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SOFTWARE PIRACY: AN ANALYSIS OF PROTECTION STRATEGIES*

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Software piracy by users is generally believed to harm both software firms (through lower profits) and buying customers (through higher prices). Thus, it is thought that perfect and costless technological protection would benefit both firms and consumers. The model developed here suggests that in some circumstances, even with significant piracy, not protecting can be the best policy, both raising firm profits and lowering selling prices. Key to the analysis is joining the presence of a positive network externality with the fact that piracy increases the total number of program users. The network externality exists because consumers have an incentive to economize on post-purchase learning and customization costs.

(SOFTWARE; COMPUTERS; PIRACY; STRATEGY; NETWORK EXTERNALITY)

1. Introduction

User piracy is claimed to be a major problem for the microcomputer software industry. It has been estimated that for every legitimate copy sold there are between two and ten illegal copies[1] "bootlegged" from friends or colleagues.[2] Programs can be protected by special coding, fingerprinting, and other devices, but no technological protection system yet devised is completely effective. Consequently, despite the clear specification of property rights, piracy exists due to the high cost of policing consumer behavior and enforcing the law.

The general question addressed here is whether a software publisher should pursue a strategy of software protection by installing a technological protection device on the program copies that it sells or licenses. Our study also has application to the firm attempting to raise the risk of pirating through litigation against offenders.

Our results help characterize the product-market contexts within which protection is most helpful and those within which it should be avoided. Of special interest are those regimes in which both firms and consumers can be better off without piracy protection. In such regimes, piracy acts to increase the quality of a software program as rationally perceived by users, thereby increasing legitimate demand and profit.

The key to our analysis is joining piracy's impact on the size of the user base with positive network externalities in the use of software. It is commonly assumed that piracy has only one economically significant effect: to reduce retail demand for the product. However, there is an additional critical effect: piracy increases the total number of program users, since some who pirate would not buy, were protection strengthened. This increase in the user base becomes important when there exists a positive consumption or network externality which exists if consumer utility for a product increases with the number of other persons using it.

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[1] Piracy is prohibited by the Computer Software Copyright Act of 1980, 17 U.S.C. §117 (amended by 17 U.S.C. §117, 1980), as follows: "Any exact copies prepared in accordance with the provisions of this section may be leased, sold, or otherwise transferred, *along with the copy from which such copies were prepared*, only as part of the lease, sale or other transfer of *all rights in the program* [emphasis added]."

[2] Estimates of the volume of piracy are available from a number of industry sources. See, for example, *Standard and Poor's Industry Surveys*, 1989, §3, C-99 (looseleaf).

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The concept of a consumption or network externality has been developed in several recent and important papers by Katz and Shapiro (1985, 1986) and by Farrell and Saloner (1985, 1986), and used in these papers to examine the incentives for voluntary market development of compatible or standardized technologies. Katz and Shapiro (1985, 1986) focus particularly on the phenomenon of de facto standardization, studying the impact of technology "sponsorship" (existence of property rights to the technology) and the consequent use of strategic pricing. Farrell and Saloner (1985, 1986) examine the excess resistance to or momentum for major technological change when a network externality exists and producers have incomplete information about market preferences. In a particularly vivid account, David (1985) suggests that the network externality is the central factor that has allowed the QWERTY typewriter keyboard standard to persist despite widespread acknowledgement of the technical superiority of alternative designs. In a related paper, Arthur (1985) points out that when a network externality is present, "small events" may play a major role in determining which technology will come to dominate, so that history becomes important. Earlier work includes Liebenstein (1950), who pioneered the formal treatment of bandwagon effects, as well as Rolfs (1974) and Oren and Smith (1981), who examine implications of interdependent consumer demand for communications markets. Our paper extends investigation of network implications by considering them in a new context: the exploration of a software publisher's optimal protection policy against user piracy.

When an individual buys a microcomputer software program, the retail price is only the tip of the iceberg of costs that must be borne. Looming largest are the costs of learning and personalizing a software program, with complex productivity programs sometimes requiring several hundred hours for their mastery. Also important is the ease with which data can be exchanged with other software users (e.g., between co-workers or between a teacher and students), and the risk that the human capital sunk in learning may not be transferable to other situations or work environments. The perceived quality of a program will therefore strongly depend upon the product-specific opportunities for economizing on these post-purchase learning and customization costs.

Examples of ways to economize on learning and customization include the use of independently prepared guidebooks and "how-to" computer magazine articles, separate tutorial programs written for popular programs, advice from other users, and compatible programs that expand or customize the program without requiring the user to learn a new command structure. These opportunities for economizing on post-purchase costs act as *complementary products* to the original software program; with the market size, and hence the incentives for developing the complements, depending on the number of users of the original program. Note that these complements are specific to a particular program. The network externality in software arises because the larger a program's user base, the greater are the opportunities for economizing on post-purchase costs.

Critical to this analysis, the production of such complements does not depend on whether the users bought or pirated their program copy. The incentive of a guidebook writer, for example, is unaffected by whether program buyers or pirates purchase the book. What counts for the production of these complements is the size of the *total* installed base—buyers *plus* pirates.

If the value of a software program is directly enhanced by the opportunities to reduce learning and customization costs, as well as for data exchange and skill transfer, then piracy, because it increases the size of the total installed base, may raise the value of the program to all users. Of course, piracy also causes direct sales losses. The net effect of piracy—and whether a producer can be better off by not protecting—depends on balancing piracy's value-enhancing effects against the sales that are lost. One of the aims of this paper is to investigate this balance.

Our model differs substantially from previous treatments of user theft of intellectual property, primarily because these works considered piracy in the absence of a network externality. William Johnson (1985) examined the efficiency and distributional aspects of unauthorized copying of creative works for personal use. He concluded that unauthorized copying unambiguously reduces producer returns but that product price can rise or fall as a result. Besen (1986) and Liebowitz (1985), the latter concerned exclusively with photocopying of journals, independently concluded that producer returns can increase with piracy. Their analyses, however, do not pertain to the software market since they turn on the crucial assumption that pirate copies can only be made from originals (i.e., illegal copies cannot be made from other illegal copies), so that it is possible for the producer to appropriate some of the consumer gains from illegal copies. But software piracy clearly does not depend on the presence of a producer-made original; in the case of software, copies of copies are indistinguishable from originals.[3]

The first two sections of the paper establish the basic model, absent a network externality. Section 2 analyzes the individual's decision to buy, pirate, or do without a particular product. Drawing from this analysis, §3 introduces a simple demand characterization and examines the comparative statics associated with changes in the level of protection. Section 4 discusses revisions in the model of consumer choice to accommodate a network externality, and §5 examines the corresponding price and protection decisions the producer must make. Section 6 presents some insights into the structure of the protection-externality problem in a multiple-firm setting. Conclusions and potential extensions are discussed in §7.

2. The Decision to Pirate

Any model of software piracy must account for the large observed volume of legitimate sales that persists despite the ease of copying unprotected programs and many protected ones. This section offers a simple model in which consumer heterogeneity permits the concurrent existence of a large legitimate market and substantial piracy.

Indexing each potential consumer by i, let T_i be the gross use-value of the program to consumer i. This value includes the discounted value to i of the flow of services the individual expects from the program. Let L_i be that consumer's expected post-purchase cost, including learning costs and program customization costs. Then the net value v_i of the program to individual i is $v_i = T_i - L_i$. For many individuals L_i may exceed T_i, producing a negative net value. Individuals can obtain the value v_i from a single unit of the program; no additional value can be obtained from additional units. Hence, each individual demands either one unit or none.

Each individual also has a cost c_i of pirating which depends upon the level of protection technology. Components of this cost include the expected value of penalties or lost reputation if caught, and the cost the individual ascribes to violating an ethical code not to steal. Also included in c_i is the cost of searching for a copyable version of the program, the cost of any reciprocal obligation to the supplier of the program to be copied, the cost of special "unlocking" programs to break protection schemes, photocopying or buying documentation, and the cost of blank diskettes. We also include in c_i the opportunity costs of forgone performance guarantees, support facilities, trade-in rights, or symbols by which official buyers can be recognized (e.g., properly printed and bound documentation).

[3] This property is a direct result of the digital form of computer information. As digital technology invades the home music and television industries, they too will have to cope with the fact that tenth generation copies are equivalent to originals.

Although some elements of each individual's cost of piracy are beyond the influence of the producer, there are many legal and technological policies the producer can implement to increase or decrease the cost of piracy. In particular, software publishers can adopt protection technologies which make casual copying of programs much more difficult and can implement aggressive litigation policies aimed at inducing corporate users to take steps to prevent piracy by their employees. We assume that the efficacy of piracy-prevention policies can be indexed by the single variable τ and that each individual's cost of piracy is increasing in τ so that $\partial c/\partial\tau > 0$ for all i. It is assumed that buyers do not find using a protected program to be more cumbersome or inconvenient than using an unprotected version of the same program.

The product is sold at price p. Individuals are strict value-maximizers, purchasing the program only if buying creates surplus $(v_i - p \geq 0)$ and if that surplus is not exceeded by the surplus available through stealing $(v_i - p \geq v_i - c_i)$, with the latter condition simplifying to $p \leq c_i$. Similarly, an individual will pirate the program if $v_i - c_i > 0$ and $v_i - c_i > v_i - p$, with the latter condition simplifying to $c_i < p$. Finally, an individual will neither buy nor pirate if the surpluses available through both acts are negative: $v_i - p < 0$ and $v_i - c_i < 0$. Analysis of these three situations reveals that an individual's action depends upon which element of the triple $\{p, c_i, v_i\}$ is least: if price is least, the person buys; if c_i is least, the person pirates; if v_i is least, the person does without. The optimal decision is

$$\begin{array}{lll} \text{BUY} & \text{if} & p \leq \min(v_i, c_i), \\ \text{PIRATE} & \text{if} & c_i < \min(v_i, p), \\ \text{DO WITHOUT} & \text{if} & v_i < \min(c_i, p). \end{array}$$

Since the decision to buy is taken if $p \leq \min(v_i, c_i)$, $\min(v_i, c_i)$ may be interpreted as the individual's "limit price" for legitimate purchase. Hence, the demand function $q(p, \tau)$ is an ordered distribution of these limit prices and

$$q(p, \tau) = \{i : p \leq \min(v_i, c_i(\tau))\}.$$

The first and most basic implication of this model is that legitimate demand for a program can exist even in the face of piracy. For example, individuals with $c_i > v_i$ may buy the program but will not pirate it at any price. The following observations highlight the key comparative statics implications of this model of choice.

OBSERVATION 1. *Piracy is strictly decreasing in protection technology τ; demand and doing-without are nondecreasing in τ.*

OBSERVATION 2. *As protection technology τ increases (with price fixed), only the behavior of (some) pirates is affected. Buyers and those doing without do not change their actions with increases in τ.*

OBSERVATION 3. *Demand is strictly decreasing in price p; doing without and piracy are nondecreasing in p.*

OBSERVATION 4. *As price increases (with τ fixed), only the behavior of (some) buyers is affected. Pirates and those doing without do not change their actions with increases in price.*

OBSERVATION 5. *At a sufficiently low price, piracy stops. In the limiting case as $p \to 0$, where the publisher gives the product away, piracy ceases and legitimate demand rises to include the entire population for whom $v_i > 0$.*

Thus, one simple strategy always open to firms that wish to reduce piracy is to lower price. In the following section we examine the optimal choice of price when piracy is a consideration.

3. Protection Without a Network Externality

To gain tractability and provide consistency throughout the paper, we assume that demand functions are linear and marginal production and distribution costs are zero.[4] Appendix A demonstrates that the results of this section can hold when the assumption of linear demand is relaxed.

Let the demand $q(p, \tau)$ for purchased units depend upon the price p and the level of protection technology τ as follows:

$$q = z - \alpha(\tau)p, \tag{1}$$

where $\alpha > 0$ is the reduction in demand for each unit increase in price and z is the *zero-price demand* (the number of units taken were they given away freely). From Observation 5 we know that if $p = 0$, all piracy is eliminated. Hence,[5]

$$z_\tau = 0. \tag{2}$$

From Observations 1 and 2 we have $q_\tau > 0$, so that

$$\alpha_\tau < 0, \tag{3}$$

is required if (1) is to be consistent with the model of individual choice. Thus, the impact of increased protection on a linear demand function amounts to a rotation about the zero-price intercept. These restrictions lead directly to the following result:

PROPOSITION 1. *Absent any network externality, price and profit increase with the level of (exogenously chosen) protection technology.*

PROOF. Working with (1), and holding the technology τ constant, the profit maximizing price $p^* = z/(2\alpha)$ and the corresponding profit is $\pi^* = z^2/(4\alpha)$. Both p^* and π^* decrease in α and, therefore, increase in τ. Q.E.D.

Intuitively, protection raises the limit prices of at least some prospective buyers which, in turn, raises the profit maximizing price. The increase in profit from greater protection reflects the higher optimal price.

Note that this result contrasts with many of the views of industry spokespersons and analysts. Their views are that software publishers must charge higher prices to compensate for the revenue lost to pirates and that better protection would, therefore, lower prices. However, our analysis points out that technological protection and lower prices are substitutes in the fight against piracy and that the prices lowered to deter piracy unintentionally benefit the legitimate buyer. As protection technology is improved, the producer can reduce reliance on using low prices to deter piracy. Thus, improved protection technology can harm honest buyers, and piracy can help them (through forcing lower prices). Of course, this analysis does not consider the impact of piracy on the incentive to create new software: the higher profits concomitant with increased protection may permit more products to be developed and increased variety may, in turn, increase the net welfare of buyers.

[4] Very low marginal costs are the rule in the microcomputer software industry. Industry experts estimate variable publishers' costs on productivity products to be less than five percent of the retail price.

[5] Here and in what follows, where the meaning is unambiguous, partial differentiation is denoted by a subscript so that $\partial q/\partial \tau \equiv q_\tau$ and $d\alpha/d\tau \equiv \alpha_\tau$. When a function of only one variable is subscripted, the total derivative is implied.

4. The Decision to Pirate with a Network Externality

With the basic model now established, we turn to how a network externality affects the individual decision to buy, pirate, or do without. Our analysis is based on a static equilibrium concept: the dynamics of how expectations are formed and how expectations and adoptions evolve over time are suppressed.

The first important effect of the network externality is to increase the value of the program to each user as the size of the user base increases. Thus, the total value V_i of the program to individual i is[6]

$$V_i = T_i - (L_i - f_i(U)) = v_i + f_i(U),$$

where $f_i(U)$ is the *increase* in value (or reduction in post-purchase cost) when there are U program users. Each f_i is increasing in U. Note that the network externality not only changes the value of the program to existing users, but also increases the total population with positive utility for the product: as U increases so does the size of the set $\{i : v_i < 0 < v_i + f_i(U)\}$.

The second network influence on demand is that the cost of pirating declines as U increases. Perhaps the most significant source of this decrease is that a larger user base reduces a pirate's cost of searching for someone willing to let the pirate copy the program; similarly, reciprocal obligation to the supplier of a copyable disk declines as the greater the "competitive supply" of such individuals. Finally, within the industry, an increase in the pirating population is thought to affect individuals' beliefs regarding the ethics of piracy—the more individuals that pirate, the smaller the stigma attached to it. Thus, with the network effect, the cost of pirating to individual i is

$$C_i = c_i - g_i(U),$$

where c_i is the intrinsic cost of piracy and g_i is the reduction in piracy costs when there are U users. Each g_i is increasing in U.

With these revisions in the costs and values of individuals, the model of choice becomes:

$$\begin{array}{lll} \text{BUY} & \text{if} & p \le \min(c_i - g_i(U),\ v_i + f_i(U)), \\ \text{PIRATE} & \text{if} & c_i - g_i(U) < \min(p,\ v_i + f_i(U)), \\ \text{DO WITHOUT} & \text{if} & v_i + f_i(U) < \min(c_i - g_i(U),\ p). \end{array}$$

To analyze the implications of this model of choice, it is necessary to distinguish between the partial-equilibrium and full-equilibrium values for the number of users. That is, let N be the number of individuals who would buy or pirate the program if each person believed that the number of effective users were *somehow fixed at* U. Additionally, let S be the number of pirates and Q be the number of buyers.

OBSERVATION 6. *S is increasing in U.*

Increases in U make the program more valuable and piracy less costly. Consequently, the set of individuals finding C_i to be smaller then either price p or value V_i must get larger.

OBSERVATION 7. *N is increasing in U.*

The number of total users is the sum of buyers and pirates; it is the size of the set $\{i : V_i > \min(p, C_i)\}$ and clearly increases as U is increased.

With U held constant, the comparative statics results of Observations 1–5 continue to

[6] We use capital letters for values and population counts when network externalities are present.

hold. Of course, U is not fixed; in a rational expectations equilibrium, it must be that $U = N$. In what follows we assume that this is indeed the equilibrium achieved, and that it is achieved *all at once* without any market dynamics.[7] Dynamics consistent with our model could be imagined as including two periods of activity. In the first, prices and technologies are announced, and customers indicate their preference for buying, pirating, or doing without. New rounds of announcements are then made until there are no more changes. In the second period, production, exchange, and consumption takes place on the terms agreed to at the end of period one. Although in this paper we may speak of "decreases in S acting to diminish U, which feeds back to further reduce S," it should be understood that such adjustments are purely conjectural and that such description is an aid to intuition rather than a model of market dynamics.

5. Protection and Network Externalities

In the model of §2 we focused on buyers; to analyze the impact of network externalities we must also model the total number of users. To that end, first consider the situation absent network externalities: the number u of users is decreasing in p and must be equal to the zero-price demand z if $p = 0$. The simplest relationship satisfying these conditions is

$$u = z - \omega p,$$

where $\omega > 0$. To take account of the network externality, recall that Observation 7 indicates a positive relationship between U and N. Again for simplicity, assume that the effect of the network externality is multiplicative in U; that is,

$$N = [z - \omega p][1 + \gamma U], \tag{4}$$

where $\gamma \geq 0$ is a single parameter expressing the cumulative impact of increases in U on the value of the program, the cost of piracy, and thence on the actual number of users.

Observation 5 requires that if $p = 0$ the number S of pirates is zero, and from Observation 6 we know that S increases with the number of users. Let

$$S = (\alpha - \omega)(1 + \gamma U)p, \tag{5}$$

where $\alpha > \omega > 0$. Then the number of buyers Q is the number of users N less the number of pirates S:

$$Q = (z - \alpha p)[1 + \gamma U]. \tag{6}$$

As in the model of §3, Observations 1 and 5 imply that $z_\tau = 0$ and $\alpha_\tau < 0$. Additionally, Observation 1 implies that the number of individuals doing without increases with τ; consequently, N must be decreasing in τ so we must require

$$\omega_\tau > 0. \tag{7}$$

The rational expectations equilibrium is the unique $\hat{U}$ solving $N(U) = U$. From (4),

$$\hat{U} = \frac{z - \omega p}{1 - \gamma(z - \omega p)}. \tag{8}$$

Inspection of (8) shows that we must require

$$0 \leq \gamma z < 1 \tag{9}$$

[7] In general there may be more than one value of U for which $N = U$. Absent a dynamic model there is no reason to favor one of these equilibria over another. Fortunately, in the bilinear specification we advance in §5 the equilibrium is unique.

to insure a positive number of equilibrium users at all feasible prices. Substitution of (8) into (5) and (6) gives the rational equilibrium number of pirates and buyers:

$$\hat{S} = \frac{(\alpha - \omega)p}{1 - \gamma(z - \omega p)}, \tag{10}$$

$$\hat{Q} = \frac{z - \alpha p}{1 - \gamma(z - \omega p)}. \tag{11}$$

Profits are maximized by the price p^* which sets marginal revenue equal to zero. Working with (11), p^* solves

$$\alpha\phi p^2 + 2\alpha p - z = 0, \tag{12}$$

where $\phi = \gamma\omega/(1 - \gamma z)$. Given (9), $\phi \geq 0$. The smaller root of (12) is negative and the larger root is[8]

$$p^* = \left[\frac{1}{\phi^2} + \frac{z}{\alpha\phi}\right]^{1/2} - \frac{1}{\phi}. \tag{13}$$

PROPOSITION 2. *Increases in the network externality (γ) produce lower prices and higher profits.*

PROOF. Since $\phi_\gamma = \omega/(1 - \gamma z)^2 > 0$, it suffices to verify that $p^*_\phi < 0$. Taking the derivative of (13) and multiplying by $-\phi^2$, this inequality becomes

$$\frac{1}{\phi} + \frac{z}{2\alpha} > \left[\frac{1}{\phi^2} + \frac{z}{\alpha\phi}\right]^{1/2},$$

and squaring both sides verifies the inequality. Turning to the impact of changes in γ on π^*, and using the Envelope Theorem, we have $\pi^*_\gamma = p^*\hat{Q}_\gamma(p^*, \gamma)$. From (11) is clear that $Q_\gamma > 0$ for feasible prices, which establishes the stated result. Q.E.D.

How does an increase in protection affect price and profit now that network externalities are present? The following two propositions indicate that if externalities are strong enough, both price and profit can decrease with increasing protection. In what follows it is useful to introduce the parameter

$$\lambda = -\frac{\alpha_\tau/\alpha}{\omega_\tau/\omega}, \tag{14}$$

with $\lambda > 0$ guaranteed by the sign restrictions on the underlying parameters. This composite parameter may be interpreted as the ratio of the protection elasticity of buyers to the protection elasticity of those doing without. That is, increased protection reduces piracy: some of the marginal pirates buy while others do without. If λ is large, then relatively more move to buying (staying in the user base) whereas if λ is small, relatively more do without (leaving the user base).

PROPOSITION 3. *With a network externality, price can fall or rise as the level of piracy protection is increased. In particular, for every τ there is an $X(\tau)$, $0 < X \leq 1$, such that if $\gamma z < X$ then price is increasing in τ and if $\gamma z > X$ then price is decreasing in τ.*

PROOF. Working with (13), it can be established that the sign of p^*_τ has the same sign as $X - \gamma z$, where

$$X = \left[1 + \frac{(1 - \lambda)^2\omega/\alpha}{4\lambda}\right]^{-1}. \tag{15}$$

[8] If $\phi = 0$, then $p^* = z/2\alpha$.

Since λ, α, and ω are all positive, $0 < X \leq 1$, with the equality $X = 1$ holding if $\lambda = 1$. Q.E.D.

Recall that absent network externalities, more protection led to higher prices (Proposition 1). With network externalities, more protection can lead to lower prices if the externality is strong enough ($\gamma z > X$). Intuitively, increases in protection directly increase the limit prices of prospective buyers, but when γ is large they also cause large reductions in the size of the user base, producing an indirect reduction in limit prices.

Turning to the impact of protection on π^*, there is a critical strength of network externality beyond which increases in protection have a negative effect on profit.

PROPOSITION 4. *With a network externality, profit can fall or rise as the level of piracy protection is increased. In particular, for every τ there is an $Y(\tau)$, $0 < Y < 1$, such that if $\gamma z < Y$ then profit is increasing in τ and if $\gamma z > Y$ profit is decreasing in τ.*

The proof parallels that of Proposition 3 with

$$Y = \left[1 + \frac{\omega/\alpha}{\lambda(\lambda + 2)}\right]^{-1}. \tag{16}$$

Thus, for $\gamma = 0$ an increase in τ has a positive impact on profit. But if the network externality becomes large enough, increases in protection reduce profits.

The relative magnitudes of X and Y depend upon the magnitude of λ:

PROPOSITION 5. *If $\lambda > 2$ then $Y > X$, otherwise $Y < X$.*

PROOF. Working with (15) and (16), $Y > X$ if

$$(1 - \lambda)^2(\lambda + 2) - 4 > 0.$$

The cubic expression on the left has two unique roots $\{-1, 2\}$ and the inequality holds for $\lambda > 2$. Q.E.D.

The main features of the relationships described by Propositions 3–5 are summarized in Table 1. As can be seen, all four combinations of price and profit sensitivity to changes in protection are possible. In the first two regimes, where γz is less than either X or Y, price and profit are both increasing in τ, just as in the no-externality case. By contrast, if γz is greater than both X and Y (the fifth and sixth regimes), both price and profit decrease with increases in protection. If γz falls between X and Y, price and profit move in opposite directions with a change in τ; if $X > Y$ then price rises while profit falls and if $Y > X$ then price falls while profit rises.

Note that general welfare results are not obtainable in this setting. Two issues deserve mention in this regard. First, buyers' surplus cannot be obtained, as is customary, by integrating the demand function. Here the price corresponding to the Qth unit sold is not necessarily the value V_i of the program to that user, but may be his cost of piracy C_i. Thus, the demand-function measure understates buyers' surplus by an unknown

TABLE 1
Changes in Price and Profit with Increased Protection

Regime	λ	Ordering	p^*_τ	π^*_τ
1	$\lambda > 2$	$\gamma z < X < Y$	+	+
2	$\lambda < 2$	$\gamma z < Y < X$	+	+
3	$\lambda > 2$	$X < \gamma z < Y$	−	+
4	$\lambda < 2$	$Y < \gamma z < X$	+	−
5	$\lambda > 2$	$X < Y < \gamma z$	−	−
6	$\lambda < 2$	$Y < X < \gamma z$	−	−

amount. Second, even were buyers' surplus known, the welfare of pirates would also have to be considered. As specified, the model does not contain sufficient structure to do this and any such specification appears to require numerous *ad hoc* assumptions.

Thus far we have treated the level of anti-piracy protection as exogenous. If this assumption is relaxed, what can be said about the producer's selection of a level of protection?[9] To simplify matters we shall take cost of protection to be negligible. With $p^*(\tau)$ chosen to maximize profits *given* the level of protection τ, the problem is to find the level of protection $\hat{\tau}$ which maximizes $\pi^*(\tau)$. Let the admissible levels of protection be contained in the closed interval $[L, H]$. Then the fact that $Y(\tau) - \gamma z$ has the same sign as π^*_τ leads directly to the following observations:

OBSERVATION 8. *There is a relative maximum of π^* at $\tau^\dagger$ if and only if one of these three conditions is satisfied*:
1. $\tau^\dagger = L$ *and* $Y(\tau^\dagger) < \gamma z$.
2. $\tau^\dagger = H$ *and* $Y(\tau^\dagger) > \gamma z$.
3. $L \le \tau^\dagger \le H$, $Y(\tau^\dagger) = \gamma z$, *and* $Y_\tau(\tau^\dagger) < 0$.

OBSERVATION 9. *If $Y(\tau) > \gamma z$ for all admissible τ then $\hat{\tau} = H$. If $Y(\tau) < \gamma z$ for all admissible τ then $\hat{\tau} = L$.*

Thus, the profit-maximizing level of protection may be the lowest available, the highest available, or an interior point, depending upon the specification of $\alpha(\tau)$ and $\omega(\tau)$, the magnitude of the positive network externality γ, and the size of the zero-price demand z. In the case of an interior maximum, more can be shown.

PROPOSITION 6. *If $\hat{\tau}$ is an interior maximum of $\pi^*(\tau)$, then the corresponding optimal price is*

$$p^*(\hat{\tau}) = \frac{z}{\alpha(\lambda + 2)} = \frac{\lambda}{\phi}$$

and the corresponding optimal profit is

$$\pi^*(\hat{\tau}) = \frac{z^2}{\alpha(1 - \gamma z)(\lambda + 2)^2}.$$

PROOF. Using (16), $Y = \gamma z$ implies $\alpha\lambda(\lambda + 2)/z = \gamma\omega/(1 - \gamma z) = \phi$. Substitution into (13) and (11) reveals that $p^*\phi = \lambda$ and produces the stated results. Q.E.D.

Given that the firm is operating at an interior maximum—that its policy of using an intermediate level of protection is optimal—Proposition 6 gives the optimal price and profit. In this situation, increases in the strength of the network externality increase optimal profits but have no impact on optimal price.

Little more can be said without imposing some additional restrictions on the model. To illustrate possible solution structures we offer two examples.

EXAMPLE 1. From (3) and (7) we know that α is positive and decreasing in τ and ω is positive and increasing in τ. The simplest linear specification meeting these constraints is that $\alpha = A - a\tau$ and $\omega = b\tau$, where A, a, and b are positive constants. Let $L = 0$ be the lowest admissible protection technology. The highest possible level of protection is

[9] The impact of protection derives in part from actions of the firm (e.g., aggressiveness, access to support, and technical protection measures) and, in part, from public policy (e.g., intellectual property laws and the efficiency of the legal system). Only the first part is under the control of the firm and we restrict our analysis to changes in the firm's protection policies.

then $H = A/(a + b)$; values of τ larger than H violate $\alpha \leq \omega$ (producing "negative" numbers of pirates.) Given this specification,

$$Y = \frac{2A - a\tau}{A(2 + b/a) - (a + b)\tau},$$

$Y(L) = 2a/(2a + b)$ and $Y(H) = 1 - b^2/(a + b)^2$. In this situation Y is *increasing* in τ for all admissible levels of protection. Consequently, an admissible solution to $Y(\tau) = \gamma z$ is a relative minimum rather than a relative maximum. The two candidates for global maxima are the extreme points, L and H.

If $Y(L) > \gamma z$ then $\hat{\tau} = H$, whereas if $Y(H) < \gamma z$ then $\hat{\tau} = L$. If $Y(L) < \gamma z < Y(H)$, the global maximum must be determined by direct comparison of the profits available at minimum and maximum levels of protection.

Focusing on the condition $Y(H) > \gamma z$, which guarantees the optimality of a minimum protection policy, the inequality is true if

$$\frac{b}{a + b} > \sqrt{1 - \gamma z}.$$

Conversely, full protection is the guaranteed optimum if

$$\frac{b}{2a + b} < \gamma z.$$

Interpreting these parameters is not difficult—if protection is increased by one unit, $(a + b)p$ pirates are stopped. Of these, ap buy the product and bp do without. Thus, the ratio $b/(a + b)$ is the proportion of deterred pirates who do-without rather than buy. The above conditions are thus intuitively reasonable: if protection stops pirates but fails to increase legitimate demand, do not use it. Conversely, if most deterred pirates turn to buying instead, use full protection. □

EXAMPLE 2. A simple nonlinear specification meeting the constraints on $\alpha(\tau)$ and $\omega(\tau)$ is that $\alpha = A\tau^{-a}$, and $\omega = \tau^b$, where a, b, and A are positive constants. In particular, note that this specification implies that $\lambda = a/b$ is a constant. Let the highest level of protection be $H = A^{1/(a+b)}$, the level at which $\alpha = \omega$. The lower limit on protection is L, $0 < L < H$. Substituting into (16) gives

$$Y = \left[1 + \frac{\tau^{a+b}}{A(a/b)(2 + a/b)}\right]^{-1}.$$

Clearly, Y is *decreasing* in τ for all admissible τ and its minimum value is $Y(H) = 1 - b^2/(a + b)^2$ (coincidentally the same expression as in Example 1). Consequently, there are three cases to consider. First, if $Y(H) > \gamma z$ then $\hat{\tau} = H$. Second, if $Y(L) < \gamma z$ then $\hat{\tau} = L$. Finally, if γz falls between $Y(L)$ and $Y(H)$ an interior maximum exists and the optimal level of protection is

$$\hat{\tau} = \left[\frac{A}{\gamma z}\frac{a}{b}\left(2 + \frac{a}{b}\right)\right]^{1/(a+b)}.$$

Note that at the corner solutions, marginal changes in the strength of the network externality have no effect on the level of protection. In the interior solution, by contrast, marginal increases in γ induce less protection.

The condition that guarantees $\hat{\tau} = H$ is

$$\frac{b}{a + b} > \sqrt{1 - \gamma z},$$

and the condition that guarantees $\hat{r} = L$ is

$$\frac{a}{b}\left(2 + \frac{a}{b}\right) < \left(\frac{1}{\gamma z} - 1\right)L^{a+b} \Big/ A.$$

As in Example 1, we see that $a \gg b$ forces full protection whereas $a \ll b$ forces minimum protection. □

6. Protection in a Multiple-Firm Setting

We do not attempt in this paper a comprehensive extension of the foregoing single-firm model to a multiple-firm setting, but some of the basic issues that arise in multiple-firm situations can be easily sketched.

If firms' software offerings are close substitutes, their products compete for sale and also compete for pirates. Consider, for example, a differentiated duopoly in which firm A chooses to employ software protection policies and its competitor, firm B, does not.

In the monopoly case an increase in A's protection drives some of A's pirates to either purchase the program or do without. With competition, pirates have two additional options: they may turn to pirating or buying B's program instead. The existence of these options will attenuate A's increase in legitimate demand induced by its increase in protection. That is, firm A's effective λ is reduced by the presence of a competitor. *The closer the net value of pirating (or buying) B's program comes to the net value of pirating A's program, the more B's presence acts to rob A of the benefits of protection.*

Turning to the role of a network externality, increased protection reduces A's user base, but B's user base may actually rise as the result of A's action. If there is a network externality, these adjustments in user bases act to reduce the perceived value of A's program and increase the value of B's. Of course, the shift in relative program values will itself induce an additional shift in buying behavior. Consequently, the presence of a positive network externality amplifies the deleterious effects of competition on unilateral increases in protection.

Thus, whereas both firms might benefit from industry-wide protection policies, neither may be able unilaterally to adopt a protection policy. This result may explain the pressure within the software industry (largely expressed via trade associations) for cross-firm *coordinated and uniform* protection policies. In addition, an interesting strategic possibility is raised: nonprotecting firms may overstate the extent and magnitude of the "piracy problem" in order to either gain from rivals' mistake adoption of protection or to encourage common industry-wide action.

7. Conclusion

Our objective in this paper was to examine software piracy protection policies. In the simplest setting we found that increased protection raised both price and profit. However, with a network externality present, the model developed in this paper suggests that, even when substantial piracy exists, it is possible for increased protection to harm both the manufacturer and the buying customer. The core of the result lies in recognizing that protection drives some would-be pirates to forego obtaining the product, thereby diminishing the total number of program users. Although the demonstrations developed in this paper depend upon a particular model, the existence of these phenomena is not restricted to the particular setting analyzed.

Increased protection acts to raise the cost of pirating, causing some pirates to buy and others to do without the product. Those who decide to do without represent a reduction in the user base. With a network externality present, the smaller user base produces a lower program value and may, therefore, actually reduce profits. In certain regimes (i.e., $X > \gamma z > Y$) increases in protection have the perverse effect of reducing profits, diminishing the user base, and inducing the firm to increase price. Everyone is worse off.

That a policy of no protection might be optimal—even though protection costs nothing—is perhaps surprising. As illustrated in the examples, the policy of minimum protection is best if protection acts chiefly to push pirates out of the user base rather than to move pirates into the buying camp, and if the network externality is strong. Given the nonintuitive character of this result, it may be worthwhile to discuss the actual product-market situations that tend to make a no-protection policy optimal.

Drawing from the analysis in the introductory section, the network externality will be strong under three conditions: if the program (1) is complicated and difficult to master, (2) allows or demands extensive user customization, via "macro" programs or other means, or (3) is useful for multiple-user data processing or formal networking. This is the profile of the multi-faceted, high-powered "productivity" packages used for, among other things, spreadsheet analysis, large database assembly and manipulation, complex wordprocessing, and desktop publishing.

The second set of conditions is that protection act chiefly to drive pirates out of the user base rather than change them into buyers. The most extreme form of such a situation would be one in which there were two sub-populations: honest buyers who choose between purchase and doing without and dishonest buyers who choose between piracy and doing without. Clearly, in such a setting protection cannot increase legitimate demand; it can only reduce the user base. Two sub-markets which presently approximate this extreme are the corporate and university markets. Many large corporations, to protect themselves against criminal charges, and to ensure that users have properly functioning and well supported software, have instituted programs to prevent and check software piracy. Universities, by contrast, are hotbeds of software piracy. Yet few of the many program copies used in universities would have been purchased were piracy impossible.

Looking at the reverse situation, full protection can be expected where the network externality is weak or where deterred pirates become buyers rather than do without. These conditions are met by a high value (high consumer surplus) niche product. For example, a program that helps fuel oil companies plan home deliveries might well fall in this category.

Piracy also has implications for producers attempting to expand the size of their installed base by giving gifts of free software to "multiplier" recipients, such as universities and retailers. Piracy is an extremely efficient "gift-giving" method because all of the costs of the gift are borne by the consumer rather than by the producer. Piracy is also reasonably efficient in assuring that the "gift" actually goes to someone with utility for it. Compare piracy to the alternative of mailing free copies to all computer owners. In addition to the producer having to pay the costs of making and distributing these copies, many of the copies would be discarded instead of winding up in the hands of individuals who want the copy badly enough to pay the costs of pirating it.

There are a number of avenues through which our analysis could be extended. One concerns the dynamics of the network effect. Here we have presumed perfect foresight by all customers. However, a more reasonable assumption might be that customers have varying degrees of foresight. In such a setting we expect that the more myopic customers would have a disproportionately large effect on the market. Another direction for extension is obviously a more formal treatment of the competitive dynamics in a multiple-firm setting.

Finally, we note that an interesting ethical issue is posed in those situations in which not attempting to prevent piracy benefits the firm, the buying customer, and industry investment. In such situations the "benefits" of piracy can be captured because a significant sub-population refrains from this illegal activity and makes legitimate purchases. Put somewhat differently, the firm gains both from the externalized network benefits of piracy and the externalized costs of law enforcement. The issue is especially piquant if a producer benefits from the network effects of piracy and, at the same time, uses costly legal proceedings to sanction a few large organizations in which piracy has been observed. The implication is that the type and degree of protection employed is a critical element of a software firm's competitive strategy.[10]

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Appendix A

In this appendix we examine the conditions under which increasing protection raises prices and profits for general demand functions (and absent any network externality). Let the demand for Q units depend on price p and the level of protection technology τ. We assume that $Q_p < 0$ and that $Q_\tau \geq 0$; the latter condition ensures that increased protection never lessens demand. As before, we ignore costs, taking profits $\pi(p, \tau) = pQ(p, \tau)$.

Firms choose price to maximize profits, taking protection technology as a given. The profit-maximizing price $p^*(\tau)$ solves

$$\pi_p = Q + pQ_p = 0, \tag{A-1}$$

and satisfies the second-order condition

$$\pi_{pp} = 2Q_p + pQ_{pp} < 0. \tag{A-2}$$

Our first proposition establishes that in this simple setting, increasing protection never decreases profits.

PROPOSITION A-1. *Optimal profits $\pi(p^*, \tau)$ are nondecreasing in τ.*

PROOF. Using the Envelope Theorem, $\pi_\tau(p^*, \tau) = p^*Q_\tau(p^*, \tau)$. The assumption that $Q_\tau \geq 0$ therefore guarantees that $\pi_\tau \geq 0$. Q.E.D.

Define the price-elasticity of demand

$$\epsilon(p, \tau) = -pQ_p/Q. \tag{A-3}$$

The following proposition asserts that the optimal price p^* increases with protection if the price elasticity of demand (evaluated at p^*) decreases with protection, and vice-versa.

PROPOSITION A-2. *If $\epsilon_\tau(p^*, \tau) < 0$ then $p^*_\tau > 0$; if $\epsilon_\tau(p^*, \tau) > 0$ then $p^*_\tau < 0$.*

PROOF. Working with (A-1), the derivative of $\pi_p(p^*, \tau)$ with respect to τ is

$$p^*Q_{p\tau} + Q_\tau + p^*_\tau(2Q_p + p^*Q_{pp}) = 0. \tag{A-4}$$

The partial derivative of $\epsilon(p, \tau)$ with respect to τ is

$$\epsilon_\tau(p, \tau) = -(pQQ_{p\tau} - pQ_pQ_\tau)/Q^2. \tag{A-5}$$

Using the fact that $Q + p^*Q_p = 0$, (A-5) evaluated at p^* simplifies to

$$\epsilon_\tau(p^*, \tau) = -(p^*Q_{p\tau} + Q_\tau)/Q. \tag{A-6}$$

Using (A-2) and (A-6), (A-4) may be rewritten as

$$p^*\pi_{pp}(p^*, \tau) = Q\epsilon_\tau(p^*, \tau),$$

which establishes the stated relationship. Q.E.D.

With regard to whether ϵ_τ is positive or negative, the following argument is offered. When faced with a price increase, buyers may elect either to do without or become pirates. At higher levels of protection, the option of piracy is blocked for many, so that fewer buyers are lost when price is increased. Hence, we would normally expect to find $\epsilon_\tau < 0$ and, as a consequence, optimal price *rising* with increased protection.

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