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Containing piracy with product pricing, updating and protection investments

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ABSTRACT

We consider a monopolistic producer offering software that is updated periodically, but, by the end of one period, a pirated version is available at a transaction cost. This presents the consumers, who are different in terms of their willingness to pay for the original compared to the pirated version, with possible strategies for either buying a new product or pirating it. We address pricing and protection investment strategies to regain the profits affected by the piracy. In particular, we find that even when the transaction cost is exogenous, the producer does not necessarily want to fully price out the piracy. The decisive factor in such a case is the level of product newness relative to the transaction cost. If the producer is able to achieve high newness for the updated product relative to the transaction cost, then a high retail price ensures that he will gain the largest profit possible even though some of the demand will be lost due to piracy. On the other hand, when the transaction cost is endogenous, the producer may have two alternatives, in terms of profit, for dealing with the piracy—pricing the software out or investing heavily in software protection. As newness levels rise, the option of pricing out the piracy becomes increasingly preferable.

1. Introduction

Software piracy, or the illegal duplication and distribution of computer software, causes vast losses to software firms. According to reports from the software industry, in 2009 alone piracy was associated with global losses of $51.4 billion, and illegally-obtained programs software accounted for 43% of the software installed on personal computers worldwide (Business Software Alliance, 2009). The growing popularity of mobile devices such as personal digital assistants and smart phones may also induce greater piracy. To prevent piracy, software companies seek to increase the attractiveness of legal products, while simultaneously increasing security measures (Jaisingh, 2009).

Modern commercial software is rarely static. Software companies frequently release updates, patches and additional content for existing software. In many cases, companies release updates that are so extensive that they are essentially new versions of the software and are hardly compatible with older versions of the same software. This is also true for entertainment software with supposedly fixed content, such as computer games. There is a growing trend in the gaming industry to release downloadable content (DLC), i.e., additional chapters and bonuses for an already sold, full game.

The need to continually update software presents potential pirates with a dilemma. For example, the iPhone operating system iOS4 can be hacked relatively easily, thereby allowing the user free access to applications that would otherwise cost money. These pirated applications, however, will not be updatable. Moreover, many updates to these applications require the newer iOS5 operating system, which, as of now, cannot yet be easily hacked. Therefore, the consumer is presented with the choice of updating the software legitimately or staying with the illegitimate outdated software. This choice is highly dependent on the extra utility gained by the consumer from an up-to-date product. We refer to this extra utility as newness. Further intensifying this dilemma is the fact that, beyond the mere technological aspect, companies provide the licensed user with other benefits such as customer services, software implementation assistance, IT support, and product warranty.

Of course, the additional utility gained by the user from the extra benefits of a licensed product varies depending of the product. In some instances an unlicensed or pirated version of a product is almost useless. For example, in the case of massively multiplayer online games (e.g., World of Warcraft, Everquest), merely obtaining the game files illegitimately would barely afford the user any utility without the license to play the game on the company server. On the other hand, the benefits of a licensed product may provide very little utility for the consumer. Software applications with simple primary functions that rarely change or evolve and therefore need little updating are good examples of such products. Specifically, this category can include media player

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software (Real Player, Quicktime) and CD burning software (Nero burning ROM).

Accordingly, to prevent piracy, companies face a trade-off between lowering the prices of their products, providing higher product newness and extra benefits for licensed users, and investing in security measures. In fact, many of the above mentioned updates often have security and anti-piracy measures integrated into them.

In this paper we consider a monopolistic company selling a software product while competing with a secondary market of pirated versions of the product. The goal is to study possible consumer strategies and the corresponding pricing and security investment policies that the company should adopt in order to sustain its profits. Special attention is paid to the effect of the transaction cost (the cost to the consumer for obtaining a pirated version of the product) on both consumer behavior and company pricing policies. In particular, we show that when the transaction cost is endogenous (set by the company), low product/service newness leads to higher prices, while high newness implies low prices. Conversely, when the transaction cost is exogenous (cannot be affected by the company), low newness induces low prices, while high newness implies higher prices.

2. Literature review

The literature on piracy of digital goods is wide-ranging, especially in the software, music and media industries (see an extensive review by Peitz and Waelbroeck, 2006). The vast majority of research in this area deals with pricing, copyright protection, and government policies as tools to reduce piracy (Khouja and Rajagopalan, 2009). The nature of digital piracy may vary across different types of digital goods, owing to the different characteristics of these products. Among these characteristics are the types of payments possible. Music and media, for example, may allow for a system of micro payments, e.g., pay-per-song, whereas software can rarely accommodate such an approach, more often relying on licensing for certain periods of time. In addition, firms' anti-piracy activity differs across products. In digital software such activity often includes changes to the product itself, whereas prevention of digital-media piracy relies almost exclusively on legislation. Another difference is that software products can be updated unlike hit songs, e-books and similar digital products, whose degradation over time is a negligible factor (Domon and Yamazaki, 2004; Khouja et al., 2010; Parry et al., 2011).

The effect of externalities on piracy and piracy prevention is also product-type-dependent. An increase in the number of users of a software program may boost its value; thus, a company might even benefit from tolerating some piracy when it creates positive network externalities (Shy and Thisse, 1999; Prasad and Mahajan, 2003; Khouja and Rajagopalan, 2009, Liu et al., 2011). King and Lampe (2003), however, oppose the idea of beneficial piracy under any circumstances. King and Lampe claim that, regardless of network externalities, piracy will interfere with profit maximization. Piracy in the music and media industries is less affected by positive externalities (Khouja and Rajagopalan, 2009; Jeong et al., 2012). In Table 1 we classify the literature on digital piracy according to the different industries.

Pricing strategies play an important role in fighting piracy of digital goods in general and of software products in particular. Khouja and Rajagopalan (2009) consider piracy in the music and motion picture industries with copies being identical in quality to the original and a long product lifecycle. They assume no investing in product protection and suggest a two-price strategy and dual distribution channel for limiting piracy. Prasad and Mahajan (2003) develop a continuous-time, infinite horizon diffusion model with demand saturation and immediate piracy. They show that a monopoly should start with minimum protection of its software but well before the product has diffused half way, impose maximum protection. Unlike Prasad and Mahajan (2003), we assume that a period of time is needed to hack a software program, and we consider software products that become quickly outdated. Moreover, we assume that, even if the company continuously works on product innovation, consumers are provided with updates only periodically.

Bae and Choi (2006) propose a model of a monopoly that suffers from piracy. They consider two costs associated with piracy: a constant (transaction) cost for reproduction and a variable degradation cost. Like Bae and Choi (2006), who claim that the effects of piracy depend heavily on the nature of piracy costs, we assume that there is a strong negative relationship between the cost of piracy to consumers and its proliferation. Specifically, we designate a transaction cost parameter representing the time and effort required to locate and acquire a pirated product, and we examine the effects of this cost on the demand for piracy. Domon and Yamazaki (2004) use a model similar to that of Bae and Choi (2006) to explore the relationship between piracy and pricing of digital content. They assume that consumers initially consider the quality of the content to purchase, and then decide whether to obtain it at an online store or through unauthorized file-sharing. They derive a condition whereby a producer, facing unauthorized file-sharing, may raise prices depending on transaction cost. Similarly to Domon and Yamazaki (2004), we study the effect of transaction costs on pricing authorized products.

Another stream of literature focuses on firms' investments in piracy protection measures. For example, in the case of software piracy, Gopal and Sanders (2000) classify security measures into deterrent and preventive measures. Among the deterrent measures are educational programs and legal activities such as lawsuits brought against copyright infringers and attempts to expand the scope of current copyright laws. Novos and Waldman (1984) study the effect of increased copyright protection on social welfare. Their model assumes that individuals differ in terms of the costs they incur by obtaining a pirated product. Preventive measures usually rely on technologies that make piracy more difficult and costly, such as tamper-proofing and watermarking (Colberg and Thomborson, 2002).

In this paper we assume that a firm can affect the rate of piracy (see Khouja and Smith, 2007), and we include the option of a firm investing in software protection in order to reduce piracy. Khouja and Smith (2007) assume that the rate of piracy is reduced by the firm's protection investment, but that complete eradication of piracy is prohibitively expensive and therefore virtually impossible. We employ a similar approach to define the transaction cost as a function of the protection investment.

An important factor to account for when attempting to study digital piracy is the dynamic nature of technology. Khouja et al. (2008) consider the relation between technological advancement and pricing strategies of information goods. Specifically, they show the adverse effect of technology advances on the profitability of skimming strategies. Jaisingh (2009) touches on the aspect of technological progression by examining the effect that anti-piracy polices have on incentives for innovation. We also account for technological advancement in the form of product updates and new versions released by the company and the erosion of consumer utility from older outdated products.

It is normally assumed that there are differences between an original and its copy, and that consumers are heterogeneous in terms of their willingness to pay for the original compared to the copy (see Table 1). There are two common approaches in the

Table 1
Basic modeling features in the current literature on piracy.

	Media type			Pirated product		Product lifespan		Consumer's heterogeneity		Type of update	
	software	Movies	Music	Inferior	Perfect substitution	Long/ indefinite	Short with updates	Groupings	Continuous	Periodic	Continuous
Bae and Choi (2006)	x			x		x		x			
Belleflamme (2003)	x			X		x			x		
Cremer and Pestieau (2009)	x	x	x	X		x		x			
Domon and Yamazaki (2004)	x	x	x		x	x		x			
Jaisingh (2009)	x			X		x		x			
Jeong et al. (2012)			x		x	x					
Khouja and Rajagopalan (2009)		x	x		x	x					
Khouja and Smith (2007)	x	x	x		x	x					
King and Lampe (2003)	x			X		x		x			
Liu et al. (2011)	x				x	x		x			
Novos and Waldman (1984)	x	x	x		x	x			x		
Prasad and Mahajan (2003)	x				x	x					x
Yoon (2002)	x			x		x			x		
The current paper	x			x			x		x	x	

literature for expressing the heterogeneity of consumer valuations. One divides consumers into discrete groups based on their valuation of the product (see Takeyama, 1994; Bae and Choi, 2006; Cremer and Pestieau, 2009). Cremer and Pestieau, for example, consider a population with high and low valuations. The other, more general approach, assumes that consumers' product valuations are distributed along a continuum; in most cases, the distribution is considered to be uniform across an interval (Belleflamme, 2003 and Yoon, 2002). Specifically, both Belleflamme (2003) and Yoon (2002) consider three possible consumer strategies: buying new, copying/pirating, or not using the product at all. This implies that the product has an indefinite lifetime. Yoon (2002) identifies two pricing regions and three optimal protection levels for a monopolistic producer. Belleflamme (2003) shows that when the copyright technology involves a fixed cost, the producer's pricing behavior is much more intricate to analyze. Due to the complexity of the system of demands, Belleflamme (2003) studies only symmetric pricing equilibria, showing that producers tend to set higher prices when it comes to deterring copyright and that they undercut the price when it comes to accommodating copyright.

Similar to Belleflamme (2003) and Yoon (2002), we consider consumer strategies in our investigation of pricing and protection policies. The major distinction (see Table 1, which shows where our work fits in with existing literature and where we fill gaps) is that we focus on piracy of modern software goods that quickly become obsolete and are updated regularly, rather than on products with indefinite lifetimes that are not updated. This expands the range of possible consumer strategies and demand levels, inducing diverse protection and pricing scenarios that depend on the level of new services provided with updates and the type of the fixed copyright (transaction) cost. In particular, we assume that the software products are updated periodically, and that by the time of update, the previous version can be hacked. The updated product then provides higher newness, reflected in better services. We find that newness has different effects on pricing strategies when there are different endogenous and exogenous transaction costs. Furthermore, we show that when the transaction cost is endogenous, the producer may have two comparable alternatives by which he can combat piracy, in terms of maximizing profit: He can lower the price of his product significantly or invest heavily in protection. Therefore, the choice of action might be related more to the firm's strategy rather than the expected profit. However, when product newness increases, a strategy of flooding the market with cheaper, less piracy-resistant products becomes increasingly profitable.

3. The model

Consider software which is updated periodically. We assume that the newly updated product cannot be immediately pirated regardless of how smart the hackers are. On the other hand, by the end of a period a pirated version (one-period-old) is always available at a transaction cost P_T no matter how well the product is protected. This description is applicable to any number of mass-produced and widely used products such as, for example, Microsoft and Apple software.

Due to the vulnerability of software products, a consumer can buy each period an updated version/subscription from a retailer at a price, P_N, or search for a pirated version at a transaction cost, P_T. Furthermore, if the consumer has bought an updated product at the beginning of a period, then she may decide to keep the purchased software for one more period without updating and thereby avoid having to make a new purchase.

We consider software products that have value for consumers only for two periods. The value is composed of the value of basic services, v, and of supplementary ones, k, available only to legitimate users. We assume that when software is upgraded, a pirated version of the upgrade becomes available only in the following period. Thus a consumer choosing to pirate, can obtain a "new" pirated version of the product every period, i.e., pirating over both periods implies obtaining a pirated product for each of the periods. Therefore, the pirated version is always "just one step behind" the normal licensed product and is characterized by only basic services v. Furthermore, at the beginning of a period, advanced services from the previous period become outdated as the software company provides an upgrade with new advances for its legitimate users.

The newness, k, represents all the extra utility that a consumer derives from holding a licensed product. Beyond the technological aspect, which includes updates, bug fixes and DLCs (extra downloadable content packs), this extra utility includes access to customer services, software implementation assistance, IT support, product warranty etc.

Since we assume that the software has no value if it is not updated after two periods, the two-period model cycle which we have described repeats endlessly. Although certain products may have greater longevity and might be used over several periods even when a major upgrade or new version is available, we attempt to capture the prevailing behavior of consumers in the software market, in which products become obsolete extremely quickly. Specifically, the current trend among software companies is to use various measures/incentives to induce consumers to upgrade their software rather than keep older versions. For example, the company Maplesoft upgrades its mathematical software program Maple each year, rendering some computational features incompatible with previous versions. As a result, many files prepared with a new version of Maple do not run even with the one-year-old version. Consequently, among university students, who are the main users of Maple, one can rarely find a mathematical package that is more than two years old. Microsoft Corporation adopts a similar tactic in updating their Microsoft Office products. Many users are forced to upgrade to newer versions of Office because their older versions cannot load files from newer versions. This is, of course, a deliberate design element implanted by the company.

Thus, over a two-period span, the options available to consumers are

a: renew/update subscription every period
b: renew subscription only every other period
c: obtain a pirated unsubscribed version of the product at each period
z: do not buy the product at all

We assume that there are different valuations of these services according to a parameter $\theta\in[0,1]$, with a higher θ denoting consumers with a greater willingness to pay. In addition, there is no added value from possessing multiple duplicates of the same product (for example, no individual requires more than one copy of the same software). Consequently, the two-period utility, U, that a consumer derives under each of these options is

$$U_A=\theta(2v+2k)-2P_N, \quad (1)$$

$$U_B=\theta(2v+k)-P_N, \quad (2)$$

$$U_C=\theta 2v-2P_T, \quad (3)$$

$$U_Z=0. \quad (4)$$

Denote with θ_{AB}, θ_{BC} and θ_{CZ} a point of indifference between options *a* and *b*, options *b* and *c*, and options *c* and *z*, respectively. Then, from Eqs. (1)–(4) we have

$$\theta_{AB}=P_N/k, \quad (5)$$

$$\theta_{BC}=(P_N-2P_T)/k, \quad (6)$$

$$\theta_{CZ}=P_T/v. \quad (7)$$

Clearly, all four consumer strategies are possible if $0<\theta_{CZ}<\theta_{BC}<\theta_{AB}<1$. Analyzing this condition enables us to point out when specific consumer strategies are feasible. Specifically, if the cost of piracy is greater than the value of the product, $P_T\geq v$, then piracy does not make sense, $\theta_{CZ}>1$. Therefore, we exclude this trivial case by assuming that $P_T<v$. Recalling that $\theta\in[0,1]$, we also observe that if $\theta_{AB}<1$, then $P_N/k<1$. That is, the consumer updates the product each period if the retail price of the product is lower than the value of its newness; otherwise, nobody updates the software each period. Furthermore, $\theta_{AB}>\theta_{BC}$ implies the transaction cost is non-zero, $P_T>0$. Accordingly, if the transaction cost is positive, there are always consumers who update the product and then keep it for two periods. Otherwise, $P_T=0$, $\theta_{AB}=\theta_{BC}$ and each period consumers either update or get a pirated product (nobody updates the software at one period and then keeps it for another period without updating). Finally, $\theta_{BC}>\theta_{CZ}$ implies $(P_N-2P_T/k)>P_T/v$, i.e., $(P_N/k)>P_T((1/v)-(2/k))$; otherwise, nobody pirates. This condition may not hold unless $1/v>2/k$, i.e.,$k>v/2$. This is quite intuitive. If the added value k of the updated service is very high compared to the currently available one, v, then nobody pirates.

4. Consumer demands

Consider first the most general case when all strategies exist. Assuming that the consumers are uniformly distributed on θ. D_N, denotes the fraction of consumers (the demand) buying a legitimate (updated) product over the two periods. D_P denotes the fraction of consumers pirating, and D_Z not using the product at all.

$$D_N=2(1-\theta_{AB})+\theta_{AB}-\theta_{BC} \quad (8)$$

$$D_P=2(\theta_{BC}-\theta_{CZ}) \quad (9)$$

$$D_Z=2\theta_{CZ} \quad (10)$$

In addition to the demands (8)–(10), there are consumers retaining outdated products. Outdated products are products that have been legally purchased and to which consumers are subscribed during the first period. Since the owners have decided not to update them for the second period, the product has a value similar to that of a pirated one, v. The demand for the outdated product, D_U, is

$$D_U=\theta_{AB}-\theta_{BC} \quad (11)$$

To study the demands under various system parameters, we next categorize the level of transaction costs and degree of newness. Specifically, the transaction cost P_T, such that $(k/(2+(k/v))\leq P_T<v$ is viewed as high and $0<P_T<(k/(2+(k/v))$ is viewed as low. Furthermore, k, $k\leq 2\,P_T$ is considered as low newness, while $k>2\,P_T$ is high.

4.1. High newness products

In our analysis we first explore the case of high newness, i.e., $2P_T\leq k$. Fig. 1 illustrates the demand for new and pirated products for both sub-cases of high and low transaction cost, under high newness.

We now examine each of the sections in Fig. 1 starting from left to right. First consider the case when the price of the product is so low that $\theta_{BC}\leq 0$, while $\theta_{AB}<1$. Then, regardless of the level of the transaction cost, only strategies *a* and *b* are feasible as shown in the following proposition.

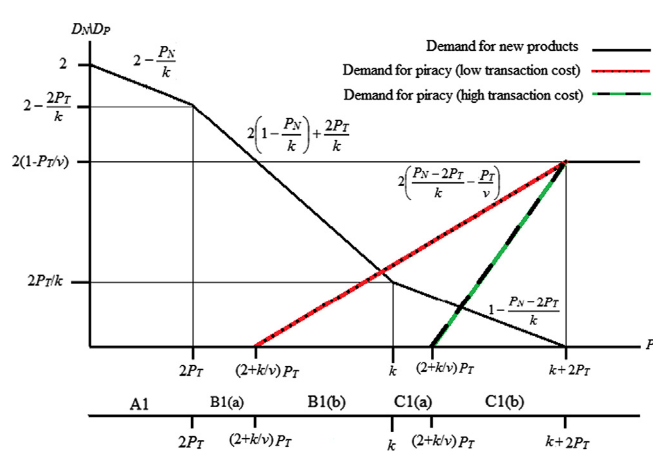

Fig. 1. Demand for legitimate products versus piracy under high newness.

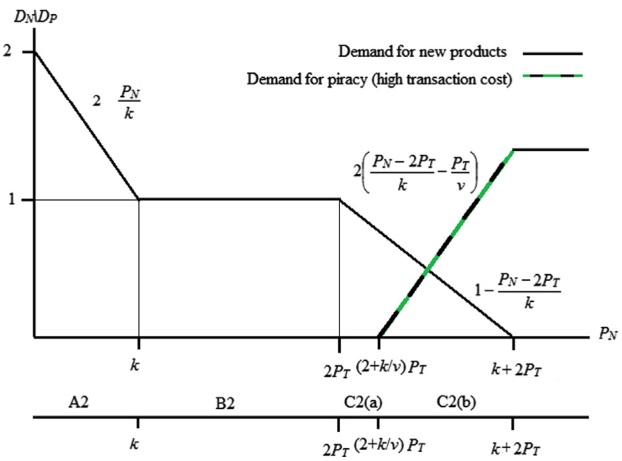

Fig. 2. Demand for legitimate products versus piracy under low newness.

Proposition 1. If $0 \le P_N < 2P_T$, *then everyone buys the product and updates it at least every other period,* $D_N = 2-(P_N/k)$; $D_U = (P_N/k)$; $D_P = 0$; $D_Z = 0$.

Proposition 1 implies that pirating can be eliminated when the price for the updated products is low relative to the transaction cost of searching for a pirated version (see region A1 in Fig. 1 and region A2 in Fig. 2). As the price increases within range A1 (A2), more consumers prefer to keep their products over updated ones. However, the prices in this region are so low that everyone updates the product either every period or every other period and no one pirates or chooses not to have the product at all. Naturally, as newness levels rise, more consumers prefer the updated product over keeping the older version. Computer hardware drivers are an example of software priced in this way. Hardware drivers usually have a very low price. In fact, quite often the only "price" is the cost of the time it takes to go online and find the software, download it (legally from a distributor's website) and install it. And yet, not everyone takes the time out to make sure that all of their hardware drivers are constantly up to date.

4.1.1. High transaction costs

Similar to the result for low prices (region *A*), pirating the product (strategy *c*) can be eliminated with a high transaction cost. Substituting Eqs. (5)–(7) into Eqs. (8)–(11) respectively and considering the case wherein strategy *c* does not exist i.e., $\theta_{BC}=\theta_{CZ}$, we arrive at the following result.

Proposition 2. Let $(k/(2+(k/v))) \le P_T < v$. *If* $2P_T \le P_N < P_T(2+(k/v))$, *then the transaction cost is so high compared to the price of the product, that no one pirates. Furthermore, if* $2P_T \le P_N < k$, *then there are consumers updating their products each period and* $D_N = 2-(2P_N/k)+(2P_T/k)$, $D_U = 2P_T/k$, $D_Z = 2((P_N-2P_T)/k)$, *and* $D_P = 0$. *Otherwise, if* $k \le P_N < P_T(2+(k/v))$, *then no one chooses to update the product every period and* $D_N = 1-((P_N-2P_T)/k)$, $D_U = 1-((P_N-2P_T)/k)$, $D_Z = 2((P_N-2P_T)/k)$, *and* $D_P = 0$.

Proposition 2 defines pricing regions *B*1 and *C*1(a) (see Fig. 1) at which nobody pirates the product due to the high transaction cost. As the price of the product increases in region *B*1, more consumers prefer not to update the product each period or not to have the product at all. Eventually nobody updates the product each period which features region *C*1(a). Naturally, this trend can slow down due to increased newness. When the prices are higher than those defined by region *C*1(a), strategy *c* of pirating a product over two periods is always feasible. That is, similar to the previous result, by considering the case where piracy exists, i.e., $\theta_{BC} > \theta_{CZ}$, we arrive at the following proposition.

Proposition 3. Let $(k/(2+(k/v))) \le P_T < v$. *If* $P_T(2+(k/v)) \le P_N < k+2P_T$, *then no one chooses to update the product and piracy exists and* $D_N = 1-((P_N-2P_T)/k)$, $D_U = 1-((P_N-2P_T)/k)$, $D_P = 2((P_N-2P_T)/k-(P_T/v))$ *and* $D_Z = (2P_T/v)$.

This proposition relates to region *C*1(b) in Fig. 1. At the beginning of this region, as prices rise, more consumers switch from strategy *b*, keeping the product for one more period, to strategy *z*, not buying at all. Furthermore, from the price aspect, $P_N = P_T(2+(k/v))$ and onward, piracy becomes worthwhile and the demand for pirated products emerges and increases with price. Higher newness levels, on the other hand, curb piracy and induce the consumers to opt for strategy *b*.

Note that if $\theta_{BC} \ge 1$ and $\theta_{AB} \ge 1$, then $P_N \ge k+2P_T$ and both strategies *a* and *b* are not feasible. This is true even if $P_T = 0$. That is, the price is so high in such a case that nobody is buying legitimate products. Since this is not in the interest of the sellers, we limit the price range by $P_N < k+2P_T$.

4.1.2. Low transaction costs

Substituting Eqs. (5)–(7) into Eqs. (8)–(11) respectively, and considering the condition $\theta_{BC}=\theta_{CZ}$, we arrive at the following low transaction costs.

Proposition 4. *Let* $0 < P_T < (k/(2+(k/v)))$. *If the price for the updated products is so low that* $2P_T \le P_N < P_T(2+(k/v))$, *then nobody pirates regardless of the value of the transaction cost,* $P_T > 0$ *and* $D_N = 2-(P_N/k)-((P_N-2P_T)/k)$, $D_U = (P_N/k)-((P_N-2P_T)/k)$, $D_Z = 2((P_N-2P_T)/k)$ *and* $D_P = 0$.

This proposition refers to region B1(a) in Fig. 1. In this range, as the price increases, more consumers choose strategy *z*, not buying at all, rather than strategies *a* and *b*, buying updated every period and buying updated only every other period, respectively. However, due to the fact that the price remains relatively low, there is still no piracy.

From $\theta_{BC} > \theta_{CZ}$, we derive the following conditions for piracy.

Proposition 5. Let $0 < P_T < (k/(2+k/v))$. *If* $P_T(2+(k/v)) \le P_N < k$, *then the demands for the updated, outdated, pirated, and no products are* $D_N = 2-(2P_N/k)+(2P_T/k)$, $D_U = 2Pt/k$, $D_P = 2(((P_N-2P_T)/k)-(P_T/v))$, *and* $D_Z = 2P_T/v$. *Furthermore, if* $k \le P_N < k+2P_T$, *then no one would choose to update the product every period and* $D_N = 1-((P_N-2P_T)/k)$, $D_U = 1-((Pn-2Pt)/k)$, $D_P = 2((P_N-2P_T)/k-(P_T/v))$ *and* $D_Z = 2P_T/v$.

Proposition 5 defines pricing regions *B*1(b) and C1 in Fig. 1. In region *B*1(b), as the price increases, more consumers switch from strategy *a*, updating every period to strategy *b*, keeping the product for two periods. This trend persists until $P_N \ge k$ (region *C*1), where there are no consumers who prefer strategy *a*. Higher newness opposes this effect by inducing more demand for strategies *a* and *b* at the expense of strategy c (pirating). The difference in this case, compared to the case described in Proposition 3 is that piracy emerges much earlier due to the low transactions cost.

Many software products are within the price regions described in Propositions 2–5. Microsoft's Windows and Office are classic examples. For all of these products, depending on the ratios between price, transaction cost and utility, there can be demands for all four product types (new, outdated, pirated and none). The results for Propositions 1–5 imply that the demand for updated products constantly drops when their price increases. This is true up to the point where the price is so high that no consumer is willing to buy an updated product. This result is reminiscent of the declining linear demand often used to portray the demand of homogenous consumers. The difference is that with heterogeneous consumers, the demand function becomes kinked, i.e., the demand slope changes (see Fig. 1) for both new and pirated products under high newness.

4.1.3. Zero transaction costs

When $P_T=0$, then, $\theta_{AB}=\theta_{BC}$, i.e., the updating of a subscription only every other period (strategy b) is unfeasible. Moreover, if $\theta_{AB}\geq 1$ (so that, $\theta_{AB}=\theta_{BC}\geq 1$), then the price for the updated goods is higher than their newness value $P_N>k$. Consequently, everybody pirates at zero transaction cost instead of buying a legitimate version. This case is clearly not in the interest of the producer. Therefore we assume $P_N\leq k$ when $P_T=0$. By substituting Eqs. (5)–(7) into Eqs. (8)–(11) respectively and then setting $P_T=0$, we arrive at the following result.

Proposition 6. *Let $P_T=0$. If $P_N\leq k$, then nobody updates the product at one period and then keeps it for another period without renewing, $D_N=2(1-(P_N/k))$, $Dp=2Pn/k$, $D_U=0$, and $D_Z=0$.*

Proposition 6 identifies consumers who buy the product solely for the benefit of its newness, k. The natural condition for this is that the price for the update is lower than the value of newness. The result is due to the fact that under zero transaction costs, pirated products are always a superior alternative to used products. Hence the producer, basically, only “sells newness”.

4.2. Low newness products

We now examine the case of low newness, i.e., $k\leq 2P_T$. Fig. 2 illustrates the demands for new and pirated products under the case of low newness.

Note that with low newness the transaction cost will always appear as high. Indeed, if $k\leq 2P_T$, then it will always hold that $k/(2+(k/v))\leq P_T$. What is unique about this state is that when $k\leq P_N<2P_T$, the demands for updated and non-updated products are price independent since only strategy b is feasible. This is shown in the following proposition and illustrated by region B2 in Fig. 2.

Proposition 7. *Let $k\leq 2P_T$. If $0\leq P_N<k$, then nobody pirates and everyone buys the product and updates it at least every other period, $D_N=2-(P_N/k)$ $D_U=P_N/k$ and Otherwise, if $k\leq P_N<2P_T$, then everyone buys the updated product and updates it only every other period, $D_N=1$, $D_U=1$, $D_Z=D_P=0$.*

Similar to the demands in region A2 (Proposition 2), we observe in region B2 (Proposition 7) that, due to the high transaction cost, piracy (strategy c) is not worthwhile. Furthermore, due to the low newness, updating every period (strategy a) is also not beneficial. Therefore everyone chooses only strategy b, buy and keep for two periods regardless of the update price as long as this price is reasonable, i.e., in region $B2$.

Possible examples of products in the price region $B2$ are media player software (Windows Media Player, Real Player, Quicktime, etc.). This kind of software, while relatively cheap, hardly ever warrants periodic renewal and rarely changes in any significant manner.

Note that when the price is higher than twice the transaction cost, i.e., out of region B2, $2P_T<P_N$, then the demands are identical to the ones described in Propositions 2 and 3, except that the price region division is different (see regions $C2$(a) and $C2$(b) of Fig. 2 versus $C1$(a) and $C1$(b) of Fig. 1). Typical examples for products in these price ranges are *CD* burning software (Nero Burning ROM) and image mounting software (Alcohol 120%, Daemon Tools). These products, like the media player software products, undergo very few significant changes between successive released versions. However, the retail price of such products can amount to tens of dollars. Therefore, for certain price levels, there is a definite demand for pirated versions of the product.

5. Interrelationship between the demands

Consider pricing regions $C1$(b) in Fig. 1 and $C2$(b) in Fig. 2 when the demand for piracy exists, but where piracy has high transaction costs, i.e., $k/(2+k/v)\leq P_T<v$. In this case the impact of the price of an updated product on the demand for updated and pirated software is $(\partial Dn/\partial Pn)=-1/k$, $\partial Dp/\partial Pn=2/k$. Significantly, the higher the newness, k, the less both demands are affected by pricing. Furthermore, although the piracy has a negative effect on the updated goods market, $(\partial Dn/\partial Dp)=(\partial Dn/\partial Pn)\cdot(\partial Dp/\partial Pn)^{-1}=-1/2$, the loss of demand for updated products is slower than the gain in demand for piracy. That is, any increment in the number of consumers acquiring a pirated product results in a loss of half that increment in the number of consumers buying an updated product. From $\partial Du/\partial Pn=-1/k$ and $\partial Dn/\partial Du=(\partial Dn/\partial Pn)\cdot(\partial Du/\partial Pn)^{-1}=-1/2$ we learn that the other half of the lost demand for updated products is due to the possibility of keeping the legitimate product for one more period instead of updating it, as stated below.

Proposition 8. *Let $k/(2+(k/v))\leq P_T<v$. If $P_T(2+(k/v))\leq P_N<k+2P_T$, then an increment in the demand for pirated products results in a loss of half that increment in the number of consumers buying an updated product.*

Next consider pricing region $B1$(b), which defines the conditions required for the demand for the pirated product to exist, but with low transaction costs, i.e., $0<P_T<k/(2+k/v)$. In this case, if the price is such that$P_T(2+(k/v))\leq P_N<k$, then, in accordance with Proposition 5, $\partial Dn/\partial Pn=-2/k$ and $\partial Dp/\partial Pn=2/k$. These results imply full negative interaction between the two demands, $\partial Dn/\partial Dp=(\partial Dn/\partial Pn)\cdot(\partial Dp/\partial Pn)^{-1}=-1$. That is, any increase in the number of consumers acquiring a pirated product results in the identical loss in the number of consumers buying an updated product. On the other hand, if the price of an updated product is such that $k\leq P_N<k+2P_T$, i.e., in region $C1$, then the interaction between the demands is similar to the one described in Proposition 8.

6. Pricing updated products

Assuming that the firm's profit is only due to the sale of updated products, that is, $\Pi=D_NP_N$, we next determine the optimal updated product price for different price regions. We begin with the state of high newness. From the first order optimality condition, it immediately follows that for the pricing region $A1$, the optimal price is k if k is within region A. Otherwise, the optimal price, $P_N^*=2P_T$, is at the upper bound of region A if k is greater than $2P_T$. Proceeding this way along regions $A1$ and $B1$, we obtain the result stated in the following proposition.

Proposition 9. *Let $0\leq P_N<k$. If $P_T<k/3$, then the optimal updated product price is $P_N^*=(P_T+k)/2$. Otherwise, if $k/3\leq P_T<k/2$ then $P_N^*=2P_T$.*

When expanding the price range to include all three possible pricing regions, A1, B1 and C1, i.e., the price range of $0\leq P_N<k+2P_T$, we find that the pricing policy described in Proposition 9 is globally optimal under high newness. Of course, if $P_T=0$, then we readily have, $P_N^*=k/2$.

Considering, the case of low newness, i.e., $k\leq 2P_T$, the first order optimality condition immediately reveals that for the A2 pricing region, the optimal product price is $P_N^*=k$. Similar to Proposition 9, we expend the price range to include all pricing regions and obtain the next proposition.

Proposition 10. *Let* $k/2 \le P_T$. *If* $0 \le P_N \le 2P_T$, *i.e., within pricing regions* A2 *or* B2, *then the optimal price is* $P_N^* = 2P_T$. *Furthermore,* $P_N^* = 2P_T$ *is the globally optimal price over all pricing regions.*

Recalling our assumption $P_T < v$, we note that if $P_T \ge v$, then the phenomenon of piracy does not exist, and we arrive at a demand curve with only one kink and two pricing regions. The regions are such that in the first region the demand for updated products is $D_N = 2-(P_N/k)-(P_N/(2v+k))$and in the second region it is $D_N = 1-(P_N/(2v+k))$. Consequently, the optimal price for the first region is $k(2v+k)/(2v+2k)$. If $v \ge k/2$, the optimal price for the second region is $v+(k/2)$; otherwise ($v<k/2$) it is equal to k. That is, the optimal profit depends on the ratio between v and k:

$$\Pi^* = \begin{cases} \dfrac{v}{2}+\dfrac{k}{4} & \text{if } k \le v \\ \dfrac{k(2v+k)}{2v+2k} & \text{otherwise.} \end{cases}$$

We use this result in the next section to estimate the efficiency of investing in pricing and protection in order to regain the profits lost to piracy.

Based on optimal pricing defined by Proposition 9 and 10 and the corresponding consumer demands (Propositions 1–5), we conclude with the following profits conditions:

$$\text{If } k/2 \le P_T, \text{ then } P_N^* = 2P_T,\ D_N = 1 \text{ and } \Pi_1^* = 2P_T, \text{ with } D_P = 0. \text{ (This condition places the optimal price on the right bound of pricing region B2)} \quad \text{(i)}$$

$$\text{If } k/3 \le P_T < k/2, \text{ then } P_N^* = 2P_T,\ DN = 2-\frac{2P_N}{k}+\frac{2P_T}{k} \text{ and } \Pi_2^* = 4P_T-\frac{4P_T{}^2}{k} \text{ with } D_P = 0. \text{(This condition places the optimal price on the left bound of region B1).} \quad \text{(ii)}$$

$$\text{If } P_T < k/3, \text{ then } P_N^* = (P_T+k)/2,\ D_N = 2-\frac{2P_N}{k}+\frac{2P_T}{k} \text{ and } \Pi_3^* = \frac{(P_T+k)^2}{2k} \text{ with } D_P = \begin{cases} 2\left(\frac{P_N-2P_T}{k}-\frac{P_T}{v}\right) & \text{if } \frac{k/2}{3/2+k/v} > P_T \\ 0, & \text{otherwise.} \end{cases}$$

(This condition places the optimal price within region B1) (iii)

(12)

From conditions (12) we observe that the optimal price is always within region B (or on its bounds). Accordingly, even when the transaction cost is exogenous, the producer may not necessarily want to fully price out the piracy. The decisive factor in such a case is the level of newness relative to the transaction cost. If the producer is able to achieve high newness for the product (to meet condition (12)(iii)), then a higher retail price ensures the largest profit gained (compared to (12)(i)–(ii)) even though some of the demand is lost to piracy. On the other hand, if the newness is low relative to the transaction cost, then the strategy of flooding the market with low price products to kill off the piracy is the most efficient one.

Based on (12), we next facilitate the presentation by introducing three cost regions: D where $0 \le P_T < k/3$; E where $k/3 \le P_T < k/2$; and F which covers the area of the transaction costs, $P_T \ge k/2$. Naturally, we observe from (12) that when the newness level is fixed, the higher the transaction cost (the cost of piracy) and the higher the profit that the producer gains from selling updated products (see Fig. 3). However, this is true only when the transaction cost is exogenous which is not always the case as the

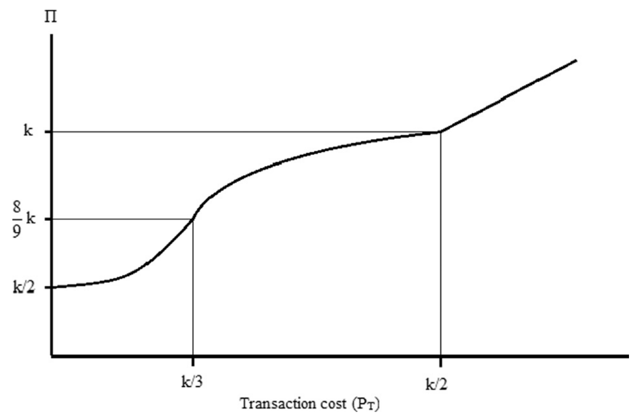

Fig. 3. The impact of transaction cost on profit.

producer may invest in product protection. We study this option in the next section.

7. The effect of endogenous transaction costs

While most software companies can choose at any time to invest in anti-pirating measures, it is virtually impossible to fully eliminate piracy. Especially since, the broader the product's market or appeal, the more attractive it is for hacking. Therefore, we follow Khouja and Smith (2007) by assuming a hyperbolic relation between investment into preventing piracy and the actual result of such an investment. This implies that the greater the investment, the less efficient it is in terms of piracy, i.e., in terms of aggravating the transaction cost,

$$P_T = w\left(1-\frac{1}{1+i}\right), \quad (13)$$

where i represents the investment into piracy prevention and w is the maximal amount of possible protection that is inherent in the technology that the product uses, which will henceforth be referred to as the technological potential. Consequently, by substituting (13) into (12) we have,

$$\text{If } k/2 \le P_T, \text{ then } \Pi_1^* = 2w\left(1-\frac{1}{1+i}\right)-i, \quad \text{(region F)},$$

$$\text{If } k/3 \le P_T < k/2, \text{ then } \Pi_2^* = 4w\left(1-\frac{1}{1+i}\right)-\frac{4(w(1-(1/(1+i))))^2}{k}-i, \quad \text{(region E)}$$

$$\text{If } P_T < k/3, \text{ then } \Pi_3^* = \frac{(w(1-(1/(1+i)))+k)^2}{2k}-i \quad \text{(region D).} \quad (14)$$

Our goal now is to examine the producer's profit (14) as a function of investment into piracy prevention. We use the first and second order optimality conditions (see the Appendix A) to identify optimal investment policies for each transaction cost region. For this we straightforwardly redefine the regions in terms of the investment level by substituting Eq. (13). That is, region F is for i, $i > k/(2w-k)$; region E is for i, $k/(3w-k) \le i < k/(2w-k)$; and region D is for i, $0 \le i < k/(3w-k)$.

7.1. Locally optimal investments

We contrast local interior solutions for each region determined by (A1)–(A6) (see the Appendix A) and the corresponding region bounds. Specifically, for region F we find that if $\sqrt{2w}-1 > k/(2w-k)$, then the optimal investment is

$$i^* = \begin{cases} \sqrt{2w}-1, & \text{if } \sqrt{2w} > 1 \quad \text{(i)} \\ 0, & \text{otherwise} \quad \text{(ii)} \end{cases} \quad (15)$$

The result implies that the optimal investment in region F is an interior solution if $w>1/2$. Otherwise it is not worthwhile investing in a boundary solution.

Similarly, we describe the local maximum for range E. Let $k/(2w-k)>i>k/(3w-k)$, the solution of equation $\partial \Pi_2/\partial i=0$ in i be $\gamma 1$ and of equation $\partial \Pi_2/\partial i^2=0$ be $\beta 1$. Then the optimal investment in region E is

$$i^*=\begin{cases}\gamma 1, & \text{if} \quad \beta 1<0,\gamma 1>0 \quad (i)\\ 0, & \text{if} \quad \beta 1<0,\gamma 1\le 0 \quad (ii)\\ \frac{k}{2w-k}, & \text{if} \quad \beta 1\ge 0,\Pi\left(\frac{k}{2w-k}\right)>\Pi\left(\frac{k}{3w-k}\right) \quad (iii)\\ \frac{k}{3w-k}, & \text{if} \quad \beta 1\ge 0,\Pi\left(\frac{k}{3w-k}\right)>\Pi\left(\frac{k}{2w-k}\right) \quad (iv)\end{cases} \tag{16}$$

Finally, Eq. (17) determines the local maximum for region D. Formally, let $0<i<k/(3w-k)$, the solution of equation $\partial \Pi_3/\partial i=0$ in i be $\gamma 2$ and of $\partial \Pi_3/\partial i^2=0$ be $\beta 2$. Then the optimal investments is

$$i^*=\begin{cases}\gamma 2, & \text{if} \quad \beta 2<0,\gamma 2>0 \quad (i)\\ 0, & \text{if} \quad \beta 2<,\gamma 2\le 0 \quad (ii)\\ \frac{k}{3w-k}, & \text{if} \quad \beta 2\ge 0,\ \Pi\left(\frac{k}{3w-k}\right)>\Pi(0) \quad (iii)\\ 0, & \text{if} \quad \beta 2\ge 0,\Pi(0)>\Pi\left(\frac{k}{3w-k}\right) \quad (iv)\end{cases} \tag{17}$$

From Eqs. (15)–(17) we observe that there are multiple, locally optimal investments that should be compared in order to find a globally optimal investment policy for a specific set of system parameters. This implies several dozens of global optimal solutions each corresponding to a combination of conditions from (15)–(17). We, therefore, next present our numerical analysis to gain main insights into the underlying processes, without overloading the text with extensive equations and conditions.

8. Sensitivity analysis

In this section we study the profits of the producer with respect to factors such as different levels of transaction costs, protection investments and newness. We first analyze the effect of each factor separately and then discuses their interactions.

8.1. Transaction cost

As the transaction cost grows, the utility gained by a consumer from a pirated product decreases. As this utility decreases, the competing legitimate licensed product becomes more appealing to consumers whose valuation of the product is moderate. Thus, as more consumers switch from pirating the product to updating it only every other period the demand for licensed products grows. This added demand, in turn, allows the company to raise the price of a new product, thus, ultimately, boosting the company's revenue (see Fig. 4).

8.2. Protection investment

The impact of investments in protection against piracy is portrayed in Figs. 4–6. As the investment grows, so does the demand for licensed products, while the demand for pirated products decreases (Fig. 6). Therefore, as the protection improves, the company may raise the product price (Fig. 5) and gain greater revenues (Fig. 4). However, protection investments elevate transaction costs at a hyperbolic rate, so there will be eventually a point at which the cost of investment exceeds the benefit that the company gains from a higher transaction cost. This is discussed below and illustrated in Fig. 7.

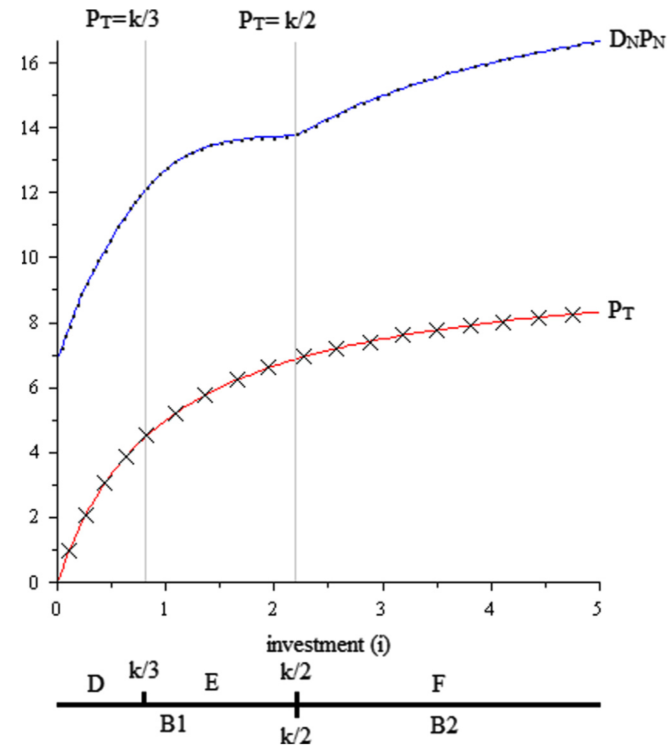

Fig. 4. The impact of protection investment on sales and transaction cost with $w=10$ and $k=13.75$.

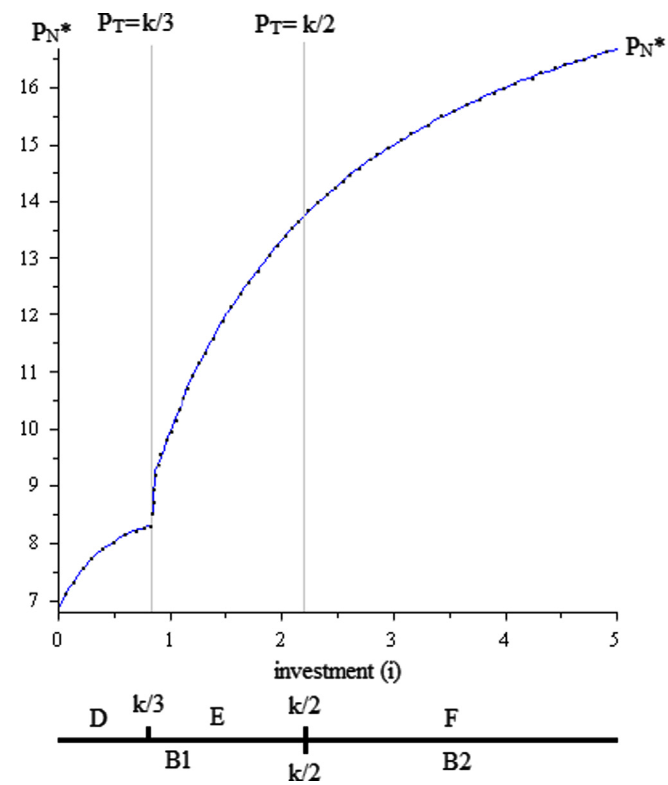

Fig. 5. The impact of protection investment on the optimal price with $w=10$ and $k=13.75$.

8.3. Newness

As newness increases, the customer's utility from a licensed product grows, so the licensed product is able to compete better

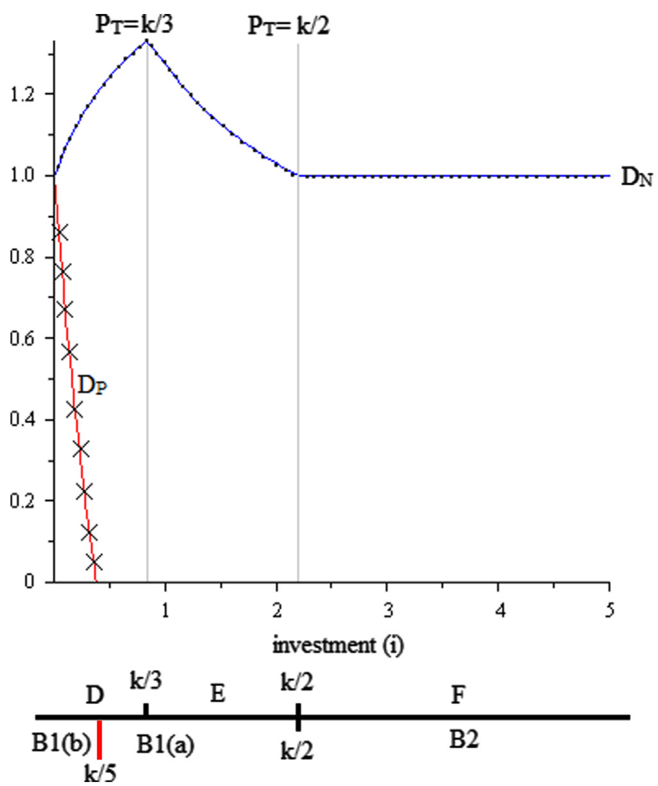

Fig. 6. The impact of protection investment on demand for updated products and pirated products with $w=10$, $k=13.75$ and $v=26$.

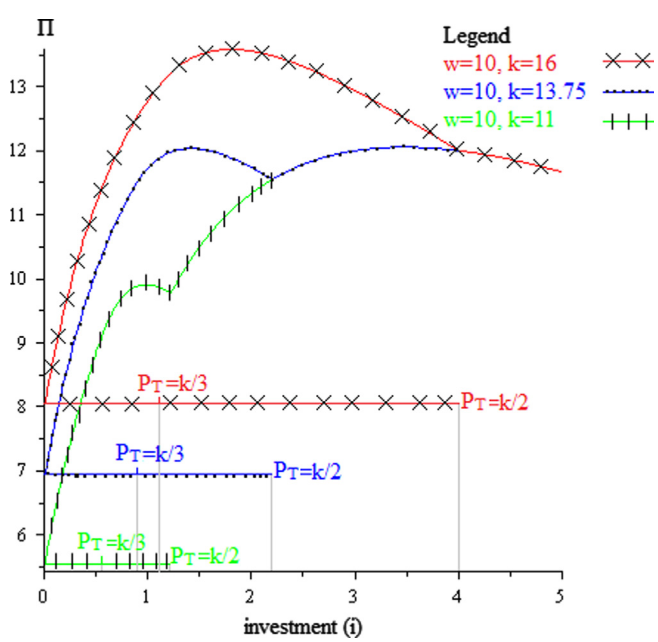

Fig. 7. The impact of protection investment on profit with $w=10$ and alternating k.

with the pirated version, i.e., the licensed version becomes increasingly superior to the pirated one. Therefore, the higher the newness of the product, the lower the company's need to inflict a high transaction cost in order to curb piracy. This, in turn, prompts the company to invest less in protection aimed at raising the transaction cost. Fig. 7 illustrates how high newness is associated with very high profits. Specifically, the upper red crossed graph in Fig. 7 illustrates how, for products with very high newness levels, optimal profits can be achieved with a much smaller protection investment as compared with products with lower newness.

8.4. Interactions

In order to examine the interactions between the demand levels and the above mentioned key parameters, we analyze each of the pricing regions D, E and F (Fig. 7), i.e.,

$$0 \le i < \frac{k}{3w-k},\quad \frac{k}{3w-k} \le i < \frac{k}{2w-k}\ \text{and}\ i > \frac{k}{2w-k}\ \text{respectively}.$$

Consider first the evaluation of the profit for $w=10$ and $k=13.75$ (blue dotted curve on Fig. 7) along investment region D. This case corresponds to the high transaction cost pricing region $B1$, indicating that the newness is high (see Fig. 1). In region D, as the protection investment rises along with the transaction cost, demand for pirated products drops and demand for updated products grows (see Propositions 5 and 8, Fig. 6). In addition, the increased transaction cost allows the company to charge a higher price (see (12)(ii)). While this may hurt the demand for updated products, the higher price more than compensates for the lost demand, thus boosting revenue (see Fig. 4). Since this trend is beneficial to the company, the company pursues it by investing in protection. Therefore, the optimal protection investment in region D is the region's upper bound (see (17)(iii)).

Investment region E, located to the right of region D along the same curve, corresponds to pricing region $B1$. This investment region continues the trend started in investment region D, where the rising investment, associated with a rising transaction cost, allows the company to charge a higher price, thus generating higher profits. However, in region E, the investment in protection becomes increasingly less efficient, and we finally arrive at a point at which the cost of investment that the company incurs exceeds the benefit it gains from a higher transaction cost (see 16(i)). After this locally optimal investment point, profits fall with further investments. Note that while the transaction cost in this region is relatively low when compared to the transaction cost in region F (see Fig. 4), the low product price keeps piracy contained. Furthermore, although in the specific example piracy demand is completely quashed under optimal investment, the company may very well tolerate some piracy in region E under high newness k and low w and v. This is because, effectively, pirated products only compete with products updated in one period and kept for another one. Since such products only offer every other period the basic product value, v, the higher k is compared to v, the less of a threat piracy poses, and the lower the loss of profit due to piracy.

Next, we consider region F along the same curve. This region is defined as having high transaction costs. As the transaction cost increases, the newness becomes low relative to this cost, which corresponds to region B2 (see Fig. 2). Due to the high transaction cost, piracy is not beneficial to consumers, while low newness implies that the strategy of updating the product every period is also not justified. Therefore, all consumers choose only strategy b, updating the product and keeping that version for two periods, regardless of the update price. The demand remains insensitive to the product price, as long as the price is in region $B2$ (see Proposition 7). Furthermore, as in investment regions D and E, when the protection investment rises, the piracy transaction cost grows, which, in turn, enables the firm to charge a higher price for the new product (see Proposition 9). Thus, profits that declined after the first optimal investment point in region E increase once more. Again, however, the decreasing efficiency of the protection investment results in a point at which the cost of investment to the company exceeds the benefits, i.e., a local profit maximization point (see 15(i)). In this region, piracy is contained mostly by heavy investments in protection rather than low prices.

The company must now compare locally optimal profits in order to find the globally optimal solution. Since high/low newness is defined as the ratio of P_T to k, the company may, in a roundabout way, effectively switch or choose between high or low newness. This choice is in fact identical to the choice of whether to be in region E or region F of investment, with high newness corresponding to region E and low newness corresponding to region *F* (region *D* also corresponds to high newness, but, as can be seen in Fig. 7, given a choice of all three regions, the company would never choose to be in region *D*).

Choosing to be in region *E* implies investing very little in protecting products with low sale prices. Choosing to be in region *F* implies investing a great deal in protecting products with high sale prices. The answer to the question of where the company should choose to be, i.e., where its maximum profits will be higher, depends on the ratio between w and k. The higher the newness, k, as compared to the available technology, w, the greater the likelihood that profits will be greater in region *E*. Of course, for certain values of w and k, the maximum profits in regions *E* and *F* are very close, and the company is indifferent about the choice from a profit perspective. This case is portrayed by the middle blue dotted graph in Fig. 7. In this specific case, the company is presented with two different yet equivalent (i.e., yielding similar profits) possible courses of action. The company may invest in protection, thus making the product harder to pirate but also more expensive, resulting in fewer sales, but at a higher price. On the other hand, the company may invest little in protection and thus be in a position to offer a much cheaper product that is more capable of competing with pirated versions of the product. Since in this case the company is indifferent as to which course of action to choose when considering only profit maximization, the choice is strategic: to hone the protection and anti-piracy programming or to reach as many people as possible and become a “household brand name” by flooding the market with less expensive products.

We now examine the upper, red, crossed graph in Fig. 7 ($w=10$, $k=16$). The general behavior of this graph is similar to that of the middle blue dotted graph, except that in this case the newness level is higher, and the company achieves higher profits by investing less in protection against piracy. Note that the optimal investment point for region *F* in this case is on the left bound of the region. The lower green segmented graph ($w=10$, $k=11$) in Fig. 7 portrays an opposing case to the one depicted by the upper red crossed graph. In this case the newness level is lower, and the strategy of heavy investment in protection is preferable, as it yields higher profits.

Finally, Table 2 presents a comparison of profits under no piracy (perfect law enforcement, ensuring very high transaction costs without investments on the part of the company) with profits based on optimal pricing of the updated products combined with protection investments for each of the cases portrayed in Fig. 7 ($\nu=26$).

Table 2
Profit comparisons.

	Newness	Profit (without piracy)	Profit (with piracy)	% of profit loss due to piracy
Upper/red crossed graph	16	17	13.75	19
Middle/blue dotted graph	13.75	16.44	12.03	26.80
Lower/green segmented graph	11	15.75	12.03	23.60

From Fig. 7 and Table 2 we observe that although optimal pricing and protection investments almost double the producer's profit, and that the profits increase with newness, the losses due to piracy are substantial regardless of product newness. Specifically, for the data from Table 2, the losses range from 19% to 26.8%, with the highest gap corresponding to the case in which the producer's two alternative strategies for dealing with piracy are equivalent in terms of the profit they yield.

9. Conclusions

Most software firms suffer from piracy and need to decide how to handle pricing to prevent profit loss. We present a model for a monopolistic company offering software which is updated periodically, but, by the end of one period, a pirated version is always available at a transaction cost regardless of how tough the product's protection measures are. This presents the consumer with four possible strategies: buying an updated product every period; buying an updated product for one period and then keeping the product for one more period; pirating the product over two periods; or not obtaining the product at all.

When the transaction cost is exogenous, we find that there are three major pricing regions that can assist the producer to handle sales and piracy (see Table 3 for all scenarios studied and the corresponding policies). In particular, the first region implies that pirating can be eliminated with the price for the updated products low relative to the transaction cost of searching for a pirated version. As the price increases within this region, more consumers prefer not to update their products. However, the prices in this region are so low that everyone updates the product either every period or every other period and no one pirates or chooses not to have the product at all. The next region implies that piracy can be reduced by higher transaction costs rather than very low prices. In such a case, as the price of the product increases, the number of consumers who are reluctant either to update the product or to acquire it increases. Moreover, when the newness is low, updating every period is not beneficial at all. Therefore, as the price increases further, piracy increases at this final region so that the demand for updated products lost by the producer is divided evenly between the consumers who pirate and those who keep products that have not been updated.

Furthermore, we find that even when the transaction cost is exogenous, the producer does not necessarily want to fully price out the piracy. The decisive factor in such a case is the level of newness relative to the transaction cost. If the producer is able to achieve high newness for the product, then a higher retail price ensures the largest profit gain even though some of the demand is lost to piracy (see scenario I and II). On the other hand, the less the newness, the lower the utility to consumers considering buying legitimate products and the greater the threat posed by piracy. Consequently, if the newness is low relative to the exogenous transaction cost, then the only way to fight piracy is by cutting the price thereby flooding the market with low price products (see scenario III).

We find that endogenous transaction costs induce quite an opposite effect—low newness leads to high prices and vice versa (see scenarios IV and IV in Table 3). Specifically, when transaction costs are endogenous with respect to an investment in protection measures, the greater the investment and the less efficient the measures are in terms of preventing the piracy. Accordingly, there are two possible courses of action for the producer to deal with piracy: (a) pricing out the pirated product with low product selling prices and a low investment in their protection or (b) investing heavily in piracy prevention by increasing the transaction cost. When the technological potential is high and the newness is low,

Table 3
Pricing policies for different scenarios.

	Scenario				
	I	II	III	IV	V
Transaction cost feature endogenous/exogenous	Exo	Exo	Exo	Endo	Endo
Newness	High	High	Low	High	Low
Transaction cost level	High	Low	High	Low	High
Product price	High	High	Low	Low	High
Protection investment	n.a	n.a	n.a	Low	High

the firm is better off by investing extensively in anti-piracy measures and thereby setting higher prices. As newness levels rise, piracy becomes less of a threat, prompting the company to invest less in protection. The lesser investment implies lower costs, that is, the option of pricing piracy out becomes increasingly preferable. At some point between these newness conditions, the two options may become equivalent in terms of profit. In such cases, the choice of action is strategic rather than just maximization of profits. This is also observed in real life. Maple Software, for example, has shifted strategically from marketing its high price, heavily protected, mathematical software (which was still pirated when sold for an unlimited time usage) to selling low-priced, one-year licenses which are updated annually. Due to frequent updates, the transaction cost of piracy is relatively high without investing in protection, while low pricing kills off the piracy. As a result, Maples' sales increased dramatically and the legitimate copies of the package are now being used by many universities around the world.

There are many directions for extending this research. Specifically, in this paper, we assume fixed exogenous periods for newly released products. However, companies may affect the newness level of their products by trickling into the market slightly more advanced products at shorter periods or releasing the most advanced version of the product straight away but over longer periods. That is, a company may choose how often to release the newer product versions and for how long to let the older versions remain on the market. Piracy can be considered as a continuous effort with newer pirated versions available at higher transaction costs. Other challenging extensions include considering the effect of consumer uncertainty and network externalities.

Appendix A

Following are the first and second derivatives for each transaction cost region.

$$\frac{\partial \Pi_1}{\partial i} = \frac{2w}{(1+i)^2} - 1 \tag{A1}$$

$$\frac{\partial \Pi_1}{\partial i^2} = -\frac{4w}{(1+i)^3} \tag{A2}$$

$$\frac{\partial \Pi_2}{\partial i} = \frac{4w}{(1+i)^2} - \frac{8w^2(1-(1/(1+i)))}{k(1-i)^2} - 1 \tag{A3}$$

$$\frac{\partial \Pi_2}{\partial i^2} = -\frac{8w}{(1+i)^3} - \frac{8w^2}{(1+i)^4 k} + \frac{16w^2(1-(1/(1+i)))}{k(1+i)^3} \tag{A4}$$

$$\frac{\partial \Pi_3}{\partial i} = \frac{(w(1-(1/(1+i)))+k)w}{k(1+i)^2} - 1 \tag{A5}$$

$$\frac{\partial \Pi_3}{\partial i^2} = \frac{w^2}{(1+i)^4 k} - \frac{2(w(1-(1/(1+i)))+k)w}{k(1+i)^3} \tag{A6}$$

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