen optimally. Consequently, there exist situations in which accommodating the pirate continues to be the best policy, but the simulation evidence suggests that they are the exception rather than the rule.

Further, circumstances were considered whereby exclusion of the pirate under a given uniform royalty rate was not feasible; i.e., no real roots to $f(p)$ in (27) exist with $\lambda_1 = \lambda_2$. The question then arises, if $\lambda_1 \neq \lambda_2$ and the constant royalty income constraint is satisfied, can exclusion/accommodation equilibria emerge? The answer is in the affirmative. For example, consider the parameter set $c = 0.01$; $k = 0.5$; $b = 0.01$. When $\lambda_1 = \lambda_2 = 0.05$, exclusion of the pirate is not possible

[12]Parameter sets investigated included the following: $k \in \{0.0,\ 1.0\}$; $b \in \{0.0,\ 0.05\}$; $c \in \{0.01,\ 0.10\}$; $\lambda \in \{0.0,\ 0.08\}$.

no matter what price is set in period 1 by the producer of originals. In these general circumstances, the producer then sets its best monopoly price for period 1 independently of any strategic considerations involving period 2, and then either competes (on a cost-disadvantageous basis) as a Cournot duopolist in period 2, or exits the market, leaving the second-period market to the pirate. When λ_1 and λ_2 are set optimally, however, an optimal accommodation equilibrium exists with $\lambda_1 = 0.075$ and $\lambda_2 = -0.0174$. The producer's profits are 4.38 percent greater than when $\lambda_1 = \lambda_2 = 0.05$ and where the pirate could not be excluded whatever price was set in period 1. With λ_1 and λ_2 set optimally as above, the producer now has the capacity to set a first-period price to exclude the pirate but does better to follow an accommodation policy. At the optimal accommodation values of λ_1 and λ_2, the best exclusion strategy generates profits that are 35.88 percent lower than when the pirate is accommodated, and 33.07 percent lower than when a uniform royalty rate of 5 percent is adopted.[13] Note that in each royalty scenario described, the general outcome is observationally equivalent in the sense that the pirate enters the market in period 2, but only for the case where royalty rates are time-dependent is the pirate's entry welcomed. For this parameter set, if the uniform royalty structure were adopted, the producer of originals would happily support the introduction of copyright law. If λ_1 and λ_2 are set optimally, however, and enforceable copyright law exists, the producer would not bring suit against an infringing pirate if the pirate could mount an affirmative defence on the basis that the producer has suffered negative harm by the joint purchase of the delivery good and its subsequent use as a template for illicit copying.

Finally, although the search over the feasible parameter space was reasonably exhaustive, it cannot by its nature be comprehensive given continuity of the parameters.

What seems to be the case is that the microsimulation evidence evaluated in this article is strongly suggestive of a weakening, if not removal, of the capacity for indirect appropriability to sustain piracy ".... as an activity that should be embraced by the party being pirated, if they are farsighted and enlightened enough" (Liebowitz (2005, p. 5)), at least in the context of Watt's model of copyright piracy when royalty rates can be targeted to sales in different periods.

4. Concluding Remarks

This article examines the robustness of results obtained by Watt (2000) showing that a producer of an original delivery good in an initial period may find it profitable to accommodate the subsequent entry of a pirate and engage in Cournot competition rather than exercise a feasible exclusionary pricing strategy. Although the theoretical literature contains a number of similar results, Watt makes life relatively tough sledding for himself in that many of the familiar means that utilize the concept of indirect appropriability for generating such results, including team consumption, price discrimination and network externalities, are assumed away.

[13] As a policy, accommodation is both feasible and more profitable than exclusion of the pirate for a range of values of λ_1 somewhat less than 7.5 percent and somewhat greater than 15 percent (with corresponding compensating decreases in λ_2 in each case, and with $\lambda_2 < 0$). Further, these accommodation equilibria all generated higher profits for the producer than when $\lambda_1 = \lambda_2 = 0.05$ and the exclusion or accommodation of the pirate was not a feasible choice.

Nevertheless, Watt produces a number of simulation results for which accommodating the pirate pays, although whether it does so depends critically on the value of chosen parameters.

In his basic framework, Watt assumes that a simple linear royalty contract applies, with the producer of originals paying an amount to the creator that is a fixed proportion λ of total sales made over time. Further, in this framework, λ is treated as exogenous.[14] The present article generalizes this model by admitting nonlinear royalty contracts characterized by royalty rates that are proportional to sales, but where the factor of proportionality can differ between periods. Thus, whatever is the value of λ, it is assumed that the producer of originals either accepts the linear contract or is able to replace it with a feasible nonlinear contract that leaves total royalty payments to the creator unchanged.

A critical strategic variable in this type of model is the choice of the first-period price of originals. It is shown that this price is dependent on the choice of royalty rates in each period, and that the producer can strategically select such rates, along with first-period prices, such that total profits are raised. In the examples used by Watt to illustrate the optimality of accommodating a pirate, the accommodation results are overturned; the producer does better to choose a feasible first-period price that excludes the pirate. This result, however, does not hold over all parameter sets examined. Nevertheless, it appears that the set of optimal accommodating equilibria is smaller when nonlinear royalty contracts are implemented. Conversely, in the examples used by Watt to illustrate the optimality of exclusion, optimal differentiation of royalty rates over time did not upset the general nature of these results in these or any other examples examined. Further, it is also shown that the additional degrees of freedom offered by nonlinear royalty contracts can transform a situation where the producer cannot feasibly exclude a pirate into a situation where exclusion becomes possible and yet the producer may still prefer to accommodate entry of its free-loading rival. Nevertheless, it remains the case that when accommodation is an optimal policy, the producer sets a first-period price at a level that generates a relatively small second-period market, and the producer captures by far the most of their intertemporal profits in the period for which entry is not threatened.

The most important general result obtained from the simulation exercises, however, concerns the structure of optimal nonlinear royalty contracts in the sense used in this paper. In every simulation exercise considered where the producer possesses the discretion as to whether or not to accommodate entry by the pirate, and whether the optimal policy is to accommodate or exclude, the optimal policy is to increase the royalty rate in period 1 and reduce the corresponding royalty rate in period 2 sufficiently that it becomes negative, i.e., the creator subsidizes the producer's output in the second period. While many creators may look askance at such a proposal, the rationale is that the effect is to more than offset the producer's marginal cost disadvantage against the pirate in period 2, thus giving the producer larger shares of output and profits should the pirate enter and which may, but need

[14] In Watt (2000, chapter 3), the creator's choice of an optimal linear royalty contract with a nonzero intercept and deterministic demand is addressed. Although general analytical results for this complex problem are not obtained, some numerical illustrations are provided.

not, deter entry of the pirate. No theorem is claimed here, but the results appear to be quite robust.[15]

Further work along these lines might account for the following issues. First, the impacts of optimal nonlinear royalties on social welfare deserves investigation, particularly in respect of cases where accommodation of the pirate is replaced with (privately) optimal exclusion. Second, the apparently general result that (privately) optimal nonlinear royalty policy requires using a first-mover advantage to gain a cost advantage over a potential entrant might be usefully be compared with (or analysed in conjunction with) some similar standard industrial organization analyses such as the role of investment in capacity as a potential entry deterrent to subsequent Cournot competition as in Dixit (1980). Third, the analysis maintains Watt's assumption of potential Cournot duopoly competition only.[16] As Watt (2000, p. 68, fn. 54) notes, additional potential pirates increase the demand for originals to serve as copies but also reduce the producer's ability to compete in the second period. The analysis of the use of nonlinear royalties so as to gain a cost advantage over multiple pirates that could enter in the face of positive second-period industry profits would also be enlightening.

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[15]Robustness would be threatened if the creator simply takes the money in period 1 and runs, and either cannot later be found or turns out to be judgment-proof. A contract assigning an appropriate part of period 1 royalty payments to a disinterested third party given strong incentives to ensure the distribution of these proceeds as period 2 subsidies, however, should deter such opportunism.

[16]In an an analysis of piracy using a strategic entry-deterrence framework, Banerjee (2006, fn. 5) also assumes a duopoly market structure on the grounds that evidence suggests that "there are usually only one or two organizations that produce bootlegged copies of licenced software and sell it through different retail channels". The number of firms in equilibrium, however, will presumably be a function of the strength and enforceability of copyright law which is not presumed to exist in either Watt (2000) or the present paper.

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