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Fighting Information Good Piracy with Versioning

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Abstract

Information goods piracy is a pervasive problem as advanced information and communication technologies become so inexpensive and so easy to access. This problem, if not alleviated, can pose a serious loss to society as it can reduce information goods providers' incentives to develop information goods or threaten the use and growth of the Internet as a distribution media for valued digital information goods. Contrasting with previous literature, which mainly consider instruments, such as law enforcement or technology-based solutions, that work on increasing individual piracy cost, we consider using versioning as a complementary means to these other methods. While the previous literature has shown that versioning may not be the optimal strategy for information goods (having negligible or concave marginal costs), we show that versioning could be a very effective and profitable instrument to fight piracy. Furthermore, we also show that it is possible to do this without sacrificing the consumer's surplus and, as a result, the entire social welfare could increase. This suggests that by using versioning along with other instruments that work on increasing individual piracy cost, information goods providers can fight piracy more efficiently.

Keywords: Information goods, piracy, versioning, social welfare

Introduction

The emergence of the Internet and many advanced information and communication technologies (for example, peer-to-peer computing) have provided a very low-cost reproduction and distribution medium for *digitized* information goods of all forms, including text, images, data, audio, and video. On the other hand, these digital contents can be copied, or more exactly pirated, easily and cheaply using the same technologies. As people rapidly gain access to the Internet and many new information and communication technologies, the threat of piracy has never been greater.

The threat of piracy is nothing new for information goods due to their distinctive properties: an information good usually has a high fixed cost of production but a low marginal cost of reproduction; it is also nonrival and often nonexcludable. Nonrival means one person's consumption doesn't diminish the amount available to other people, while nonexcludable means that one person cannot exclude another person from consuming the good in question (Varian 1998). Traditional ways to cope with piracy include intellectual property laws that allow information goods to be excludable (although these laws are not necessarily being enforced).

In addition, traditional information goods are usually attached to some physical media that is excludable, such as books that only one person can consume at a time. The bundle of information with excludable media also increases the cost of reproduction, and thus the cost of piracy. Moreover, the pirated copy is usually of lower quality than the original copy with these traditional media; for instance, a copied book doesn't read as comfortably as the legal copy itself, which greatly reduces an individual's incentive to pirate.

On the other hand, the new medium itself (e.g., the Internet) does not allow purely digital information goods to be excludable beyond the legal regime. Not only is excludability much more difficult to enforce, but quality for a pirated copy usually does not degrade due to the digital nature of the information goods. As a result, the piracy problem becomes serious. If the piracy problem is not alleviated, it will reduce information goods providers' incentives to develop information goods and also seriously threaten the use and growth of the Internet as a distribution media for *valued* digital information goods, because the information goods provider may not want to put their valued information goods online, and this can potentially hurt society if most of the information online is "trash." These concerns have contributed to researchers' renewed interests in information goods piracy. Several researches have discussed welfare implications of these new information and communications technologies as a distribution media for digital information goods (Boldrin and Levine 2002; Duchene and Waelbroeck 2001; Klein et al. 2002), while others explore possible government instruments or technology-based solutions to combat information goods piracy (Chen and Png 2003; Gayer and Shy forthcoming).

Similar to previous literature on information goods piracy, we assume there is a monopolist information goods provider. However, in contrast to previous studies on information goods piracy which generally focus on government instruments or technology preventive controls, we consider versioning or quality differentiation as a possible instrument for the information goods provider to fight piracy along with other commonly studied instruments that work to raise customer piracy cost through copyright enforcement by the government or a technology-based solution (for example, encryption). Quality differentiation is a common practice when there is customer heterogeneity and the seller can distinguish between them (e.g., second or third degree price discrimination), for example, many software publishers sell a student version and a professional version; textbook publishers also sell an international edition to some developing countries. Quality differentiation is also common for physical goods and has been shown to boost profits for traditional physical goods. However, previous literature on information goods pricing has generally shown that market segmentation with quality differentiation (or second degree price discrimination) is not optimal for digital information goods with zero marginal costs or concave cost function (Bhargava and Choudhary 2001, 2002; Jones and Mendelson 1997). Although versioning may not be optimal for an information goods provider when there is no threat of piracy, we show that it can be an effective and profitable instrument to fight piracy for digital information goods. We provide a practical model that allows us to determine how many versions the information goods provider should offer, and at what quality levels and prices under the threat of piracy. In addition, we show that versioning not only can enhance the producer's profit, but can also be social-welfare enhancing.

The rest of the paper is organized as follows. The previous literature is surveyed. We introduce our base model and a more general model is formulated as a nonlinear mixed integer program. Some text examples are shown and discussed, followed by concluding remarks.

Literature Review

Much attention has recently been paid to information goods piracy. Boldrin and Levine (2002), Duchene and Waelbroeck (2001), and Klein et al. (2002) have studied the welfare implications of the new distribution technologies (in particular, peer-to-peer distribution technology) and how these technologies might affect the copyright values of information goods. Other researchers discuss possible strategies to combat information goods piracy. Gayer and Shy (forthcoming) study the effects of using hardware taxation to compensate copyright owners. Chen and Png (2003) examine how the government should respond to information goods piracy using three instruments—fines, taxes, and subsidies. In addition to these government initiated strategies, Ben-Shahar and Jacob (2001) study how information goods creators can engage in selective copyright enforcement. Some other researchers have studied information goods pricing under the threat of piracy. For example, Belleflamme (2002) studies how different copy technologies (either with fixed cost or with marginal cost) affect information goods pricing, under the assumption that copies are low-quality alternatives to originals.

Other research that may be relevant to information goods piracy is software piracy, which has also received extensive attention previously due to one of its special characteristics, namely, demand-side network externality. Conner and Rumelt (1991), Shy and Thisse (1999), and Takeyama (1994) suggest that, in the presence of network externality, piracy increases the installed base,

which in turn raises the demand and willingness to pay for the legitimate copy of the software and thus can potentially increase the producer's profit. As a result, they conclude that not protecting, even with serious software piracy, can be the best policy. Other issues about software piracy have also been studied. For example, Gopal and Sanders (1997) have discussed both preventive and deterrent controls for software piracy, where preventive controls employ technology-based solutions to make copying software more difficult; deterrent controls attempt to dissuade users from copying software through legal, investigative, and educational campaigns. They also study, in the context of international software piracy, the government's incentive to enforce laws against piracy and the cultural differences in piracy propensity and behavior. Cheng et al. (1997) have identified some of the reasons why people pirate software.

The Base Model

Varian (1997) suggests that "the right way to design the product will generally be to design for the high end of the market first, and then downgrade the product to get the versions for the other segments of the market". Therefore, in our base model, we first assume that the firm has already sunk its investment in producing the information good of best quality with quality index 1, and can degrade the product at negligible cost. Following previous literature (Belleflamme 2002; Bhargava and Choudhary 2001; Mussa and Rosen 1978), we assume a customer's (say i) reservation price for the product with quality index Q, $0 \le Q \le 1$, decreases linearly, that is, V_iQ, where V_i is the customer's willingness to pay for the good with quality index 1. Given our context of digital information goods, it is reasonable to assume zero or very small marginal cost in reproducing any version of information goods, furthermore, we assume that the pirated copy will have the same quality level as the original copy since these goods are digital in nature. Each individual also has a cost of piracy, T_i, which depends on the level of protection technology (in the case that a preventive control is used) and also includes the cost of the copying medium (which can be zero) and moral cost, if any, as well as the expected loss if caught (which equals the probability of being caught times the fine demanded).

As a base model, we assume there are two types of customers in the market. The high type has a reservation price of V_H for the good with best quality normalized to one, which is greater than the reservation price of a low type, V_L, for the good of best quality. The reservation price for the product with reduced quality, $0 \le Q \le 1$, is thus V_iQ, with $i = H$ or L. Suppose there are α high type and $(1-\alpha)$ low type, and the firm can't distinguish between these two types of customers.

Optimal Pricing Strategy Wthout Considering Piracy

Given that there are two types of customers, the firm will offer at most two versions of the product : one with the best quality with quality index 1 and price P_1, which is intended to be sold to the high-end type customers and the other at quality level Q with price P_Q for the low-end type customers. For simplicity, we write these two versions as $(1, P_1)$ and (Q, P_Q). Note that we are not constraining the firm to offering two versions. If the optimal Q is found to be one, then we know only one version, $(1, P_1)$, will be offered and both types of customer will buy it. When the optimal Q is found to be zero, then again only one version, $(1, P_1)$, is offered, and only the high-end type customers will buy it. Note also that it is never the best strategy to offer a single version of the product with quality level less than one since the firm can always increase profits by increasing quality.[1]

With these two versions, $(1, P_1)$ and (Q, P_Q), offered, a high-end type customer will buy $(1, P_1)$ if and only if her net surplus from buying is greater than that from not buying (with zero utility) and from buying (Q, P_Q). That is, the following two constraints must hold for the high-end type customer to buy $(1, P_1)$.

$$V_H - P_1 \ge 0 \Rightarrow P_1 \le V_H \qquad \text{(1) H is willing to buy } (1,P_1) \text{ over not buying.}$$

$$V_H - P_1 \ge V_HQ - P_Q \Rightarrow P_1 \le V_H(1-Q) + P_Q \qquad \text{(2) H is willing to buy } (1,P_1) \text{ over } (Q,P_Q)$$

Likewise, for a low-end type customer to buy (Q, P_Q), we must assure that her net surplus from buying is greater than that from not buying (with zero utility) and from buying $(1, P_1)$. That is, the following two constraints must hold for the low-end type customer to buy (Q, P_Q).

[1]This is due to zero marginal cost and the fact that the firm has already sunk the investment in producing the best quality.

$V_L Q - P_Q \geq 0 \Rightarrow P_Q \leq V_L Q$ (3) L is willing to buy (Q,P_Q) over not buying

$V_L Q - P_Q \geq V_L - P_1 \Rightarrow P_Q \leq P_1 - V_L(1-Q)$ (4) L is willing to buy (Q,P_Q) over $(1,P_1)$.

It is in seller's interest to increase the price as much as possible, so in general one of the first two inequalities, (1) and (2), will be binding, and one of the latter two inequalities, (3) and (4), will be binding. We can show that (1) and (4) will not be binding through proof by contradiction, so we know that constraints (2) and (3) are binding.

$$P_Q = V_L Q$$
$$P_1 = V_H(1-Q) + P_Q = V_H(1-Q) + V_L Q$$

The firm's profit function is thus:

$$\pi = \alpha P_1 + (1-\alpha)P_Q = \alpha[V_H(1-Q) + V_L Q] + (1-\alpha)V_L Q$$

The firm will then choose Q to maximize its profit. Since $\frac{\partial \pi}{\partial Q} = -\alpha V_H + \alpha V_L + (1-\alpha)V_L = V_L - \alpha V_H$, which is a constant, we know the optimal Q is of boundary values, either one or zero depending on whether $V_L \geq \alpha V_H$ or not. Thus the firm's optimal strategy is always to provide only one version, that is, versioning is never optimal!

Proposition 1: When the marginal cost for the digital information good is zero, the provider's optimal pricing strategy is always to provide only one version with the highest quality when the piracy problem is ignored and to set price at V_H when $\alpha \geq \frac{V_L}{V_H}$ and at V_L when $\alpha < \frac{V_L}{V_H}$.

Note that this result can be extended to cases where there are more than two types of customers, which has been demonstrated by Bhargava and Choudhary (2002) and by Jones and Mendelson (1997).

Optimal Pricing Strategy When Considering Piracy: When Piracy Cost Is Symmetric

Now let's take a look at the case with piracy. Assume the customers face a common piracy cost, T. Note that for any price higher than this piracy cost, a customer will prefer to pirate the produce than to buy it. In addition, we assume an individual will always pirate the product with the best quality once she decides to pirate (since it gives the highest surplus).

For the high-end type (H) customers, there is an additional constraint in addition to constraint (1) and (2) introduced earlier: the surplus from buying must be greater than the surplus from pirating:

$$V_H - P_1 \geq V_H - T \Rightarrow P_1 \leq T$$

Likewise, there is an additional constraint for the low-end type customers (L):

$$V_L Q - P_Q \geq V_L - T \Rightarrow P_Q \leq T - V_L(1-Q)$$

To summarize, here's the objective function faced by the seller:

$$\pi = \alpha P_1 + (1-\alpha)P_Q$$
s.t.
$V_H - P_1 \geq 0$.....(1) H is willing to buy over not buying
$V_H - P_1 \geq V_H Q - P_Q$.....(2) H is willing to buy (1,P_1) over (Q,P_Q)
$V_H - P_1 \geq V_H - T$.....(5) H is willing to buy over pirating
$V_L Q - P_Q \geq 0$.....(3) L is willing to buy over not buying
$V_L Q - P_Q \geq V_L - P_1$.....(4) L is willing to buy (Q,P_Q) over (1,P_1)
$V_L Q - P_Q \geq V_L - T$.....(6) L is willing to buy over pirating

As before, equations (1) and (4) will not be binding, so we know that to induce the high-end type customers to buy, the following constraints need to hold:

$$P_1 \leq V_H(1-Q) + P_Q$$

$$P_1 \leq T$$

And to induce the low value customers to buy, the following constraints need to hold:

$$P_Q \leq V_L Q$$

$$P_Q \leq T - V_L(1-Q) = T - V_L + V_L Q$$

This implies that when $T < V_L$, we need $P_Q \leq T - V_L(1-Q)$ only; when $T \geq V_L$, we need $P_Q \leq V_L Q$ only.

With this setting, we can show that when $T < V_L$, the firm's optimal strategy considering piracy is always to offer just one version at best quality and set price at *T* and get profit *T*, consistent with previous result without considering piracy. Interesting results come when we have $V_L \leq T \leq V_H$.

Proposition 2: When $V_L \leq T \leq V_H$ and $\alpha \geq \frac{V_L}{V_H}$, the firm can increase its profits by versioning (Figure 1). Specifically, the firm's optimal pricing strategy is to offer two versions: (1, *T*), which is sold to the high-type customers, and $(\frac{V_H - T}{V_H - V_L}, \frac{V_L(V_H - T)}{V_H - V_L})$, which is sold to the low-type customers.

Since the piracy cost is also, to some extent, under the control of the firm, we can derive the seller's optimal investment level for piracy control. This investment may include the investment in technology-based preventive control to make it more difficult to pirate or to enhance the investment's monitoring infrastructure to increase piracy detection rate, which will then influence end users' piracy cost in turn since the probability a pirate will get caught increases. Assume that the firm can increase the piracy cost at cost, *F*(*T*), where $F'(T) > 0$ and $F''(T) \geq 0$. For analytical convenience, we'll simply assume it takes the quadratic function form: $F(T) = \frac{a}{2}T^2$, where *a* is the cost parameter. With this cost function, we can show the optimal level of piracy cost, which is set indirectly by the firm.

Proposition 3: When $\alpha \geq \frac{V_L}{V_H}$, the optimal level of investment in piracy control (*T**) by the information good provider is (depicted in Figure 2):

$$T^* = \begin{cases} \dfrac{1}{a}, \text{ when } a \geq \dfrac{1}{V_L} \\ V_L, \text{ when } \dfrac{\alpha(V_H - V_L)}{V_L(V_H - V_L)} \leq a \leq \dfrac{1}{V_L} \\ \dfrac{\alpha(V_H - V_L)}{a(V_H - V_L)}, \text{ when } \dfrac{\alpha(V_H - V_L)}{V_H(V_H - V_L)} \leq a \leq \dfrac{\alpha(V_H - V_L)}{V_L(V_H - V_L)} \\ V_H, \text{ when } a \leq \dfrac{\alpha(V_H - V_L)}{V_H(V_H - V_L)} \end{cases}$$

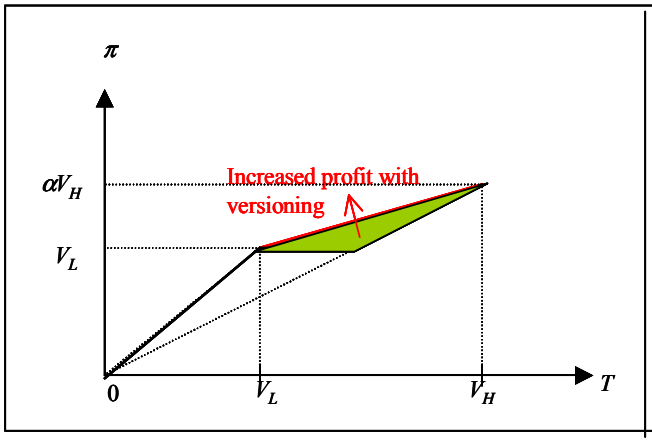

Figure 1

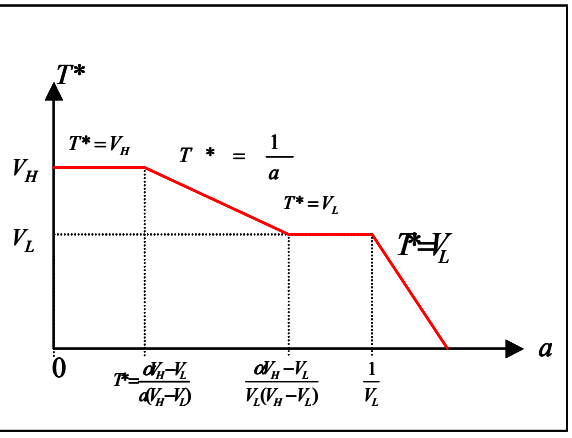

Figure 2

Optimal Pricing Strategy When Considering Piracy: When Piracy Cost is Asymmetric

Previous results can be generalized to the case when people have different piracy cost, for example, some people might face very high piracy cost and will never pirate. Following Chen and Png (2003), we call these people the ethical people, and assume that a proportion, *e,* are the ethical people and will never pirate, while the others with proportion (1-*e*) will consider pirating if there is greater surplus for doing so. We further assume that whether a customer is ethical or not is independent on whether the customer is a high-end type or low-end type. As before, we assume that for people who will consider to pirate (i.e., the unethical group), they face a non-zero piracy cost, *T*, and a customer will always pirate the product with the best quality if deciding to pirate.

In this case, we have four types of customers:

WTP for a product with Q	High-end type (α)	Low-end type (1-α)
Ethical (*e*)	V_HQ	V_LQ
Unethical (1-*e*)	**Min** $\{T, V_HQ\}$	**Min** $\{T, V_LQ\}$

As before, we find that under some conditions, the single version with best quality is still optimal, but when piracy cost, *T*, is within some range, the firm can use versioning to increase its profits when facing the threat of piracy.

Proposition 4: When $T < V_L$, the firm's optimal strategy considering piracy is always to offer just one version at best quality and set price at V_H and get profit $e\alpha V_H$ when $\alpha \geq \dfrac{V_L}{V_H}$ and $T < e\alpha V_H$, or at V_L with profit eV_L when $\alpha < \dfrac{V_L}{V_H}$ and $T < eV_L$, or at T when $T > \max\{e\alpha V_H, eV_L\}$.

Proposition 5: When $V_L \le T \le V_H$ and $\alpha \ge \frac{V_L}{V_H}$, the firm can increase its profits by versioning. Specifically, the firm's optimal pricing strategy is to offer two versions: (1, *T*), which is sold to the high-end value customers, and $(\frac{V_H - T}{V_H - V_L}, \frac{V_L(V_H - T)}{V_H - V_L})$, which is sold to the low-end value customers.

Results from Proposition 4 and 5 are summarized in Figure 3. As before, we derive optimal investment level for piracy control in Figure 4.

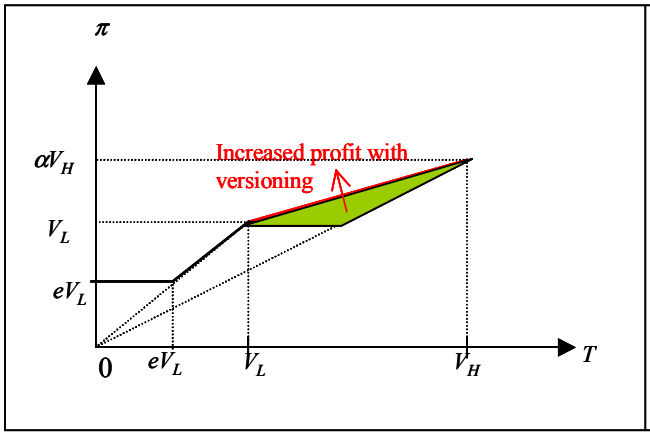

Figure 3

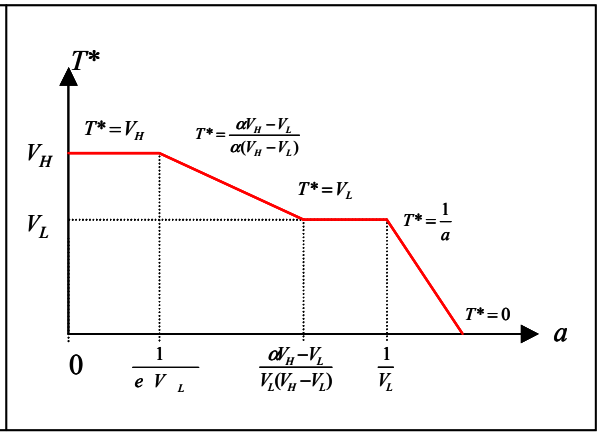

Figure 4

Note that results from the previous two subsections show that when piracy cost, *T,* is under a certain range, versioning can boost the seller's profits, suggesting that versioning can be an effective complementary instrument to other instruments available to the seller that increases individual piracy cost, such as investment in technology to make it harder to pirate or increase piracy detection rates. On the other hand, versioning can also be a substitute forthe seller's investment of piracy control, because without versioning, the seller may have to investment more in technology or monitoring infrastructure, but with versioning, the seller can get higher profit with less cost invested in piracy control. Overall, our findings here suggest that by using versioning along with other instruments that work on increasing individual piracy cost, information goods providers can fight piracy more efficiently.

The General Model

In the previous section, we consider the base model in which there are high-end and low-end types of customers who could have either high or low piracy cost. In this section, we consider a more general model of the problem in which there are more than two types of customers and possibly more than two versions offered. In other words, we formulate the optimal pricing and versioning problem for a monopoly information goods provider that sells one product (but possibly multiple versions in quality) to *I* types of customers (or market segments), each type, *i*, is characterized by two parameters: reservation price, V_i, and piracy cost, T_i. Note that *I* can be as small as one and as many as the total number of customers out there, depending on the similarity among customers in the market. Also, if two groups of customers have the same reservation price but different piracy cost (or vice versa), they will be accommodated in our model as two different types. While it may be possible for the information goods provider to distinguish customers by their reservation prices, it will be very difficult for the provider to also know their piracy cost, therefore, in our model, we assume that the provider cannot distinguish between customers of different types.

The model is developed from the seller's perspective. The problem for the seller is to decide how many different versions to offer, and at what quality levels and prices to maximize its net profit subject to a set of consumer participation and incentive constraints under the threat of piracy. From the customer's perspective, each customer will want to maximize her consumer surplus based on the difference between the reservation price for each version provided by the supplier (as well as the unauthorized or piracy copy) and the price they pay. The seller has to take into account dimensions of the customer's optimization problem which appear as constraints in the seller's problem.

Our goal is to offer a general model that can be used in practice, so we will accommodate in our model some of the practical constraints often observed in practice. While the marginal cost of information goods may be zero, the provider may still incur some other cost for having different versions of the product for sale. This may include costs from greater management complexity (we call it menu cost here) due to multiple versions and/or possible product completion cost (which is a fixed cost to the seller), which may be due to the cost to tailor and modify the product for different quality level versions. Although for some digital information goods, product completion cost may be small, in some other cases, there may exist a fixed cost to change or degrade product quality. Another practical constraint in reality is that it is rarely the case that quality can be treated as a continuous variable and that the provider can set any quality level it wishes. In fact, the possible quality levels achievable are often limited by available technology. So, the maximum number of versions, J, the provider can possibly offer is constrained by both the technology and by consumer processing capability. Note that this assumption does not restrict the applicability of our model, but rather, it enriches the scenarios we can possibly accommodate since J can be as small as one or as large as infinity. However, it is also important to note that the provider will never want to offer more versions than the number of customer types, I, out there.

We model the problem of optimal pricing and versioning of information goods as a nonlinear mixed integer program. Table 1 provides the definitions of all the parameters and variables used in this model.

The primal problem is given by:

Primal Problem IP:

$$\text{Max} \sum_{i=1,...,I} \sum_{j=1,...,J} N_i (P_j - M_j) X_{ij} - \sum_{j=1,...,J} C_j Y_j \qquad (1)$$

s.t.

$$S_i = \sum_{j=1,...,J} (V_i Q_j - P_j) X_{ij} + (V_i - T_i) Z_i, \qquad i = 1,...,I \qquad (2)$$

$$S_i \geq (V_i Q_j - P_j) Y_j, \qquad i = 1,...,I;\ j = 1,...,J \qquad (3)$$

$$S_i \geq V_i - T_i, \qquad i = 1,...,I \qquad (4)$$

$$(V_i Q_j - P_j) X_{ij} \geq 0, \qquad i = 1,...,I;\ j = 1,...,J \qquad (5)$$

$$(V_i - T_i) Z_i \geq 0, \qquad i = 1,...,I \qquad (6)$$

$$\sum_{j=1,...,J} X_{ij} + Z_i \leq 1, \qquad i = 1,...,I \qquad (7)$$

$$X_{ij} \leq Y_j, \qquad i = 1,...,I;\ j = 1,...,J \qquad (8)$$

$$P_j \geq 0, \qquad j = 1,...,J \qquad (9)$$

$$X_{ij} = 0 \text{ or } 1, \qquad i = 1,...,I;\ j = 1,...,J \qquad (10)$$

$$Y_j = 0 \text{ or } 1, \qquad j = 1,...,J \qquad (11)$$

$$Z_i = 0 \text{ or } 1, \qquad i = 1,...,I \qquad (12).$$

The objective function (1) is to maximize the total net profits of the vendor. This is calculated by the summation of profits obtained from each type of customer net the total fixed cost, if any, incurred by the vendor. Each constraint is explained in the following.

Constraint (2) defines consumer surplus as the difference between the customer's reservation price for version j (with quality index Q_j) and the market price of the version she chooses or, if she decides to pirate, the difference between her reservation price of the product and her piracy cost. As before, we assume that the consumer will always pirate the product with highest quality if she decides to pirate. Constraints (3) and (4) ensure that each customer maximizes her surplus S_i. This is achieved by requiring the final consumer surplus to be no less than the consumer surplus from any other version offered by the seller or from pirating (incentive compatible constraints). Constraint (5) and (6) ensure that a consumer will choose a version (or piracy copy) only when her surplus on this choice is nonnegative (individual rationality constraints); otherwise, she won't choose this version (or piracy copy). Constraint (7) ensures the assumption that each customer will purchase exactly one version (or the unauthorized copy), or won't make a purchase at all. Constraint (8) ensures that only when the vendor offers the j^{th} possible version of the product, can customers choose this kind of version; otherwise, no such choice is available. Constraint (9) is a nonnegative constraint for

the product price. Constraints (10) to (12) enforce the integer property of the decision variables with respect to consumer choices and version offering.

We provide an approach using Lagrangean relaxation and subgradient methods to solve this complicated nonlinear mixed integer program. A relaxed problem is solved first, and then heuristics are used to obtain optimality of the original problem *IP*. But due to the space limit enforced by the conference, detailed technique about how to solve the problem is omitted here and only the computational results are presented in the following section.

Table 1. Definitions of the Parameters and Variables Used in the Model

	Given Parameters
I:	There are total I types of customers (or market segments) in our target market.
J:	The maximum number of different quality levels (or versions) the vender is able to offer to the users. These different quality levels are indicated by Q_j, where $0 < Q_J < \ldots < Q_{j+1} < Q_j < \ldots < Q_1 = 1$. For simplicity, we'll simply assume these quality levels are evenly distributed, that is, $Q_j = (J\text{-}j + 1)/J$.
C_j:	Product completion cost as well as the menu cost for providing the jth possible version of the product on the menu. $C_j \geq 0$.
M_j:	Marginal cost for providing the jth possible version of the product to a customer. $M_j \geq 0$
N_i:	Anticipated size of market segment i.
T_i:	Piracy cost for type i customers.
V_i:	Reservation price for type i customers for the product with quality index 1.
	Decision Variables
P_j:	The price the vender would charge for the jth possible version of the product.
S_i:	Consumer surplus of a customer in market segment i.
X_{ij}:	The decision variable which is 1 if type i customers choose to buy the jth possible version of the product and 0 otherwise.
Y_j:	The decision variable which is 1 if the vender chooses to offer the jth possible version of the product on the menu and 0 otherwise.
Z_i:	The decision variable which is 1 if type i customers choose to pirate and 0 otherwise.

Numerical Results and Case Analysis

A Detailed Example

In this subsection, we first randomly generated a test example and use it to demonstrate the ideas of providing multiple quality versions to fight piracy. Some more examples are presented later, but due to the space constraint, only the final results are presented.

The major assumptions and parameters used in this subsection are listed below:

1. We assume there are five market segments ($I = 5$) and the firm can only provide up to four different quality versions ($J = 4$) with quality index $Q_1 = 1$, $Q_2 = 0.75$, $Q_3 = 0.5$, and $Q_4 = 0.25$, which are constrained by available technology.

2. The product completion cost C_j and marginal cost M_j of providing different versions to the customers are assumed to be 0.

3. The number of customers in the market segments are randomly generated between 1k ~ 10k with $N_1 = 6000$, $N_2 = 7000$, $N_3 = 2000$, $N_4 = 2000$, and $N_5 = 7000$.

4. The piracy cost of the customer in market segments are randomly generated between 0 ~ 100 with $T_1 = 26$, $T_2 = 51$, $T_3 = 66$, $T_4 = 11$, and $T_5 = 67$.

5. The market segment's reservation prices for the most high-end version of the product are randomly generated between 0 ~ 100 with $V_1 = 96$, $V_2 = 76$, $V_3 = 22$, $V_4 = 3$, and $V_5 = 12$.

The Single Version Case

If the firm is only offering the most high-end version of the product to the customer, it is not hard to see that in order to make the product attractive to the customers in a given market segment, the price of the product should not be higher than both this market segment's reservation price V and piracy cost T. For example, to sell the product to market segment 1, the price of the product shouldn't be higher than T_1. When the firm sets the price at T_1, the customers in segment 1 will be indifferent between buying the product from the firm and buying the pirated copy as these both give them the same consumer surplus. It follows that the demand of the product from this market segment will be somewhere between 0 and N_1, depending on how these indifferent customers decide. This indifference could be resolved easily by charging a price slightly less than T_1 on the product (even just a small fraction of one cent). By doing so, these customers will be willing to buy the official version of the product since now they get higher utility from buying than copying. Actually, the distinction between a price of exactly T_1 and a price slightly less than T_1 is purely theoretical and the distinction can be safely ignored in practice. The same tie breaking idea could be used in the case of offering multiple quality versions. We could reasonably assume that, faced with two alternatives that give the same consumer surplus, the customer will choose the official copy over the pirated copy and the high-end version over the low-end version.

In addition, because we assume all customers within a market segment have the same reservation price, the demand curve is a step function and the possible optimal values of the price are given by $\min\{V_i, T_i\}$, $i = 1,\ldots, I$. To find the optimal price of the single version offering, we only have to compute and compare all profits we could get from these possible values of the price. The conclusion: the firm should offer the most high-end version of the product at 51. This choice promises the highest profit level for the firm of 357,000 and customers in market segment 2 will buy the product while the customers in market segments 3, 4, and 5 won't buy the product and market segment 1 will do the piracy.

The Multiple Versions Case

The question we would like to ask is, given the market research parameters above, could the firm do better by offering more than one quality version of the product? If so, which versions should it offer? At what prices?

We apply our algorithm proposed in the previous section to this test example and our algorithm suggests the following solution: the firm should offer two quality versions of the product, with quality index 1 and 0.75, priced at 26 and 9 respectively to the market. With this product offering, market segments 1 and 2 will buy the high-end version of the product and market segments 3 and 5 will now buy the low-end version of the product. Note that in order to attract segment 1 while keeping segment 2 buying the high-end product, the firm has to lower the high-end product price from 51 to 26. Although market segment 4 is still left out of the market because they have too low a reservation price, market segments 3 and 5 will now buy the low-end product and get to enjoy the benefit of the product; in addition, market segment 1 will no longer pirate but will now buy the product (the results are summarized in the Table 2)! The profit level achievable with versioning is now 419,000, or 17.37 percent more than the highest net profit with only the most high-end version of the product.

Table 2. : Using Versioning to Fight Piracy

	Segment 1	Segment 2	Segment 3	Segment 4	Segment 5
Single Version Case	Pirate	Buy	Not Buy	Not Buy	Not Buy
Multiple Versions Case	Buy (High-end)	Buy (High-end)	Buy (Low-end)	Not Buy	Buy (Low-end)

The Total Social Welfare

Based on the test example just shown, we find that offering several quality versions of the product has two welfare implications. First, the firm is able to improve its profit level with versioning under the threat of piracy. In this case, the profit improvement

comes from the consumers in two ways: from segments 3 and 5 who won't buy the product and from segment 1 who will pirate if only one high-end version is offered. Although the sales from market segment 2 shrink due to lower price, it is still well compensated by the sales from the new customers. Second, versioning can reduce social deadweight loss by bringing more customers to the market since more people can enjoy the products with versioning.

In addition, it is worth noting that that no customers lose any surplus when the firm offers multiple versions of the product in this case. Instead, more customers are covered in the market with higher surplus. As a result, the total social welfare increases about 26.47 percent in this example: the firm is able to earn more and more customers are able to enjoy the benefits of the product. In other words, versioning can be a win-win situation for both the firm and the customers (although not for thepirated-copy merchants).

Other Test Examples

In this section, we present more test examples, however, due to the space constraint, only the final results of the examples are presented in Table 3. Detailed results are available upon request. The results, once again, suggest that versioning can be an effective and profitable instrument to fight piracy in many cases.

Table 3. Final Result of Some Test Examples

	(I, J)	Fixed Cost C_j	Marginal Cost M_j	Market Segment Size N_i	Piracy Cost T_i	WTP V_i	Final # Versions Offered	Firm's Profit Improvement	Social Welfare Improvement
Case 1	(3, 2)	0	0	1k ~ 10k	0 ~ 100	0 ~ 100	2	24.61 %	14.71 %
Case 2	(3, 2)	10 ~ 50	0	1k ~ 10k	0 ~ 100	0 ~ 100	2	28.81 %	9.17 %
Case 3	(3, 2)	100 ~ 500	0 ~ 10	1k ~ 10k	0 ~ 100	0 ~ 100	2	24.60 %	29.95 %
Case 4	(6, 4)	0	0	1k ~ 10k	0 ~ 100	0 ~ 100	2	12.17 %	15.14 %
Case 5	(6, 4)	10 ~ 50	0	1k ~ 10k	0 ~ 100	0 ~ 100	2	18.18 %	12.47 %
Case 6	(6, 4)	100 ~ 500	0 ~ 10	1k ~ 10k	0 ~ 100	0 ~ 100	2	22.45 %	40.71 %
Case 7	(10, 10)	0	0	1k ~ 10k	0 ~ 100	0 ~ 100	2	11.69 %	9.69 %
Case 8	(10, 10)	10 ~ 50	0	1k ~ 10k	0 ~ 100	0 ~ 100	2	16.09 %	20.23 %
Case 9	(10, 10)	100 ~ 500	0 ~ 10	1k ~ 10k	0 ~ 100	0 ~ 100	2	16.08 %	6.31 %

Concluding Remarks

Information goods piracy is a pervasive problem as advanced information and communication technologies become so inexpensive and easy to access. This problem, if not alleviated, can pose a serious loss to society. For example, piracy may reduce information goods providers' incentives to develop information goods if they can't cover their fixed cost. In addition, piracy may threaten the use and growth of the Internet as a distribution media for *valued* digital information goods.

Several instruments have been proposed previously to alleviate the information goods piracy problem, such as stronger enforcement of the laws or technology preventive means, both of which directly increase the piracy cost faced by individuals. However, stronger law enforcement can be difficult and very costly, and technology preventive controls can often be "cracked." In this paper, we consider using versioning as a complementary means to these other methods. We construct a model that allows us to determine how many versions, at what quality level, and at what prices the information goods provider should adopt given the demand it has and the piracy costs its customers face. We show that versioning can be a very effective and profitable instrument to fight piracy. The improvement in profit level could come from two sources: from those who did not buy without versioning and from those who pirated. Furthermore, we also show that it is possible to do this without sacrificing the consumer's surplus and, as a result, the entire social welfare could increase. This suggests that by strategically using all of the instruments available, including versioning and other piracy controls which raise customer piracy cost, information goods providers can fight piracy more efficiently, and this has important welfare implication in the long run, as it can preserve the information goods provider's incentive to develop information goods and use the Internet as an efficient distribution channel.

References

Belleflamme, P. "Pricing Information Goods in the Presence of Copying," Working Paper, Department of Economics, Queen Mary University of London, 2002.

Ben-Shahar, D., and Jacob, A. "Preach for a Breach: Selective Enforcement of Copyrights as an Optimal Monopolistic Behavior," Working Paper, Arison School of Business, Herzliya, Israel, 2001.

Bhargava, H. K., and Choudhary, V. "Information Goods and Vertical Differentiation," *Journal of Management Information Systems* (18:2), Fall 2001, pp. 89-106.

Bhargava, H. K., and Choudhary, V. "One Size Fits All? Optimality Conditions for Market Segmentation via Second-Degree Price Discrimination," Working Paper, Graduate School of Industrial Administration, Carnegie Mellon University, Pittsburgh, PA, 2002.

Boldrin, M., and Levine, D. K. " The Case Against Intellectual Property," *American Economic Review* (92:2), May 2002, pp. 209-212.

Chen, Y., and Png, I. "Information Goods Pricing and Copyright Enforcement: Welfare Analysis," *Information Systems Research* (14:1), March 2003, pp. 107-123.

Cheng, H. K., Sims, R. R., and Teegen, H. "To Purchase or to Pirate Software: An Empirical Study," *Journal of Management Information System* (13:4), Spring 1997, pp. 49-60.

Conner, K. R., and Rumelt, R. P. "Software Piracy: An Analysis of Protection Strategies," *Management Science* (37:2), February 1991, pp. 125-139.

Duchene, A., and Waelbroeck, P. "Welfare Implications of Illegal Copies: The Case of Peer-to-peer Distribution Technologies," Working Paper, Center of Education and Research in Socio-economic Analysis-Ecole Nationale des Ponts et Chaussées, Paris, 2001.

Gayer, A., and Shy, O. "Copyright Protection and Hardware Taxation," *Information Economics & Policy*, forthcoming.

Gopal, R. D., and Sanders, G. L. "Preventive and Deterrent Controls," *Journal of Management Information System* (13:4), Spring 1997, pp. 29-47.

Jones, R., and Mendelson, H. "Product and Price Competition for Information Goods," Working Paper, Graduate School of Business, Stanford University, 1997.

Klein, B., Lerner, A. V., and Murphy, K. M. "The Economics of Copyright 'Fair Use' in a Networked World," *The American Economic Review* (92:2), May 2002, pp. 205-208.

Mussa, M., and Rosen, S. "Monopoly and Product Quality," *Journal of Economic Theory* (18:2), 1978, pp. 301-317.

Shy, O., and Thisse, J. F. "A Strategic Approach to Software Protection," *Journal of Economics and Management Strategy* (8), 1999, pp. 163-190.

Takeyama, L. N. "The Welfare Implications of Unauthorized Reproduction of Intellectual Property in the Presence of Network Externalities," *Journal of Industrial Economics* (62), 1994, pp. 155-166.

Varian, H. R. "Versioning Information Goods," Working Paper, School of Information Management and Systems, University of California, Berkeley, Berkeley, CA, 1997.

Varian, H. R. "Markets for Information Goods," Working Paper, School of Information Management and Systems, University of California, Berkeley, Berkeley, CA, 1998.

Appendix

Proposition 2:

Proof sketch: $\pi = \alpha P_1 + (1-\alpha) P_Q$

s.t.

$V_H - P_1 \geq 0$.....(1) H is willing to buy over not buying

$V_H - P_1 \geq V_H Q - P_Q$.....(2) H is willing to buy $(1,P_1)$ over (Q,P_Q)

$V_H - P_1 \geq V_H - T$.....(5) H is willing to buy over pirating

$V_L Q - P_Q \geq 0$.....(3) L is willing to buy over not buying

$V_L Q - P_Q \geq V_L - P_1$.....(4) L is willing to buy (Q,P_Q) over $(1,P_1)$

$V_L Q - P_Q \geq V_L - T$.....(6) L is willing to buy over pirating

When $V_L \le T \le V_H$, by reorganizing terms, we will notice that only one of the latter three inequalities, equation (4), will be binding, and that equation (1) will not be binding. So we need to consider equations (2), (3), and (4) only. Given that the seller will want to charge P_1 and P_Q as high as possible, we have:

$$\begin{cases} P_Q = V_L Q \\ P_1 = \min\{T, V_H(1-Q) + V_L Q\} \end{cases}$$

The seller will then choose a Q that maximizes its profit subject to these two equalities. $Q^* = \arg\max \ \alpha P_1 + (1-\alpha) P_Q$. Thus we get:

$$Q^* = \frac{V_H - T}{V_H - V_L},\ P_Q = \frac{V_L(V_H - T)}{V_H - V_L}, P_1 = T\ .\ \text{QED.}$$

Proposition 3:

Proof sketch: T^* is solved by maximizing the seller's net profit, i.e. $T^* = \arg\max \ \ \alpha P_1 + (1-\alpha) P_Q - F(T)$. QED.

Propositions 4 and 5:

Proof sketch: $\pi = D_1 P_1 + D_Q P_Q$

s.t.

$V_H - P_1 \ge 0$.....(1) H is willing to buy over not buying
$V_H - P_1 \ge V_H Q - P_Q$.....(2) H is willing to buy (1,P_1) over (Q,P_Q)
$V_H - P_1 \ge V_H - T$.....(5) H is willing to buy over pirating
$V_L Q - P_Q \ge 0$.....(3) L is willing to buy over not buying
$V_L Q - P_Q \ge V_L - P_1$.....(4) L is willing to buy (Q,P_Q) over (1,P_1)
$V_L Q - P_Q \ge V_L - T$.....(6) L is willing to buy over pirating

Where D_1 is the demand for version *(1, P_1)* and D_Q is the demand for version *(Q,P_Q)*. Also we use E to indicate ethical consumers, and NE to indicate customers who might pirate, so EH represents ethical high-end type people while NEH stands for non ethical high-end type people.

To induce EH to buy, constraints (1) and (2) need to be satisfied, while to have NEH to buy, (1), (2), and (5) need to hold. Likewise, to have EL to buy, we need (3) and (4) satisfied, and to have NEL to buy, (3), (4), and (6) need to hold.

With these conditions, we have some observations: EH will always buy; if NEH buys, all the rest will buy; if NEL buys, then EL will also buy; and when $T > V_L$, NEL will buy whenever EL buy. With these observations, we can get demand under different situations, and with the demand and the condition's need to be satisfied, we can solve the profit maximization problem in a similar manner as the proof of proposition 2. QED.