On Software Piracy when Piracy is Costly∗

Sougata Poddar
Department of Economics
National University of Singapore (NUS)
10 Kent Ridge Crescent
Singapore 119260

E-mail: ecssp@nus.edu.sg

January 2004

Abstract

The pervasiveness of the illegal copying of software is a worldwide phenomenon. However, the level of piracy across various markets as well as across various countries varies a great deal. In some markets (countries), we observe rampant piracy while in some other markets (countries) piracy is rare. In this paper, we develop a simple economic model to explain both these features when there is one original software firm caught up in two situations of piracy (a) commercial/retail piracy (b) end user piracy. We investigate under what condition piracy will take place and when it will cease to exist. We find that whether or not the pirate(s) survives in the market, depends on three important factors: (i) the income distribution of the potential software users, (ii) the enforcement policy against the pirate, and (iii) the quality and reliability of the available pirated product. Our general conclusion is, piracy survives in the market when the income inequality is relatively high in a society, enforcement policy against the pirate is less strict (i.e. cost of piracy is not too high), and when the pirate produces a software copy that is moderately reliable and moderately differentiated from the original product.

Keywords: Software piracy, Copyright Violations, Raising rival’s cost, Deterrence, Product reliability, Product differentiation, Competition

JEL Classifications: D23, D43, L13, L86

∗ I would like to thank the seminar participants at the IO Workshop at NUS (2003), and at the University of Tokyo (2003); the conference participants at the Indian Statistical Institute, (2003) and EARIE Meeting (2003), Helsinki for the most helpful comments and suggestions. Financial support from NUS in the form of research grant (R-122-000-040-112) is gratefully acknowledged.
1. Introduction

The pervasiveness of the illegal copying of software is a worldwide phenomenon. It is not only having a profound effect on the users of the software, but also on the software industry as a whole. It is also having a tremendous effect on the development of digital intellectual properties and technologies. However, the level of piracy across various markets varies a great deal. In some markets, we observe rampant piracy while in some other markets piracy is rare.¹ There exists some empirical studies (see Gopal and Sanders (1998, 2000), Husted (2000), Donald and Steel (2000), Holm (2003)) to explain the varying piracy rates across countries and regions, but to the best of our knowledge no rigorous theoretical study has been done so far to explain the same phenomenon. In this paper, we attempt to do that. We develop an economic model to explain why do we observe varying rates of piracy across nations, and more specifically, between the developed and developing nations?

In this analysis, we will consider two types of piracy that are widely observed, (i) End user Piracy (ii) Commercial/Retail Piracy. End user piracy is observed more or less everywhere, whereas commercial piracy is more prevalent in the poor and developing countries where the laws against piracy or in general enforcement against copyright violations are rather weak.² In end user piracy, pirates are the end users; this is equivalent to private coping; while in commercial/retail piracy, pirates copy and sell their products to consumers with a profit motive. To capture the notion of commercial piracy in a simple way, here we consider a model of an original software firm and a retail pirate. Under both types of piracy, we find out under what condition piracy will take place and when it can be stopped. The basic assumption we use here is stopping piracy is a costly activity, but if such costly activity is undertaken, it raises the cost of piracy to the pirates, which consequently limits/stops piracy. In this paper, we assume the original developer of the software or the original firm takes the costly effort to stop/limit piracy. It invests in something that raises the cost of piracy. For example, in the case of commercial piracy, the original firm may set up an operation to monitor the market in order to catch the retail pirate and stop piracy. In other words, setting up an arrangement of monitoring by the

¹ Piracy rates defined as the ratio of the number of pirated copies to total installed copies, vary from 24 percent in US to 95 percent in Vietnam in the year 2002. (Source: IPR report for BSA 2003)
² Widespread corruptions, weak legal systems are some of the reasons for that.
original firm raises the cost of piracy to the pirate. We capture this notion by assuming that the pirate’s marginal cost of producing a copy increases with the monitoring effort of the original software developer. So higher the monitoring level, higher the marginal cost of producing pirated copies. Thus, overall piracy becomes costly with the degree of monitoring arrangement made by the original firm. Secondly, instead of monitoring or in addition to monitoring, the original firm can invest in R&D, so that it can develop a technology (like putting a protective device into the software), which increases the cost of copying its software. Now to develop such technology usually costly R&D must be undertaken before. So the idea is, the original firm can increase the cost of pirate’s activity by investing in something (in terms of setting up the monitoring arrangement and/or doing R&D) before the pirate could start its operation. In the situation of end user piracy, the original firm does similar thing to limit piracy, the only difference in this case is, the private coping is done by the end users of the software.

Now, since this investment made by the original firm is costly, the question that naturally arises, whether it is profitable to the original firm to actually undertake such deterrence operation. And if at all it undertakes such deterrence operation, under what circumstances it will be effective. We show that the answers to these questions depend on the overall profitability of the original firm as well as of the pirate and on the net utility of the potential software users. This in turn depends on three important factors of the economy: (i) the income distribution of the potential software users, (ii) the strictness of the enforcement policy against the pirate (i.e. enforcement against copyright violations), and (iii) the quality and reliability of the available pirated product. Analyzing the model, we are able to explain, why sometime pirates operate in the market, and why the original firm cannot do anything about it. We show when the original firm will actually be able to stop piracy successfully. In other words, our analysis works out the condition when there will be pirate(s) in the market, and when there will be no pirate operating. As we will see the results we obtain here also confirm our intuition on this matter to a large extent. Our general conclusion is, the pirate(s) survives in the market when the income inequality is relatively high in the society, enforcement policy against the pirate is less strict (i.e. cost of piracy is not so high), and when the pirate(s) produces a software copy that is
moderately reliable and moderately differentiated from the original product available in the market.

The effects of installing protection device into software as well as monitoring piracy have been analyzed in Chen and Png (2003) and Banerjee (2003) among others. Chen and Png (2003) studies how original developers of the software should set price and determine enforcement policy (monitor) in order to stop piracy in a model when the government sets the fine for copying, tax on copying medium or provide subsidy for legitimate purchases. They show while monitoring reduces overall usage of the software and hence reduce social welfare, appropriate pricing policy increases overall usage of the software and society’s welfare. So they suggest society should favour dealing with piracy through price rather than monitoring. On the other hand, Banerjee (2003) examines the government’s as well as the original firm’s role in restricting piracy and shows that welfare maximization results in not monitoring as the socially optimal outcome. He also shows in order to eliminate piracy, price discrimination and limit pricing are two possible pricing strategies available to the original firm. In contrast, in this paper, we approach the problem from a new angle and explore the possibility of stopping piracy by the original firm by raising the (rival) pirate’s cost of production in the case of commercial piracy and increasing the deterrence effect (i.e. cost of piracy) in the case of end user piracy. There is no direct government intervention (like tax, fine, subsidy etc.) in the model and it is only the original software firm’s responsibility to limit the activity of the pirates. In our analysis, government’s involvement comes indirectly through the given environment where the market for software operates, namely, through the strictness of the legal enforcement policies against copyright violations, which is taken to be a parameter of the model.

Raising rivals’ cost of production in order to induce its rivals to exit the industry has been studied for the first time by Salop and Scheffman (1983). They focused their study in an industry consisting of a dominant firm and a competitive fringe, where the low cost dominant firm can cause injury to the rivals by strategically raising the cost of the fringe firms. Interestingly, further studies of this feature (of raising rival’s cost) had not been done much in other type of industries or market structures. The only exception is
vertically related markets. In this paper, in the case of commercial piracy, we introduce this feature in a simple duopoly framework where one competitor (the original firm) endogenously raises the rival’s (pirate) cost by undertaking some costly investment in the form of R&D (or arranging to monitor the market) before. We believe apart from the piracy aspect of this paper, studying the strategic option of raising rival’s cost in this fashion in a simple duopoly model is also a contribution to the literature of strategic entry deterrence.

On software piracy, there is also a literature (see Conner and Rumelt (1991), Takeyama (1994), Slive and Bernhardt (1998), Shy and Thisse (1999) among others) which comes up with a fairly general explanation of the existence of the piracy phenomenon. There the argument basically stands on the feature of network externality that is observed in the software user market. They show that when the network effect is strong (i.e. in the presence of high network externality), the original firm will allow (limited) piracy as it turns out to be the more profitable option than protection. In contrast, in this paper, we come out with an alternative explanation of the existence of software piracy without relying on the feature of network externality at all. In this model, the existence (or non-existence) of piracy comes out as an endogenous outcome of the strategic game between the pirate and the original firm in the situation of commercial piracy, while as a result of the monopoly software firm’s profit maximizing policy in the situation of end user of piracy.

The plan of the paper is as follows. In the next section, we describe the model of retail/commercial piracy in detail. In section 3, the main analysis is done under retail piracy and the results are derived. An example is provided in section 4 under retail piracy. Section 5 considers the case end user piracy. Finally, Section 6 concludes.

---

4 The idea of network externality stems from the work of Katz and Shapiro (1985), (see also Rohlfs 1974, Gandal 1994, and Shy 1996). Generally, the idea is that the utility that a given user derives from some products depends upon the number of other users who consume the same products. In other words, consumers’ preferences are said to exhibit network externality if the utility of each consumer increases with the cumulative number of other consumers purchasing the same brand. When this is the case, each additional purchase raises the value to existing users as well as the expected value to future adopters. A classic example of a product that exhibits such a characteristic is found in the telephone network.
5 If we incorporate network externality in our model, it can be shown that the results we obtain here will qualitatively remain unchanged, only the computations will be little more involving.
2. The Model of Retail/Commercial Piracy

2.1 The Software Firm and the Pirate

Consider an original software firm and a pirate. The pirate has the technology to copy the original software. We assume the pirate produces software copies, which may not be as reliable as the original product. The probability that a pirated software works is \( q \), \( q \in (0,1) \) and this probability is common knowledge.\(^6\) Therefore \( q \) serves as a proxy for the quality of the pirated software. Usually pirated copies do not come with the supporting services, so one can think even if the pirated software is exactly same as the original one (because of digital coping), but the lack of supporting service does not allow the user to get the full value of the pirated software, hence quality of the pirated software \( q \) can also be interpreted like this.

There are two time periods, where in the first period \((t = 1)\), the original developer makes costly arrangement to monitor the market for any future potential pirate’s activity and/or undertakes some costly R&D in order to make piracy costly technologically.\(^7\) We assume all these costly actions of the original developer essentially raise the marginal cost of producing a copy by the pirate. The potential pirate appears in the market of the original product in the second time period \((t = 2)\). We assume the higher the investment effort by the original software developer in the first period, the higher the marginal cost of copying of the pirate. The pirate if survives, competes with the original developer in price by possibly producing less reliable yet cheaper products.

2.2 Costs and Profits of the Competing Firms

We assume at \( t = 1 \), the cost of investment by the original developer to increase the marginal cost of the pirate by an amount of \( x \) is given by \( c_o(x) = \frac{x^2}{2} \). Let us call \( x \) as the level of deterrence.

\(^6\) \( q = 0 \) will eliminate the pirated product, while \( q = 1 \) will make two products identical. Hence to avoid these two degenerate cases we assumed \( q \in (0,1) \).

\(^7\) One can imagine when the original firm makes it technologically harder (due to R&D) to copy the product, that would increase one time fixed cost of the pirate, say, to break the security code. However, for simplicity, in this analysis we assume that fixed cost part to be zero. Since it is just a constant, the qualitative results of the analysis remain unaffected without it.
Thus, if the profit of the software developer at \( t = 2 \) is denoted by \( \pi_2 = p_o D_o \), where \( p_o \) is the price charged by the developer and \( D_o \) is the demand it faces, then the net profit of the developer at \( t = 1 \) becomes \( \pi_o = \pi_o^2 - c_o(x) = \pi_o^2 - \frac{x^2}{2} \)  

On the other hand, if the pirate is in the market at \( t = 2 \) then it’s profit function becomes \( \pi_p = (p_p - cx) D_p \), where \( p_p \) is the price charged by the pirate and \( D_p \) is the pirate’s demand and \( c \) is a positive constant \( (c > 0) \) exogenously given. \( c = 0 \) means piracy is costless or in other words, original firm’s investment effort in the earlier period has no effect in deterring piracy. On the other hand, higher \( c \) increases the cost of piracy, which says, original firm’s investment to stop piracy becomes more effective. \( c \) is important to our model and we can interpret the exogenous cost coefficient \( c \) as follows. It can be interpreted as strictness of the enforcement policy against piracy of a particular country. For example, we can generally find a relatively high \( c \) in the developed countries where piracy is taken as a serious crime; hence it raises the cost of piracy significantly. On the other hand, in most of the developing countries, we will probably find \( c \) to be relatively low, because the enforcement policies against piracy may not be as strict as the developed nations, hence cost of piracy would remain relatively small. Thus, \( c \) can be interpreted as the legal environment where the market for software operates.

### 2.3 Consumer Demand

Consider a continuum of consumers indexed by \( X, X \in [\theta_L, \theta_U] \), \( \theta_U > \theta_L \geq 0 \). A consumer’s willingness to pay for the software depends on how much he/she values it – measured by \( X \). A high value of \( X \) means higher valuation for the software and low value of \( X \) means lower valuation for the software. Therefore, one consumer differs from another on the basis of his/her valuation for the particular software. Valuations are uniformly distributed over the interval \( [\theta_L, \theta_U] \) and the size of the market is normalized to 1.

---

8 Assuming the marginal cost of production of the software is zero for the original firm.

9 Even if the law against piracy is there, the pirate can get away by offering bribes to the authorities due to widespread corruption in most poor and developing countries.
A consumer’s utility function is given as:

\[
U = \begin{cases} 
X - p_o & \text{if buy original software} \\
q X - p_p & \text{if buy pirated software} \\
0 & \text{if buy none}
\end{cases}
\]

There is no way a consumer can get defected pirated software replaced since there is no warranty for the pirated software.\(^{11}\) Hence, the consumer enjoys the benefit of the pirated software only with probability \(q\). In the event that the pirated software purchased does not work at all, the loss to the consumer is the price paid for it. The original software is fully guaranteed to work.

\(p_o\) and \(p_p\) are the prices of the original and pirated software respectively. It must be true that \(p_o > p_p\). \((p_o - p_p)\) can be viewed as the premium a consumer pays for buying “guaranteed-to-work” software.

3. Analysis

3.1 Deriving Demand of the Software Developer and the Pirate

\(D_o\) and \(D_p\) can be derived from the distribution of buyers as follows.

---

\(^{10}\) \(q X - p_p = q (X - p_p) + (1 - q)(- p_p)\). If the pirated software is not working, consumer does not derive any benefit from the software and instead only incurs a loss equivalent to the amount paid for the pirated software.

\(^{11}\) In most markets pirates operate using some makeshift arrangement, if the parted software turns out to be defected, there is no chance of getting software replaced.
Recall that consumers are heterogeneous with respect to their values towards the software. Thus, the marginal consumer, $\hat{X}$, who is indifferent between buying the original software and the pirated version is given by:

$$\hat{X} - p_o = q\hat{X} - p_p$$

$$\hat{X} = \frac{p_o - p_p}{1 - q}$$

The marginal consumer, $\hat{Y}$, who is indifferent between buying the pirated software and not buying any software is:

$$q\hat{Y} - p_p = 0$$

$$\hat{Y} = \frac{p_p}{q}$$

Thus the demand for original software is:

$$D_o = \frac{1}{\theta_H - \theta_L} \int_{\hat{X}}^{\theta_H} dx = \frac{\theta_H (1-q) - (p_o - p_p)}{(\theta_H - \theta_L) (1-q)}$$

Demand for pirated software is:

$$D_p = \frac{1}{\theta_H - \theta_L} \int_{\hat{Y}}^{\theta_H} dx = \frac{qp_o - p_p}{(\theta_H - \theta_L) q (1-q)}$$

Next, we look for subgame perfect equilibrium of the two period game and solve using the usual method of backward induction. Let’s first focus on the second period of the game.

### 3.2 Price Competition in the Product Market

In the second period, if the pirate operates, the two firms engage in a Bertrand price competition and choose the profit maximizing prices of the respective products.

The profit function of the pirate is:

$$\pi_p = (p_p - cx) D_p = (p_p - cx) \frac{qp_o - p_p}{(\theta_H - \theta_L) q (1-q)}$$

The profit function of the original firm is:

$$\pi_o^2 = p_o D_o = p_o \frac{\theta_H (1-q) - (p_o - p_p)}{(\theta_H - \theta_L) (1-q)}$$

The reaction functions of the original firm and the pirate are as follows.

$$R_o (p_p) = \frac{p_p}{2} + \frac{(1-q)\theta_H}{2(\theta_H - \theta_L)}; \quad R_p (p_o) = \frac{qp_o}{2} + \frac{cx}{2}$$
Notice that as the original firm increases investment effort in the first period, higher will be \( x \) in the second period, which means higher will be the marginal cost of copying to the pirate. Thus a increase in \( x \) (or an increase in the exogenous parameter \( c \)) will shift the reaction function of the pirate upward. This will result higher equilibrium prices for both the original firm and the pirate. It is easy to see that the original firm will gain from this change in the product market competition stage as it is now charging higher price while its costs in that period remains the same. However, for the pirate since the total cost of piracy goes up for this change, the net effect in the change in total profit remains ambiguous. The possibility that there could be no real change in profit or even a decline in profit of the pirate cannot be ruled out.

The Nash equilibrium in prices are given by

\[
p_O = \frac{1}{4-q} \left[ \frac{2\theta_H (1-q)}{(\theta_H - \theta_L)} + cx \right], \quad p_p = \frac{1}{4-q} \left[ \frac{\theta_H q (1-q)}{(\theta_H - \theta_L)} + 2cx \right]
\]

Equilibrium demands are given by

\[
D_O = \frac{1}{(4-q)(1-q)(\theta_H - \theta_L)} \left[ \theta_H (4-q)(1-q) - \frac{\theta_H (2-q)(1-q)}{(\theta_H - \theta_L)} + cx \right];
\]

\[
D_p = \frac{1}{(4-q)q(1-q)(\theta_H - \theta_L)} \left[ \frac{\theta_H q (1-q)}{(\theta_H - \theta_L)} - cx (2-q) \right]
\]

The equilibrium profits are given by

\[
\pi^2_O = p_O D_O \quad \text{and} \quad \pi_p = p_p D_p
\]

### 3.3 Pirate’s Decision

The pirate will be in business as long as it can make positive profit, which consequently puts an upper bound on \( x \).

Equating \( \pi_p = 0 \), we get \( \hat{x} = \frac{\theta_H q (1-q)}{c(2-q)(\theta_H - \theta_L)} \)

Thus for all \( x \geq \hat{x} \), the profit of the pirate becomes non-positive hence, the pirate will not operate, and piracy will be deterred.

### 3.4 Choice of Optimal Level of Deterrence by the Software Developer
Now we move on to the first period of the game. In this period, original firm decides on its optimal choice on the level of $x$ to deter piracy.

Thus it maximizes its net profit $\pi_o = \pi_o^* - c_o(x) = \pi_o^* - \frac{1}{2}x^2$ with respect to $x$.

Solving, we get the optimal level of deterrence

$$x^* = \frac{\theta_H c(1-q)}{(4-q)^2 (1-q)(\theta_H - \theta_L) - 2c^2 \left[ \frac{q}{(\theta_H - \theta_L)} + 4 - q \right]}$$

Now given the fact that when $x = \hat{x}$, the pirate stays out; the actual optimal level of deterrence is given by $\min (x^*, \hat{x})$.

Note that if $c = 0$ i.e. when the original firm’s investment effort has no effect in deterring piracy, the original firm will not choose any investment in the first place, hence $x^* = 0$.

$x^* = 0$ is also true when the pirate produces exactly the same product (i.e. $q = 1$) as the original firm. When the product is same, the original firm’s costly investment has no deterring effect at all. So it will not invest in the first place.

Apart from the above restriction, to ensure $x^* > 0$ we must have

$$(4-q)^2 (1-q)(\theta_H - \theta_L) > 2c^2 \quad \text{i.e. when } c < \sqrt{\frac{(1-q)(\theta_H - \theta_L)}{2}} (4-q) = \alpha(q, \theta_L, \theta_H);$$

(say). Hence, the effective range of $c$ for which the analysis is valid is given by

$$0 < c < \alpha(q, \theta_L, \theta_H).$$

### 3.5 Main Result

Now we would like to see under what condition the optimal level of deterrence $x^* \geq \hat{x}$, where $\hat{x}$ is the actual level of deterrence of the pirate.

$$x^* \geq \hat{x} \quad \text{implies} \quad c \geq \sqrt{\frac{q(4-q)(1-q)(\theta_H - \theta_L)}{q + (2-q)(\theta_H - \theta_L)}} = \beta(q, \theta_L, \theta_H);$$

(say).

Note that this condition is well defined. Each term of the expression in the right hand side is non-negative, hence $\beta(q, \theta_L, \theta_H) \geq 0$. Also it is easy to verify $\beta(q, \theta_L, \theta_H) < \alpha(q, \theta_L, \theta_H)$. Thus we have the following result.

---

12 Note that this effective restriction is coming on the range of $c$ because our concerned $q$ is less than one.
Theorem 1

When the pirate faces a deterrent to operate and stopping piracy is also a costly activity to the software firm,

(i) piracy will actually be stopped if \( \beta(q, \theta_L, \theta_H) \leq c < \alpha(q, \theta_L, \theta_H) \).

(ii) the pirate survives in the market if \( 0 < c < \beta(q, \theta_L, \theta_H) \).

3.6 Economic Interpretation

As we can see, there are three important factors that determine the above conditions (i) \( \beta(q, \theta_L, \theta_H) \leq c < \alpha(q, \theta_L, \theta_H) \) and (ii) \( 0 < c < \beta(q, \theta_L, \theta_H) \). This in turn determines whether piracy will take place or not. These three factors are (1) the distribution of the valuation (recall \( X \sim U[\theta_L, \theta_H] \)) of the software users towards the software, which is same as the distribution of the willingness to pay for the software, and which can also be approximated as the income distribution of all potential software users (i.e. population). (2) the strictness of the legal enforcement system against the pirate \( c \); which effectively determines how costly for the pirate to survive in the market. (3) the quality and reliability \( q \) of the available pirated product. This parameter also determines how much the pirated product is differentiated from the original one. In our analysis, we find that it is the interaction of these three parameters that determine the existence (or non-existence) of the pirate in the market.

Given this, first we would like to explain, given a certain income distribution under what environment (i.e. parametric configuration of \( c \) and \( q \)), it is more likely that one of the above (in the theorem) inequalities will be satisfied, and as a result piracy will be stopped or continue. After that we will discuss the impact of income distribution itself on the existence of piracy.

First we note that \( c < \alpha(q, \theta_L, \theta_H) \) in condition (i) has to be satisfied for any meaningful discussion. It guarantees that the optimal deterrence level \( x^* \) is strictly positive for the original firm. We implicitly assume that there is enough heterogeneity in the market, thus enough income dispersion in the economy so that the above condition
will always be satisfied. Henceforth, we only concentrate on the comparison of $c$ and $\beta(q, \theta_L, \theta_H)$ in condition (i) and (ii).

**Environment conducive to stop piracy:**
In condition (i), $c$ becomes higher as the legal enforcement against the pirate gets stronger. For example, a country with a tough legal enforcement system can make the cost of piracy high for the pirate, which naturally makes difficult for the pirate to survive. On the other hand, in condition (i) $\beta(q, \theta_L, \theta_H)$ will be lower if the pirate produces a copy which is either very unreliable (i.e. $q$ close to zero) or very similar to the original product (i.e. $q$ close to 1). If it produces unreliable (low quality) product then very few people will buy from the pirate, hence that will make it difficult for the pirate to survive in the market. While if it produces a product very similar to the original one, it will face a very tough price competition from the original producer, and being producing the pirated product at an cost disadvantage (due to deterrence effect) compared to the original producer, the pirate will be at great disadvantage in competition. Under these conditions, it is more likely that the inequality will be satisfied and piracy will be stopped.

**Environment conducive for the pirate’s survival:**
On the contrary, the inequality (i) is less likely to be satisfied (or (ii) is more likely to be satisfied), when the legal enforcement system against the pirate is not strong i.e. low $c$, hence piracy is not that costly to the pirate. At the same time $\beta(q, \theta_L, \theta_H)$ gets bigger when the pirate produces a product which is moderately reliable (i.e. $q$ is away from zero) and at the same time moderately differentiated (i.e. $q$ is away from one) from the original product. This will leave the pirate with enough demand to sell its product and survive profitably. The combining effect of these two will make it easier for the pirate to survive, hence piracy cannot be stopped.

In the following analysis, we vary the degree of income inequality in the society $(\theta_H - \theta_L)$ while taking $(c)$ and $(q)$ as given to see the impact of the distribution of income of all potential software users on the existence of piracy.
### 3.7 Some Limit Results

\[
\frac{q(4-q)(1-q)(\theta_H - \theta_L)}{q + (2-q)(\theta_H - \theta_L)} = [\beta(q, \theta_L, \theta_H)]^2 = \lambda(q, \theta_L, \theta_H); \text{ (say)}
\]

It can also be written as: \( \lambda(q, \theta_L, \theta_H) = \frac{q(4-q)(1-q)}{(\theta_H - \theta_L) + (2-q)} \)

Now as \((\theta_H - \theta_L) \to \infty; \frac{q}{(\theta_H - \theta_L)} \to 0\), hence \(\lambda(q, \theta_L, \theta_H) \to \frac{q(4-q)(1-q)}{(2-q)} = \phi^*(q)\); a positive finite value.

On the other hand as \((\theta_H - \theta_L)\) gets smaller, \(\frac{q}{(\theta_H - \theta_L)}\) gets bigger and as a result \(\lambda(q, \theta_L, \theta_H)\) gets smaller. This makes it easier to satisfy the condition for stopping piracy \((c \geq \beta(q, \theta_L, \theta_H), \text{ see theorem})\), for a certain level of enforcement against the pirate.

In the limit as \((\theta_H - \theta_L) \to 0; \frac{q}{(\theta_H - \theta_L)} \to \infty\), hence \(\lambda(q, \theta_L, \theta_H) \to 0\), and thus \(\beta(q, \theta_L, \theta_H) \to 0\); which means even a very small level of enforcement policy is enough to eliminate piracy, when income inequality is very low in an economy.

Combining above two possible features of income distribution we have the following result.

**Proposition 1**

(i) If the income inequality in the economy is large enough and the enforcement policy against piracy is relatively weak i.e. \(c\) is low and in particular less than \(\phi^*(q)\), then piracy will always be there in that economy.

(ii) If the income inequality in the economy is not large, then for any moderate (or even small) degree of enforcement against the pirate will eliminate piracy from that economy.
Effect of income distribution on piracy with reference to developed and developing nations:

In most poor and developing nations the income gap between rich and poor is rather large giving rise to higher income inequality and a bigger value to \((\theta_d - \theta_l)\). It is also true that the enforcement policies against piracy or in general copyright violations are rather weak (as compared to developed nations due to corruption, bribery etc.) in these countries, giving rise to a lower value of \(c\). Hence, the possibility of piracy looms large in such situations. This is also captured by the data (source: BSA 2003), where it shows the rates of piracy in most of the developing countries are rather high.

On the other hand, in general, relatively less income inequality is observed in the rich and developed nations compared to developing nations. Also one can expect to be a higher \(c\) in the developed nations due to strict enforcement policies against copyright violations. Hence, given a certain quality \((q)\) of the pirated software, according to this theory, we will expect less piracy in the developed countries compared to developing countries. This result is also confirmed by the data (source: BSA 2003), which shows that the rates of piracy are much lower in developed nations compared to elsewhere. Thus, we believe this model gives us one way to explain the varying degree of piracy rates across countries, and in particular, the wide gap in the observed piracy rates between developed and developing nations.

4. An Example

Here we workout an example assuming that the continuum of consumers, denoted by \(X\) are uniformly distributed over the interval \([0,1]\). The size of the market is normalized to 1.

The demand for original software is: 
\[
D_o = (1 - \hat{X}) = 1 - \frac{p_o - p_p}{1 - q}
\]

Demand for pirated software is: 
\[
D_p = \hat{X} - \hat{Y} = \frac{qP_o - P_p}{q(1 - q)}
\]
4.1 Second Period: Price Competition in the Product Market

In the second period, if the pirate operates, the two firms engage in a Bertrand price competition and choose the profit maximizing prices of the respective products.

The profit function of the pirate is: \( \pi_p = (p_p - cx)D_p = (p_p - cx) \left( \frac{qp_o - p_p}{q(1-q)} \right) \)

The profit function of the original firm is: \( \pi_o = p_oD_o = p_o \left( 1 - \frac{p_o - p_p}{1-q} \right) \)

The reaction functions of the original firm and the pirate are as follows.

\[
R_o(p_r) = \frac{p_r}{2} + \frac{1-q}{2}; \quad R_p(p_o) = \frac{qp_o}{2} + \frac{cx}{2}
\]

The Nash equilibrium in prices are given by

\[
p_o = \frac{2(1-q) + cx}{4-q}, \quad p_r = \frac{q(1-q) + 2cx}{4-q}
\]

Equilibrium demands are given by

\[
D_o = \frac{2 - 2q + cx}{(4-q)(1-q)}; \quad D_p = \frac{1}{4-q} \left( 1 - \frac{cx(2-q)}{q(1-q)} \right)
\]

The equilibrium profits are given by

\[
\pi_o^* = \frac{(2(1-q) + cx)^2}{(4-q)^2(1-q)} \quad \text{and} \quad \pi_p^* = \frac{(q(1-q) - cx(2-q))^2}{(4-q)^2q(1-q)}
\]

4.2 Pirate’s Decision

Equating \( \pi_p = 0 \), we get \( \hat{x} = \frac{q(1-q)}{c(2-q)} \).

Thus for all \( x \geq \hat{x} \), the profit of the pirate becomes non-positive hence, the pirate will not operate, and piracy will be deterred.

4.3 First Period: Choice of Optimal Level of Deterrence by the Software Developer

The developer maximizes its net profit \( \pi_o = \pi_o^* - c_o(x) = \pi_o^* - \frac{1}{2}x^2 \) with respect to \( x \).

Solving, we get the optimal level of deterrence \( x^* = \frac{4c(1-q)}{(4-q)^2(1-q) - 2c^2} \)
Hence, the actual optimal level of deterrence is given by \( x^* \).

To ensure \( x^* > 0 \) we must have \((4-q)^2(1-q) > 2c^2 \) i.e. when \( c < \sqrt{\frac{1-q}{2}}(4-q) = \alpha(q) \); (say). Hence, the effective range of \( c \) for which the above analysis is valid is given by the following.

**Lemma 1**

The optimal level of deterrence \( x^* \) is strictly positive if and only if \( 0 < c < \alpha(q) \).

A necessary condition for the existence of \( x^* > 0 \) is: \( 0 < c < \max \alpha(q) = 2\sqrt{2} = 2.8284 \).

**Proof:** Note that \( \sqrt{\frac{1-q}{2}}(4-q) \) is decreasing in \( q \). Hence the maximum value is reached when \( q = 0 \); which is \( 2\sqrt{2} \). Recall that \( q \in (0,1) \).

**4.4 Towards the Main Result**

Now we would like to see under what condition the optimal level of deterrence \( x^* \geq \hat{x} \), where \( \hat{x} \) is the actual level of deterrence of the pirate. \n
This implies when \( c \geq \sqrt{\frac{q(1-q)(4-q)}{2}} = \beta(q) \); (say)

In other words, when \( c \) is more than or equal to \( \beta(q) \), the piracy will be stopped. Thus we have the following result.

**Lemma 2**

The original firm will be able to successfully stop piracy if \( c \geq 0.6631 \).

**Proof:** The maximum value that \( \beta(q) \) can attain is 0.6631 (For details see appendix).

Hence, for any \( c \geq 0.6631 \), the pirate will be out of business and the piracy will be stopped; otherwise we will always observe piracy.
Recall, previously we found that $\exists x^* > 0$ for $0 < c < 2.8284$. Now we found that the pirate may operate in the market and compete with the original firm as long as $c < 0.6631$.

Thus, the final effective range of $c$ where the analysis of price competition between the original developer and the pirate is valid is $0 < c < 0.6631$.

Thus, we have our main result in this particular situation.

**Proposition 2**

*When the pirate faces a deterrent to operate and stopping piracy is also a costly activity to the software firm, piracy will actually be stopped if*

(i) $0.6631 \leq c < \alpha(q)$ and

(ii) if $0 < c < 0.6631$, the condition for stopping piracy is $c \geq \beta(q)$.

**4.5 Economic Interpretation**

Case (i) is obvious in the sense that one, when $c$ is too high (thus the marginal cost $cx^*$ becomes too high) for the pirate to operate profitably.

Case (ii) is interesting, as it says whether piracy will be stopped or not depends on the two parameters of the model, the cost coefficient of piracy, that is $c$ (which is in the left-hand side), and the reliability of the pirate’s product that is $q$, which is combined in the expression $\beta(q)$ (in the right-hand side).

Result in (ii) implies, when cost of piracy is relatively low, then unless the product is very unreliable (i.e. $q$ is close to 0) or almost similar to the original product (i.e. $q$ is close to 1), there will be piracy (see the expression of $\beta(q)$). In this case, the pirate can operate profitably because first of all, cost of piracy is low and secondly, pirate’s product is moderately reliable (i.e. $q$ is away from zero) and at the same time moderately differentiated (i.e. $q$ is away from one) from the original product. This gives enough demand to the pirate to operate profitably and thus the pirate survives.

On the other hand, in case (ii) when $c$ is relatively high and the pirate’s product is very unreliable (i.e. $q$ is close to 0) or almost similar to the original product (i.e. $q$ is close to 1), the pirate cannot operate profitably. The reasons are as follows. First of all, in this
case, piracy becomes costly, so to cover that cost the pirate has to earn enough profit. Now when the product is very unreliable (i.e. \( q \) is close to 0), the demand of the pirate becomes very low, as a result pirate cannot survive in the market when piracy comes with significant cost. On the other extreme, when its product becomes very similar to the original firm’s product (i.e. \( q \) is close to 1), then very tough competition in price lowers the pirate’s profit significantly. Also note that in the situation when \( c \) is relatively high, in the product market competition, the pirate competes with the original firm with a significant cost disadvantage. Thus, in this situation, the pirate finds very hard to survive profitably.

4.6 Other Possible Deterrence

When \( x^* < \hat{x} \) (i.e. optimal level of deterrence is less than the actual deterrence level of the pirate), the whether piracy will be actually deterred or not by the original producer depends on whether entry-deterring monopoly profit of the original producer is more or less than its accommodating duopoly profit.

In this case, the entry deterring monopoly profit of the original producer is given by

\[
\pi^M_o(\hat{x}) = \frac{1}{4} - c_o(\hat{x}) = \frac{1}{4} - \frac{1}{2}(\hat{x})^2 = \frac{1}{4} - \frac{1}{2}\left(\frac{q(1-q)}{c(2-q)}\right)^2
\]

On the other hand, the accommodating duopoly profit the original producer is given by

\[
\pi^A_o(x^*) = \frac{2(1-q) + c}{(4-q)^2(1-q) - 2c^2} \left(\frac{4c(1-q)}{(4-q)^2(1-q) - 2c^2}\right)^2 - \frac{1}{2}\left(\frac{4c(1-q)}{(4-q)^2(1-q) - 2c^2}\right)^2
\]

**Proposition 3**

*When optimal level of deterrence is less than the actual deterrence level of the pirate (i.e. \( x^* < \hat{x} \)), piracy will be stopped if and only if \( \pi^M_o(\hat{x}) > \pi^A_o(x^*) \).*

If the above fails to hold, the original producer will fail to deter the pirate and as a result piracy will take place anyway.
4.7 Discussion on Welfare

Here we will try to make a comparison on social welfare in two cases, namely (i) when the pirate is out of the market due to successful entry deterrence by the original firm, and (ii) when the original firm is unable to deter the pirate.

Case (i) corresponds to a monopoly situation and it is true when \( \min(x^*, \hat{x}) = \hat{x} \). Welfare is defined as sum of consumer surplus (CS), industry profit (\( P \)) minus the cost of deterrence (DC). In this monopoly situation, let’s say welfare \( W^M \) is given by,

\[
W^M = CS + P - DC = \frac{1}{8} + \frac{1}{4} - \frac{1}{2} \left( \frac{q(1-q)}{c(1-q)} \right)^2 = \frac{3}{8} - \frac{1}{2} \left( \frac{q(1-q)}{c(1-q)} \right)^2
\]  

(3)

Case (ii) corresponds to the duopoly situation when the pirate is present and it is true when \( \min(x^*, \hat{x}) = x^* \) and \( \pi^*(x^*) > \pi^M(\hat{x}) \).

In this case, total welfare \( W \) is given by,

\[
W = \pi_o + \pi_p + CS_o + CS_p - \frac{1}{2} \left( \frac{4c(1-q)}{(4-q)^2(1-q)-2c^2} \right)^2
\]  

(4)

The following is true.

**Lemma 3**

In the case of successful deterrence, the monopoly price \( p_M = \frac{1}{2} \) is greater than the price of the original firm \( p_o \) in the duopoly case.

**Proof:** See appendix.

Thus we have the following: \( p_M > p_o > p_p \) which implies the total consumer surplus (CS) is higher in the presence of the pirate (duopoly case) compared to the monopoly situation. On the other hand, the total industry profit in the duopoly case is lower than the industry profit in the monopoly case.

Finally, \( c(\hat{x}) \) in case (i) is greater than \( c(x^*) \) in case (ii) as \( x^* < \hat{x} \).

So comparing (3) and (4) we get,

\[
W^M - W = \Delta CS + \Delta P + \Delta DC
\]
From above we get $\Delta CS < 0$, $\Delta P > 0$, and $\Delta DC < 0$, so the overall difference is ambiguous.

Thus, the overall effect on social welfare due to the presence of the pirate is ambiguous. Contrary to other situations (where piracy hugely increases the usage of software in a society, and thus enhances welfare, see Chen and Png, 2003) here we find the overall effect on social welfare due to the presence of the pirate may not be necessary welfare improving. This is mainly because the pirate faces a significant deterring cost of piracy while operating and at the same time presence of monitoring/R&D cost of the original firm may result in lower industry profit.

5. The Model of End User Piracy

Here there is no retail pirate in the economy. The consumers (all potential software users) are the potential pirates. There is one original software developer (monopoly). Like before, consumers’ valuations are uniformly distributed over the interval $[\theta_L, \theta_U]$; $\theta_U > \theta_L \geq 0$ and the size of the market is normalized to 1. Consumers can buy the original product from the monopolist or pirate without paying anything. We assume the probability that a pirated software works is $q$, $q \in (0,1)$ and this probability is common knowledge. Interpretation of $q$ is same as before. The activity of the original software firm remains exactly the same as before, except that now it targets the end user pirates to stop piracy as opposed to commercial pirate. Here it does not face any direct competition from anybody in the market; however, it stands to lose its potential market because of end user piracy. Under this circumstance, it invests to raise the cost of piracy to the end users.13 Thus a consumer’s utility function is given as:

$$U = \begin{cases} 
X - p & \text{if buys original software} \\
qX - cx & \text{if pirates} \\
0 & \text{otherwise}
\end{cases}$$

13 Here, we do not need the two period time structure as before, everything can be formulated within a single period in a simple manner.
where $x$ is the level of deterrence for piracy and $c > 0$ is the exogenous cost coefficient like before.

5.1 Deriving Demand of the Original and Pirated Software

**Figure 2: DISTRIBUTION OF BUYERS**

The marginal consumer, $\hat{X}$, who is indifferent between buying the original software and pirating is given by:

$$\hat{X} - p = q \hat{X} - cx$$

$$\hat{X} = \frac{p - cx}{1 - q}$$

The marginal consumer, $\hat{Y}$, who is indifferent between pirating the software and not buying any software is:

$$q \hat{Y} - cx = 0$$

$$\hat{Y} = \frac{cx}{q}$$

Thus, the demand for the software firm is:

$$D_O = \int_{\theta_H - \theta_L}^{\theta_H - \theta_L} \frac{1}{\theta_H - \theta_L} dx = \frac{\theta_H (1 - q) - (p - cx)}{(\theta_H - \theta_L)(1 - q)}$$

Demand for the pirated software is:

$$D_P = \int_{\theta_H - \theta_L}^{\theta_H - \theta_L} \frac{1}{\theta_H - \theta_L} dx = \frac{qp - cx}{(\theta_H - \theta_L)q(1 - q)}$$

5.2 Choice of Optimal Price and Level of Deterrence by the Software Developer

The developer maximizes its net profit:

$$\pi_o = pD_O - c_O(x) = p \left( \frac{\theta_H (1 - q) - (p - cx)}{(\theta_H - \theta_L)(1 - q)} \right) - \frac{1}{2} x^2$$

with respect to $p$ and $x$. 

21
Solving, we get, optimal price \( p^* = \frac{\theta_H (\theta_H - \theta_L) (1-q)^2}{2(\theta_H - \theta_L) (1-q) - c^2} \)

and the optimal level of deterrence \( x^* = \frac{\theta_H c (1-q)}{2(\theta_H - \theta_L) (1-q) - c^2} \)

### 5.3 Condition for No Piracy
Nobody will find piracy worthwhile if the person, who is just indifferent between buying the original product and pirating finds it not worthwhile to pirate. In other words, piracy is not worthwhile for anybody if

\[
q \left( \frac{p-cx}{1-q} \right) - cx \leq 0 \Rightarrow cx \geq pq
\]

Recall \( \hat{X} = \frac{p-cx}{1-q} \) is the indifferent person between buying and pirating.

Hence the condition for no piracy is given by: \( cx \geq pq \).

### 5.4 Main Result
Substituting the optimal price \( p^* \) and optimal level of deterrence \( x^* \) into no piracy condition, we get the following result.

**Theorem 2**

*When the pirates are the end users and stopping piracy is a costly activity to the software firm, the piracy will actually be stopped if* \( c \geq \sqrt{\frac{2(\theta_H - \theta_L) q (1-q)}{\theta_H}} \).

### 5.5 Economic Interpretation
Here also we find that the existence (or non existence) of piracy depends on there factors, namely, income distribution, legal enforcement, and the quality of pirated software. Low overall income (i.e. when \( \theta_H \) is low), and/or high income inequality (i.e. \( \theta_H - \theta_L \) is high) associated with reliable and differentiated available pirated product (i.e. medium \( q \)) will make RHS of the condition (theorem 2) bigger. This associated with weak legal enforcement against pirates (i.e. low \( c \), LHS) will make much harder to satisfy the
condition. Hence, in such situations we would expect more piracy to happen. It is not hard to see that most developing countries generically satisfy those conditions, which also explains higher rates of piracy in those countries. On the other hand, in most developed countries except for the quality of the pirated software, which could possibly vary to a large extent, the reverse is true. Hence, it is more likely that the above inequality would be satisfied in such conditions, and consequently, we should observe relatively less piracy in those countries. This is also quite evident from the available data on piracy (Source: BSA 2003). Thus, again this model explains well the varying piracy rates across countries (in particular, developed and developing countries) when the pirates are end users.

6. Conclusion
In this paper, we looked for a theoretical justification to explain the phenomenon, why do we observe a big difference in software piracy rates across countries and regions and in particular, why there exists a wide gap in the piracy rates between developed and developing nations? Although there are some empirical studies to understand this phenomenon, but to the best of our knowledge no rigorous theoretical attempt has been made to explain the same phenomenon. We believe this model provides us a satisfactory explanation of the varying rates of software piracy across markets, countries and regions under two very prevalent forms of piracy, namely, commercial/retail piracy and end user piracy. We show that the great degree of variance in piracy rates across markets and across countries can well be understood through three important parameters of a particular economy. The first one is the income distribution of all potential software users (i.e. population in general), second one, is the strictness of the enforcement policy against piracy in a particular society or country, which effectively determines the cost of piracy in that country/society, and third one is the quality and reliability of the pirated software product. Our analysis shows if we have reasonably good information on these three parameters (or if we can estimate reasonably well about the values) in a particular software market, then we can have a reasonably accurate prediction regarding the extent of software piracy in that market. Of course, this is probably a much simplified situation than the real life case; nevertheless, the analysis does give some insights about the
phenomenon of varying degree of software piracy across regions. We also believe that this explanation verifies our natural intuition on this phenomenon.

Reference


**Internet Source**

Appendix

Proof of Lemma 2:

Let’s denote \( q(1-q)(4-q) \) as \( f(q) \). It can be easily shown that for \( q \in (0,1) \), \( f(q) \) attains maximum when \( q = 0.4648 \).

Hence, the maximum value of \( f(q) \) is 0.8794.

Now from section 3.5, note that \( f(q) = 2(\beta(q))^2 \)

Thus maximum value of \( 2(\beta(q))^2 = 0.8794 \).

This implies maximum value of \( \beta(q) = 0.6631 \). Result follows.

Proof of Lemma 3:

To show \( p_M = \frac{1}{2} > p_o = \frac{2(1-q)+cx}{4-q} \) when \( x = x^* \)

Above implies \( 3q > 2cx^* \)

After simplification this implies \( c < \sqrt{3}\beta(q) \).

Now since we are under the subcase (i.e. the case of piracy) \( c < \beta(q) \), the above is true.

Hence, the result follows.