IMPACT OF DIGITAL PIRACY ON THE E-BOOK MARKET: INSIGHTS FROM AN AGENT-BASED MODEL*

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Although the digital piracy is believed to be a significant threat to the marketers of digital service products, there is a contradictory empirical evidence whether it is really the case. Nevertheless, a lot of effort from the industry and policy makers is put to attenuate that practice. Methods such as pricing strategies, education campaigns, legal regulations and prosecutions are typically used to decrease the tendency to pirate. Within this paper, we used a simple agent-based model to explore the role of the piracy on the digital goods market, as well as the impact of preventives and deterrents on the piracy itself. Our particular attention was paid to the e-book market, which has not been studied in the context of piracy so much yet. From our simulations, it follows that in the short term, some degree of the piracy may be beneficial for publishers of e-books, because it enhances the diffusion of a new title. In the long run, it is rather harmful for the publishers, because it usually forces the diffusion process to saturate at lower market penetration rates. We have also observed the ambiguous effect of piracy on the total welfare of the market participants. Moreover, we found that the final penetration rates of both the legal copy and the pirate one do not depend on the level of advertisement (including educational campaigns), but the advertisement significantly speeds up the process of adoption. The findings of the model can provide some hints for the publishers and policy makers as well as for the modelers aiming at more realistic models of digital markets.

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1. Introduction

There are many attempts in the existing literature to define an e-book. Usually, four perspectives are used for that purpose: media, content/file format, device and delivery [1]. According to Gardiner and Musto [2], an e-book is a book publication made available in digital form, consisting of text, images, or both, readable on the flat-panel display of computers or other electronic devices. Reitz [3] defines an e-book simply as a digital version of a traditional printed book. Based on an analysis of many aspects of various definitions, Vassiliou and Rowley [1] proposed a two-part one: An e-book (1) is a digital object with textual and/or other content, which arises as a result of integrating the familiar concept of a book with features that can be provided in an electronic environment, and (2) typically has in-use features such as search and cross reference functions, hypertext links, bookmarks, annotations, highlights, multimedia objects and interactive tools. The latter definition will be used throughout this paper.

E-books have arguably caused the greatest transformation to the long-established publishing industry since Gutenberg and his printing press [4]. They have been around since the 1970s, when the Project Gutenberg was started, but until recently, they were not very popular due to the lack of reasonable devices allowing to read the material. The advent of touchscreen devices and the rapid development of tablets, smartphones and dedicated reading devices (such as Kindle) in the last decade enabled e-books to reach the mainstream adoption. Due to the still increasing number of titles available in an electronic form, the e-books have now a significant market share in publishing industry.

The digital piracy has been identified as one of the risks that may attenuate the development of the e-book market. The scope of this problem is country-dependent and may range from 5% up to over 92% of the market [5]. From some empirical studies, it follows that piracy leads to significant revenue losses to the digital content providers [6–9]. For instance, according to the report of the Spanish Federation of Publishers Associations and the Spanish ISBN Agency, the e-book piracy resulted in 350 million euro losses in the 3 billion euro Spanish publishing market in 2012 [9]. From the report of a major Japanese publishing house, it follows that illegal uploads of comics may have generated revenue losses up to 300 billion yen from 2007 to 2011 [10]. Similar estimates for the US market indicate a loss of 315 million dollars in 2016 [11]. Taking into account the size of the US market, the level of the e-book piracy in the USA seems to be rather low.

A closer look at the data for the US market reveals some interesting characteristics of the pirates [11]. E-books are more often stolen by men (66%) than by women. The pirates are relatively young (88% under 45), well-educated (72% college and post-college graduated) and surprisingly well-

paid (65% over 66K $). As far as the sources are concerned, they get their e-books from public torrent sites (31%); public cyberlockers (31%); friends via instant messengers, e-mails or flash drives (30%); online auctions (27%) and friends via closed internal networks (27%). Such a variety of sources is one of the reasons for failures of many attempts to undermine the distribution of illegal copies. Instead, one should probably focus more on some deterrent strategies. As for the reasons of piracy, convenience and economic considerations are the two main triggers for illegal downloading (58% and 51%, respectively). However, there is a group of people who simply prefer this method of acquiring e-books (33%). A part of the population do not think they should have to pay for any content (17%). The latter ones will be referred to as 'hard' pirates in the rest of the paper.

It should be mentioned though that not every e-book author is against piracy. Some of them accept the presence of illegal copies of their books on the Internet, because it increases their recognition [12, 13]. According to Julia Reda, a member of the European Parliament representing the German Pirate Party, the European Union commissioned in 2014 a study on how piracy impacts the sales of copyrighted music, books, video games and movies. The resulting report was not published by the EU, probably due to the fact that it has not found any evidence that piracy is a major problem. On the contrary, the authors of the report, the Dutch firm Ecory, found, for instance, that illegal downloads and streams can actually boost legal sales of games. The only negative exception were the blockbuster movies — a displacement rate of 40 per cent was found meaning that "for every ten recent top films watched illegally, four fewer movies are consumed legally". The report has finally come to light, because Reda got a hold of a copy via a request through an EU Freedom of Information access to documents policy and she posted it on her personal blog [14].

In the scientific literature devoted to piracy, the emphasis is put mainly on software, music and film industries. The authors focus their attention on the impact of piracy on the market share and pricing [15–17], producer's profits [18, 19], as well as the effectiveness of the anti-piracy policies [8, 20]. There is also a variety of models aiming to provide some information on how a given product diffuses and how pirating influences the market share and the legal seller's revenue [8, 21–23]. However, the literature regarding e-books markets is still very scarce [12, 24]. To the best of our knowledge, there are no models describing the e-book market explicitly and trying to give some insight into the role of piracy on the evolution of the market.

Our goal is to fill this gap in the literature. We will build a simple agent-based model to examine the interplay between attitudes of agents (*e.g.* reservation prices of an e-book and aversion to illegal downloads), social influence and some external factors including pricing strategies and advertise-

ment efforts of a publisher as well as the punishment levels (corresponding to prosecution risk). Within the model, we want to answer the following questions:

1. How does piracy influence the legal consumption of e-books?
2. Do advertisement efforts of a publisher influence both legal and illegal downloading?
3. Is there any relation between prices, punishment levels and piracy rates?
4. What is the best strategy for a publisher to maximize profits in the presence of piracy?
5. Are there any differences in the short- and long-term optimal strategies?

The paper is structured as follows. In the next section, a brief summary of the literature on piracy and attempts to attenuate is given. Then, we will present the state-of-the-art regarding modeling approaches to piracy aiming to provide some insights into the phenomenon and its impact of the diffusion of digital goods. Next, our model is introduced. Finally, the simulation results are presented. The paper is concluded with a discussion of the results.

2. Literature review

An exhaustive review of theoretical papers focused on piracy, both end-user and organized by firms (*i.e.* counterfeiting), may be found in [25]. The vast majority of research in this area focuses on pricing, copyright protection and government policies as tools to reduce this practice. Digital piracy is investigated from various points of view. While some of the authors focus on moral and ethical aspects of piracy [26, 27], others investigate negative and positive social influence [28], piracy habits [26], rewards or perceived risks and sanctions [29–31].

Due to the differences in the history and characteristics of diverse goods, the nature of piracy varies across different branches of the digital industry [22]. Most of the attention is paid, for instance, to the software piracy [17, 19, 20, 32–36]. The reason is twofold. First of all, in the 1980s and early 1990s, software was actually the only digital goods available. Moreover, in contrast to music, movies and books, it has not its traditional analogue. As a result, the piracy seemed to be a bigger threat for the software than for the other goods. With the development of mobile devices allowing a comfortable consumption of other goods in the digital form, the traditional distribution channels are becoming less and less important. This process is reflected in the growing literature on the implications of piracy other than the software

one. Some effort was already put into understanding the implications of piracy on the music market [37–39], movies [40, 41] and to much lesser extent — on e-books [12, 24]. In the remaining part of this section, the main findings from the available literature with some importance for the e-book market are presented.

2.1. Digital piracy — pricing strategies, influence on demand and profit maximization

One of the issues extensively studied in the context of the digital piracy is its impact on legal sellers' profits [23]. Minniti and Vergari [18] suggested that piracy may actually increase the profits, provided a pirate copy of one item increases the utility derived from the purchase of another one. Banerjee showed that a similar effect is to expect in the presence of network externalities [42]. On the other hand, Barker found, for instance, that a 10% increase of illegal downloads in peer-to-peer networks reduces the legitimate purchases by 0.4%, thus reducing the sellers' profits [43]. Similar findings concerning the negative role of piracy have been presented by Jaisingh [8] and Kozlowski [9].

From the above examples, it follows that there is no clear evidence about the impact of piracy on the diffusion of legal goods. There are some hints, however, that it may control the process of adoption of a new item (or title) to some extent [16, 18, 42, 44]. Moreover, its role depends on the condition of the market itself. As it follows from the model by Minniti and Vergari [18], piracy may be beneficial for the sellers in emerging markets, since it allows them to reach a broader customer base and helps to lock their products in as standards. Such a positive effect was absent in established markets.

The perception of digital piracy may differ among the key players in the market, based on the welfare they derive. Walters [23] found that the legal sellers always prefer no piracy at all. For the providers of illegal copies, moderate piracy rates seem to be the optimal ones and the customers like high piracy rates.

Pricing strategies are one of the important tools to combat piracy. Effective pricing strategies in the presence of piracy have been proposed, for instance, by Sundararajan [45]. The author also suggested how to combine those policies with technology-based protection and how to vary the protection levels in response to a weakening of sellers' DRM (Digital Right Management) technologies.

The effect of the piracy rates on the demand curve has been studied in the literature as well. In the case of a publisher, it is similar to the effect of an increased market competition — the copyright holders' demand curves become more price elastic [46–48].

2.2. Digital piracy and policy tools

According to Chen and Png [49], there are three main policy tools to control the piracy level: (1) to tax the copying medium, (2) to subsidize legal sales, and (3) to fine offenders. Although legal activities are perceived as the desirable ones to combat the piracy, from a welfare perspective providing subsidies to users turned out to be the optimal strategy.

Reference [48] identified seven strategic responses that copyright holders can pursue: (1) to adopt a permissive stance to piracy, (2) to counter piracy by providing free samples, (3) to lower the price of the legal goods, (4) to offer something extra to consumers who purchase the legal goods, (5) to switch to a business model that is less vulnerable to piracy, (6) to embrace the technology used by pirates (such as peer-to-peer networks), and (7) to increase the perceived moral intensity associated with the decision to participate in the market for pirated products. Surprisingly, the involvement of copyright holders in the prosecution by judiciary has not been found to play any important role among reasonable responses.

Jaisingh [8] showed an interesting correlation between the quality (innovation) of the product, the choice of a particular anti-piracy policy and the behavior of the copyright holders in the market. For instance, when a firm is aware of having a superior product and a not very restrictive policy has been chosen, then it should price aggressively to make it unprofitable for the pirate to exist. If a restrictive policy is chosen, but the quality of the product is low, then it is better not to engage in an aggressive pricing and leave a small segment of the market for the pirates.

Some of the studies focus on firms' investments in piracy protection measures. In general, those measures may be divided into two classes. Educational programs and legal activities (*e.g.* lawsuits) fall into the category of deterrent measures. Preventive ones usually rely on technologies that make piracy more difficult and costly [37]. According to Novos and Waldman, increased copyright protection may have a negative effect on social welfare, because it leads to an increase in the welfare loss due to underproduction [50].

2.3. Digital piracy and consumers' moral dilemmas

Digital piracy is also considered an ethical issue [26]. Interestingly, although a strong support for intellectual property exists in principle, most of the pirates are not motivated to change their present behavior [51, 52]. From the paper by Lysonski and Durvasula [53], it follows that an appeal to ethic or guilt are not likely to deter illegal downloading significantly.

Al-Rafee and Cronan [54] suggested that the attitude toward digital piracy is influenced by beliefs about the outcome of behavior (cognitive beliefs), happiness and excitement (active beliefs), age, the perceived impor-

tance of the issue, Machiavellianism and the influence of important others. The latter factor seems to be of particular importance, since piracy has been reported to be positively associated with social pressure, social approval and the peer pressure [51]. Moreover, illegal downloaders are significantly more likely to have a network of family and friends who also engaged in digital piracy [55].

Other results provide evidence that power users able to control the technology are inclined towards piracy, whereas value consciousness decreases illegal downloading and is crucial for the customers' acceptance of a higher price [24]. It also seems that there is a link between low self-control and digital piracy mediated by the rational choice theory [56].

Finally, Ref. [21] compares the utility of purchasing copyright files and the utility of downloading pirated files in order to examine the consumers motivation to pirate. It emphasized that while making a choice between unauthorized downloading of files and purchasing them, consumers compare the utilities of these alternatives. The authors assumed that downloading pirated files increases the benefits for those who download them, whereas purchasing copyrighted files benefits primarily artists and industries.

3. Modeling of piracy

The effect of piracy on legal sellers' profits as well as on the diffusion of a legal digital product has been studied for many years. Recently, a meta-analysis of the factors maximizing the prediction of digital piracy has been provided by [57]. The authors concluded that experimentation is rarely used in piracy research. In most cases, self-reporting surveys on piracy [21, 51, 58] or surveys based on hypothetical piracy scenarios and vignettes [29, 56] were conducted. The third stream of piracy research is based on modeling and simulation [8, 21–23, 59]. All of this research has its roots in one of the social theories, like *e.g.* the theory of the planned behavior, social cognitive theory, self-control theory, deterrence theory and others.

Modeling and simulating literature dealing with digital piracy is rather limited to software and sometimes to music and movies. To the best of our knowledge, the piracy on the e-book market has not been modeled yet. Below, we will shortly summarize the main aspects of digital piracy models, *i.e.* the types of the agents, the research questions and the important findings.

3.1. Agents

In most cases, the authors assume that there is a difference between an original item and its pirated copy in its quality, in access to supplements or additional service. Further, they postulate heterogeneity of consumers in terms of their willingness to pay for the original item compared to a

copy [22]. In the literature, two main approaches are known: in the first one, consumers are divided into discrete groups based on their appraisal of the product [59]; in the second one, consumers' product valuations are distributed along a continuum (*i.e.* in most cases, the distribution is considered to be uniform across the interval) [22, 60, 61]. In some of the papers, the authors propose some groups of factors influencing the consumer's utility and valuation perceptions of the original and a copy: the utility of the original, the cost of the copy and the degree of substitution between them [21]. The most popular consumers' strategies distinguished in the models are: to buy a legal (new) product, to copy/pirate or not to use a product at all [60, 61]. In particular, [22] proposed that a software can be updated periodically. A consumer can then buy at each period an updated version from a retailer at a given price or search for a pirated version at a given transaction cost. He/she is also allowed to give up an update of the product (*i.e.* to avoid a new purchase).

3.2. The research questions and main findings

As mentioned before, the literature explores digital piracy from various points of view. Let us examine a few examples of the digital piracy models.

In Ref. [59], the authors present a model of software piracy to examine the short-run effects of piracy on software usage and the long-run effects on software development incentives. They distinguish two types of costs of pirating: the reproduction cost that is fixed among consumers and the degradation cost that depends on the consumers' appraisal of the original product. The model includes also copyright protection issues. The authors revealed that the consumers' option to use illegal copies constrains the copyright holder's ability to charge a monopoly price. In other words, monopolist's pricing decision is affected by the threat of piracy. Moreover, the results of the model showed that there is a trade-off between short-run and long-run efficiency. The effects of the increased copyright protection depend on how it affects the two margins of the piracy costs (reproduction and degradation cost). The authors concluded that an increase in the reproduction cost may increase or decrease social welfare in the short run. In the long run, however, due to the marginal consumer's lower valuation for the software, the monopolist has less incentives to provide a high-quality product.

In many papers, the authors model the competition between legal and pirate providers. They tried to describe the conditions of legal seller's profit and surplus maximization in the presence of piracy. For example, Walters [23] proposed a pricing model in the presence of piracy. Similarly to Ref. [8], the diffusion of a legal product is divided into acquisitions from a legal seller and from pirate providers. Potential buyers are heterogeneous in their valuation of the goods, so that the price could act as a control variable

on diffusion. The number of pirate providers increase with the number of previous buyers. There is a single legal producer of the goods. The legal producer is interested only in profit maximization and possesses the ability to produce his own goods. The producer could instantly produce copies of the goods at a constant unit cost that equals zero. The author explored three offsetting pricing mechanisms such as skimming, compressing price changes and delaying product launch. Piracy was found to trade off two effects on sale time and welfare in the presence of market growth, by both delaying product launch and accelerating subsequent sales. Based on the welfare analysis, Walters concluded that piracy accelerates sale times and increases welfare in fixed size markets, and does the opposite in growing markets.

Some of the authors distinguish also an additional entity in the model, which is a legal or governmental authority (like BSA in the U.S.) who imposes some policy to deal with piracy. Jaisingh [8] inspected the impact of such a policy (its low, medium or high level) on quality and pricing strategies of a legal producer. Policy here is assumed to affect the demand side of the market. For example, a stricter piracy policy increases the ethical cost for consumers to pirate and may in some cases lead to an increase in piracy and a decrease in product quality. Why? Because both quality and policy choices can be to some extent substitutes in the fight against piracy. Thus, an increase in the policy variable makes a firm to choose a lower quality of a product. Dependent on the likelihood that the pirated software will be functional, a certain level of policy is desired. For example, if this likelihood is high, then also a high level of policy is needed.

To conclude, so far most of the models investigate digital piracy from supplier's side of the market [8, 23, 59]. They focus on welfare and legal seller's profit maximization.

4. Model

We are going to investigate the effects of digital piracy by developing an agent-based model that captures the important details of the e-book consumption. In the proposed approach, three types of market participants are considered: consumers (called later 'agents'), a publisher and a government.

4.1. Consumers

In our model, it is assumed that there are N potential readers. Each of the agents is characterized by two binomial variables

$$B_i \in \{0,1\},\ P_i \in \{0,1\},\ i \in \{1,\ldots,N\}\,, \tag{1}$$

and may be in one of three possible states:

— a legal buyer: $B_i = 1$, $P_i = 0$,

— a pirate: $B_i = 0$, $P_i = 1$,

— not having an e-book: $B_i = 0$, $P_i = 0$.

Moreover, the agents are characterized by two other attributes:

— e-book's appraisal R_i, understood as an agent's reservation price, *i.e.* the highest price the agent is willing to pay for the book,

— aversion to illegal purchase ζ_i describing agent's attitude towards piracy.

The last parameter includes also consumer's aversion to risk and unwillingness toward low quality of pdf files, which is common in cast of illegal copies generated with help of an OCR software.

4.2. Publisher

For the sake of simplicity, we assume that there is only one publisher on the market and that he offers one particular title. Although quite unrealistic, in general, it reasonably captures the process of diffusion of a single title just after introducing it to the market. The publisher sets the price p and the advertising expenditures h for the book, at the beginning of the simulation. The publisher is interested in profit which is calculated according to the formula

$$\pi = p \sum_{i=1}^{N} B_i - H(h)\,, \tag{2}$$

where $\sum_{i=1}^{N} B_i$ is the quantity legally purchased by agents and $H(h)$ is a fixed cost related to advertising. As a result, the marginal costs of an e-book are equal to zero and the total costs are limited to advertisement. Since we are mainly interested in the short-term evolution of the system, both the price p and the advertisement level h are kept fixed in the simulation, *i.e.* the publisher does not adjust his pricing strategy according to the situation on the market.

4.3. Government

While dealing with digital piracy, one cannot forget about anti-piracy regulations or laws by a government and the legal prosecution risk from acquiring pirated products [62–64]. To take this issue into account, we introduce an additional parameter Z, representing the level of punishment risk due to anti-piracy laws and law-suits. Together with ζ_i, it will influence the agents' costs of an illegal e-book copying.

4.4. Model details

We are going to simulate the model by means of Monte Carlo techniques [65]. We assume a complete graph (every pair of distinct agents is connected by a unique link) as the underlying social network. One would probably expect a more realistic network topology at this point. However, from our *in silico* experiments, it follows that although such a topology slows down the process of diffusion of innovation, the most important findings remain qualitatively the same. Every time step of the simulation consists of N events, N being the number of agents. In every event, we pick randomly an agent and let him decide on obtaining the book. The decision process of the agent is depicted schematically in Fig. 1. It may be divided into following steps:

1. If not having the book, then with probability
$$\min(\alpha + \rho + h, 1) \tag{3}$$
consider obtaining it. Otherwise do nothing. The variables α and ρ are the fractions of buyers and pirates in the population, respectively. The variable h stands for advertisement efforts of the publisher.
2. If you are inclined to obtain the book, then with probability
$$\rho^* = \omega\rho + (1 - \omega)\rho_0 \tag{4}$$
decide on an illegal download. Otherwise go for a legal purchase. Here, ρ^* measures the impact of pirates on the agent, magnified by the total fraction of e-book owners $\omega = \alpha + \rho$. The parameter ρ_0 is the initial inclination towards piracy in the whole population.
3. If you are for the purchase, buy the book if
$$R_i \geq p\,. \tag{5}$$
Otherwise do nothing.
4. If you are for an illegal copy, download it if
$$R_i \geq Z + \zeta_i\,. \tag{6}$$
Otherwise do nothing.

Equation (3) gives the probability that an agent has been informed about a new title. The information is spread either by advertisement (h) or by word-of-mouth via agents who already have the e-book ($\alpha + \rho$). If the agent is informed, he/she is pushed either towards piracy or a legal purchase by the influence of other agents according to formula (4). In either case, he

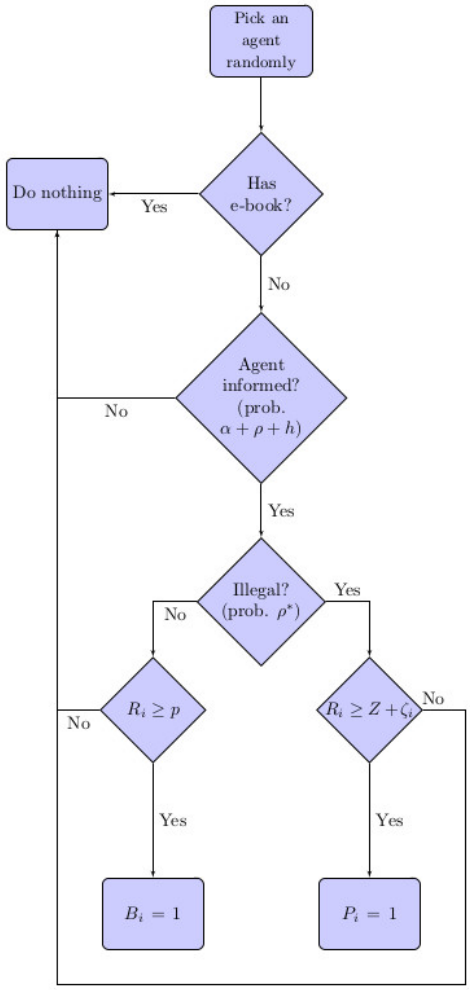

Fig. 1. Decision process of a single agent.

decides to obtain the book if its real or perceived costs are not larger than the agent's reservation price (Eq. (5) or Eq. (6) depending on the acquisition channel).

The parameters of the model are summarized in Table I together with some important variables. From an agents' perspective, the parameters may be divided into two classes: (1) internal parameters characterizing the attitude towards an e-book (agent's reservation price R_i) and towards piracy (aversion ζ_i), (2) external ones including the e-book price p, advertisement efforts h of a publisher, the punishment level Z and the initial inclination toward the piracy, ρ_0.

TABLE I

Variables and parameters in the model. If not stated otherwise, the quantities are dimensionless.

Variable	Meaning
N	number of agents
B_i	binomial variable characterizing legal purchase
P_i	binomial variable characterizing illegal download
R_i	reservation price (measured in dollars)
ζ_i	aversion to piracy (measured in dollars)
p	e-book price (measured in dollars)
h	advertisement level
Z	punishment level (measured in dollars)
ρ_0	initial inclination towards piracy in the system
α	fraction of buyers
ρ	fraction of pirates
ω	$(= \alpha + \rho)$ fraction of e-book owners
ρ^*	influence of pirates
π	publisher's profit (measured in dollars)

4.5. E-books versus other digital goods

Although e-books share many characteristics with other digital goods, in the context of piracy, there are some subtle differences between them. Leaving scanned copies of traditional books out of consideration, there is usually no difference in quality between a legal and a pirated copy of an e-book. On the other hand, illegal copies of music and movies suffer very often from quality loss (sound compression, limited video resolution). Moreover, with pirated software, one usually has no access to typical add-ons (technical support, periodic updates, additional functionality upon registration). These characteristics lower the appraisal of those goods. Thus, our model should be extended accordingly in order to apply it to software, music or movie piracy.

5. Results

5.1. Simulation setup

We simulated the system consisting of $N = 100$ agents by making use of the Matlab/GNU Octave platforms for scientific computing [66, 67]. Although the assumed system size may seem too small to be realistic, from our simulations it follows that the results do not depend on the size (see Sec. 5.7 for more details).

As for the initial setup of the model, we started with no e-book owners in the population ($\alpha = \rho = 0$). The reservation price was normally distributed with the expected value $\tau = 20$ corresponding to the average price of the book and with the variance $\sigma = \tau/3$. This choice of parameters ensured a positive evaluation of the e-book by the majority of agents. The aversion to piracy was normally distributed as well with the mean equal to 0. If not stated otherwise, the same variance was used as for the reservation price. We took $\rho_0 = 0.9$, meaning a high initial bias towards piracy in the community.

In order to evaluate the effects of government and publisher decisions on the e-book market, we considered the following values of external parameters:

— punishment Z: values ranging from 0 to 50,

— e-book price p: from 10 to 30,

— advertisement h: from 0.01 to 0.99.

Due to the stochastic nature of the model, we performed 1000 independent runs for each parameter set and took the averages over the runs to wash out the effects induced by random fluctuations.

5.2. Fraction of pirates

We start our analysis by looking at the fraction of pirates on the market as a function of the e-book price for different punishment levels Z and different time steps. Corresponding results for low (top row) and high (bottom row) advertisement levels are shown in Fig. 2. First of all, we see that the higher is the punishment Z for owing an illegal copy, the smaller is the number of pirates in the system. This result is in agreement with our intuition.

Note that the system reaches its asymptotic state very quickly. For these two particular sets of parameters, for instance, there is practically no difference between the data after 10 and 20 Monte Carlo steps (MCS) (middle and right columns in Fig. 2, respectively).

There is one interesting point in Fig. 2. If you look at the data at times 10 and 20, they are actually the same for both low and high levels of advertisement. Thus, the advertisement seems to have no impact on the final number of pirates. However, it significantly changes the dynamics of reaching the final values. Indeed, at the beginning of the simulation (left column in Fig. 2), the numbers of pirates are much larger (and closer to their final values) for the high advertisement level $h = 0.9$ than for the low one. So, the publisher's advertisement speeds up the process of illegal downloads just after the introduction of a new e-book on the market.

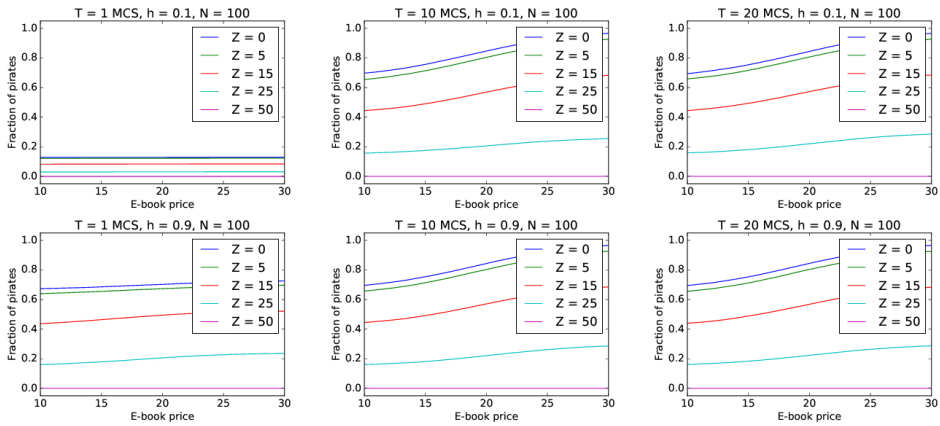

Fig. 2. The fraction of e-book pirates as a function of e-book prices at different simulation steps for two levels of advertisement: $h = 0.1$ (top row) and $h = 0.9$ (bottom row).

5.3. Demand curves

From the publisher's point of view, it would be interesting to check the relationship between the price of the e-book and the number of legal buyers. In Fig. 3, demand curves illustrating this relationship are shown at different time steps and for two advertisement levels. Please note that following the convention, we drew the demand curves with price on the vertical axis, *i.e.* we actually plotted the inverse demand functions. Hence, attention has to be paid while comparing the results with Fig. 2.

In agreement with our findings for the pirates, the final penetration rates of the market (right column in Fig. 3) do not depend on the advertisement level, but the dynamics in the transient regime does. Higher level of advertisement speeds up the process of adoption of a new e-book, hence pushing the system towards the asymptotic state.

We pointed already the fact that the piracy is diminished by an increase of the punishment level Z. As for the market penetration, one would expect the opposite, *i.e.* a higher level of punishment should enhance the inclination towards a legal purchase. The data presented in Fig. 3 is consistent with this intuition — in most of the plots and for any prices, the penetration increases with Z. There is only one interesting exception at intermediate steps and low advertisement level (see the middle plot in the top row of Fig. 3). The curves for $Z = 25$ and $Z = 50$ intersect at a price of about 13. For lower prices, the penetration is surprisingly higher for $Z = 25$ meaning that the legal adoption is faster if there are more pirates on the market.

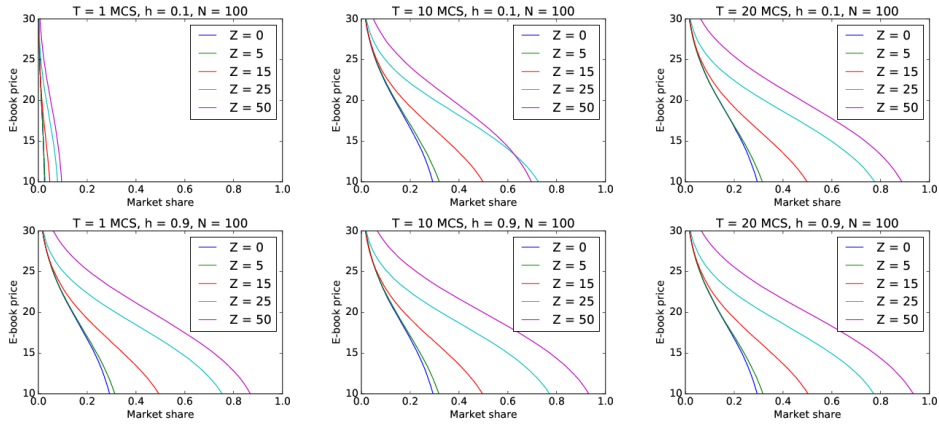

Fig. 3. Demand curves depicting the relationship between the e-book prices and the fraction of legal buyers at different simulation steps for two levels of advertisement: $h = 0.1$ (top row) and $h = 0.9$ (bottom row).

5.4. Time evolution of the system

To elaborate on the last finding, let us look at the time evolution of the model. Results for three different advertisement levels are shown in Fig. 4. The left plot in the figure corresponds to the intersection observed

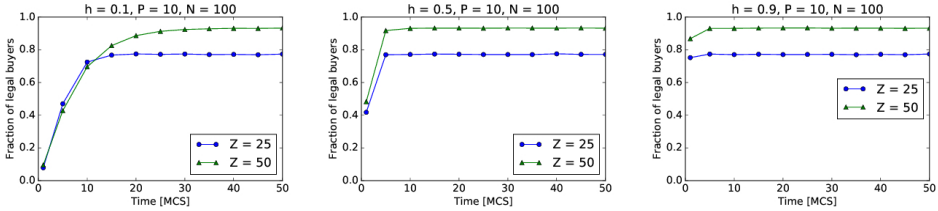

Fig. 4. Number of legal buyers as a function of time for two different punishment levels. The left, center and right plots correspond to three different levels of advertisement: $h = 0.1$, 0.5 and 0.9, respectively. The e-book price was set to 10.

in Fig. 3. Indeed, we see that for $h = 0.1$, there are slightly more buyers at the beginning of the simulation for smaller Z, but then the curves intersect and the case $Z = 50$ takes over, in line with our expectations.

The reason for such a behavior is the following. The punishment level $Z = 25$ is large enough to make the legal purchase appealing to agents. On the other hand, it still does not scare off agents with well-pronounced inclination towards piracy from an illegal download. Consequently, at the beginning, there are more book owners (both buyers and pirates) in the system for $Z = 25$ than $Z = 50$. They drive next potential owners towards

a purchase and that is why initially, the adoption is faster in the presence of pirates. However, because of these pirates the number of buyers saturates at a smaller value than in the case of $Z = 50$. That is the reason for the intersection observed in the left plot of Fig. 4.

We do not observe a similar behavior at higher values of advertisement, because in those simulations, agents are pushed towards a purchase from the beginning and the effect is much larger than the one induced by the presence of pirates.

There are two other interesting points in Fig. 4. First of all, although the adoption is very quick in all cases, its rate increases with advertisement h. Indeed, for $h = 0.9$, the system is close to its saturation demand already after 1 simulation step.

Even more interesting is the fact that the number of buyers at the end of the simulation does not depend on advertisement and increases with Z. Thus, from the publisher's perspective, efforts put into penalizing pirates are in the long run more favorable than those put into advertisement.

5.5. Role of ρ_0

All results presented up to this point were obtained from simulations starting from a high initial inclination to piracy, $\rho_0 = 0.9$ (see Eq. (4) for the meaning of the parameter). Now, we would like to discuss the role of this parameter in more detail.

In Fig. 5, we present the demand curves again. As before in Fig. 3, the columns correspond to different simulation steps ($T = 1$, 10 and 20 from left to right). The rows mean the different values of ρ_0 (0.9, 0.5 and 0.1 from top to bottom). We see that qualitatively the curves are very similar, however they differ in many aspects. First of all, note that the spread of the market shares decreases with decreasing ρ_0. Indeed, while the values for $\rho_0 = 0.9$ at $T = 20$ and price equal to 10 range from about 0.3 ($Z = 0$) to about 0.9 ($Z = 50$), the difference between these extreme values of Z is hardly observable for $\rho_0 = 0.1$.

At the intermediate step ($T = 10$), we observe intersections of the demand curves for all values of ρ_0. However, while for $\rho_0 = 0.9$, the effects of a piracy induced temporary speed up of the legal adoption is small, it is much larger for the other two values. For $\rho_0 = 0.5$, for instance, the $Z = 50$ curve not only intersects with the $Z = 25$ one, but approaches the $Z = 15$ one as well. For $\rho_0 = 0.1$, all curves appear in a temporarily inverted order.

If you look at the right column of Fig. 5 (*i.e.* $T = 20$), you will see that the market shares for $Z = 50$ are essentially the same and independent of ρ_0. However, the maximal shares for smaller values of Z increase with decreasing ρ_0. It seems that ρ_0 impacts the level of piracy, which is lower

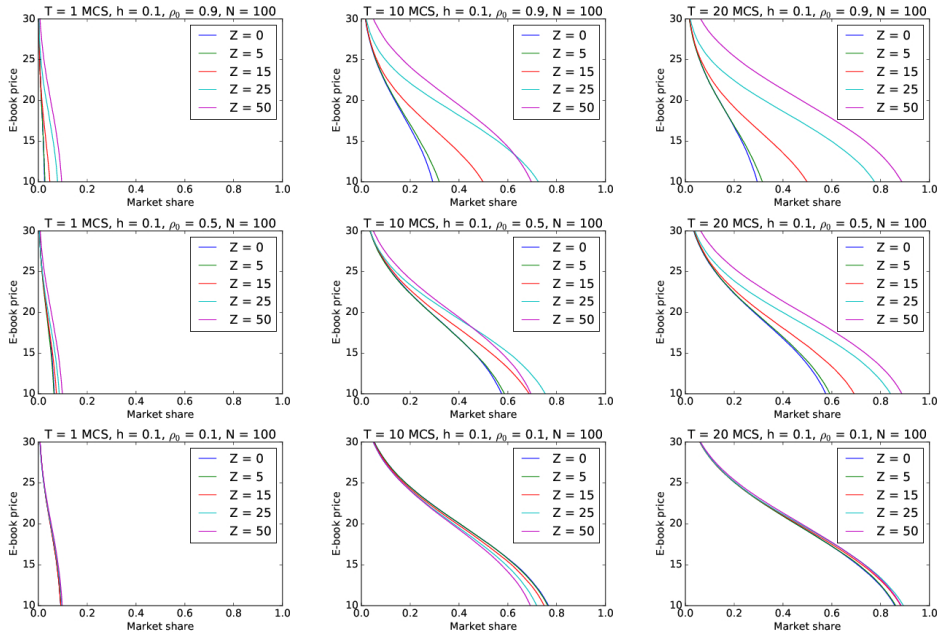

Fig. 5. Demand curves for three different values of initial influence of pirates: $\rho_0 = 0.9$ (top row), $\rho_0 = 0.5$ (middle row) and $\rho_0 = 0.1$ (bottom row). The columns correspond to $T = 1$, 10 and 20, respectively. Advertisement level h is equal to 0.1.

with decreasing ρ_0, thus allowing for more legal purchases. This is not observed for $Z = 50$, because such a high punishment level reduces piracy significantly anyway and covers the effects induced by ρ_0.

5.6. Optimal pricing and welfare analysis

Another interesting issue is the price at which the publisher maximizes his profits. In order to determine the optimal price, we calculated publisher's profit according to Eq. (2) for each parameter set and then looked for its maximum with respect to price. The results as a function of punishment for two time steps and different levels of advertisement are shown in Fig. 6. We see that the optimal prices do not change much with time and depend weakly on the advertisement level. Interestingly, the prices have a minimum at $Z = 15$. One would rather expect the minimum to be located at $Z = 0$, *i.e.* in case there are no obstacles for pirates and the price has to be kept low for a purchase to be competitive.

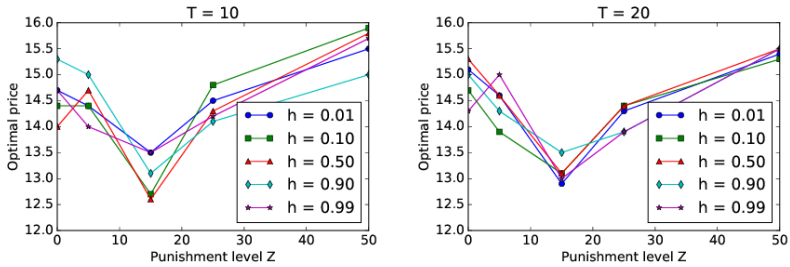

Fig. 6. Optimal price after 10 (left) and 20 (right) simulation steps as a function of the punishment level Z for different advertisement levels.

The role of the punishment in optimal pricing and its sensitivity to the initial propensity to pirate ρ_0 is shown in Fig. 7. In countries, where the propensity ρ_0 is very low (*e.g.* $\rho_0 = 0.1$), the punishment level is not relevant in establishing the optimal price of the e-book. The consumers generally prefer to buy a legal book, and the producers do not need to encourage them by decreasing the price. It allows the producer to benefit by keeping the price high. The situation is different in countries, where the propensity to pirate increases (*e.g.* to $\rho_0 = 0.5$ or $\rho_0 = 0.9$). In such a case, as long as the punishment level is low ($Z \leq 15$), the producer needs to decrease the price of the goods significantly to convince consumers to buy a legal copy. If the punishment is severe enough to discourage consumers from piracy, the producers may increase the optimal price, knowing that most of the consumers will prefer to buy a legal book (*i.e.* because of the fear of the punishment).

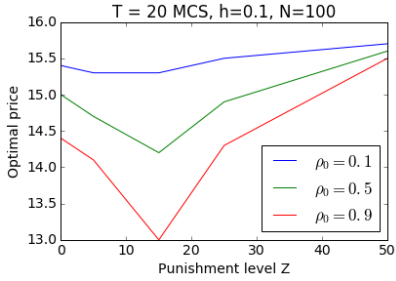

Fig. 7. Optimal price after 20 MCS as a function of the punishment level Z for different values of initial inclination to piracy ρ_0.

In order to analyze effects of piracy on the social welfare, three types of market participants are considered: consumers, producers and pirates. The literature focuses mainly on the producer surplus, which is computed as the difference between the entrepreneur income and costs [23]. On the other

hand, in most of the papers, the demand curve is an input to the model and, therefore, the consumer surplus is not widely analyzed. Here, the demand is endogenous and is an output of the diffusion process, as in Refs. [68, 69]. Therefore, in the presented setup, the consumer analysis gains the importance and could shed a new light on the piracy issues. The consumer surplus is computed as the difference between the consumers' willingness to pay for an e-book (*i.e.* their reservation price) and its market price, set optimally by the producer. Since the product diffusion depends on both the price and the punishment Z, it is expected that both variables will affect the level of the consumer surplus and its share in the total surplus of legal market participants. Finally, a surplus of pirates is considered. It is computed as the difference between the pirates' willingness to pay and the piracy costs approximated by the sum of the aversion to piracy ζ_i, and the punishment level Z. As long as the welfare of consumers and a producer is considered, it is clear that a social planner aims at its maximizing [70]. The approach toward pirates is more ambiguous. Social planner should, in general, discourage consumers from piracy by decreasing the welfare associated with it. On the other hand, when the share of pirates in the society is high, the costs of such policy may be severe enough to deter its realization.

The results of the welfare analysis are shown in Fig. 8. The top row presents the surplus of the three types of market participants as the function of the punishment level, Z, and the initial inclination towards the piracy, ρ_0. It can be noticed that both the consumers' and producers' surpluses increase with Z. It is an outcome of the diffusion process: the higher the punishment, the larger share of the potential buyers decides to purchase a legal version of the e-book. The growth of the quantity balances the behavior of prices. When Z increases from a very low level to $Z = 15$, the market price is decreasing (see Fig. 7), which affects positively the consumers' surplus and reduces the producer surplus. On the other hand, for $Z > 15$, the optimal price is increasing with Z, which is beneficial for the producer and disadvantageous for consumers. The pirate surplus, presented in the right upper panel of the Fig. 8, shows the opposite situation. Now, the increase of the punishment Z lowers the benefits of the pirates because it both decreases the number of pirates and increases the piracy costs computed as the sum of $\zeta_i + Z$.

The bottom panel of Fig. 8 presents the total legal surplus and the consumer share in this surplus. The total legal surplus is simply the sum of consumer and producer surplus, and it summarizes the economic welfare of buyers and sellers. Two conclusions can be derived. First, the higher is the punishment level Z, the greater is the total welfare. Second, systems with a weak inclination towards the piracy, which are characterized by low values of ρ_0, obtain more welfare from selling e-books. Hence, from the point of

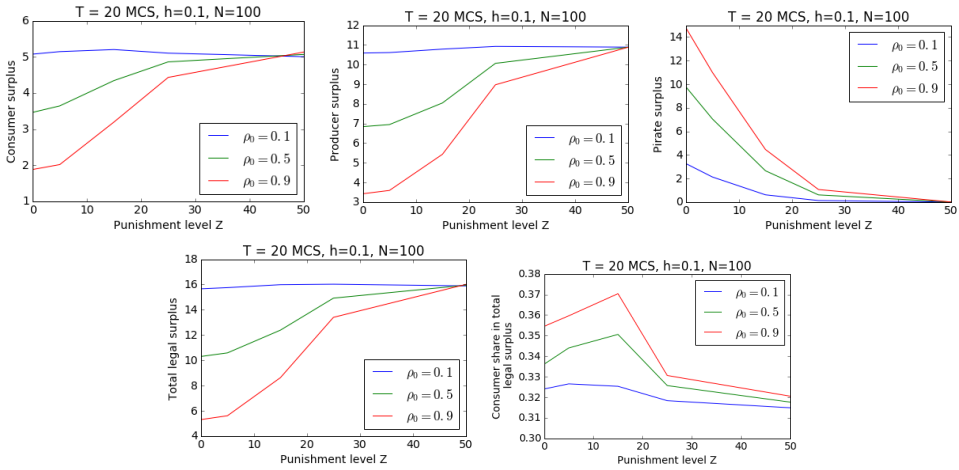

Fig. 8. Consumer, producer, pirate and total surplus as a function of the punishment level Z for different levels of ρ_0. Note the range changes of the vertical axes.

total legal welfare, the existence of pirates has only negative effects on the e-book market and hence the punishment should be set as high as possible. The conclusions change, when a share of consumers in the total welfare is analyzed. The results show that piracy may provide an additional market power to consumers, which a monopolist seller needs to face. In general, the consumer share is increasing with ρ_0, so a country with a low inclination to piracy, for example $\rho_0 = 0.1$, allows the seller to execute more of its market power. Moreover, the share depends strongly on the punishment level. It can be observed that it increases with Z, when the punishment level is lower that 15, and decreases with Z, when $Z > 15$. This property is particularly evident when a system with $\rho_0 \geq 0.5$ is considered and is closely related to the behavior of prices. It shows that existence of piracy forces sellers to decrease price and transfer part of its profits to consumers in order to gain additional buyers.

5.7. Note on the system size

As already mentioned at the beginning of this section, we usually worked with $N = 100$ agents, *i.e.* with a small size of the system. The reason for that choice was simply no observed dependence of the results of the model on its size. To illustrate that we present in Fig. 9 example demand curves after 10 Monte Carlo steps for 4 different values of N $(= 100, 200, 500, 1000)$. There is indeed no difference between different values of N. Having this in mind, we chosen a small N to work with for the sake of computational efficiency.

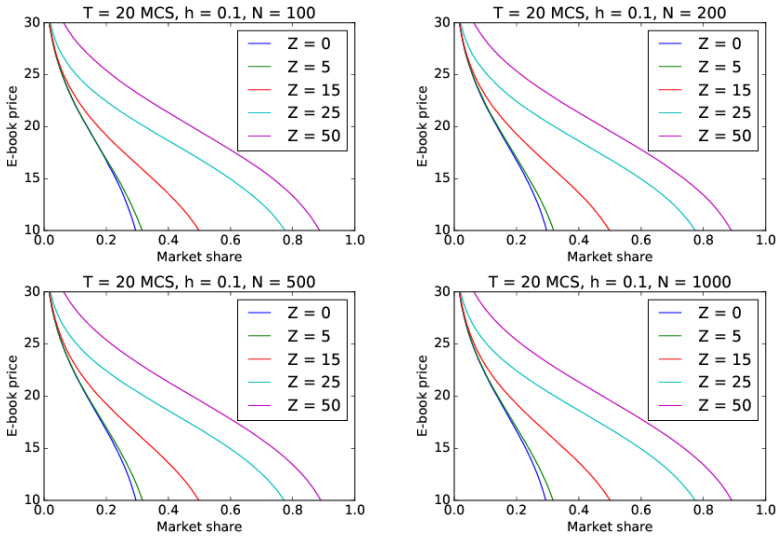

Fig. 9. Demand curves after 10 Monte Carlo steps of the simulation for four different sizes of the system, $N = 100, 200, 500$ and 1000. Note that the results do not depend on the size.

6. Discussion and conclusions

The goal of our paper was to study the impact of piracy on the e-book market. In particular, we focused our attention on the interplay between agent's appraisal of an e-book (identical to the reservation price), its market price, punishment levels for piracy and advertisement efforts of a publisher, and the welfare analysis of all market participants. By the means of a simple agent-based model, we captured some interesting relations between those variables.

Firstly, according to our intuition, we have shown that with the increase of advertisement effort, the adoption of an e-book accelerates. However, at the same time, the advertisement efforts may change the dynamics of reaching the final level of piracy, especially in the short run. In other words, the advertisement may accelerate the process of illegal downloading.

Secondly, we have presented that the number of pirates in the market decreases with the level of the punishment, which is quite intuitive. However, we observed that the legal adoption is faster in the short term, if there are some pirates in the market. It seems that there is a certain level of punishment at which piracy may have a positive impact on the total adoption rate, as it stimulates the diffusion. In that sense, some piracy rate in the market may play a vital role of sharing the information about the e-book and advertising it via word-of-mouth among the consumers. On the other hand,

we have observed that in the long run, it is more effective for the publisher to penalize the pirates than to invest in advertising, since the latter may strengthen piracy as well.

Third, we have found out that the optimal prices do not change much within the time and they do not depend significantly on the level of advertisement. Finally, we have shown that the lower is the initial inclination to piracy, the higher is the level of legal purchases, and the lower is the consumer share in the total surplus. It is so, because in a country with a low inclination to piracy, the seller has a greater market power and hence may dictate higher prices. We have shown that the existence of piracy forces sellers to decrease prices and transfer part of their profits to consumers in order to gain additional buyers.

Finally, from the point of total legal welfare analysis, the existence of pirates has only negative effects on the e-book market and hence the punishment should be set as high as possible. However, on the other hand, piracy may provide an additional market power to consumers, by forcing the producers to decrease the prices of e-books.

To conclude, our model has shown the ambiguous effect of piracy on the e-books' diffusion. It seems that dependent on the publisher's advertising effect, piracy may enhance the diffusion in the short run. It is especially true for the low levels of advertisement and punishment, which is quite typical for the e-book's market, where the advertisement expenditures are not very high, the promotion time is rather short and there is actually no or very small punishment for the illegal downloading. In such a case, allowing some piracy rate, for example by imposing low punishment levels or giving a free, time-limited access to the e-book could be a good marketing strategy. Why? Because illegal downloading of e-books provides information spreading about the new product among consumers. Hence, it replaces the traditional advertising and supports the diffusion also of legal e-books. In the long run, however, high piracy rates may be dangerous for the legal publisher's profits and may limit the diffusion of a legal e-book. That is why within the increase of the time horizon, the raise of punishment levels is in the interest of the publisher.

Last but not least, we would like to stress that in our model, the demand for e-books is endogenous and it is an output of the diffusion process. Such an approach distinguishes our model from the others.

We believe that our finding can be valuable for legal distributors not only of the e-books, but actually of all digital goods. They allow to look for a compromise between external punishment levels, usually imposed by the legal authorities, publisher's advertisement efforts and optimal prices of those goods.

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