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The optimal level of technical copyright protection: A game-theoretic approach

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c	Marginal reproduction cost of media product
D^O	Development cost of media product
$K(p_s)$	Total cost of ownership for strong DRMS
$K(p_w)$	Total cost of ownership for weak DRMS
O	Original content provider
p_s	Protection probability for strong DRMS
p_w	Protection probability for weak DRMS
p^{opt}	Overall optimal level of technical copyright protection
p_w^{opt}	Optimal level of technical copyright protection for weak DRMS
P	Re-seller Pirate
P_O	Price set by Original
P_P	Price set by Pirate
P_O^M	Price set by Original (in monopoly case)
P_O^D	Price set by Original (in duopoly case)
P_P^D	Price set by Pirate (in duopoly case)
Π_O^D	Margin by Original (in duopoly case)
Π_O^M	Margin by Original (in monopoly case)
$\Pi_O(P_O)$	Margin by Original, depending on P_O

$\Pi_P(P_P)$	Margin by Pirate, depending on P_P
$\prod_O^{tot}$	Overall expected profit of Original
$\prod_M^{tot}$	Profit of Original for monopoly case
$\prod_D^{tot}$	Profit of Original for duopoly case
$\Delta\Pi$	Difference between monopoly and duopoly margin ($\prod_O^M - \prod_O^D$)
q	Degradation factor of media product
θ	Willingness-to-pay for media product
$\bar{\theta}$	Maximum willingness-to-pay for media product
$\theta', \theta'', \theta'''$	Marginal consumers´ willingness-to-pay for media product
U	Consumer utility for media product
Y	Total cost of ownership for strong DRMS

1 Introduction

Immaterial information products ("content") can be represented in digital form, which is an advantage but also a source of problems. It is fundamentally impossible to prevent copying of digital data, which is just a stream of bits – ones and zeros: Once you can read it, you can copy it. With the help of copying techniques it is very easy and cheap to make an unlimited number of perfect copies of an original digital media product. This can lead to massive information product piracy[1], i.e. illicit copying of copyrighted work, resulting in detrimental effects on the media industry and the society as a whole.[2]

In a situation where it becomes almost impossible to enforce intellectual property rights on an end customer level and content turns to a "perfect public good"[3], media companies look for self-help mechanisms to ensure their means of existence. *Digital Rights Management Systems* (henceforth referred to as DRMS) use technical copyright protection measures to protect content against digital piracy.

DRMS solutions offer a wide range of protective strength, ranging from very weak to strong forms. Actually, it is not possible to isolate a standard DRMS platform architecture. From a security perspective, DRMS pursue the following three objectives: (i) control access to content (e.g. through authentication techniques), (ii) monitor authorized consumption (e.g. through copy control mechanisms) and (iii) detect and prosecute copyright infringements (e.g. through watermark-based web-crawlers).[4] To achieve these functional objectives,

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[1] For example, the Business Software Alliance (BSA) estimates that over 24% of business software in the United States is unlicensed, and that in the year 2000, over US$2.6 billion in revenue was lost and over 107,000 jobs were lost due to unauthorized reproduction of software. See the website of Business Software Alliance (www.bsa.org).

[2] Compare Picot / Fiedler (2003) for a discussion of DRMS-induced innovation effects.

[3] Compare Bechtold (2002), p. 284.

[4] The last functional objective will not be relevant in our model, as it does not prevent piracy from happening in the first place.

DRMS architects combine and integrate core security technologies such as encryption, watermarking techniques and rights management languages.[5] The protective force of DRMS depends on various factor that can be designed into the DRMS architecture, such as the scope of security functionalities (does the DRMS include only a basic copy control mechanism or also biometric authentication procedures, etc.), sophistication of technical components (asymmetric encryption is harder to crack via brute force attempts than symmetric encryption; high-bit key symmetric encryption is stronger than low-bit key symmetric encryption) and quality of component integration (a flawless integration of these heterogeneous technical components will increase the robustness of the protective features and reduce security loopholes).

However, in terms of protective strength, the most important distinction has to be drawn between software and hardware-based DRMS. **Software-based DRMS** (e.g. Acrobat eBook reader) use special front-end software browsers or players to render the content on the client of the user, usually a general-purpose PC. A media firm just needs to implement in-house the corresponding back-end architecture (usually encryption key and content delivery servers) to enable seamless rights and content delivery with the customer front-end. However, software-based DRMS front-ends are easy to circumvent with special debugger and disassembler software. **Proprietary Hardware-based DRMS** (e.g. a Set Top Box with a proprietary, i.e. non-public, encryption algorithm) offer a much stronger level of protection, as the process of encryption and decryption is done in a closed hardware environment and it is very difficult to access the decrypted data flows that are necessary to produce pirate copies.

DRMS have the potential to prevent the unauthorized distribution and consumption of media products. In spite of these benefits, media companies are hesitant to implement DRMS.[6] There are two plausible explanations for this:

(i) The cost-benefit relationship of DRMS investments has not been understood yet. Beside the potential to re-privatize media products, DRMS also imply substantial costs. Depending on the desired level of security, media companies have to make investments in DRMS, in the integration of these systems in their system landscape, in training of the staff and in alignment of the business processes. As a consequence, we are confronted with a trade-off problem between costs and benefits of varying degrees of content protection with the need to identify an appropriate level of technology-based protection.

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[5] Compare Rosenblatt et al. (2002), pp. 45-83.

(ii) Media firms are afraid of adverse public policy reaction towards DRMS, due to possible negative welfare implications of (strong forms of) content protection. A restrictive stance by the government towards DRMS may result in a prohibition of certain protective features of DRMS[7] and could make existing DRMS installations obsolete or require additional investments to downward adjust the technological protection level, which may be expensive, technologically difficult and sometimes even impossible to implement. Obviously, the expected government reaction has direct repercussions on the choice of a concrete DRMS installation.

As a consequence, it is essential to analyze the economics of DRMS not only from the perspective of an individual media firm but also from a public policy viewpoint. The plan of this paper is as follows: First, we present the research methodology, which should be capable to give rational decision support for both the managerial and policy level. After presenting a brief survey of related literature, we set up our model in the next section and calculate the equilibria. This section concludes with comparative static analysis that will help us to understand the behavior of this model. Section 5 focuses on the policy implication of DRMS. The last section discusses some results of the paper and concludes with an outline of possible model extensions.

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[6] Compare Seyboldreports (2001) for a gloomy assessment of the market for DRMS solutions.

[7] Compare Bechtold (2002), p. 407.

2 Methodology

Given the problem structure of section 1 and the necessity to analyze the business strategy aspects as well as the public policy implications of DRMS techniques, we will employ a game-theoretic **Industrial Organization** (IO)[8] approach.

IO is the study of the way firms and markets are organized and of their interactions.[9] IO is often mistaken to be an exclusive research area of microeconomics. However, IO has to be distinguished clearly from analytical microeconomic theory, which is primarily concerned with tightly defined theoretic issues that are analyzed with abstract mathematics.[10] Microeconomists do not make reference to empirically plausible assumptions and the implications of the theory have no necessary link with practical managerial and public policy decision making. The following comments of Machlup (1967) manifests the abstract nature of microeconomics:

> *"The model of the firm is not … designed to serve to explain and predict the behavior of real firms: instead, it is designed to explain and predict changes in observed prices … as effects of particular changes on conditions … In this casual connection the firm is only a theoretical link, a mental construct helping to explain how one gets from the cause to the effect."*

By contrast, the researcher of IO must ground his work in the reality of the business environment in which firms operate. An understanding of empirical reality is essential. The industrial economist is concerned with a normative framework in order to be able to appraise the functioning of the industry. Thus, IO models are empirically more concrete than microeconomic models. However, due to its subject area, IO models are often too abstract to be applied to a concrete business decision problem. This is the classical domain of **Operations Research** (OR), which is the study of mathematical methods that can be used in

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[8] Compare Shepherd (1979), pp. 19-23 for a brief history of IO.

[9] Compare Carlton / Perloff (1990), p. 2.

[10] Compare Reid (1989), pp. 1-2.

solving managerial decision problems, especially in functional areas such as production, finance, or marketing.[11]

This discussion shows that economic models can be designed on different levels of abstraction and illuminate different perspectives of economic phenomena. IO models have an intermediate level of model abstraction and are, in this sense, positioned between Operations Research and classical analytical microeconomic models.

There is another factor that distinguishes IO from microeconomics: IO, in contrast to microeconomics, is profoundly concerned with policy questions, i.e. government policy towards business.[12] The public policy reaction is also highly relevant in the presented problem context: the chosen DRM protection strategy of a media firm might imply substantial investments in DRMS installations and possibly turn out ex-post to violate law. From this viewpoint, it is important for media companies to anticipate the governmental reaction towards certain levels of technical copyright protection measures, in order to avoid unnecessary investments in technology that is not backed by lawmakers.

We can conclude with the following statement: IO is concerned with the structure and behavior of firms (market structure and internal organization) and is not only useful for academic economists and public policy makers but also for business and resource management. [13] The study of IO models and concepts enables managers to analyze the determinants and structure of the industry in which their firm operates and the reaction of public policy makers that will influence in turn business strategy. As a consequence, IO models are a valuable source of insight for all the above mentioned camps.

IO research is undertaken with diverse theories including transaction-cost theory, theory of contestable markets, information theory and so on. We will use a game-theoretic approach because it provides valuable tools for analyzing an imperfect market characterized through strategic interaction.[14] **Game theory** (sometimes referred to as “Interactive Decision Theory”)

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[11] Compare Ellinger et al. (2003), pp. 1-3.

[12] Compare Cooter / Ulen (1988), pp. 1-12 and Martin (1994), pp. 1-2 for an overview of the application of IO models in public policy decision making, Examples include antitrust policy, regulation, public ownership, etc. The main body of law & economics research has been undertaken in antitrust policy.

[13] Compare Tirole (2002), p. 3.

[14] Compare Forges / Thisse (1992), pp. 13-14

is the study of mathematical models of conflict and cooperation between rational decision makers (players).[15] Stated so broadly, it would seem that most situation of interest to economists can be studied with game-theoretic tools. However, its applications are not restricted to economics but extend to other fields, such as to political science, sociology, military studies and so on. Actually, game theory can be considered a lively sector of applied mathematics, and is much more than a part of economic theory.

IO is primarily concerned with analysis of oligopolies, markets in which firms are neither monopolists nor perfect competitors, but something in between.[16] Oligopolistic market structures are predominant in the real world. This fits nicely with game theory, which is especially useful when the number of interactive agents is small.[17] In this case, the action of each agent may have a significant effect on the payoff of the other players. The goal of a game-theoretic model is to predict the outcomes (a list of actions adopted by each participant), given the assumed incentives of the participating agents. Thus, game theory is extremely helpful in analyzing industries of a small number of competing firms, since any action of each firm has strong effects on the profit levels of the competing firms.[18]

Nevertheless, game theory is not an exclusive domain of IO research. In general terms, the mathematical language of games permits economists to ask questions about the dynamics of competitive interactions. The major success has come from providing a common language for economic contexts and formalizing the nature of competition between economic agents (be they cooperative or noncooperative).[19]

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[15] von Neumann is considered the modern founding father of game theory. von Neumann / Morgenstern (1944) present the notion of a cooperative game, with transferable utility, its coalitional form and its von Neumann-Morgenstern stable sets. After this seminal work, the most important ideas by game theorists are those expounded by Nash (1950) with regards to non-cooperative, many-person games, together with the idea of refinements of the Nash equilibrium with the concept of subgame perfect equilibria by Selten (1965). A good introduction to game theory can be found in Osborne / Rubinstein (1994).

[16] Compare Martin (1994), p. 1

[17] Compare Shy (1995), pp. 11-12

[18] Influential articles by Fisher (1989) and Shapiro (1989) deal with the usefulness of game theory in understanding industrial structure

[19] Compare Kreps (1992), pp. 87-89 and Carlton / Perloff (1990), pp. 299-300.

The following quotation from Fuldenberg and Tirole, two of the most distinguished researchers in IO, confirms this point:

> *"Game theory has had a deep impact on the theory of industrial organization. … The reason it has been embraced by a majority of researchers in the field is that it imposes some discipline on theoretical thinking. It forces economists to clearly specify the strategic variables, their timing and the information structure faced by firms. As is often the case in economics, the researcher learns as much from constructing a model as from solving it because in constructing the model one is lead to examine its realism."*[20]

It is thus the integration of the analytical tools of game theory at an intermediate level of economic abstraction that is most adequate approach to analyze the problem outlined in section 1.

[20] Fudenberg / Tirole (1987), p. 176.

3 Related Work

The economic literature on copyright issues is traditionally divided in the following two areas: *economics of copying* and *economics of copyright*.[21] The first body of literature is concerned with the implications of the availability of copies on media companies and social welfare. The latter branch researches the impact and costs of the legal copyright regime on the trade off between limited access to and incentives for the production of information goods. The following papers fall in one these categories:

A pioneering analysis has been undertaken by Novos / Waldman (1984). They look at a market for a non-excludable good and analyze if a higher level of (exogenous) copyright protection leads to a higher social welfare. They show in a very stylized model that this is the case because the production of the qualitatively better original product increases. However, the competitive effect of piracy is completely ignored in their model.

Conner / Rumelt (1991) consider a model with positive network externalities of copying. If a software is very widespread, this will increase each user's valuation, resulting in positive externalities. This paper analyses a model with a given degree of copyright protection. They show that if such network externalities are present, a higher degree of protection can lead to a higher or lower profit of the original. The profit can be higher because higher protection leads to lower competition but it can also be lower because consumers' valuation decrease since the external effect is lower.

A model in the same vain is analyzed by Takeyama (1994). Her goal is to show the consequences of copying and external effects on social welfare. In her model the original content provider can price discriminate. As a consequence, this leads to a Pareto improvement because different consumers may pay different prices which means that low value consumers might also buy since their reservation prices are low.

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[21] Compare Landes / Posner (1989).

Only recently, with the advent of large-scale digital piracy and the failure of legal copyright regime, another related research area has come into existence: The *economics of technical copyright protection* deals with the impact of technical protection measures on media firms and the rational, wealth-maximizing, policy reaction.

Tze / Poddar (2000) is one of the first papers to deal with this subject and is close in spirit to ours. They are mainly concerned with the question if protection of software products are good from a welfare point of view. It is shown that the chosen protection level does not coincide with the optimal welfare level. In contrast to our model, they do not analyze the optimal protection level of the original content producer. In our model an additional stage is added to the model of Tze / Poddar (2000) in which a firm can made this decision. Another difference is that the consumers' valuations can change which allows to derive some comparative static results.

There are some relatively new papers which are directly concerned with the optimal level of copyright protection. Yoon (2001) is the first paper to analyze this question. He constructs a very elaborate model but the level of copyright protection is exogenously given and not a control variable of the original firm. The optimal level for the firm can be the whole range from no protection to full protection depending on the parameters of the model. Yoon (2001) shows that this level does not necessarily coincide with the optimal level from a welfare point of view.

Empirical literature on this topic is very limited. Holm (2001) applies a contingent valuation method to study willingness-to-pay for originals when illegal copies are available. He shows that piracy is insensitive to price cuts. The results can be used in the calculation of damages of piracy. Based on international panel data for music CDs and cassettes, Hui / Png / Cui (2001) provide empirical evidence that the demand for both goods decreased after piracy took place.

Habbaugh / Khemka (2001) consider a model with targeted copyright enforcement. This means that piracy is only penalized for high value consumers such as governments but not for low value buyers such as private users. They show that this can even lead to more piracy because the original firm may want to charge super-monopoly prices and consumers try to avoid this through piracy.

Gayer / Shy (2002) analyze a model in which the original content provider can be compensated for its losses due to piracy. The idea is that the government can impose levies on hardware, while allowing piracy of software, and redistribute these levies to the original content providers. Yet, Gayer / Shy (2002) show that this leads to an inefficiency.

King / Lampe (2002) analyze a simple model in which the original firm can price discriminate. The consumers are divided in two groups, those who have the ability to pirate and those who do not. It is shown that if the original firm can price discriminate between these two groups either no piracy or complete piracy is optimal.

Sundararajan (2003) looks at a model where the level of protection is a definitive control variable of the original firm. The level of technical protection not only lowers the quality of the pirate's product but also the consumers´ valuation for the original media product. The original can also price discriminate with non-linear pricing schemes. Sundararajan (2003) shows that because of price discrimination possibility the level of protection is very low. The reason is that price discrimination and protection are substitutes in his model. If price discrimination is not allowed, the level of protection would be higher.

Bae / Choi (2003) take the level of protection as given and analyse the trade-off between short-run and long-run development incentives. They show that a pricing policy to prevent entry of the pirate in the short-run (if the content is already developed) can be very different from the long-run optimum (if the content is not yet developed).

We can conclude that only few papers analyze the impact of technical copyright protection measures from a managerial and policy viewpoint. Furthermore, there has been almost no research effort to relate the model design to empirically observable copyright protection systems. This paper tries to close this gap by determining the optimal level of technical protection systems by taking close reference to existing content protection systems.

4 The Model

We consider a market for a specific media product (a piece of music, digital movie or software, for example) which has been produced by a media firm O (O stands for Original). All fixed costs incurred during content development are considered to be sunk; in addition, the producer incurs a constant marginal cost for each additional unit, denoted by c.

Beside the original content firm O, the market is made up of pirate firm P.[22] P is a re-seller pirate firm and has certain knowledge and technology to crack the technical protection of the original content firm O. All investments incurred by P to build up this piracy knowledge and in hacking equipment is assumed to be either zero or sunk. Furthermore, all agents are assumed to be rational, risk-neutral profit maximisers.

Firm O is a monopolist, when the pirate P does not succeed in cracking the protection measures and then generates the monopolist margin $\prod_{O}^{M}$. In case of a successful cracking attempt the pirate P enters the market and initiates duopolistic competition. In this case, the firm O generates the duopolistic margin $\prod_{O}^{D}$.

Firm O can decide on the level of technical copyright protection, which is viewed as the probability that the pirate can not crack the protection measures. In other words, the higher the protection level, the less the likelihood that the pirate P will crack the protection measure. Firm O can choose between one of two types of DRMS (later to be denoted “weak” and “strong” forms) with the corresponding protection probabilities p_s und p_w. An additive combination of these systems and their protection probabilities is not possible and would make little sense empirically.

Hence, the level of content protection (either p_s or p_w) is viewed as the probability that firm O remains in a monopolistic position. With the counter probability (1 - p_s) or (1 - p_w) firm O will

[22] Information good piracy can be divided in two classes: (i) End-user Piracy, which involves unauthorized copying by individuals (e.g. through -to-Peer networks) and (i) Re-seller Piracy, which involves large-scale reproduction of copyrighted products for subsequent sale to end-users.

generate a duopolistic margin. Both forms of protection are related with respective protection costs $K(p_s)$ and $K(p_s)$, which will be further detailed in section 4.2. Hence, the expected overall profit $\prod_O^{tot}$ for firm O can be formulated as follows:[23]

$$\prod_O^{tot} = \begin{cases} p_w \prod_O^M + (1-p_w)\prod_O^D - K(p_w) & \text{; if choice of weak protection} \\ p_s \prod_O^M + (1-p_s)\prod_O^D - K(p_s) & \text{; if choice of strong protection} \end{cases}$$

We model this production-consumption problem of the media product as a three-stage game. In the first stage, the firm O decides on the level of technical copyright protection. In the second stage there is no decision to be made. The pirate P will either crack successfully or not the protection measure, based on the level of technical copyright protection set in the first stage. In the third stage, firm O will know directly if the pirate P was successful and both firms will determine their market prices P_O and P_P. Finally, consumers decide from which firm to buy the media product, given their respective valuations .Therefore, the first stage is the "protection stage", while the third stage is the "consumption stage" or "utilization stage". The corresponding generic game tree is depicted in figure 1. This generic tree structure will be further refined in section 4.

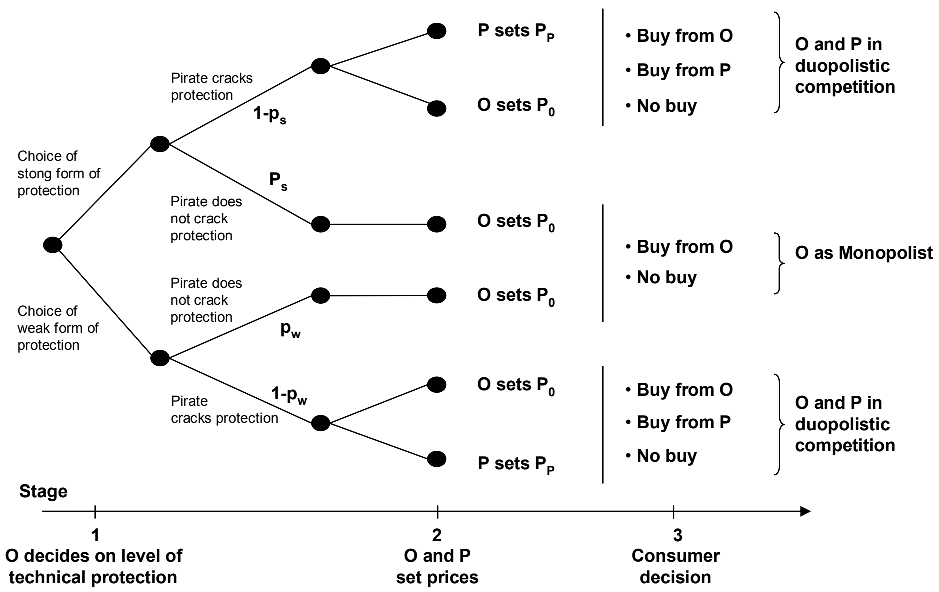

Figure 1: Game tree of generic piracy model

[23] Due to the fact that all players are rational, risk-neutral agents, it is permissible to apply the simple

This three-stage-game is solved through backward induction. In the first step, we calculate the market prices of the third stage, depending on the market structure. Based on these results, we can then calculate the optimal level of protection of firm O. Hence, we are looking for a subgame-perfect-equilibrium of the game.[24]

4.1 Third stage: Utilization

There are consumers interested in the media product. Each consumer consumes either zero unit or one unit of the product. The preferences of a customer for a media product is represented by the utility function U(q, θ), where θ represents the consumer's willingness-to-pay for the content and q the degradation factor of pirated content. We assume that θ is uniformly distributed on the interval [0, $\bar{\theta}$].

The degradation factor q can be interpreted as the quality of the pirated media product vis-à-vis the original product and lies between 0 and 1.[25] The assumption that the quality of pirated content is lower than the quality of original content is common in models such as Gayer / Shy (2002) and can be explained as follows: For analogue reproduction, copies represent poor substitutes to originals. Although this is no longer true for digital reproduction, original content often provides a consumer with a higher level of utility, insofar they are bundled with valuable complementary products, which are difficult or not to obtain through the pirate.[26]

µ-rule.

[24] Compare Selten (1965) for a discussion of subgame perfectness.

[25] We do not consider a situation where q>1, i.e. pirate adds product utility and, thus, increases willingness-to-pay above the level of the original product.

[26] For instance, software products often come with manuals and supporting services, such as technical support, or with discount on upgrades.

The consumer's utility function is given as:

$$U = \begin{Bmatrix} 0 & ; & \text{if consumer buys no content} \\ \theta - P_0 & ; & \text{if consumer buys original content} \\ q\theta - P_P & ; & \text{if consumer buys pirated content} \end{Bmatrix}$$

The prices for the original and pirated content are P_O and P_P respectively. Note that $P_O > P_P$, which means that the content offered by the pirate is definitely worth less to consumers than the original's product.

Unlike in other piracy models, we do not consider positive network externalities. These externalities are often significant in the software industries. However, in classical media industries such as music, video and text-based content, the occurrence of direct network effects is less prevalent. Furthermore, we assume that both firm O and pirate P can not price discriminate. Finally, we do not consider possible legal sanction costs due to copyright infringement imposed against pirates or consumer who buy pirate products.

We will now consider two cases: First, where firm O protects its content -and, thus, its monopoly status- successfully against the pirate P (discussed in section 4.1.1), and secondly, where the protection measures are cracked by pirate P, resulting in a duopolistic competition (discussed in section 4.1.2).

The equilibria calculations are based on Tze / Poddar (2000), however, extended by considering also the reproduction cost c. The marginal consumer is calculated in the same way as in Hotelling´s (1929) model of the linear city. He analyses a model of horizontal product differentiation, in which products are of the same quality, but consumers have different preferences for the products depending on their location. In contrast to Hotellings model, the products of our model (and also the one by Tze / Poddar (2000) or Banerjee (2003)), are of different quality. Consumers have different prefences in terms of quality, but they all agree on which product is the better one.

4.1.1 Monopoly situation

In case that the DRMS protection measures prove successful, firm O will remain in a comfortable monopoly situation. And consumers are left with only one choice of content - the original one. Depending on their valuation for the content, they can choose between either buying the original one or not buying at all.

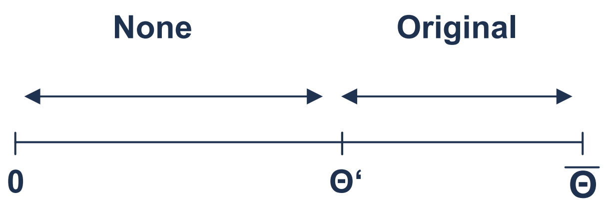

Figure 2: Location of buyers in monopoly case

The marginal consumer with the valuation Θ‘, who is indifferent between buying the original content or not buying at all is characterized by the following equation:

$$\Theta' - P_O = 0$$

$$\Theta' = P_O$$

Demand for the original media product is therefore:

$$\int_{P_O}^{\overline{\Theta}} \frac{1}{\overline{\Theta}} dx = \frac{1}{\overline{\Theta}} [x]_{P_O}^{\overline{\Theta}} = \frac{1}{\overline{\Theta}} [\overline{\Theta} - P_O] = 1 - \frac{P_O}{\overline{\Theta}}$$

The monopolist margin for O is:

$$\Pi_O^M = (P_O - c)(1 - \frac{P_O}{\overline{\Theta}})$$

After calculating the first order condition and solving for the monopolist's price we get:

$$P_O^M = \frac{\overline{\Theta} + c}{2} \quad (1)$$

The margin of the original content producer is then:

$$\Pi_O^M = \frac{(\overline{\Theta} - c)^2}{4\overline{\Theta}}$$

4.1.2 Duopoly situation

In the case where the technical protection measures of the original content provider are not successful, the pirate enters the market and competes for a share of the content market with the original content firm. Consumer's with the highest valuations buy from the original because this content is not degradated. Consumers with intermediate valuation buy from the pirate at a lower price and consumers with very low valuations still do not buy at all. This leads to the following distribution of buyers:

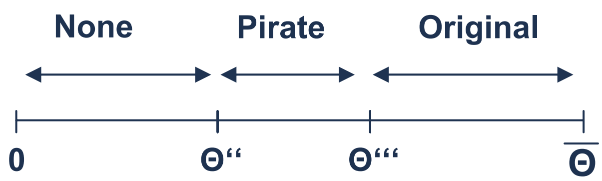

Figure 3: Location of buyers in duopoly case

Like before, the marginal consumer with the valuation Θ''', who is indifferent between buying the original content and the pirated media product, is given by:

$$\Theta - P_O = q\Theta - P_P$$

$$\Theta = \frac{P_O - P_P}{1 - q}$$

The marginal consumer with the valuation Θ'', who is indifferent between buying the pirated content and not buying any content, is:

$$q\Theta - P_P = 0$$

$$\Theta = \frac{P_P}{q}$$

Demand for original content is therefore:

$$\int_{\frac{P_O - P_P}{1-q}}^{\overline{\Theta}} \frac{1}{\overline{\Theta}} dx = \frac{1}{\overline{\Theta}}[\overline{\Theta} - \frac{P_O - P_P}{1-q}] = 1 - \frac{P_O - P_P}{(1-q)\overline{\Theta}}$$

Demand for pirated content is:

$$\int_{\frac{P_P}{q}}^{\frac{P_O - P_P}{1-q}} \frac{1}{\overline{\Theta}} dx = \frac{1}{\overline{\Theta}}[\frac{P_O - P_P}{1-q} - \frac{P_P}{q}] = \frac{1}{\overline{\Theta}} \frac{(qP_O - P_P)}{(1-q)q}$$

O and P engage in a Bertrand game of price competition and set the margin maximizing prices of the media product.

The margin functions of the original and the pirate are:

$$\prod_o (P_O) = (P_O - c)(1 - \frac{P_O - P_P}{(1-q)\overline{\Theta}})$$

$$\Pi_P (P_P) = (P_P - c) \frac{1}{\overline{\Theta}} \frac{(qP_O - P_P)}{(1-q)q}$$

The following reaction functions of the O and P are calculated from the first order margin maximizing conditions:

$$\frac{\partial \prod_O}{\partial P_O} \overset{!}{=} 0 \quad ; \quad P_O(P_P) = \frac{(1-q)\overline{\Theta} + P_P + c}{2}$$

$$\frac{\partial \prod_P}{\partial P_P} \overset{!}{=} 0 \quad ; \quad P_P(P_O) = \frac{qP_O + c}{2}$$

The Nash Equilibrium prices for O and P are given by:

$$P_O^D = \frac{2(1-q)\overline{\Theta} + 3c}{4-q} \tag{2}$$

$$P_P^D = \frac{q(1-q)\overline{\Theta} + 2c + qc}{4-q} \tag{3}$$

Hence, the margin of the original content firm O in the case of a successful hacking attempt is:

$$\Pi_O^D = \frac{(1-q)(2\overline{\Theta}-c)^2}{(4-q)^2\overline{\Theta}}$$

To keep the analysis simple, we now set the marginal costs of reproduction c equal to zero. This assumption is realistic especially for digital content where there are almost no duplication costs. The margin is then:

$$\Pi_O^D = \frac{(1-q)4\overline{\Theta}}{(4-q)^2}$$

4.2 First stage: Decision on technical copyright protection level

We can now determine the optimal level of technical protection for firm O in stage 1. As mentioned in section 4, the protective strength relates to the probability that pirate P can crack the DRMS installation. Therefore, we have a continuum of possible protection levels, reaching from 0 (no protection) to 1 (full protection).

In the following section, firm O can decide between a “weak” and “strong” DRMS in stage 1. The weak system offers a protection level between 0 and 1, while the strong system guarantees full protection.[27] From an empirical point of view, weak protection system would correspond with software-based DRMS, where the effective level of protective strength can be designed into the architecture. The strong protection system would be associated with proprietary hardware-based DRMS that inherently offer a very high level of security.[28]

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[27] In this context the term “weak” protection is somehow a misnomer, as it can eventually reach full protection with p_w=1.

[28] Compare with section 1.

4.2.1 Weak Protection System

Protective measures imply costs, which can be interpreted in our model as the Total Cost of Ownership (TCO), which consists of all costs incurred throughout the lifecycle of an IT system, including acquisition, deployment, operation, support, and retirement.[29] With the weak protection system, the original content provider has to incur a high TCO to ensure strong protection but a low degree of protection can be achieved at small costs. This cost-protection relationship can be expressed with a convex cost function:

$$\frac{\partial K}{\partial p_w} > 0 \,;\; \frac{\partial^2 K}{\partial^2 p_w} > 0$$

In the following, we assume that the cost function is quadratic to simplify the calculation:

$$K(p_w) = (p_w)^2$$

This cost-protection relationship also holds empirically: More secure weak-DRMS will demand a higher TCO. With increasing protective strength, the following cost items tend to increase as well: (i) licensing costs for back-end DRMS software (more functional requirements and more advanced technical components) (ii) costs of system implementation (due to more complex interfaces between components) and (iii) costs of organizational alignment (training, adoption to new process flows, etc.).

[29] TCO analysis originated with the Gartner Group several years ago and has since been developed in a number of different methodologies and software tools. Compare, for example, Gartner Research (2003).

4.2.2 Strong Protection System

If firm O decides to implement a strong protection system, it has to incur costs of Y. In turn, it gets a DRMS which offers full protection (p_s=1) that guarantees monopoly in the third stage. If this system is not installed, costs are zero. Therefore, the strong protection system can be represented with the following binary cost function K(p_s):

$$K(p_s) = \begin{cases} Y & ;\text{if} \quad p_s = 1 \\ 0 & ;\text{if} \quad p_s = 0 \end{cases}$$

Strong protection systems correspond empirically with proprietary hardware-based DRM systems.[30] They provide a superior level of content security, however, are associated with a very high TCO. Especially set up costs are tremendous, because a media firm has to design and produce a new hardware-based front-end DRMS-client and entertain an organization to maintain and upgrade this technology. For example, the now bankrupt Kirch Group decided in favor of this approach and developed its own proprietary Set Top Box (called “d-Box”) in alliance with other technology partners and set into life its own technology provider Beta Research.

4.3 Profit calculation including DRMS implementation costs

Let’s return from the empirical view to the formal model. Firm O must decide in stage 1 which level of protection it wants to set. There are two possibilities: The first one is to decide in favor of strong protection. The firm is then fully protected, since p_s=1, and is a monopolist in the next period. Expected profit of firm O with **strong DRMS installation** is then:

$$\Pi_O^{tot} = \Pi_O^M - Y \,. \tag{4}$$

[30] Compare section 1.

The second possibility is to implement the weak protection system, which offers a protection degree of p_w. The profit function of firm O using a weak DRMS is then:

$$\prod_O^{tot} = p_w \prod_O^M + (1 - p_w) \prod_O^D - {p_w}^2$$

which yields a first order condition of:

$$\frac{\partial \prod_O^{tot}}{\partial p_w} = \prod_O^M - \prod_O^D - 2p_w \overset{!}{=} 0 \tag{5}$$

The difference between the monopoly and duopoly margin $\prod_O^M - \prod_O^D$ is

$$\prod_O^M - \prod_O^D = \frac{8q\overline{\theta} + q^2\overline{\theta}}{4(4-q)^2}. \tag{6}$$

We will call (6) in the following $\Delta \prod$.

Solving the first order condition of (5) for p_w, we get an optimal protection level for the weak DRMS of:

$$p_w^{opt} = \frac{\prod_O^M - \prod_O^D}{2} = \frac{\Delta\Pi}{2}\text{; for } \Delta\prod \leq 2. \tag{7}$$

Expected profit of firm O with the **weak DRMS installation** is then:

$$\Pi_O^{tot} = \Pi_O^D + \frac{\Delta\Pi^2}{4}. \tag{8}$$

Comparing the two profit levels of strong (4) and weak (8) DRMS protection, the original firm O will implement the weak protection system, if this DRMS promises a higher profit than the strong protection DRMS, or expressed in mathematical form:

$$\prod_O^D + \frac{\Delta\Pi^2}{4} > \prod_O^M - Y$$

$$Y > \Delta\Pi - \frac{\Delta\Pi^2}{4} = \Delta\Pi(1 - \frac{\Delta\Pi}{4}).$$

Thus, the optimal level of technical content protection is:

$$p_{opt} = \begin{cases} \frac{\Delta\Pi}{2} & ;\text{if} \quad Y > \Delta\Pi(1-\frac{\Delta\Pi}{4}) \text{ and } \Delta\Pi < 2 \\ 1 & ;\text{if} \quad Y \leq \Delta\Pi(1-\frac{\Delta\Pi}{4}) \text{ or } \Delta\Pi \geq 2 \end{cases}$$

This shows that the higher the costs for the strong protection Y are, the less firm O will favor strong protection.

For the final model, that reflects all assumptions and the equilibrium prices of (1) (2) and (3), we can depict the following game tree in figure 4.

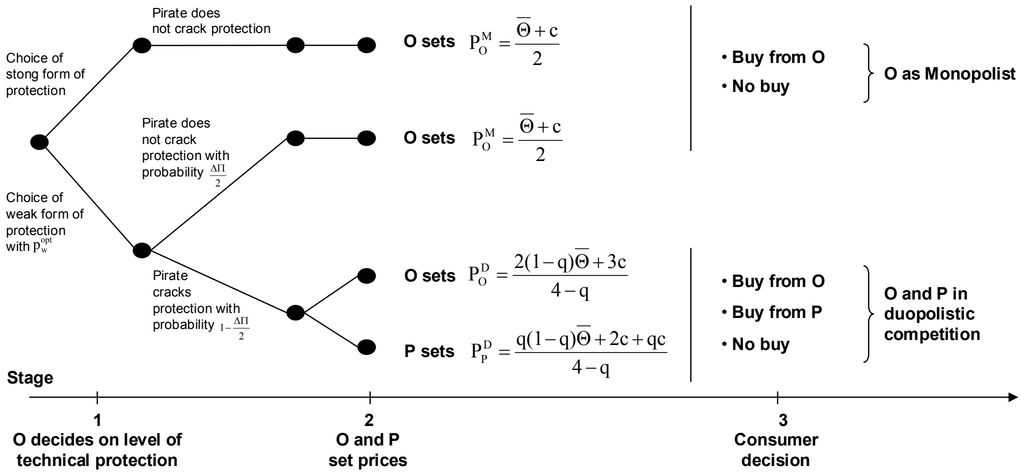

Figure 4: Game tree for specific piracy model

In contrast to the generic game tree depicted in figure 1, the model assumptions of sections 4.2.1 and 4.2.2 have lead to a reduction of the number of possible outcomes. We can ignore the two ramifications related to a successful cracking attempt after the choice of a strong DRMS installation by O, as this scenario is no longer possible with a probability of zero.

In this section, we have calculated the overall profit functions, combining the equilibrium margins of section 4.1 and cost functions of section 4.2. Based on the input variables q and $\overline{\theta}$, firm O will either choose a weak or strong DRMS, depending on which one offers a higher profit level. This lead us directly to the optimal level of technical copyright protection, which is $p_{opt} = \frac{\Delta\Pi}{2}$ (with the restriction $\Delta\Pi \leq 2$) for a weak DRMS and $p_{opt} = 1$ for a strong DRMS (and also for weak DRMS with $\Delta\Pi > 2$).

4.4 Comparative Static Analysis

To get some further understanding of the behavior of the model, we will analyze in this section the dependence of the optimal protection level on the parameters $\overline{\theta}$ and *q*. In this comparative static analysis we are interested in the change of the optimal protection level (here: p_s and p_w) if one parameter varies, but all other parameters remain fixed (ceteris paribus).

Let us start first with the analysis of an increase in $\overline{\theta}$. This means that the valuation of the consumers increases. We can then compare products with low value versus products of high value, where the degradation factor remains constant.

First look at the case, where $Y > \Delta\Pi(1-\frac{\Delta\Pi}{4})$, in which firm O will choose weak protection. From (7) we know that $p_w^{opt} = \frac{\Delta\Pi}{2}$. Since $\Delta\Pi = \frac{8q\overline{\theta}+q^2\overline{\theta}}{4(4-q)^2}$ it is obvious, that $\frac{\partial\Delta\Pi}{\partial\overline{\theta}} > 0$. This means the difference between monopoly profit and duopoly profit is increasing in $\overline{\theta}$. Therefore p_w^{opt} is also increasing with $\overline{\theta}$. We get as a result that products with higher valuation have a higher protection level. The intuitive reason is that it pays off to be a monopolist if consumers' valuations are higher and firm O would therefore choose a higher probability to be a monopolist.

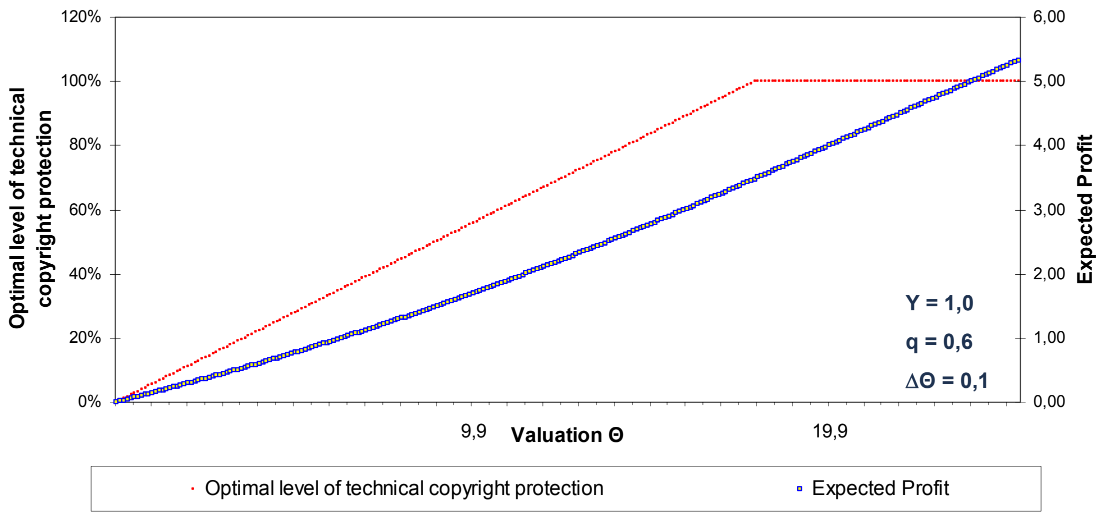

Figure 5: Effects of an increase in $\overline{\theta}$ (weak protection only)

We can also look at the threshold value of $Y = \Delta\Pi(1 - \frac{\Delta\Pi}{4})$. If we assume that $\Delta\Pi$ is not too high (in this case $\Delta\Pi$ <2), the right hand side is increasing in $\Delta\Pi$. Since $\frac{\partial \Delta\Pi}{\partial \overline{\theta}} > 0$, there is some value of $\overline{\theta}$, at which this threshold is reached and if $\overline{\theta}$ surpasses this value, the original will decide in favor of strong protection. Thus, we get as a result that a higher valuation leads to a higher level of protection.

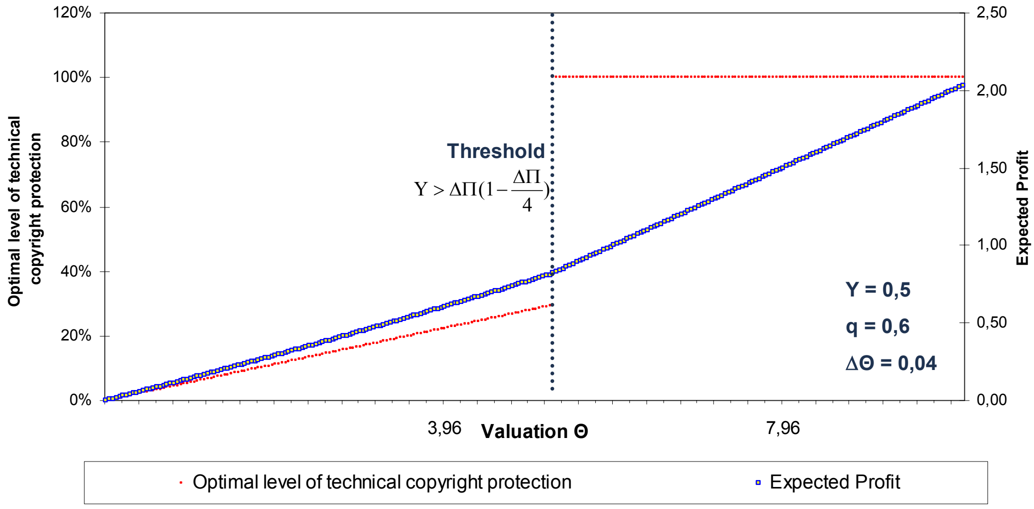

Figure 6: Effects of an increase in $\overline{\theta}$ (Transition from weak to strong protection)

Furthermore, we look at the case of an increase of q, which means a lower degradation, so that the product of pirate P becomes more valuable to consumers.

If we conduct the same analysis as before, we see that $\frac{\partial \Delta\Pi}{\partial q} > 0$. This means that a lower degradation (higher *q*) causes the original firm O to set a higher protection level. The intuition is different to the case of a higher $\overline{\theta}$. If the degradation is lower, the pirate is a stronger competitor to the original. Since both firms are in Bertrand competition this leads to a strong decrease in profits. In the extreme case, if q goes to 1, the duopolistic profit of firm O goes to zero. To avoid this scenario, the original will choose a higher protection level. This means that a higher protection level is in some sense a substitute for a high degradation.

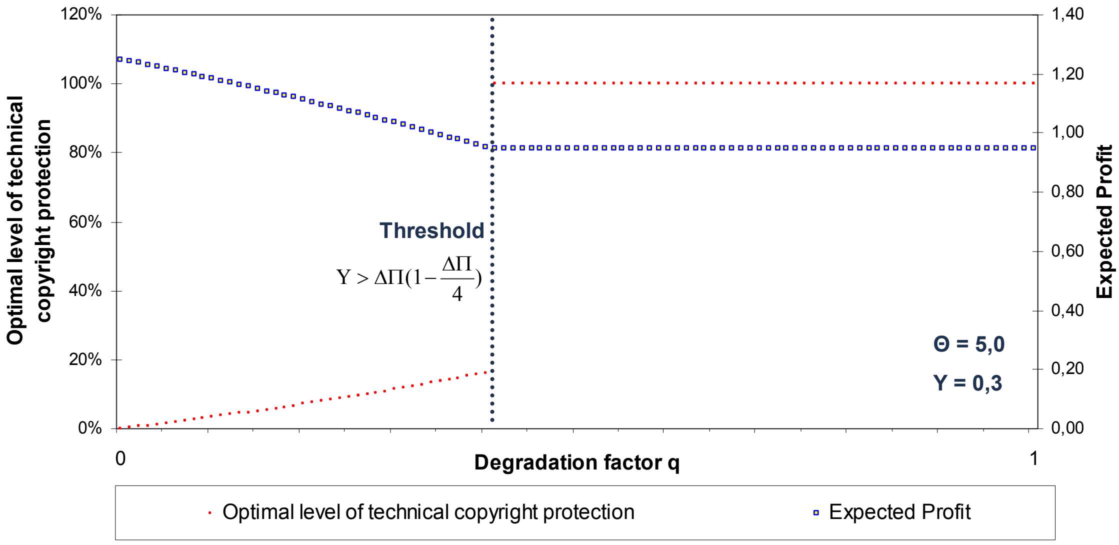

Figure 7: Effects of an increase in q (Transition from weak to strong protection)

5 Policy implications

As outlined in section 1, it is important for managerial decision makers to anticipate the reaction of public policy towards DRMS to avoid that costly DRMS installations may turn out later to be in conflict with law.

For this reason, we will assess the likely reaction of policy makers with a (normative) law and economics approach, which is the application of economic theory "…to examine the formation, structure, processes and impact of law and legal institutions."[31] Specifically, we will analyze the welfare implications of DRMS from an ex-ante and ex-post efficiency perspective.[32]

5.1 Ex-post efficiency analysis

If the original content firm is a monopolist, consumers between $\frac{\overline{\theta}+c}{2\overline{\theta}}$ and $\overline{\theta}$ are buying the product. If instead both firms are active in the market place, then consumers between $\frac{(2-q)\overline{\theta}+c}{(4-q)\overline{\theta}}$ and $\overline{\theta}$ are buying from firm O. A comparison between the lower limits shows that $\frac{\overline{\theta}+c}{2\overline{\theta}}$ is strictly higher than $\frac{(2-q)\overline{\theta}+c}{(4-q)\overline{\theta}}$. This means that in the duopoly more consumers are buying from firm O than in the monopoly case. This result seems a bit strange but the reason is that competition leads firm O to a very strong decrease in it's price which makes more consumers buying firm O's product. Since in the duopoly case there are also some consumers who buy from the pirate P the demand in duopoly is strictly higher in monopoly than in duopoly. This comparison is shown graphically in figure 8.

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31 See Rowley (1989), p. 125.

32 For a discussion of different efficiency criteria, compare Schäfer / Ott (1995), pp. 21-47.

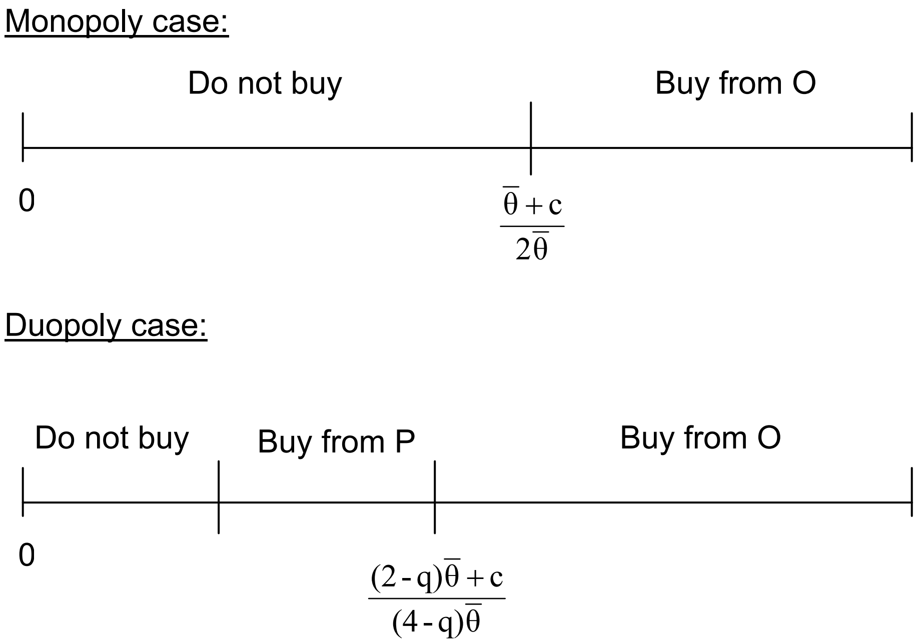

Figure 8: Comparison of buyers in monopoly and duopoly situation

From an ex-post efficiency point of view, the duopoly case is therefore better than the monopoly case because more consumers buy the better product and also more consumers are buying the product altogether. This means that it would be socially optimal to have a protection level of zero to make the duopoly situation more probable. Thus, the result we get in the former sections, namely that a protection level above 0 is better for the original firm O in most cases, is not efficient from a welfare perspective. Given that the content is developed, a protection level of zero should be preferable and endorsed by legislation.

5.2 Ex-ante efficiency analysis

This result only holds for already existing or developed content. The result might no longer be valid if we are interested in ex-ante efficiency, which means in this context that a product does not exist up to now but a firm can develop the product, which makes it necessary also to take development costs into account.

Assume that firm O has development costs of D^O for research and development of the content. It does now depend on the magnitude of D^O if there is a trade-off between ex-post and ex-ante efficiency. There are three possible cases that are discussed below:

(i) First assume that $D^O > \Pi_M^{tot}$. This means that even if firm O implements a strong protection system and is a monopolist for sure, the development costs are higher than its profit. In this case the content would not be developed. Thus, there is no difference between ex-post and ex-ante efficiency.

(ii) Second consider the case if $D^O \leq \Pi_D^{tot}$. In this case, the development costs are lower than the duopoly profit. This means that even if piracy takes place, firm O would make profits. The content is therefore developed for sure and ex-post and ex-ante efficiency coincide as well.

(iii) The interesting case arises if $\Pi_D^{tot} < D^O \leq \Pi_M^{tot}$. Firm O would develop the content if piracy is forbidden, since $D^O \leq \Pi_M^{tot}$, but would not develop the content if piracy is allowed, since $D^O > \Pi_D^{tot}$. In the last case, there is a trade-off between ex-post and ex-ante efficiency and policy makers have a strong argument to advocate a laissez-faire attitude towards technical copyright technologies. Obviously, it is an empirical question, whether this case is relevant. However, the long-lasting existence of the classical copyright regime, which establishes a legal property right to give incentives for the production of information goods, so that authors can recoup their initial development costs, indicates that this case is highly relevant and should be used to guide legislative action.

We can conclude this section with the following remarks: The welfare analysis brings forward mixed results. Once the content is developed (and D^O is sunk), it is optimal for the government to promote piracy by restricting all forms of DRMS protection. But if firm O anticipates before the development phase that it will make a loss, the content will probably not be developed at all in the first place. Therefore, from an ex-ante point of view, it is optimal take governmental action against piracy by not restricting or even promoting the use of DRMS installations. Based on these normative law and economic results, media companies can breathe a sigh of relief: Their optimal choice of DRMS protection is not affected by policy considerations, as technical self-help mechanisms promote overall welfare from an ex-ante point of view.

6 Conclusion

In this paper the optimal level of technical copyright protection is analyzed in a mathematical model. There are three main results. At first we show that if a media product is more valuable to consumers, the original media firm will choose a higher level of protection. An empirical example would be blockbuster Hollywood movies or expensive market research documents that are habitually protected with DRM techniques, while low-value content (e.g. generic novels) may not be protected at all.

The second main result is that a lower degradation leads the original media firm to increase its level of protection. The reason is that this might avoid strong price competition. Empirical evidence is given by highly degradated media products, which offer substantial (physical) added services (e.g. software with call center support), that often waive or reduce DRMS protection, as the valuation of pirated content is very low. Media companies should focus on endogenizing this factor and add (physical) services around the information product that are hard to copy (e.g. through individualized art work, accompanying audio CDs)

Finally, it is shown that from a welfare point of view, it is optimal for the legislator not to restrict or even promote the use technical copyright protection measures from an ex-ante-efficiency perspective.

These results are based on a normative, model-based IO approach. However, this model exhibits a low level of homomorphism, which would be necessary for real world decision making. In particular, the model:

(i) simplifies market structure: The market is collapsed to an oligopoly game with only two rational, risk-neutral players, the original firm O and pirate P. Furthermore, only re-seller piracy and no end-user piracy is considered

(ii) simplifies cost functions for DRMS implementation by assuming a quadratic or binary relationship between protection level and related costs

(iii) neglects positive network externalities, the faculty of price discrimination and the existence of transaction and sanction costs

(iv) assumes that a 100% level of protection is possible. However, even if DRMS technology should be hacker-proof, media firm are still challenged with the fundamental problems of the “analogue hole” and “digital hole”.

These points demonstrate that significant simplifications have been made, which reduces the structural similarity between model and the real world. On the other hand, simplifications can also be very useful, insofar as they help to cope with empirical complexity.[33] As a matter of fact, most models focus their analysis on a particular issue while neglecting or simplifying other structural aspects of empirical context. This can also be observed in the field of economics of copyright, where analysts focus their model design to concentrate on special aspects, such as the implications of network externalizes [e.g. Takeyama (1994), Slive / Bernhardt (1998), Shy / Thisse (1999)], price discrimination [e.g. Bhargava / Choudhary (2001), Sundararajan (2003)], sanction costs [e.g. Polinsky / Shavell (1992), Chen / Png (2003)] and so on.

Furthermore, the model causes a problem in the process of reinterpreting the model results back into the empirical context. After having calculated the variable *p*, the decision maker has to translate this abstract piece of information into a suitable DRMS installation. This is not an easy task, as there is no authority to certify that a particular DRMS delivers the protection level *p* as defined in our model. To complicate this issue even more, the strength of a DRMS depends on the actual state of technology and the strength of the pirate, which are both are subject to change.

In spite of these drawbacks, the model provides managerial and policy makers with new insights that past research has neglected so far. In contrast to our model, none of the mentioned papers in section 2 considers the protection level as the probability that a potential pirate can “crack” the technical copyright protection measures. Furthermore, our model is closer to the current empirical context, as original media firm can choose between two real-world forms of DRMS installations, with different protection profiles and cost functions. Another difference is that consumers’ valuations can change, which allows us to do some comparative static analysis.

At the end of the paper we discuss some possible extensions of the model. The aim of the discussion is to give an intuition how these extensions might change the previous results.

[33] Compare Varian (1996), p. 2.

One possible extension might be to introduce transaction costs. If a consumer wants to buy from an original content provider, she can go to an (online) shop and buy the content legally. If instead she wants to buy from the pirate, she has to find the pirate product, which will probably imply higher search costs and possibly additional download cost (as compared to the transaction with the original product). Thus, the consumer possibly has to incur higher transaction costs when buying the pirated product. This results clearly in a competitive advantage for the original firm. Therefore profits of the original content provider will increase while profits of the pirate will decrease. The effects on the optimal level of protection is a bit less clear. An intuition would be that the protection will fall. Since protection implies costs the reason why a firm installs protection measures is to have a competitive advantage. But this advantage is now present because of the transaction costs. Thus, it is no longer necessary to build up a high level of protection. Transaction costs and protection are substitutes. Summing up, transaction costs are likely to work in favor of the original firm.

Another extension might be network effects, which is especially relevant in the software industries. This means that consumers' reservation values for the product increases with the total number of consumers (original and pirated) of that product.[34] Thus, with an increasing customer base, a consumer is willing-to-pay more for the content, independent of the firm at which she buys. This would certainly lead to a lower level of protection. Since the selling of a pirated product now also helps the original content provider in some sense, its duopoly profit increases. This obviously results in a lower protection level.[35]

A third extension might be that protective measures also hurt the original firm because it leads to a reduction in the valuation of the original media product. As the level of technical protection increases, it often simultaneously places more restrictions on the flexibility of usage for the legal user and thus reduces the value of the legal product. A case in point is Sony´s Key2Audio protection technology that was introduced in 2002 to prevent audio CDs from being played on PCs. Consumer value was significantly reduced due to restricted inter-device portability. Furthermore, a significant number of these CDs did not work on regular CD and DVD players. On the other hand, the success of Apple´s iTune music service which (at the risk of a higher piracy threat) places fewer restrictions on legal usage than its

[34] Compare Katz / Shapiro (1985) for a formal presentation of network externalities.

[35] As discussed in section 3, some authors argue that positive network effects induces the original to allow duopolistic competition rather than remain a monopolist, a phenomenon which is sometimes called "myth of profitable piracy". But the overall literature does not give a definitive answer to that.

predecessors (like MusicNet and Rhapsody) is a further illustration of this point.[36] This model extension should also lead to lower protection level and to a higher probability of the duopoly outcome. The reason is that if protection also hurts the original content provider then it should reduce profits. A lower valuation of the original product makes competition more fierce and lowers duopoly profit since the quality difference is lower than before.

Ongoing research will show if the main results of this paper -the intriguing relationships between protection level, consumer valuation and degradation rate- will continue to hold under more general assumptions, although this generalization is mathematically beyond the scope of this paper. However, it is our intention to enrich the model in the next step by relaxing some of the restrictive assumptions.

[36] Compare von Walter / Hess (2003) for an analysis of the success factors of iTunes.

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