Information Goods Pricing and Copyright Enforcement: Welfare Analysis

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We consider how the government should set the fine for copying, tax on copying medium, and subsidy on legitimate purchases, whereas a monopoly publisher sets price and spending on detection. There are two segments of potential software users—ethical users who will not copy, and unethical users who would copy if the benefit outweighs the cost. In deciding on policy, the government must consider how the publisher adjusts price and detection to changes in the fine, tax, and subsidy. Our key welfare result is that increases in detection affect welfare more negatively than price cuts. We also show that the tax is welfare superior to the fine, and that a subsidy is optimal. Generally, government policies that focus on penalties alone will miss the social welfare optimum.
(*Copyright*; *Pricing*; *Enforcement*)

1. Introduction

Article I, Section 8, Clause 8 of the U.S. Constitution (the Copyright and Patent Clause) provides that, "The Congress shall have power . . . To promote the progress of science and useful arts, by securing for limited times to authors and inventors the exclusive right to their respective writings and discoveries." In developing copyright law, Congress has been interpreted as always seeking to strike a balance between the public interest in access to information and financial incentives for authors and composers.[1]

A major concern for producers of computer software, motion pictures, recorded music, and other information goods is piracy, the making of unauthorized copies of copyrighted works. Claiming massive losses to piracy, producers of information goods have repeatedly pressed the U.S. Congress to expand the scope of criminal sanctions and raise the penalties for copyright infringement.[2] Responding to industry sentiment, Congress passed the No Electronic Theft Act in 1997 and the Digital Millennium Copyright Act in 1998. With regard to Europe, the business software industry has called for "harmonised criminal penalties at a level commensurate with other forms of theft" (Business Software Alliance 2000).

The recorded music industry has emphasized another instrument of government policy—taxation of copying equipment and media. In 1992, Congress passed the Audio Home Recording Act to levy a tax on digital audio technology recording equipment and media. In 1997, Canada amended the Copyright Act to impose levies on all blank analog and digital audio recording media. Levies on recording equipment and media are common throughout Europe. In April 2000, the German copyright society, VG Wort, sued Fujitsu

[1]The following review of U.S. copyright law is based on the *Harvard Law Review* (1999).

[2]For instance, in 1999, business software publishers claim to have lost \$12 billion (International Planning and Research Corporation 2000), while recording studios claimed losses exceeding \$4 billion (International Federation of the Phonographic Industry 2000).

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Siemens and other computer manufacturers for levies on sales of computers (*Wall Street Journal*, April 9, 2001).

The third instrument of government policy relevant to markets for information goods is a subsidy on purchases of the legitimate item. This has been advocated as a way to discourage copying of databases (Tyson and Sherry 1997), as well as books (de Freitas 1994).

How should the government use its various policy instruments—penalties, taxes, and subsidies—in the market for an information good? This question is especially difficult because the government, in setting policy, must consider how legitimate producers will adjust their pricing and enforcement in response to government policy. To our knowledge, ours is the only comprehensive analysis of copyright enforcement and pricing of an information good that takes account of the interactions among government policy, the producer's business strategy, and users' choices.

In our model, the government sets the penalty, tax, and subsidy for a copyrighted information good, which we take to be computer software. The monopoly publisher sets a price and spending on detection. There are two segments of potential software users: ethical users who will not copy, and unethical users who would copy if the benefit outweighs the cost. Potential users choose among buying the legitimate product, copying the item and risking detection, and not using the software. We apply the model to address the impact of government policy on the publisher's price and detection expenditure, and then analyze the consequences for social welfare. Following the previous literature (Novos and Waldman 1984, Johnson 1985, Gopal and Sanders 1998), we take a utilitarian approach to welfare. This takes into account benefits from usage of both legitimate and pirated items.

We find that the publisher will adjust price and detection to the government's policy in complex ways, depending on whether the publisher chooses to allow copying or engage in limit pricing to deter copying. For instance, when copying occurs, an increase in the tax would directly lead the publisher to raise the price. However, the tax increase would also lead the publisher to reduce detection, which would indirectly induce the publisher to cut the price.

We derive three welfare results. Our key result is that whereas the publisher may consider a price reduction and an increase in detection as simply two alternative ways to boost legitimate demand (Gopal and Sanders 1998), the two changes have qualitatively different welfare effects. Society prefers the publisher to manage piracy through lower prices rather than increased enforcement.

Next, we show that, where copying occurs, a tax on the copying medium is welfare superior to the penalty. Compared with the penalty, the tax has less effect on the legitimate price and leads the publisher to reduce rather than raise spending on detection. This finding provides theoretical support for the levies imposed by the United States, Canadian, and European governments.

Finally, we show that it is optimal to subsidize legitimate purchases. Besides the standard reason that a monopoly restricts sales below the economically efficient level, the other reason is that the subsidy leads the publisher to reduce spending on detection.

Our paper proceeds as follows. Section 2 reviews the prior literature, §3 introduces the model setting, and §4 analyzes the behavior of potential users. In §5, we characterize the publisher's strategy and how it varies with government policy. In §6, we discuss the optimal policy. Section 7 applies an example to illustrate the publisher's choice between limit pricing and allowing copying. Section 8 discusses limitations and directions for future research.

2. Literature Review

Previous research on piracy and copyright enforcement can be broadly grouped into three themes. The first theme has been the impact of piracy on the legitimate producer's sales and profit. The legitimate demand may increase with buyers' supply of copies to others (Liebowitz 1982 and 1985, Besen and Kirby 1989, Varian 2000) and sharing among peer users (Gopal and Sanders 1997, Bakos et al. 1999). Piracy may also raise the legitimate demand by enabling the producer to credibly commit to not reduce its price in the future (Takeyama 1997) and to drive out potential legitimate competitors (Jacob and Ben-Shahar 2000).[3]

[3]See Besen and Raskind (1991) for a general introduction to the law and economics of intellectual property, Landes and Posner (1989) on the economics of copyright law, and Polinsky and Shavell (2000) on the economics of enforcement generally.

The second theme has been the impact of piracy on social welfare and the optimal government policy. Generally, the impact of piracy on social welfare is complex. Tougher copyright laws would increase the production and variety of information goods, while, on the other hand, reducing the utilization of information that has already been created (Novos and Waldman 1984, U.S. Congress, Office of Technology Assessment 1989). One policy recommendation is unambiguous: the government's incentive to enforce laws against piracy increases with the size of the domestic software industry (Gopal and Sanders 1998). Johnson (1985) discussed the implications of a tax on copying and subsidy for legitimate purchases, but did not analyze how a publisher would adjust its strategy in response to the government policy.

The third theme has been how the legitimate producer should respond to piracy both through conventional business strategy, specifically pricing, and instruments particularly directed at piracy—copy protection and enforcement. Under particular conditions, enforcement is more cost-effective than copy protection (Gopal and Sanders 1997). Wide enforcement may be better than enforcement targeted at high-value users (Harbaugh and Khemka 2001). Whereas most research has focused on end-user piracy, Banerjee (2003) considered enforcement against commercial piracy.

Within the third theme, a major strand has been to consider network effects in demand: piracy increases the user base, benefits legitimate users through network effects, and so raises the demand for the legitimate product (Conner and Rumelt 1991, Takeyama 1994, Shy and Thisse 1999). In the presence of network effects, the producer may deliberately facilitate piracy by choosing a low degree of copy protection for its product.

By contrast with the previous research, we consider three instruments of government's policy—fines, taxes, and subsidies—and we explicitly consider how the publisher will adjust its business strategy in response to government policy. Furthermore, whereas previous research did not distinguish between ethical and unethical users, our analysis takes account that some potential users are ethical and would never engage in copying.[4] Accordingly, in deciding on price and enforcement expenditure, the producer must take account of government policy, and balance marginal profits from ethical and unethical users. For simplicity, we do not consider the producer's decision on copy protection of the software.

3. Model

Our analysis considers the impact of three instruments of government policy on the market for a piece of software that has already been produced. The three policy instruments have been variously advocated for copyrighted products. One is a fine, $f \geq 0$, that a user detected to have copied the software must pay to the government.[5] Another is a tax, $t \geq 0$, on the copying medium. (For simplicity, we assume that each unit of the copying medium may be used to make only one copy of the legitimate software.) The third policy instrument is a subsidy, $s \geq 0$, on legitimate purchases.

There is a single profit-maximizing publisher that sets a price, p, for the legitimate product. The publisher is aware that potential users may copy the software, and it may monitor and bring enforcement action against those who make copies. Let $\mu \in [0,1]$ represent the rate at which a user who makes a copy is detected and prosecuted. The cost of detection is $C(\mu)$, where the function $C(\cdot)$ is convex and satisfies $C(0) = 0$, $C'(0) = 0$, and the relevant second-order condition.[6] At the

[4]In earlier work (Chen and Png 1999), we studied a setting with only ethical users and considered only fines.

[5]Realistically, a person detected to have copied may also be subject to civil remedies, including being required to purchase the legitimate product (Gilman 1992). However, such civil remedies alone are not likely to deter piracy. Indeed, over the 20th century, the U.S. Congress was repeatedly persuaded that civil remedies were insufficient, and so enhanced and widened the scope of criminal penalties (*Harvard Law Review* 1999). Accordingly, our analysis focuses on deterrence through criminal fines.

[6]The publisher must monitor the entire population of potential users to distinguish copiers from legitimate buyers. Below, we characterize the potential user population in terms of a probability distribution, hence the total population is one. Accordingly, the cost of detection for the entire population is $C(\mu) \times 1 = C(\mu)$.

time of the publisher's decision, the software has already been developed, hence the development cost is sunk. For simplicity, we assume that the fixed and marginal costs of producing the software are zero.

Potential software users divide into two segments. We label the proportion, e, who will not copy software under any circumstances as "ethical," and the remaining fraction $1 - e$ who copy when the benefit outweighs the cost as "unethical."[7]

Within each segment, potential users are characterized by their benefit, v, from the software. Their benefits are uniformly distributed on the range [0,1], or equivalently, the demand curve is linear. The assumption of linear demand underlies analytical research into choice between legitimate and illicit alternatives in information systems (Gopal and Sanders 1998) and marketing (Ahmadi and Yang 2000). Following the previous research, we also assume linear demand for analytical tractability.[8] All users are risk neutral.[9]

Each ethical user maximizes her net expected benefit by choosing between buying the legitimate product and not using. Each unethical user maximizes her net expected benefit by choosing among buying the legitimate product, copying the software and possibly being detected, and not using. The only cost of copying is the tax (if any) on the copy medium. When a user is indifferent between buying and copying, she chooses to buy the legitimate product, and when a user is indifferent between buying or copying and not using the software, she chooses to buy or copy.

To summarize, the ethical proportion, e, and detection cost, $C(\cdot)$, are exogenous. The following is the sequence of choices. The government sets the fine, f, tax on copying medium, t, and subsidy on legitimate purchases, s. Given the exogenous parameters and the government's policy, the publisher sets its price, p, and detection rate, μ. Then, given the exogenous parameters, the government's policy, and the publisher's strategy, each ethical user decides whether to buy, and each unethical user chooses among buying, copying, and not using.

4. User Behavior

Let us analyze the choices of people in the unethical segment. Consider an unethical user with value v. If she buys the legitimate product, she must pay the price, p, to the publisher and will receive a subsidy, s, from the government. Hence, her net benefit would be

$$v - p + s. \tag{1}$$

If the unethical user copies the item, she must incur the tax, t, on the copying medium. She will be detected with probability μ, and then will be deprived of the (illegally copied) software and must pay the fine, f. Hence, her net expected benefit from copying is

$$[1 - \mu]v - \mu f - t.$$

If she does not use the software, her net benefit is simply zero.

The unethical user will buy the legitimate product under the following two conditions. First, buying must provide more net benefit than copying, $v - p + s \geq [1 - \mu]v - \mu f - t$, or $v \geq v_2$, where

$$v_2 \equiv \frac{p - s - t}{\mu} - f. \tag{2}$$

Second, buying must provide more net benefit than not using, $v - p + s \geq 0$, or

$$v \geq p - s. \tag{3}$$

She will copy the software under the following two conditions. First, copying must provide more net benefit than buying, $[1 - \mu]v - \mu f - t > v - p + s$, or

$$v < v_2. \tag{4}$$

Second, copying must provide more net benefit than not using, $[1 - \mu]v - \mu f - t \geq 0$, or

[7]Individuals place more emphasis on the teleological process in forming ethical judgments, hence are more likely to copy software if the expected negative consequences of being caught are less than the expected benefits (Thong and Yap 1998). A sample of 340 business students rated "software too expensive" as the most important reason for copying software (Cheng et al. 1997).

[8]Our key welfare result—that the publisher overspends on detection—holds with any distribution of benefits with a hazard rate that increases sufficiently fast.

[9]In our analysis, all buyers are end-users. By contrast, Liebowitz (1982 and 1985) and Varian (2000) focus on the demand of intermediaries, such as libraries, and emphasize that their demand is derived from their supply of copying.

$$v \geq v_1 \tag{5}$$

where

$$v_1 \equiv \frac{\mu f + t}{1 - \mu}. \tag{6}$$

In the ethical segment, each potential user chooses between buying, which provides net benefit (1), and not using, which provides zero net benefit. Hence, she will buy under condition (3). Table 1 displays the net benefits of the potential users from each of their available choices.

As we emphasized in the Introduction, the potential users' pattern of choice among buying, copying, and not using depends on the government policy and publisher's strategy. Specifically, in our model, the choices depend on f, t, s, p, and μ. We will now derive a necessary condition for some users to make copies.

LEMMA. *Copying will occur if and only if $v_2 > v_1$, or*

$$p > s + \frac{t + \mu f}{1 - \mu}. \tag{7}$$

PROOF.

Necessity. By (4) and (5), it is necessary that $v_1 < v_2$ for some unethical users to engage in copying. By (2) and (6), the condition $v_1 < v_2$ is equivalent to (7).

Sufficiency. By (6), $v_1 > 0$, hence the condition $v_1 < v_2$ implies that a positive weight $(v_2 - v_1)$ of users make copies. □

In the case where the government's policy and publisher's strategy satisfy (7), copying will occur. Then, there would be two margins of choice among unethical users. At the lower margin, v_1, an unethical user is indifferent between copying and not using. Her benefit from the software obviously affects her decision to copy rather than not use: a person with a relatively low benefit would gain less by making a copy. The other margin is v_2, in which an unethical user is indifferent between buying the legitimate product and making a copy. Her benefit from the software affects her decision to copy rather than buy because, in the event of detection, she cannot enjoy the item—a person with a relatively high benefit will lose more from this possibility.

Table 1 **User's Net Benefits**

	Ethical	Unethical
Proportion	e	$1 - e$
Buy	$v - p + s$	$v - p + s$
Copy	NA	$[1 - \mu]v - \mu f - t$
Do not use	0	0

Accordingly, as illustrated in Figure 1, unethical users divide into three groups. Those with sufficiently high benefit, $v \geq v_2$, buy the software. The bold segment from the quantity of 0 to $1 - v_2$ represents their demand (benefit). Hence, the demand of unethical users for the legitimate product is

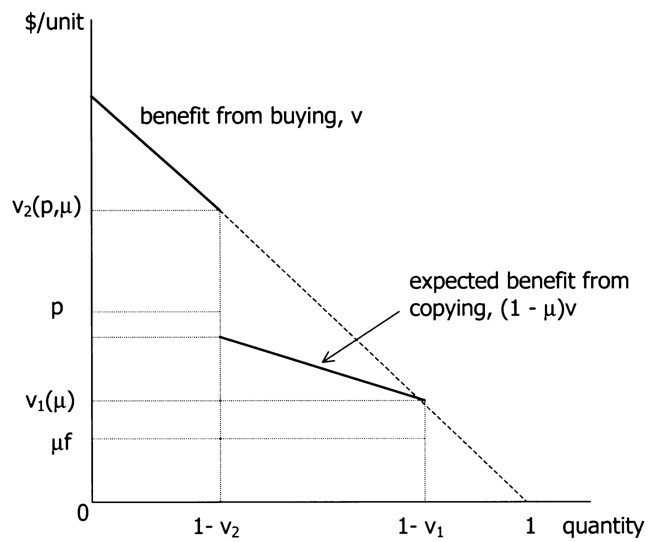
$$\int_{v_2}^{1} dv = 1 - v_2. \tag{8}$$

The unethical users with intermediate benefit, $v \in [v_1, v_2]$, copy the software, and are represented in Figure 1 by the bold segment from the quantity of $1 - v_2$ to $1 - v_1$. Analytically, the demand for copying is $\int_{v_1}^{v_2} dv = v_2 - v_1$.

Finally, the unethical users with low benefit, $v < v_1$, do not use the software. Hence, they have no demand curve in Figure 1.

Next, we derive the demand of ethical users. This is independent of the demand of unethical users and does not depend on condition (7). Those ethical users who derive benefit that exceeds the price net of the

Figure 1 **Unethical User: Benefit**



subsidy, $v \geq p - s$, buy the legitimate item, whereas those with low benefit, $v < p - s$, do not use it. Hence, the demand of ethical users for the legitimate product is

$$\int_{p-s}^{1} dv = 1 - p + s. \tag{9}$$

In the case where the government's policy and publisher's strategy satisfy

$$p \leq s + \frac{t + \mu f}{1 - \mu}, \tag{10}$$

there will be no copying. All unethical users with benefit, $v \geq p - s$, buy the legitimate item, whereas those with low benefit, $v < p - s$, do not use it. Accordingly, in this case, the demand of unethical users for the legitimate product is identical to that of ethical users, and both are described by (9).

5. Publisher's Strategy

As observed previously, the potential users' patterns of choice depend in part on the publisher's strategy. We now analyze the publisher's choice of price and detection rate in three cases: where there is no threat of copying, where the publisher engages in limit pricing to deter copying, and where there is copying.

5.1. No Copying Threat

In this case, the government's policy satisfies

$$s + 2t > 1. \tag{11}$$

Below, we show that, under this condition, even if the publisher spends nothing on detection ($\mu = 0$), the constraint (10) is not binding and unethical users do not copy. Accordingly, the publisher will set $\mu = 0$.

Since the publisher spends nothing on detection, its profit is its revenue from sales of the legitimate product. By (9), sales to ethical users are $1 - p + s$. Unethical users do not copy, hence sales to unethical users are also $1 - p + s$. Thus, the publisher's total sales are $Q_n = e[1 - p + s] + [1 - e][1 - p + s] = 1 - p + s$, and its total revenue and profit are pQ_n.

Thus, we can characterize the publisher as choosing the price, p, to maximize

$$\Pi_n = p[1 - p + s], \tag{12}$$

subject to $p \geq 0$. The profit function is concave in p. By the first-order condition for (12), the profit-maximizing price is

$$p = \frac{1 + s}{2}. \tag{13}$$

This proves:[10]

Proposition 1(a). *Suppose that there is no threat of copying. The profit-maximizing price, $p = [1 + s]/2$, is increasing in the subsidy, s, and does not change with the fine, f, or tax, t. The profit-maximizing detection rate, $\mu = 0$.*

In this case, the publisher need not worry about copying, hence does not monitor and need not bother about the fine and tax. The publisher maximizes profits like a textbook monopoly.

5.2. Limit Pricing

In this case, the government policy does not satisfy condition (11), whereas (10) binds. The publisher engages in limit pricing, setting the price just low enough and the detection high enough that (10) binds and unethical users do not copy.

The publisher's profit is its revenue from sales of the legitimate product less the cost of detection. Because there is no copying, the publisher's total sales are $Q_\ell = 1 - p + s$, and its total revenue is pQ_ℓ. The publisher's profit is revenue less the detection cost, $\Pi_\ell = pQ_\ell - C(\mu)$.

Thus, we can characterize the publisher as choosing the price, p, and detection rate, μ, to maximize

$$\Pi_\ell = p[1 - p + s] - C(\mu), \tag{14}$$

subject to (10), $p \geq 0$, and $\mu \in [0,1]$.

The profit function is concave in p and μ. Because (10) binds, we have

$$\mu = \frac{p - s - t}{p - s + f}. \tag{15}$$

Hence, by (14), the profit is

$$\Pi_\ell = p[1 - p + s] - C\left(\frac{p - s - t}{p - s + f}\right).$$

[10]Substituting (13) and $\mu = 0$, a sufficient condition for the constraint (10) not to bind is (11).

The first-order condition is

$$2p = 1 + s - C'\left(\frac{p - s - t}{p - s + f}\right)\frac{f + t}{[p - s + f]^2}. \quad (16)$$

In the following result, we report how the publisher's profit-maximizing strategy varies with the government's policy instruments.

Proposition 1(b). *Suppose that the publisher engages in limit pricing and the profit-maximizing strategy satisfies the second-order condition. The price, p, increases more slowly than the subsidy, s, in the sense that $dp/ds < 1$. The detection rate, μ, is decreasing in the subsidy, s.*

Proof. Please refer to the Appendix. □

Proposition 1(b) shows that the publisher absorbs part, but not all, of the government subsidy: when the subsidy rises by \$1, the publisher raises the price, but by less than \$1. The subsidy encourages potential users to switch from copying to buying, thus reducing the publisher's marginal return from detection. Hence, the publisher reduces expenditure on detection.

5.3. Copying

In this case, the government policy does not satisfy (11) but does satisfy (7), and hence, some unethical users make copies. By (9), the publisher's sales to ethical users are $1 - p + s$, and by (8), its sales to unethical users are $1 - v_2$. Accordingly, its total sales are

$$Q_c = e[1 - p + s] + [1 - e][1 - v_2], \quad (17)$$

and its total revenue is pQ_c. The publisher's profit is revenue less the detection cost, $\Pi_c = pQ_c - C(\mu)$.

Thus, we can characterize the publisher as choosing the price, p, and detection rate, μ, to maximize profit,

$$\Pi_c = e\, p[1 - p + s] + [1 - e]p[1 - v_2] - C(\mu). \quad (18)$$

subject to (7), $p \geq 0$, and $\mu \in [0,1]$.

The first-order condition with respect to p is

$$\frac{\partial \Pi_c}{\partial p} = e[1 + s - 2p] + [1 - e]\left\{1 - v_2 + p\left[-\frac{\partial v_2}{\partial p}\right]\right\} = 0,$$

which, by substituting from (2), simplifies to

$$p = \frac{[1 + es]\mu + [1 - e][s + t + f\mu]}{2[e\mu + 1 - e]}. \quad (19)$$

The first-order condition with respect to μ is

$$\frac{\partial \Pi_c}{\partial \mu} = [1 - e]p\left[-\frac{\partial v_2}{\partial \mu}\right] - C'(\mu) = 0,$$

which, by substituting from (2), simplifies to

$$[1 - e]p[p - s - t] = \mu^2 C'(\mu). \quad (20)$$

This states essentially that the publisher should equalize the marginal revenue from detection with the marginal cost.

By analyzing conditions (19) and (20), we derive the following result.

Proposition 1(c). *Suppose that the publisher allows copying to occur and the profit-maximizing strategy satisfies the second-order condition. The price, p, is increasing in the fine, f, and increases more slowly than the subsidy, s, in the sense that $dp/ds < 1$. The detection rate, μ, is increasing in the fine, f, and decreasing in the tax, t, and the subsidy, s.*

Proof. Please refer to the Appendix. □

To appreciate Proposition 1(c) intuitively, consider Figure 2, which illustrates the profit-maximizing strategy. In the figure, FOCp depicts the first-order condition (19). It slopes upward, as pricing is a *complement* to detection, and is convex. The locus FOCμ depicts the first-order condition (20). It slopes upward, as detection is a *complement* to pricing, and is concave. The two loci cross twice. By the second-order condition, the

Figure 2 Copying: Publisher's Strategy

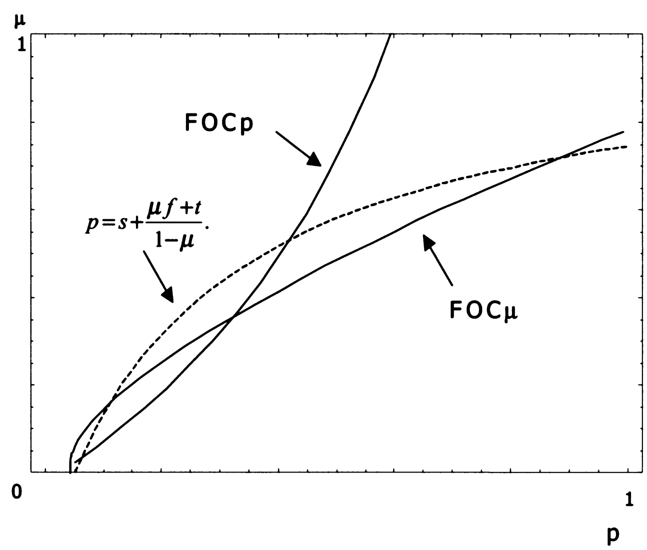


Table 2 Publisher's Strategy

	No Copying Threat			Limit Pricing			Copying		
	f	*t*	*s*	*f*	*t*	*s*	*f*	*t*	*s*
$\frac{dp}{d..}$	0	0	1/2	?	?	<1	>0	?	<1
$\frac{d\mu}{d..}$	0	0	0	?	?	<0	>0	<0	<0

publisher's profit-maximizing strategy, (p,μ), is represented by the crossing point with the higher price and detection rate.[11]

Referring to Figure 2, consider an increase in the fine, f. By (19), the locus FOCp would shift to the right, whereas by (20), the locus FOCμ would remain unchanged. Hence, the publisher would raise both the price and detection rate. Intuitively, when the fine is higher, copying is less attractive, so the publisher's direct response would be to raise the price. The higher price would raise the publisher's marginal return from detection, hence the publisher would raise detection.

Next, consider an increase in the tax, t. Both the loci FOCp and FOCμ shift to the right. From Figure 2, it is not clear how the publisher would adjust price and the detection rate. In the Appendix, we prove analytically that the detection rate, μ, would be lower. Intuitively, the tax increase would reduce the publisher's marginal return from detection, hence *directly* lead the publisher to reduce detection. The tax increase would also lead the publisher to raise the price, and so *indirectly* induce an increase in detection since detection is complementary with price. However, the direct effect outweighs the indirect effect, and so, on balance, the tax increase leads the publisher to reduce detection. The comparative statics with respect to the subsidy are similar to those for the tax.

However, we could not prove an unambiguous result for the effects of changes in the tax and subsidy on the price. In the case of the tax, our difficulties were as follows. An increase in the tax would *directly* lead the publisher to raise the price. The tax increase would also lead the publisher to reduce detection. The reduced detection would *indirectly* induce the publisher to cut the price. However, we could not identify conditions under which the direct effect would outweigh the indirect effect. We encountered a similar difficulty in analyzing the impact of a change in the subsidy.

Table 2 summarizes how the publisher's strategy depends on government policy.

[11]Generally, the profit function is not concave in p and μ. Hence, the first-order conditions are necessary, but not sufficient, for a profit maximum. Indeed, as Figure 2 shows, the first-order conditions may intersect more than once.

6. Welfare

Novos and Waldman (1984) emphasized that illegal copying affects social welfare in three ways. First, it reduces publishers' incentive to produce intellectual property ("underproduction"). Second, some users who value the product at more than the publisher's marginal cost, but less than the price, get to consume the product ("improved utilization"). In our setting, the software has already been created; hence, underproduction is not an issue. Furthermore, the marginal cost of production and cost of copying are both zero; hence, inefficient production does not arise. We focus on improved utilization and another welfare consequence of copying—the publisher's expenditures on detection.

Following the previous literature analyzing the welfare consequences of copying (Novos and Waldman 1984, Johnson 1985, Gopal and Sanders 1998) and the economics of enforcement generally (Polinsky and Shavell 2000), we adopt a utilitarian approach. This takes account of benefits from usage of both legitimate and pirated items. Then, social welfare is the sum of the net expected benefit among the ethical and unethical segments, the publisher's profit, and the government's net revenue.

6.1. No Copying Threat

The net benefit among the ethical users is

$$\int_{p-s}^{1} [v - p + s]dv, \tag{21}$$

which, since there is no copying, is also the net benefit among unethical users. Hence, the net expected benefit of ethical and unethical users is

$$e \int_{p-s}^{1} [v - p + s]dv + [1 - e] \int_{p-s}^{1} [v - p + s]dv = \int_{p-s}^{1} [v - p + s]dv. \quad (22)$$

The publisher's profit is given by (12). The government's revenue is

$$R_n = -es \int_{p-s}^{1} dv - [1 - e]s \int_{p-s}^{1} dv = -s \int_{p-s}^{1} dv. \quad (23)$$

Combining (22), (12), and (23), and substituting from (13), social welfare is

$$W_n = \int_{p-s}^{1} v\, dv = \frac{1}{8} [4 - [1 - s]^2]. \quad (24)$$

Notice that the price paid by users to the publisher and government subsidy to users are transfer payments, and hence do not appear in social welfare. Social welfare simplifies to the benefits of ethical and unethical users. The government seeks to maximize welfare (24) subject to (11).

6.2. Limit Pricing

With limit pricing, there is no copying, hence the net expected benefit of ethical and unethical users is also given by (22). The publisher's profit is given by (14). Because there is no copying, the government's revenue is also given by (23).

Combining (22), (14), and (23), and substituting from (15), social welfare is

$$W_\ell = \int_{p-s}^{1} v\, dv - C\left(\frac{p - s - t}{p - s + f}\right) = \frac{1}{2} [1 - [p - s]^2] - C\left(\frac{p - s - t}{p - s + f}\right). \quad (25)$$

Social welfare simplifies to the benefits of ethical and unethical users, less the publisher's detection cost. The government seeks to maximize welfare (25) subject to (16).

6.3. Copying

In this case, unethical users do copy, and their net expected benefit, including the benefits from legitimate and pirated items, is

$$\int_{v_2}^{1} [v - p + s]dv + \int_{v_1}^{v_2} [[1 - \mu]v - t - \mu f]dv. \quad (26)$$

As in the other cases, the net benefit among the ethical users is (21). Hence, the net expected benefit of ethical and unethical users is

$$e \int_{p-s}^{1} [v - p + s]dv + [1 - e]\left\{\int_{v_2}^{1} [v - p + s]dv + \int_{v_1}^{v_2} [[1 - \mu]v - t - \mu f]dv\right\}. \quad (27)$$

The publisher's profit is given by (18). The government's revenue is

$$R_c = -es \int_{p-s}^{1} dv + [1 - e]\left[-s \int_{v_2}^{1} dv + [t + \mu f] \int_{v_1}^{v_2} dv\right]. \quad (28)$$

Combining (27), (18), and (28), social welfare is

$$W_c = e \int_{p-s}^{1} v\, dv + [1 - e] \int_{v_2}^{1} v\, dv + [1 - e] \int_{v_1}^{v_2} [1 - \mu]v\, dv - C(\mu).$$

Note that the price paid by users to the publisher, government subsidy to users, and taxes and fines paid by users to the government are all transfer payments; hence, they do not appear in social welfare. Social welfare simplifies to the benefits of ethical and unethical users, less the publisher's detection cost:

$$W_c = \frac{1}{2} \{1 - e[p - s]^2 - [1 - e][\mu v_2^2 + [1 - \mu]v_1^2]\} - C(\mu). \quad (29)$$

The government seeks to maximize welfare subject to (7), (19), $p \geq 0$, (20), and $\mu \in [0,1]$.

As rightly observed by Gopal and Sanders (1998, p. 386), A "software publisher can reduce piracy through increased deterrent controls or by reducing market price." This observation leaves open the question of the *social* trade-off between price and detection. We now show that society prefers that the publisher attack piracy by reducing the price.

Referring to (26), an increase in detection will reduce the expected benefit of unethical users who make copies (those with $v \in [v_1, v_2)$). Consequently, the increase in detection will lead some unethical users to switch from copying to not using, raising the lower margin, v_1. By (6), at this margin, $[1 - \mu]v > 0$; hence, the switch also implies a reduction in welfare. The reduction in benefit among those who continue to copy and among those who switch to not using does not benefit the publisher. These changes cause a loss to society with no countervailing gain to the publisher.

The increase in detection will persuade some unethical users to switch from copying to buying the legitimate item, so causing the upper margin, v_2, to fall. This switch will increase welfare by increasing the user's (expected) benefit from $[1 - \mu]v$ to v. The switch also benefits the publisher by raising the demand for the legitimate product. The increased detection does not affect ethical users.

By contrast, referring to (26), a price cut does not affect the expected benefit of unethical users who make copies. The price reduction induces some unethical users to switch from copying to buying, without an adverse impact on the relatively low-value users who continue to make copies. Furthermore, the price reduction induces more ethical users to buy the product. In this sense, pricing is a more socially responsible way for the publisher to manage copying.

This contrast is the essential idea underlying the following result, which shows that the publisher chooses excessive detection. We stress that the result is fairly general in the sense that it applies to *all* prices and detection rates, and not just profit-maximizing strategies. The result holds for any distribution of benefits with a hazard rate that increases sufficiently fast and not just the uniform distribution.

Proposition 2. *Suppose that copying occurs. Then, the price and detection rate can be reduced in a way that raises welfare without affecting the publisher's sales.*

Proof. Please refer to the Appendix. □

Proposition 2 shows that a lower price can substitute for detection, so increasing welfare without affecting the publisher's sales. While the publisher may view price and detection as substitute ways to manage copying, detection has a negative impact on social welfare.

The substitution of a lower price for less detection in Proposition 2 leaves the publisher's sales unchanged. The substitution, however, might reduce the publisher's profit. We now contend that this effect is so not important in practice. The reason is that, if the publisher is maximizing profit, its strategy will satisfy

$$\frac{\partial \Pi_c}{\partial p} = \frac{\partial \Pi_c}{\partial \mu} = 0,$$

hence any slight variation of p and μ will have a second-order effect on the publisher's profit but a first-order effect on welfare.

It is important to emphasize that Proposition 2 does not concern the usual inefficiency of a monopoly setting a price above marginal cost. Rather, the proposition reveals that, given the usual monopoly inefficiency, the publisher tends to overuse detection relative to pricing.

6.4. Optimal Policy

Generally, the optimal instrument balances a direct effect on the ethical and unethical users' benefits, and indirect effects through the publisher's price and detection rate. Our next result shows that the government should use the tax and not the fine.

Proposition 3. *It is optimal to impose a tax on the copying medium and not to impose a fine on users detected to have made copies.*

Proof. Please refer to the Appendix. □

In the case of copying, the intuitive reasoning is twofold. First, the tax has a smaller effect on the price than the fine. In particular, by Proposition 1(c), the fine leads the publisher to raise the price, which reduces the net benefit of both ethical and unethical users. The tax may or may not lead the publisher to raise price, but definitely has a smaller effect on price. Hence, it provides higher welfare.

Second, the tax leads the publisher to reduce detection, which raises welfare by reducing the rate at which unethical users who make copies are deprived of usage and also by reducing detection expenditure. By contrast, the fine encourages the publisher to increase detection, which reduces welfare.

In the case of limit pricing, the intuitive reason is just that the tax has a smaller effect on price than the fine.

Proposition 3 provides theoretical support for the levies imposed by the United States, Canadian, and European governments on recording equipment and media. Realistically, however, the government must weigh the welfare gain in terms of increased usage and reduced spending on detection against the difficulties of implementing the tax where there is no simple relation between copying equipment and media and number of copies. Furthermore, the government must consider other factors beyond the scope of our analysis, including the impact of the tax on those who buy recording equipment and media for (legitimate) purposes other than copying. Owing to these limitations, we interpret Proposition 3 as showing that, within our context, the tax on the copying medium is welfare superior to a fine on users detected to have made copies.

Our final result is that the government should subsidize legitimate purchases.

Proposition 4. *It is optimal to subsidize purchases of the legitimate software.*

Proof. Please refer to the Appendix. □

The intuitive reasoning is two-fold. One part is the textbook monopoly result: the subsidy stimulates legitimate usage. Specifically, in all cases (no copying threat, limit pricing, and copying), the subsidy reduces the net price to the user, hence all users increase their purchases.

The other part of the reasoning relates to detection. In the case of limit pricing, the subsidy leads the publisher to reduce spending on detection, which itself raises welfare. In the case of copying, the subsidy also raises welfare in another way—by reducing detection, it lowers the rate at which unethical users who make copies are deprived of usage.

Realistically, however, the government must weigh the welfare gain in terms of increased usage and reduced spending on detection against the welfare cost of raising the revenue to fund the subsidy. These welfare costs include disincentive effects and administrative costs, which are beyond our scope of analysis.

7. Example

In the general analytical framework, we could not characterize the publisher's choice between limit pricing and allowing copying. We now address this issue in the context of the following example: Let $e = 0$,

$$C(\mu) = \frac{1}{3}c\mu^3, \tag{30}$$

where $c > 0$ parametrizes the marginal cost of detection, and $f = s = 0$. Then, we will show that the publisher's profit-maximizing strategy is as follows:

(i) if $t > 1/2$, no copy threat,

(ii) if $3 - 2\sqrt{2} \le t \le 1/2$, limit pricing,

(iii) if $t < 3 - 2\sqrt{2}$, allow copying if c lies within some interval $\bar{c}(t) < c < \hat{c}(t)$, and limit pricing otherwise.

By (11), if $t > 1/2$, there will be no copy threat, which proves (i). Next, consider t such that $t \le 1/2$. Suppose that the publisher allows copying to occur. Then, substituting (30) in (18), we have

$$\Pi_c = p\left[1 - \frac{p - t}{\mu}\right] - \frac{1}{3}c\mu^3.$$

The first-order conditions with respect to p and μ are

$$\frac{\partial \Pi_c}{\partial p} = 1 + \frac{t}{\mu} - \frac{2p}{\mu} = 0, \tag{31}$$

and

$$\frac{\partial \Pi_c}{\partial \mu} = \frac{p[p - t]}{\mu^2} - c\mu^2 = 0. \tag{32}$$

Let (p^*, μ^*) denote the profit-maximizing strategy. Solving (31) and (32), we have[12]

$$p^* = \frac{\mu^* + t}{2}, \tag{33}$$

and

$$\mu^* = \sqrt{\frac{1 + \sqrt{1 - 16ct^2}}{8c}}. \tag{34}$$

Now we develop necessary conditions for the publisher to allow copying. The solution μ^* exists only if

$$c \le c'(t) \equiv \frac{1}{16t^2}. \tag{35}$$

By Figure 2, given t, FOCp and the constraint (10) cross

[12]As explained previously, generally, there are two solutions to the first-order conditions, but only the solution with the higher μ satisfies the second-order condition.

twice. Let $(\underline{p}(t), \underline{\mu}(t))$ and $(\bar{p}(t), \bar{\mu}(t))$ denote the two crossing points, with $\underline{p}(t) \leq \bar{p}(t)$ and $\underline{\mu}(t) \leq \bar{\mu}(t)$. Solving (33) and (10) for the crossing point, we have

$$\frac{\mu + t}{2} = \frac{t}{1 - \mu},$$

which has distinct real roots if either $t < 3 - 2\sqrt{2}$ or $t > 3 + 2\sqrt{2}$. Because we are focusing on the case of $t \leq 1/2$, the necessary condition is

$$t < 3 - 2\sqrt{2}, \tag{36}$$

which proves (ii).

Given (36), the publisher will allow copying only if c is such that $\underline{\mu}(t) < \mu^* < \bar{\mu}(t)$. Define $\bar{c}(t)$ as the c such that $\mu^* = \bar{\mu}(t)$. By (34), μ^* is decreasing in c, hence the publisher will allow copying only if $c > \bar{c}(t)$. We can show that, if $t \leq 3/\sqrt{2} - 2$, then the publisher will allow copying only if $c < c'(t)$, whereas, if $3/\sqrt{2} - 2 < t \leq 3 - 2\sqrt{2}$, the publisher will allow copying only if $c < \underline{c}(t)$ where $\underline{c}(t)$ is the c such that $\mu^* = \underline{\mu}(t)$.

These conditions are necessary for the publisher to allow copying, but not sufficient. Sufficiency requires that copying be more profitable than limit pricing. We can derive some $\hat{c}(t)$, where $\hat{c}(t) \leq c'(t)$ and $\hat{c}(t) \leq \underline{c}(t)$ such that the publisher chooses to allow copying if and only if $\bar{c}(t) < c < \hat{c}(t)$, which proves (iii). For brevity, we omit the details.

Intuitively, if detection is not costly (c is low), the publisher will set the detection rate high to deter copying. On the other hand, if detection is very costly, the publisher will set both the price and the detection rate very low, and then (10) will bind, and hence copying does not occur. Therefore, copying occurs only when c is in an intermediate range.

8. Conclusion

We derived three welfare results. Our key result is that, whereas the producer of an information good may view pricing and enforcement as substitutes in its strategy, the two variables have quite different welfare implications. By reducing the expected benefit among those who copy, an increase in detection imposes greater social losses than a price cut. Accordingly, society prefers that information goods producers manage piracy through price cuts rather than enforcement.

Our second result is that, if copying occurs, then a tax on the copying medium is welfare superior to a fine on individuals who are detected to have made copies. The tax has less effect on the legitimate price and encourages the publisher to reduce spending on detection. Our final result is that it is optimal to subsidize legitimate purchases. Besides stimulating usage, the subsidy leads the publisher to reduce spending on detection. Generally, then, our analysis suggests that policies focusing on penalties alone while ignoring taxes and subsidies would miss the social welfare optimum.[13]

How sensitive are our results to the modeling assumptions? We first comment on the second-order conditions. In the Appendix, we show that, in the absence of government policy (when $f = t = s = 0$), the second-order conditions in each of the cases simplify to the very reasonable condition that the detection cost be a convex function of the detection rate.

Our key welfare result—that the information goods producer uses excessive enforcement—is robust to two alternative specifications of the model. The same result arises in a setting in which the subsidy is specified as a proportion of the price rather than an absolute value.

We can also prove the key welfare result in a setting where an individual who copies the software and is detected must purchase the legitimate item without the subsidy, but receives a proportionately smaller benefit owing to the inconvenience of enforcement. In this case, the net expected benefit from copying would be $[1 - \alpha\mu]v - \mu[p + f] - t$.

Our proposition that the tax is welfare superior to the fine is also robust to these two changes in the modeling assumptions. The only result that is sensitive to these changes is the proposition that legitimate purchases should be subsidized.

The limitations of our analysis suggest several directions for future research. The first direction for future work is to incorporate price discrimination. Our

[13]In the context of externalities, Polinsky (1979) and Nault (1996) analyzed whether taxes on generation of externalities are symmetric with subsidies on abatement. In that context, there is a direct relation between generation and abatement. By contrast, in the context of information goods piracy, there is substitution between buying the legitimate item and copying among high-benefit users, but among low-benefit potential users, the substitution is between copying and not using. Accordingly, the issue of symmetry does not arise.

model assumed that the producer sets the same price to all potential users. However, as Takeyama (1994) observes, copying is a way by which a publisher can implicitly effect price discrimination. What if the producer explicitly offered a lower quality product at a lower price to draw those who might otherwise make copies (Shapiro 1988, Varian 2000)?

Specifically, in the context of our model, assuming that there are no subsidies or taxes, a potential user who copies the software will receive net benefit, $[1 - \mu]v - \mu f$. The producer could offer a downgraded version that provides benefit $[1 - \mu]v$ at a price slightly below μf. Then, a potential user would prefer the downgraded version to copying the original (high-quality) version. So, the producer would gain sales and also avoid the detection cost, and hence raise profit.

There is, however, a catch. The downgraded version would cannibalize some of the demand of the ethical users for the high-quality version. For each ethical user who switches to the downgraded version, the producer would lose $p - \mu f$ in profit. The root of this problem is that the producer cannot distinguish ethical from unethical users. In these circumstances, the literature on product line pricing suggests that the producer will choose to price discriminate by offering multiple versions only under particular conditions of cost, user benefit, and the relative numbers of users in the segments (Moorthy 1984).

Realistically, producers do not have sufficient information to price discriminate completely:

> If not all consumers copy, or if consumers vary in the number of copies each makes from an original, then efficient pricing would require discriminating among these groups, charging them different prices according to their valuations of the originals, based on their ability to make copies. This type of price discrimination is usually infeasible, however, because it is costly and difficult to gather the necessary information on users' valuations of originals (U.S. Congress, Office of Technology Assessment 1989, page 178).

Even if a producer could completely price discriminate, it would still benefit from some degree of enforcement as a way of supporting the legitimate demand. To better understand these issues, we need to formally incorporate the possibility of price discrimination into the model of software pricing and enforcement.[14]

The second direction for future work is consider the producer's decision on copy protection. Our analysis assumed that a potential user incurs no cost to make a copy. Realistically, however, copying is somewhat costly, and the producer can affect the cost through choice of copy protection. Gopal and Sanders (1997) model copying as a joint activity like the formation of a club in which all members share costs. By contrast, in our framework, each potential user behaves as an individual. In future work, it would be interesting to consider the producer's trade-off between detection and copy protection in our framework and to compare the results with those of Gopal and Sanders.

The third and perhaps most important direction for future work is to embed the model of pricing and enforcement in a larger framework that considers the incentive to create new products. In this broader framework, piracy does not merely encourage the producer to spend resources on enforcement, but also affects social welfare by discouraging innovation.

Finally, it is worth emphasizing that, while we presented our results in the context of computer software, the same findings apply to other copyrightable information goods that may be easily duplicated. These include Disney videos, Metallica CDs, textbooks, and all forms of on-line content. In all of these businesses, copying is an important issue, producers face a trade-off between pricing and enforcement, and society must decide on a policy toward copyright violation.

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Appendix

Proof of Proposition 1(b). Let

$$B \equiv -\frac{d^2\Pi_\ell}{dp^2} = 2 + \frac{f + t}{[p - s + f]^3}\left[C''(\mu)\,\frac{f + t}{p - s + f} - 2C'(\mu)\right], \quad (37)$$

[14]Producers could price discriminate across international boundaries to take into account national differences in income and culture (Gopal and Sanders 1998 and 2000, Marron and Steel 2000, Husted 2000).

using (14) and with μ defined by (15). We assume that $B > 0$, which implies that the second-order condition is satisfied. (Note that a sufficient condition is that $f = t = s = 0$, which implies that $B = 2 > 0$.)

By differentiating (15) and the first-order condition (16) with respect to f, t, and s, we obtain the following:

$$B\frac{dp}{df} = \frac{1}{[p - s + f]^3} \times \left[C''(\mu)\frac{[f + t][p - s - t]}{p - s + f} - C'(\mu)[p - s - f - 2t]\right], \tag{38}$$

$$B\frac{dp}{dt} = \frac{1}{[p - s + f]^2}\left[C''(\mu)\frac{f + t}{p - s + f} - C'(\mu)\right], \tag{39}$$

$$B\frac{dp}{ds} = 1 + \frac{f + t}{[p - s + f]^3}\left[C''(\mu)\frac{f + t}{p - s + f} - 2C'(\mu)\right], \tag{40}$$

$$\frac{d\mu}{ds} = \frac{f + t}{[p - s + f]^2}\left[\frac{dp}{ds} - 1\right]. \tag{41}$$

$$B\frac{d\mu}{dt} = \frac{1}{[p - s + f]}\left[C'(\mu)\frac{f + t}{[p - s + f]^3} - 2\right]. \tag{42}$$

By (37) and (40), $dp/ds < 1$, and hence, by (41), $d\mu/ds < 0$. □

Proof of Proposition 1(c). Let

$$J \equiv \frac{\partial^2\Pi_c}{\partial p^2}\frac{\partial^2\Pi_c}{\partial\mu^2} - \left[\frac{\partial^2\Pi_c}{\partial p\partial\mu}\right]^2.$$

Substituting from (18),

$$J = 4e[1 - e]\frac{p}{\mu^3}[p - s - t] - \left[\frac{1 - e}{\mu^2}[s + t]\right]^2 + 2\left[e + \frac{1 - e}{\mu}\right]C''(\mu). \tag{43}$$

We assume that $J > 0$; hence, the second-order condition is satisfied. (Note that sufficient conditions are that $f = t = s = 0$ and $C''(\cdot) > 0$, which together imply that $J > 0$.)

By differentiating the first-order conditions (19) and (20) with respect to f, t, and s, and then applying Cramer's Rule, we obtain the following:

$$J\frac{dp}{df} = [1 - e]C''(\mu) + \frac{2[1 - e]^2}{\mu^3}p[p - s - t] > 0, \tag{44}$$

$$J\frac{dp}{dt} = \frac{1 - e}{\mu}C''(\mu) - \frac{[1 - e]^2}{\mu^4}p[s + t], \tag{45}$$

$$J\frac{dp}{ds} = 2e[1 - e]\frac{p[p - s - t]}{\mu^3} - \frac{[1 - e]^2}{\mu^4}p[s + t] + \left[e + \frac{1 - e}{\mu}\right]C''(\mu), \tag{46}$$

$$J\frac{d\mu}{df} = \frac{[1 - e]^2}{\mu^2}[2p - s - t] > 0, \tag{47}$$

$$J\frac{d\mu}{dt} = -2e[1 - e]\frac{p}{\mu^2} - \frac{[1 - e]^2}{\mu^3}[s + t] < 0, \tag{48}$$

$$J\frac{d\mu}{ds} = -[1 - e]\left[e + \frac{1 - e}{\mu}\right]\frac{s + t}{\mu^2} < 0.$$

By (43) and (45), $dp/dt < 1$, and further, by (43) and (46), $dp/ds < 1$. □

Proof of Proposition 2. Given any strategy (p,μ), consider a variation $(\Delta p,\Delta\mu)$ such that $\Delta p < 0$ and

$$[1 - e]\Delta v_2 = -e\Delta p. \tag{49}$$

By (17), (2), and (49), the variation would change the publisher's sales by

$$\Delta Q_c = -e\Delta p - [1 - e]\Delta v_2 = 0.$$

Referring to (29), the variation would change welfare by

$$\begin{aligned}\Delta W_c = {} & \frac{1}{2}\{-2e[p - s]\Delta p - [1 - e][v_2^2 - v_1^2]\Delta\mu \\ & + [1 - e][-2v_2\Delta v_2 + [1 - \mu][2v_2\Delta v_2 - 2v_1\Delta v_1]]\} \\ & - C'(\mu)\Delta\mu = -e[p - s]\Delta p - \frac{1 - e}{2}[v_2^2 - v_1^2]\Delta\mu \\ & - [1 - e]\mu v_2\Delta v_2 - [1 - e][1 - \mu]v_1\Delta v_1 - C'(\mu)\Delta\mu.\end{aligned} \tag{50}$$

Consider the first and third terms on the right-hand side of (50): by substituting from (49) and (2), $-e[p - s]\Delta p - [1 - e]\mu v_2\Delta v_2 = -e[p - s - \mu v_2]\Delta p = -e[t + f\mu]\Delta p > 0$, because $\Delta p < 0$. Furthermore, by (6), the fourth term,

$$-[1 - e][1 - \mu]v_1\Delta v_1 = -[1 - e]v_1\frac{f + t}{1 - \mu}\Delta\mu > 0,$$

because $\Delta\mu < 0$. Finally, the second and fifth terms are positive, because $\Delta\mu < 0$. Hence, $\Delta W_c > 0$, which proves the result. □

Proof of Proposition 3. We prove the result by considering the welfare effects of the tax and fine in the two cases of limit pricing and copying.

Limit Pricing

Using (15), welfare (25) can be written as

$$W_\ell = \frac{1}{2}[1 - [p - s]^2] - C(\mu). \tag{51}$$

Differentiating (51) with respect to t, and simplifying,

$$\frac{dW_\ell}{dt} = -[p - s]\frac{dp}{dt} - C'(\mu)\frac{d\mu}{dt}. \tag{52}$$

Differentiating (51) with respect to f, and simplifying,

$$\frac{dW_\ell}{df} = -[p - s]\frac{dp}{df} - C'(\mu)\frac{d\mu}{df}. \tag{53}$$

Subtracting (53) from μ times (52),

$$\mu\frac{dW_\ell}{dt} - \frac{dW_\ell}{df} = -[p - s]\left[\mu\frac{dp}{dt} - \frac{dp}{df}\right] - C'(\mu)\left[\mu\frac{d\mu}{dt} - \frac{d\mu}{df}\right]. \tag{54}$$

By (15), it can be shown that

$$\left[\mu \frac{d\mu}{dt} - \frac{d\mu}{df}\right] = \frac{f + t}{[p - s + f]^2}\left[\mu \frac{dp}{dt} - \frac{dp}{df}\right]. \quad (55)$$

Substituting (55) in (54), we have

$$\mu \frac{dW_\ell}{dt} - \frac{dW_\ell}{df} = -\left[p - s + C'(\mu)\frac{f + t}{[p - s + f]^2}\right]\left[\mu \frac{dp}{dt} - \frac{dp}{df}\right]. \quad (56)$$

By (16),

$$p - s + C'(\mu)\frac{f + t}{[p - s + f]^2} = 1 - p > 0. \quad (57)$$

By (39) and (38),

$$B\left[\mu \frac{dp}{dt} - \frac{dp}{df}\right] = -C'(\mu)\frac{f + t}{[p - s + f]^3} < 0. \quad (58)$$

Substituting (57) and (58) on the right-hand side of (56) and noting that $B > 0$, we have

$$\mu \frac{dW_\ell}{dt} - \frac{dW_\ell}{df} > 0. \quad (59)$$

Now suppose that an optimal policy includes $f > 0$. Then, consider a variation $(\Delta f, \Delta t)$ with $\Delta f < 0$ and $\Delta t = -\mu\Delta f > 0$. This would change welfare by

$$\Delta W_\ell = \frac{dW_\ell}{dt}\Delta t + \frac{dW_\ell}{df}\Delta f = -\Delta f\left[\mu \frac{dW_\ell}{dt} - \frac{dW_\ell}{df}\right] > 0,$$

using (59). Hence, the variation raises welfare, which is a contradiction. Therefore, the optimal $f = 0$.

Given that the optimal $f = 0$, we next show that the optimal $t > 0$. Suppose that $t = 0$. Substituting $f = t = 0$ in (37), (39), and (42), we have $B = 2$, $Bdp/dt < 0$, and $Bd\mu/dt < 0$, respectively. Substituting these in (52), the marginal welfare effect of a tax increase, $dW_\ell/dt > 0$. Hence, when $t = 0$, an increase in t would raise welfare, which implies that the optimal $t > 0$.

Copying

Differentiating (29) with respect to the tax, t, and simplifying

$$\frac{dW_c}{dt} = -e[p - s]\frac{dp}{dt} - [1 - e]\left[\mu v_2 \frac{dv_2}{dt} + [1 - \mu]v_1 \frac{dv_1}{dt}\right] - \left[\frac{1}{2}[1 - e][v_2^2 - v_1^2] + C'(\mu)\right]\frac{d\mu}{dt}. \quad (60)$$

Differentiating (29) with respect to the fine, f, and simplifying,

$$\frac{dW_c}{df} = -e[p - s]\frac{dp}{df} - [1 - e]\left[\mu v_2 \frac{dv_2}{df} + [1 - \mu]v_1 \frac{dv_1}{df}\right] - \left[\frac{1}{2}[1 - e][v_2^2 - v_1^2] + C'(\mu)\right]\frac{d\mu}{df}. \quad (61)$$

Subtracting (61) from μ times (60),

$$\mu \frac{dW_c}{dt} - \frac{dW_c}{df} = -e[p - s]\left[\mu \frac{dp}{dt} - \frac{dp}{df}\right] - [1 - e] \times \left\{\mu v_2\left[\mu \frac{dv_2}{dt} - \frac{dv_2}{df}\right] + [1 - \mu]v_1\left[\mu \frac{dv_1}{dt} - \frac{dv_1}{df}\right]\right\} - \left[\frac{1}{2}[1 - e][v_2^2 - v_1^2] + C'(\mu)\right]\left[\mu \frac{d\mu}{dt} - \frac{d\mu}{df}\right]. \quad (62)$$

By (2),

$$J\left[\mu \frac{dv_2}{dt} - \frac{dv_2}{df}\right] = \frac{1}{\mu}\left[\mu J \frac{dp}{dt} - J \frac{dp}{df}\right] - \frac{p - s - t}{\mu^2}\left[\mu J \frac{d\mu}{dt} - J \frac{d\mu}{df}\right] \quad (63)$$

and by (6),

$$J\left[\mu \frac{dv_1}{dt} - \frac{dv_1}{df}\right] = \frac{f + t}{[1 - \mu]^2} J\left[\mu \frac{d\mu}{dt} - \frac{d\mu}{df}\right]. \quad (64)$$

Substituting (63) and (64) in (62), we have

$$J\left[\mu \frac{dW_c}{dt} - \frac{dW_c}{df}\right] = -\left[\mu J \frac{dp}{dt} - J \frac{dp}{df}\right]\left[e[p - s] + [1 - e]v_2\right] - \left[\mu J \frac{d\mu}{dt} - J \frac{d\mu}{df}\right]\left[C'(\mu) - [1 - e] \times v_2 \frac{p - s - t}{\mu} + [1 - e][1 - \mu] \times v_1 \frac{f + t}{[1 - \mu]^2} + \frac{1 - e}{2}[v_2^2 - v_1^2]\right]. \quad (65)$$

Using (20), it can be verified that

$$C'(\mu) - [1 - e]v_2 \frac{p - s - t}{\mu} = [1 - e]\frac{p - s - t}{\mu}\left[\frac{s + t}{\mu} + f\right] > 0. \quad (66)$$

By (45) and (44),

$$J\left[\mu \frac{dp}{dt} - \frac{dp}{df}\right] = -\frac{[1 - e]^2}{\mu^3} p[2p - s - t] < 0, \quad (67)$$

whereas by (47) and (48),

$$J\left[\mu \frac{d\mu}{dt} - \frac{d\mu}{df}\right] = -2[1 - e]\frac{p}{\mu}\left[e + \frac{1 - e}{\mu}\right] < 0. \quad (68)$$

Substituting from (66), (67), and (68) on the right-hand side of (65), we have

$$J\left[\mu \frac{dW_c}{dt} - \frac{dW_c}{df}\right] > 0. \quad (69)$$

Now suppose that an optimal policy includes $f > 0$. Then, consider a variation $(\Delta f, \Delta t)$ with $\Delta f < 0$ and $\Delta t = -\mu\Delta f > 0$. This would change welfare by

$$\Delta W_c = \frac{dW_c}{dt}\Delta t + \frac{dW_c}{df}\Delta f = -\Delta f\left[\mu \frac{dW_c}{dt} - \frac{dW_c}{df}\right] > 0,$$

using (69). Hence, the variation raises welfare, which is a contradiction. Therefore, the optimal $f = 0$.

Given that the optimal $f = 0$, we next show that the optimal $t > 0$. Substituting $f = t = 0$ in (6) and (2), we have $v_1 = 0$ and $\mu v_2 = p - s$. By (2), (45), and (48),

$$J \frac{dv_2}{dt} = -\frac{1}{\mu}\left[2e + \frac{1-e}{\mu}\right]C''(\mu) - 2e[1-e] - \frac{p[p-s]}{\mu^4}.$$

Substituting the above in (60), we have

$$J \frac{dW_c}{dt} = [1-e]\frac{p-s}{\mu}\left[e + \frac{1-e}{\mu}\right]C''(\mu) + e[1-e]^2\frac{p[p-s][2p-s]}{\mu^4} - \left[\frac{1-e}{2}v_2^2 + C'(\mu)\right]\frac{d\mu}{dt}. \quad (70)$$

By Proposition 1(c), $d\mu/dt < 0$. Hence, the right-hand side of (70) is positive, which implies that $dW_c/dt > 0$ when $t = 0$. This proves that it is optimal to set $t > 0$. □

Proof of Proposition 4. We prove the result by considering the effect of a subsidy on welfare in the three cases of no copy threat, limit pricing, and copying.

No Copy Threat

Differentiating (24) with respect to the subsidy, s,

$$\frac{dW_n}{ds} = -[p-s]\left[\frac{dp}{ds} - 1\right].$$

By Proposition 1(a), $dp/ds = 1/2$, hence $dW_n/ds > 0$.

Limit Pricing

Differentiating (25) with respect to the subsidy, s,

$$\frac{dW_\ell}{ds} = -[p-s]\left[\frac{dp}{ds} - 1\right] - C'(\mu)\frac{d\mu}{ds}.$$

By Proposition 1(b), $dp/ds < 1$ and $d\mu/ds < 0$; hence, $dW_\ell/ds > 0$.

Copying

Differentiating (29) with respect to s, and simplifying,

$$\frac{dW_n}{ds} = -e[p-s]\left[\frac{dp}{ds} - 1\right] - [1-e]\left[\mu v_2\frac{dv_2}{ds} + [1-\mu]v_1\frac{dv_1}{ds}\right] - \left[\frac{1}{2}[1-e][v_2^2 - v_1^2] + C'(\mu)\right]\frac{d\mu}{ds}. \quad (71)$$

Let us analyze the right-hand terms of (71). The first term,

$$-e[p-s]\left[\frac{dp}{ds} - 1\right] > 0,$$

because, by Proposition 1(c), $dp/ds < 1$. By (2), (6), and Proposition 1(c), it may be shown that $dv_2/ds < 0$ and $dv_1/ds < 0$, hence the second term,

$$-[1-e]\left[\mu v_2\frac{dv_2}{ds} + [1-\mu]v_1\frac{dv_1}{ds}\right] > 0.$$

Finally, the third term,

$$-\left[\frac{1}{2}[1-e][v_2^2 - v_1^2] + C'(\mu)\right]\frac{d\mu}{ds} > 0,$$

because, by Proposition 1(c), $d\mu/ds < 0$. Accordingly, $dW_c/ds > 0$. □

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