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Software Piracy:
An Analysis of Protection Strategies

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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

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[1]Piracy is prohibited by the Computer Software Copyright Act of 1980, 17 U.S.C. sec. 117 (amended by 17 U.S.C. sec. 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, Sec. 3, C-99, (looseleaf).

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.

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 Farrel 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.

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 postpurchase 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 postpurchase costs act like *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 postpurchase 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.

2

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. Past 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]

2   The Decision to Pirate

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 postpurchase 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

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[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.

guarantees, support facilities, trade- in rights, or symbols by which official buyers can be recognized (e.g., properly printed and bound documentation).

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 $\partial c_i / \partial \tau > 0$ 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

BUY	if	p	$\leq \min(v_i, c_i)$
PIRATE	if	c_i	$< \min(v_i, p)$
DO WITHOUT	if	v_i	$< \min(c_i, p)$.

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 non-decreasing 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 non- decreasing 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]

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

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[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.

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

$$\alpha_\tau < 0, \qquad (3)$$

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.*

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 unintendedly 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 The Decision to Pirate With a Network Externality

Given a network externality, the value of the program to each user increases 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 postpurchase 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

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

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 the greater is the "competitive supply" of such individuals. Finally, an increase in the pirating population is thought within the industry to affect individuals' beliefs regarding the ethics of piracy—the more 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:

BUY	if	p	$\leq \min(c_i - g_i(U), v_i + f_i(U))$
PIRATE	if	$c_i - g_i(U)$	$< \min(p, v_i + f_i(U))$
DO WITHOUT	if	$v_i + f_i(U)$	$< \min(c_i - g_i(U), p)$.

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 the 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 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.

5 Protection and Network Externalities

How does the number of users vary with the network externality? 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.

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

$$\hat{U} = \frac{z - \omega p}{1 - \gamma(z - \omega p)}. \tag{5}$$

Substitution of (5) into (**??**) and (**??**) gives the rational equilibrium number of pirates and buyers:

$$\hat{S} = \frac{(\alpha - \omega)p}{1 - \gamma(z - \omega p)} \tag{6}$$

$$\hat{Q} = \frac{z - \alpha p}{1 - \gamma(z - \omega p)}. \tag{7}$$

Profits are maximized by the price p^* which sets marginal revenue equal to zero. Working with (7), p^* solves

$$\alpha\phi p^2 + 2\alpha p - z = 0, \tag{8}$$

where $\phi = \gamma\omega/(1 - \gamma z)$. Given (**??**), $\phi \geq 0$. The smaller root of (8) is negative and the larger root is[7]

$$p^* = \left[\frac{1}{\phi^2} + \frac{z}{\alpha\phi}\right]^{\frac{1}{2}} - \frac{1}{\phi}. \tag{9}$$

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

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

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

$$\lambda = -\frac{\alpha_\tau/\alpha}{\omega_\tau/\omega}, \tag{10}$$

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 then relatively more do without (leaving the user base).

Proposition 3 *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.*

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

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

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 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? The 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

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

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.

6   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 piracy, 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 actually 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 is costless—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 non-intuitive 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

11

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.

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