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Piracy in a Two-Sided Software Market*

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Abstract

This paper studies the impact of software piracy in a two-sided-market setting. Software platforms attract developers and users to maximize their profits. The equilibrium price structure is affected by piracy: license fees to developers are higher with more software protection but the impact on user prices is ambiguous. A conflict between platforms and software developers over software protection may arise: whereas one side benefits from better protection, the other party loses out. Under platform compatibility, this conflict is no longer present.

Keywords: Developer; piracy; platform; software; two-sided markets.
JEL-Classification: L11; L86.

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1 Introduction

Many software products are centered around platforms where a software platform has to attract software developers and users. One example is the market for game consoles where the console producer (such as Microsoft [Xbox 360], Nintendo [Wii], or Sony [PlayStation]) has to attract gamers and game developers. Gamers only find the console attractive if a large amount of games are available. Similarly, game developers only have an incentive to produce games if a large number of gamers can be reached. Thus, the market is characterized by two-sided externalities between gamers and game developers. The platforms' task is to charge prices so as to get both sides on board. Further examples that fit this description are the markets for operating systems (such as Microsoft's Windows), where platforms have to attract application developers and users, or e-book readers (such as Amazon's Kindle), where readers and publishers need to be attracted.

Piracy is a big issue in these markets. For example, in the market for video game consoles, it seems to be the platform sellers (Microsoft, Nintendo, Sony) who call for action against illegal sales of video games. In particular, they try to push for the prohibition of all kinds of copying modules or software.[1] At the same time, however, the availability of legal as well as illegal video games makes the video game console more attractive for gamers and hence potentially increases the platforms' profits. This ambiguity faced by video game consoles (and platforms in general) is best illustrated by a statement by David Reeves, President and CEO of Sony Computer Entertainment Europe (SCEE): "There is a piracy problem on PSP. (...) It sometimes fuels the growth of hardware sales, but on balance we are not happy about it."[2]

Another prominent example is the market for mobile-phone (smartphone) application software (so-called apps) running on a specific operating system.[3] A study by 24/7 Wall St. reports that Apple (with their operating

[1] See, e.g., www.computerbild.de/artikel/cbs-News-DS-Nintendo-R4-Kopiermodul-Verbot-5499649.html and spiele.t-online.de/sony-geht-gegen-raubkopie-technik-fuer-ps3-vor/id_42692604/index. Note that this may also be due to the fact that such platforms of video game consoles often develop their own games which means that they are hurt by piracy just like independent developers.

[2] See www.mcvuk.com/news/30912/There-is-a-piracy-problem-on-PSP.

[3] Note that typically—and different from the market for game consoles—, operating

system Apple iOS) and their application developers for the iPhone and iPod touch have lost more than $450 million in the first one and a half years after the opening of the App Store in July 2008 as a result of illegal downloads. The study comes to the conclusion that for every paid download, there are three illegal downloads on average. For some applications, illegal download rates are as high as 95%.[4] Moreover, Apple claims that software like Cydia which helps unlock (or 'jailbreak') its products "encourages the piracy of approved iPhone applications and is an expensive burden"[5] due to software problems resulting from jailbreaking. Apple's competitor Google offers an alternative operating system for smartphones (Android) and Google's developers also face lower profits due to downloads which were not legally purchased (e.g., through Google's online application store Android Market).[6]

This paper studies the issue of piracy and software protection in such a software market. We ask how platforms react to the threat of software piracy. Do they change the price structure? Are developers necessarily hurt if more users opt for unauthorized copies of software products? To this aim, we set up a two-sided-market model for the software business. There are two platforms (game-console producers, e-book platforms, operating systems) that try to attract users to buy access to their platform and software developers to offer software suited for their platform. Software developers may decide whether to manufacture software for a platform; they may multi-home and offer their products on both platforms. Single-homing users choose be-

system providers not only charge developers license fees in the market for smartphone applications but also royalties (or transaction fees) per (paid) download. Our model is restricted to license fees. This seems to be justified as a first step in light of real-life market characteristics: whereas license fees differ, royalties are indeed the same across platforms, i.e., platforms compete in license fees (support) and (indirectly) through the number of potential users. More specifically, developers keep 70% and pay a share of 30% to the platforms (see http://www.apple.com/pr/library/2008/03/06iphone.html [App Store], http://www.android.com/us/developer-distribution-agreement.html [Android Market]) but fixed developer fees range from a one-time registration fee of $25 for Google's (open-source) Android (see http://market.android.com/support/bin/answer.py?hl=en&answer=113468) to $99/year for Apple's Standard Program or $299/year for the Enterprise Program (see http://www.apple.com/pr/library/2008/03/06iphone.html).

[4]See http://247wallst.com/2010/01/13/apple-app-store-has-lost-450-million-to-piracy/ and http://www.telegraph.co.uk/technology/apple/6988942/Apples-App-Store-has-lost-450-million-since-opening.html.

[5]http://www.nytimes.com/2009/05/13/technology/13jailbreak.html?_r=1&pagewanted=all.

[6]See http://www.businessinsider.com/android-piracy-2010-8#.

tween the two competing platforms and decide whether to pirate software or purchase it legally.

As is well known from the literature on two-sided markets (see, e.g., Caillaud and Jullien, 2003; Hagiu, 2006; Rochet and Tirole, 2003; Armstrong, 2006; Rochet and Tirole, 2006; Hagiu, 2009), the price structure in two-sided markets depends heavily on the size of indirect network externalities between user groups. We show that software piracy influences these indirect network effects. On the one hand, better software protection leads to an immediate gain in profits for software developers due to higher legal sales, thereby increasing the network externality from users on software developers. On the other hand, with more protection, the expected surplus users get from the software market is lower as the market power of developers increases. This, in turn, decreases users' valuations for having more software available at a platform. Thus, the network externality from developers on users is lower with better software protection. As a consequence, more software protection means that platform competition for developers is weaker.

Our main results are the following: we show that incompatible software platforms react to more software protection by raising license fees for developers. This effect tends to decrease software developers' profits and increase platforms' profits. The impact on user prices is less clear. Platforms may increase or decrease the price depending on whether the opportunity cost of attracting an additional user increases or decreases. Thus, software protection may soften or intensify competition for users. We show that the software platforms' and individual software developers' profits may be affected in opposite directions by software protection. Software developers' profits may be decreased due to more protection and in turn the equilibrium amount of software available to users is low. Contrary to that, platforms' profits are higher under certain circumstances. Higher profits from selling licenses may compensate for lower revenues from users. Hence, our model suggests that there is a potential conflict of interest between developers and platforms. We provide an example to illustrate our findings.

The previous results are derived under the assumption that platforms are incompatible. The results change drastically in the case of compatible platforms where software developed for one platform can also be used on the other platform. It turns out that in this case, software protection is in developers' best interest and is never bad news for platforms. The reason is that with compatible platforms, competition for users is already softened and it is independent of the strength of network externalities between users and developers. This indicates that platforms may choose compatibility as a tool to join forces with software developers to fight piracy.

Most papers on software piracy model the software market as characterized by peer-group network externalities: the utility of a user increases in the number of other users who adopt the same software (Conner and Rumelt, 1991; Shy and Thisse, 1999).[7] In contrast, we take an explicit two-sided-market view where users care about the amount of software that is available on a platform. This enables us to study the impact of piracy separately on the platform and on developers which is not possible in models based on peer-group network externalities. This distinction seems to be important as we show that these two players may be affected differently by piracy.

We also contribute to previous research that analyzes conditions under which piracy may be beneficial to firms.[8] In previous contributions, it is shown that in the presence of network externalities, developers may benefit from software piracy. For a monopoly setup, Conner and Rumelt (1991) and Takeyama (1994) show that piracy may increase developers' profits as piracy increases the total number of program users.[9] This intuition also holds in oligopoly settings as demonstrated in Shy and Thisse (1999) as well as Peitz (2004).

Another mechanism why developers may benefit from piracy is that it enables users to sample products. If free samples increase users' willingness to pay for legal copies, profits may increase (Peitz and Waelbroeck, 2006b). Complementarity between products may also lead to positive effects for firms. For instance, in the context of the music industry where music sales and concert attendance (or merchandise) can be thought of as complements,

[7] Kiema (2008) takes a different route by assuming that counterfeiters who compete with the copyright owner incur advertising costs due to increased risk of punishment or digital-rights management (DRM) systems.

[8] A survey on piracy of digital products is provided by Peitz and Waelbroeck (2006a) as well as Belleflamme and Peitz (2010a).

[9] Relatedly, Slive and Bernhardt (1998) demonstrate that in the presence of network externalities, non-protection of software can also be used as an instrument of price discrimination if groups differ in their willingness to pay and in the cost of being punished when using pirated products.

piracy of records may lead to increased demand for the complementary product. Gayer and Shy (2006) show that this may lead to higher profits for artists who benefit from more concert attendance whereas record companies may suffer from lower record sales.[10]

Our paper thus complements the two strands of the literature on network effects and complementarity: in a two-sided market, network effects are present across different customer groups. Both groups buy complementary goods or services which are of no value if one side abstains from joining in. Hence, one may also interpret our results as being in line with the just mentioned results: piracy may not necessarily be detrimental to firms (platforms) in a two-sided-market context as a higher number of usage activity on one side (users) positively affects the other side at the same time (developers). However, what is different in the present paper is that we explicitly focus on software platforms acting as intermediaries between users and software developers. We show that piracy may not only lead to conflicting interests between platforms and individual software developers but may also affect the two sides differently.

The rest of the paper is organized as follows. Section 2 describes the model setup. Section 3 presents the analysis of the base model. Section 4 provides a specific example to illustrate our main results. Section 5 discusses the case of compatible platforms. Finally, Section 6 concludes.

2 Model

This section introduces a model of piracy in a two-sided-market framework along the lines of Choi (2010) as well as Belleflamme and Peitz (2010b).

2.1 Software platforms

There are two horizontally differentiated software platforms. They are located at opposite ends of a Hotelling (1929) line. Platform 1 is located at 0

[10]Relatedly, Dewenter et al. (2012) show that piracy of records may induce the music industry to adopt a business model where record companies market both records and concerts (so-called 360° contracts).

on the line of unitary length; platform 2 is located at 1. Platforms incur no marginal costs and fixed costs for setting up and running the business are normalized to zero. Platforms generate income from both users (by charging an access fee) and software developers (by charging a license fee). We allow both prices to be negative, that is, platforms may subsidize user prices or the software developers' license fee.[11]

2.2 Software users

Users are heterogeneous with respect to their preferences for the two platforms. We model users by being uniformly distributed along the unit interval. The location of a user is denoted by x. Users with a low value of x tend to prefer platform 1 whereas users with a high value of x tend to prefer platform 2. The utility of a user who is located at x and buys access to platform 1 at a price p_1 is given by

$$u_1 = v + \theta n_1 - p_1 - \tau x. \tag{1}$$

If this user chooses platform 2 and pays price p_2 instead, he derives a utility of

$$u_2 = v + \theta n_2 - p_2 - \tau(1 - x). \tag{2}$$

Users derive an intrinsic utility of v from buying access to a platform.[12] Moreover, users derive utility from software. The more software n_i is available for this platform the larger the utility.[13] The benefit from an extra unit of software is given by θ. In Section 2.4, we will detail how this parameter is influenced by the presence of piracy. Users incur linear transportation costs of τ per unit of distance traveled.

The marginal user that is indifferent between joining platform 1 and 2 is

[11] Note, however, that in equilibrium at most one side is subsidized.

[12] This stand-alone value may be due to pre-existing software. As is usual, we assume v sufficiently large such that any user along the unit line buys from one of the two platforms, i.e., the user market is covered.

[13] To be more precise, n_i in expressions (1) and (2) denotes the *expected* number of applications. We assume that users have rational expectations which means that the expected number of applications is equal to the *actual* number of applications. The same is assumed to hold for software developers' expectations below.

given by

$$x_m = \frac{1}{2} + \frac{p_2 - p_1}{2\tau} + \frac{\theta(n_1 - n_2)}{2\tau}. \tag{3}$$

The market share of platform 1 is x_m whereas the market share of platform 2 is $1 - x_m$.

2.3 Software developers

A unit mass of software developers decides whether to manufacture software. Software developers may multi-home and offer software products for both platforms. Developing software is associated with a fixed investment cost of f. Software developers differ in these investment costs which we assume to be uniformly distributed on the unit interval.[14]

Developers earn an expected amount of ϕ for each user they reach when offering their software on a platform. For now, we take this parameter as given but will show how this parameter is affected by software piracy (see Section 2.4).

Thus, the profit of a software developer producing for platform i is equal to

$$\pi_d = \phi s_i - l_i - f, \tag{4}$$

where s_i denotes the number of users at platform i and l_i denotes the license fee charged by platform i. Developers offer their product for platform i as long as they do not incur a loss, i.e., $\pi_d \geq 0 \Leftrightarrow f < \phi s_i - l_i = f_d$. All developers with $f < f_d$ enter. Under our assumption of the uniform distribution of development costs, the amount of software offered for platform i is given by

$$n_i = \phi s_i - l_i, \tag{5}$$

where $s_1 = x_m$ and $s_2 = 1 - x_m$.

[14] We assume a uniform distribution for convenience in order to get closed-form solutions. Nevertheless, our results should hold qualitatively for alternative distributions.

2.4 Effects of software protection and piracy

We now turn to the relationship between developers and users. In particular, we focus on how this interaction is affected by piracy and the degree of software protection. Suppose the parameter k measures the strength of software protection where higher levels of k denote better software protection. Note that similar to Belleflamme and Peitz (2010b) but different from most two-sided market models, the strength of the network externalities is not fixed exogenously but depends on the degree of software protection (i.e., piracy behavior).[15]

Suppose users can decide between pirating a software and purchasing it legally. The resulting revenues of a software developer from the interaction with a user are denoted by the parameter $\phi(k)$ where the immediate legal sales of developers are positively affected by software protection, i.e., $\phi' > 0$. The surplus of a user from this interaction is $\theta(k)$ (with $\theta' < 0$). As users are typically hurt from better software protection—either due to the fact that software is harder to copy or due to higher software prices resulting from a reduced threat of piracy—, the case where $\theta' < 0$ seems to be the most relevant. For the largest part of the paper, we will present our results using this general formulation but we will consider some specific applications (see Section 4) drawing on the piracy models of Yoon (2002), Belleflamme (2003), as well as Bae and Choi (2006). These models provide a microfoundation for our more general formulation.

Summarizing, we point out that increased software protection has two distinct effects. All else equal, a higher level of protection increases the benefits of software developers from the interaction with users but decreases the surplus that goes to users. It will turn out that both effects are important when it comes to competition between platforms. The strength of the two effects will essentially determine the overall market outcome.

[15] Note that in the article by Belleflamme and Peitz (2010b), network externalities are influenced by investment decisions.

2.5 Timing and assumption

The timing of the game is as follows: in the first stage, platforms simultaneously set prices for users and license fees for software developers. In the second stage, users and developers decide which platform(s) to join. In the third stage, users decide whether to buy software or copy it illegally. As is usual, we solve the game by backward induction.

Throughout the paper, we focus on a symmetric equilibrium where both platforms are active in the market. To guarantee existence of such a symmetric equilibrium, we make the following assumption:

Assumption 1. $8\tau > \theta^2 + \phi^2 + 6\theta\phi$.

The assumption states that network effects must not be too large compared to horizontal differentiation which is a standard assumption in the kind of setup with network externalities we consider here.

3 Analysis

This section analyzes the base model with incompatible platforms such that software produced for one platform cannot be used by users of the rival platform. Hence, a platform's market share on the user side depends on the amount of software available for this platform. Also, developers' incentives to offer software for a specific platform depend on the number of users that can be reached through this platform. Thus, demands of users and developers are interrelated. Given these interrelated demands, we solve equations (3) and (5) simultaneously to express demand in terms of prices only. This gives

$$x_m = \frac{1}{2} + \frac{p_2 - p_1}{2(\tau - \theta\phi)} + \frac{\theta(l_2 - l_1)}{2(\tau - \theta\phi)}, \tag{6}$$

$$n_1 = \frac{\phi}{2} + \frac{\phi(p_2 - p_1)}{2(\tau - \theta\phi)} - l_1 + \frac{\theta\phi(l_2 - l_1)}{2(\tau - \theta\phi)}, \tag{7}$$

and

$$n_2 = \frac{\phi}{2} + \frac{\phi(p_1 - p_2)}{2(\tau - \theta\phi)} - l_2 + \frac{\theta\phi(l_1 - l_2)}{2(\tau - \theta\phi)}. \tag{8}$$

Expressions (6)–(8) describe users' and developers' decisions to join a platform. Note that under *Assumption 1*, the denominator $\tau - \theta\phi$ is positive such that user demand at platform i decreases in the prices charged by this platform (p_i, l_i) but increases in the rival platform's prices (p_j, l_j). The same applies to developers' demand for a platform.

Platforms choose prices on both sides of the market simultaneously so as to maximize total profits of

$$\Pi_i = s_i p_i + n_i l_i, \tag{9}$$

where $s_1 = x_m$ and $s_2 = 1 - x_m$.

The first-order conditions for a symmetric equilibrium are

$$p^* = \tau - \phi(\theta + l^*) \tag{10}$$

and

$$l^* = \frac{\phi\tau - \theta p^* - \theta\phi^2}{4\tau - 3\theta\phi}. \tag{11}$$

It is instructive to interpret the first-order condition with respect to user prices (equation (10)) in detail. Without network effects, the equilibrium price for users coincides with the standard Hotelling price $p^* = \tau$. Taking the externalities between users and software developers into account, the price for users is corrected downwards by the term $\phi(\theta + l^*)$. This term measures the external benefit of attracting one additional user (Armstrong, 2006). The term $\theta + l^*$ is the benefit the platform gets from one extra developer through the license fee l^* and the extra revenue θ the platform can extract from users per extra developer. The term ϕ gives the number of developers that enter if one extra user is attracted (see equation (5)). Thus, the total external benefit or opportunity cost is given by the term $\phi(\theta + l^*)$. Note that the strength of this opportunity cost is affected both by user surplus in the software market (θ) and by the profitability of software developers (ϕ). As software protection has opposite effects on these two parameters, the overall effect of piracy on the opportunity costs of attracting users is a priori ambiguous.

Solving equations (10) and (11) yields the equilibrium price for users and the equilibrium license fee:

$$p^* = \tau - \frac{3}{4}\theta\phi - \frac{1}{4}\phi^2 \tag{12}$$

and

$$l^* = \frac{1}{4}(\phi - \theta). \tag{13}$$

The user price is lower than the standard Hotelling price due to the network effects. The stronger these network effects the lower is the price. The license fee charged to developers increases with the profit per user ϕ that developers can generate but decreases with the benefit users get from an additional unit of software θ. The intuition for this is as follows. If users value additional software highly, platform competition is tough so as to attract a large number of software manufacturers which in turn attracts users. In turn, license fees are low. Note that the license fee becomes negative and platforms subsidize software developers if users value additional software highly (large θ).[16]

The following proposition studies the impact of software protection on equilibrium prices:

Proposition 1. i) User prices decrease (increase) with better software protection if the change in legal sales, i.e., developer surplus ϕ, is sufficiently large (small) compared to the change in user surplus from software consumption θ. ii) The license fee charged to software developers increases with better software protection.

Proof. i) $dp^*/dk \lesseqgtr 0$ if $\phi' \gtreqless -\theta' 3\phi/(2\phi + 3\theta) \Leftrightarrow |\phi'| \gtreqless |\theta'| 3\phi/(2\phi + 3\theta)$. ii) $dl^*/dk = (\phi' - \theta')/4 > 0$. □

From expression (12) it can be seen that the user price decreases in both network externality parameters. However, as those are affected in opposite directions by stricter software protection, the overall effect is ambiguous. The intuition for this ambiguity has been explained when discussing the first-order condition (10). The overall opportunity cost of attracting additional

[16]This can also be observed in practice. Platforms subsidize developers, for instance, by providing constructions kit to make software developing easier.

users may rise or fall with better protection. Whereas the increased developers' profitability ϕ increases the incentives to compete for users, users' decreased surplus from software decreases the incentives for platforms to compete harder for users. If the impact on the developers' legal revenues is sufficiently large compared to the effect on user surplus, stricter software protection may actually lead to lower user fees. Thus, increasing software protection may weaken or intensify competition for users. Contrary to that, the impact of software protection on the equilibrium license fee is unambiguous: both effects point into the same direction. With strict software protection, users value additional software very low and platforms compete less tough for developers so that, in turn, license fees are high. This effect is reinforced by the fact that platforms can extract more from developers as their immediate legal sales are high.

Adding up revenues from license and user sales, the resulting equilibrium profit for each platform amounts to

$$\Pi^* = \frac{\tau}{2} - \frac{1}{16}\phi^2 - \frac{1}{16}\theta^2 - \frac{3}{8}\theta\phi. \tag{14}$$

The following proposition studies the impact of software protection on platforms' profitability:

Proposition 2. Platforms' profits decrease (increase) with better software protection if the change in legal sales, i.e., developer surplus ϕ, is sufficiently large (small) compared to the change in user surplus from software consumption θ.

Proof. $d\Pi^*/dk \lesseqgtr 0$ if $\phi' \gtreqless -\theta'(3\phi+\theta)/(\phi+3\theta) \Leftrightarrow |\phi'| \gtreqless |\theta'|(3\phi+\theta)/(\phi+3\theta)$. □

The proposition shows that platforms may not necessarily benefit from better software protection. There are two effects at work. On the positive side, platforms benefit from increased software protection because they are able to charge higher license fees to developers. However, on the downside, competition for users may be tougher leading to lower revenues from users which affects profits negatively. If this second effect is sufficiently strong, platforms may actually be worse off from stricter software protection.

The profit of an active software developer is[17]

$$\pi_d^* = \frac{1}{4}(\phi + \theta) - f \tag{15}$$

and the equilibrium number of developers on each platform is

$$n^* = \frac{1}{4}(\phi + \theta). \tag{16}$$

The effect of software protection on software developers is as follows:

Proposition 3. The profits of software developers decrease (increase) with better software protection if the change in legal sales, i.e., developer surplus ϕ, is sufficiently small (large) compared to the change in user surplus from software consumption θ.

Proof. $d\pi_d^*/dk \lesseqgtr 0$ if $-\theta' \gtreqless \phi' \Leftrightarrow |\theta'| \gtreqless |\phi'|$. □

Interestingly, developers may not always benefit from better secured software either. Whereas developers obviously benefit from larger legal sales if protection is high, they are also hurt by the indirect effect working via the determination of the license fees. Stricter protection leads to higher license fees which affects developers' profitability negatively. This negative effect can overturn the immediate positive effect of more protection if $|\theta'| < |\phi'|$. Thus, developers may be better off if software protection is low. Note that developers' profits depend on the sum $\theta + \phi$ which corresponds to the total surplus (user surplus plus profits) of software consumption (see equation (15)). Whenever a stricter software protection decreases the total surplus of the interaction between developers and users, profits of individual developers decrease. Thus, developers may actually benefit from reduced protection due to the two-sidedness of the market.[18]

[17] Clearly, the marginal software developer earns zero profits.

[18] Interestingly, the result here is different from the outcome in Gayer and Shy (2006). As pointed out in the introduction, in their paper, artists benefit from more piracy as it increases concert attendance but music companies lose out. Applying this logic to the present context, one would expect developers to pay the price for pirating activity here as well. This, however, is not the case as platforms also set prices on the developer side. By doing so, they indirectly profit from higher developer revenues and therefore are hit harder if piracy becomes an issue.

Profits of individual developers and the number of available software applications are affected in the same direction. Hence, it follows immediately:

Corollary 1. The number of software applications decreases (increases) with better software protection if the change in legal sales, i.e., developer surplus, ϕ is sufficiently small (large) compared to the change in user surplus from software consumption θ.

According to conventional wisdom, weak software protection (i.e., more piracy) usually has negative effects in the long run as it reduces the incentives to develop new products (Bae and Choi, 2006; Belleflamme and Peitz, 2010a). In our setup, however, under certain circumstances weaker software protection may actually lead to more software development. As argued before, the driving force for this result is the intensified competition among platforms to attract software developers.

Our results so far point to a potential conflict of interest between developers and software platforms with respect to protection strategies. *Propositions 2* and *3* highlight that platforms generally benefit from protection if the impact of protection on developers' immediate revenues is large and the impact on user surplus from software consumption is small (large $|\phi'|$, low $|\theta'|$) whereas developers benefit in the opposite case. In principle, two situations can arise where interests diverge. Firstly, platforms may benefit from more protection while developers oppose and secondly, platforms oppose stricter protection whereas developers appreciate it. The following proposition characterizes this conflict of interests:

Proposition 4. a) Suppose software protection is high ($\phi > \theta$). Then, i) platforms prefer more protection and developers less if $|\phi'| < |\theta'|$; ii) both prefer more protection if $|\theta'| < |\phi'| < |\theta'|(3\phi + \theta)/(3\theta + \phi)$; iii) platforms prefer less protection and developers more if $|\phi'| > |\theta'|(3\phi + \theta)/(3\theta + \phi)$.

b) Suppose software protection is low ($\phi < \theta$). Then, i) platforms prefer more protection and developers less if $|\phi'| < |\theta'|(3\phi + \theta)/(3\theta + \phi)$; ii) both prefer less protection if $|\theta'|(3\phi+\theta)/(3\theta+\phi) < |\phi'| < |\theta'|$; iii) platforms prefer less protection and developers more if $|\phi'| > |\theta'|(3\phi + \theta)/(3\theta + \phi)$.

This proposition complements the existing literature. Most papers focus on the impact of piracy on individual software developers. They find that in the presence of network effects, individual software developers may benefit from relaxing software protection, both in monopoly (Conner and Rumelt, 1991; Takeyama, 1994; Slive and Bernhardt, 1998) as well as in oligopoly settings (Shy and Thisse, 1999; Peitz, 2004). In contrast, the focus in our paper is on software platforms acting as intermediaries between users and software developers. We show that piracy may lead to conflicting interests between platforms and individual software developers. Software developers may benefit from piracy as the interaction between users and developers leads to more surplus in cases where piracy is possible.

Next, we are interested in the welfare impact of piracy. User surplus (net of transportation costs and the intrinsic utility of connecting to a platform[19]) is given by

$$CS^* = \theta n^* - p^* = \frac{1}{4}(\theta^2 + \phi^2) + \theta\phi - \tau. \tag{17}$$

Adding up platforms' profits, developers' profits, and user surplus gives total welfare in this market:

$$W^* = \frac{3}{16}(\phi + \theta)^2. \tag{18}$$

The following proposition characterizes the welfare properties:

Proposition 5. i) User surplus decreases (increases) with better software protection if the change in user surplus θ is sufficiently large (small) compared to the change in legal sales ϕ. ii) Total welfare decreases (increases) with better software protection if it increases (decreases) the total surplus from software consumption $(\phi + \theta)$.

Proof. i) $dCS^*/dk \lesseqgtr 0$ if $-\theta' \gtreqless \phi'(\phi+2\theta)/(2\phi+\theta) \Leftrightarrow |\theta'| \gtreqless |\phi'|(\phi+2\theta)/(2\phi+\theta)$. ii) $dW^*/dk \lesseqgtr 0$ if $-\theta' \gtreqless \phi' \Leftrightarrow |\theta'| \gtreqless |\phi'|$. □

Improved software protection influences user surplus in three ways. Firstly, there is an immediate negative influence as software users receive a lower

[19] Transportation costs and the intrinsic utility from access to a platform v are independent of the level of piracy, and hence, can be neglected.

surplus from software consumption (θ decreases in k). Secondly, the number of available software changes which may be positive or negative for users (see *Corollary 1*). Thirdly, users' price for platform access changes. According to *Proposition 1*, this last effect can be positive or negative. The overall effect on user surplus is thus ambiguous. In particular, if software protection is increased, users may suffer from more protection as prices for platform access may rise disproportionately.

As can be seen from equation (18), equilibrium total welfare depends only on the total surplus in the software market ($\phi+\theta$). As both network externality parameters are influenced by software protection in opposite directions, the overall impact on total welfare depends on the relative strength of one effect or the other. Note that for total welfare, access prices charged by the platforms do not matter as these prices are mere transfers between users and platforms. It should be mentioned again that one important factor why total welfare may be lower with more protection is that the number of software products may decrease with more protection which affects welfare negatively (see *Corollary 1*). This negative welfare effect of software protection is not in place in the absence of (one-sided or two-sided) network effects (Belleflamme and Peitz, 2010a).

4 Example

In this section, we provide a specific application of our results in order to focus on conflicting interests between developers and platforms with respect to software protection. So far, we have only analyzed the impact of marginal changes in software protection. An advantage of this example is that we are also able to analyze drastic changes in the degree of software protection.

We make use of a framework where legal and illegal types of software are vertically differentiated (Yoon, 2002; Belleflamme, 2003; Bae and Choi, 2006). Suppose that each software developer is a monopolist and that each user buys either one or no unit of software from each developer. Users differ in their valuation δ for the software. This valuation is uniformly distributed on $[0, 1]$ (and independent of users' platform preferences).[20] Each user gets

[20]Note that we assume that users' platform adoption decisions and the usage decisions

a new draw from δ for each software product. A user can choose between buying the software, copying it illegally, and not buying any software at all. The utility of a user δ in any of these cases is given by

$$V = \begin{cases} \delta - p_s & \text{if a legal copy is purchased,} \\ (1-a)\delta - k & \text{if an illegal copy is obtained,} \\ 0 & \text{otherwise} \end{cases} \tag{19}$$

where p_s represents the price charged by a software developer. The utility from obtaining an illegal copy depends on two factors.[21] As can be seen from the expression, it is assumed that illegal copies provide a lower utility than legally purchased software where $a \in (0, 1)$ measures the quality degradation of an illegal copy. Note that this quality degradation may not necessarily affect the actual product itself. For example, copying a digital product typically does not reduce its quality but reasons, which may nevertheless lead to a lower quality of the overall usage experience, include the lack of manuals or of technical support. Moreover, users who cannot register their illegal copies may be excluded from an online community. These aspects are captured by higher values of a.

Furthermore, k represents the cost of piracy associated with the reproduction of an illegal copy. These costs might include the potential threat of being detected or facing legal action and paying a penalty. Following Yoon (2002), we take the fixed costs k as our measure of software protection where a higher value of k indicates better software protection due to the high costs associated with piracy. We now analyze whether both platforms and developers are willing to invest in order to influence this cost parameter (e.g., by lobbying tougher copyright-infringement laws and higher fines).

We focus on the case where the costs of piracy are not too high, i.e., $k \leq a(1-$

(legal versus illegal) are independent. This assumption certainly helps to keep the model tractable (a similar assumption has been employed, for instance, in Belleflamme and Peitz, 2010b) but is also appropriate in our setup as software protection on both platforms is identical. Lifting this assumption would be necessary, however, if software protection differs among platforms as is analyzed in Shy and Thisse (1999) for the case of non-platform software markets. In that case, one would indeed expect adoption and usage decisions to be correlated. This issue certainly deserves more inspection but it is beyond the scope of the present paper.

[21]See Yoon (2002) and Belleflamme (2003) for a more detailed discussion on the interpretation of the two factors analyzed here.

$a)/(1+a)$ such that some users indeed choose the unauthorized copy. In this case, it is optimal for developers to accommodate piracy as setting the limit price that deters all users from copying the software illegally is only profit-maximizing if the costs of piracy are sufficiently high.[22] The marginal user who is indifferent between purchasing a legal copy and obtaining an illegal copy is given by $\bar{\delta} = (p_s - k)/a$ so that the expected profit of a developer from selling to a user is $\pi_d = (1 - \bar{\delta})p_s$. The marginal consumer who is indifferent between obtaining an illegal copy and not consuming at all is represented by $\underline{\delta} = k/(1-a)$. The price that maximizes profits $\pi_d = p_s(1 - (p_s - k)/a)$ is then given by $p_s = (a+k)/2$. Software developers can charge a higher price if software protection and, hence, costs of pirating the software are high. Then, from the interaction with each user, the developer expects profits of $\phi = (a+k)^2/4a$.

Denote by $\bar{\delta}^*$ the marginal consumer who is indifferent between copying and purchasing a legal copy given the profit-maximizing price. It follows that the expected surplus of a user for each software product can be expressed as

$$\theta = \int_{\underline{\delta}}^{\bar{\delta}^*} ((1-a)\delta - k)d\delta + \int_{\bar{\delta}^*}^{1} \left(\delta - \frac{a+k}{2}\right) d\delta. \tag{20}$$

Simplification yields $\theta = (4-3a)/8 - 3k/4 + (1+3a)k^2/(8a(1-a))$. Note that in line with the analysis in the general setup, we have $d\phi/dk > 0$ and $d\theta/dk < 0$.

Our analysis so far has only dealt with marginal changes in software protection. As a consequence, the above analysis is relevant in the case where major changes or investments to influence the fixed cost of piracy are not feasible and/or not economically reasonable. However, this concrete example allows us to take a more general perspective: we evaluate whether platforms' and developers' investment incentives concerning piracy avoidance are aligned by having a closer look at profits for different degrees of software protection. As profits are heavily dependent on market assumptions, we will make use of our example to discuss the relevant cases.

Let us first have a quick look at marginal incentives to enforce stricter soft-

[22] For a discussion of this issue, see Yoon (2002).

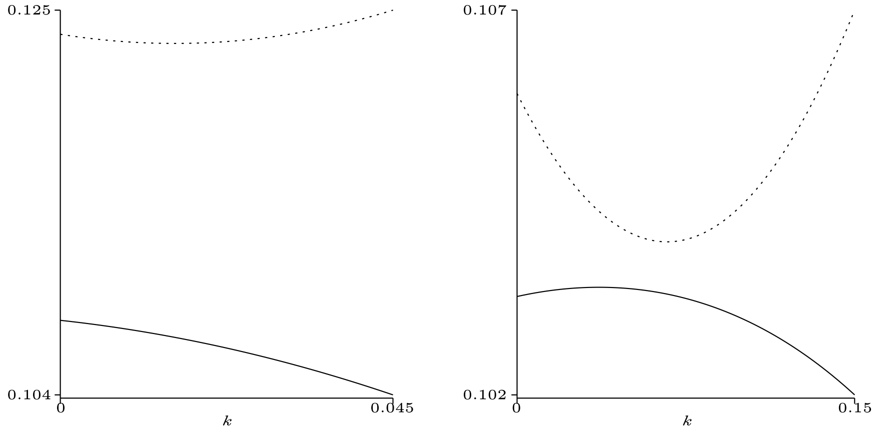
ware protection. To this end, consider the impact of the fixed cost k of piracy on profits for a given level of quality degradation as illustrated in *Figure 1*. The figure, which—like all other figures—is drawn for transportation cost $\tau = 1/4$, shows how profits of platforms and developers evolve if the degree of software protection measured by k changes. *Figure 1(b)* illustrates marginal incentives to protect the software (see also *Proposition 4*): only for intermediate values of the fixed costs of piracy, marginal incentives are aligned in that both parties are worse off from stricter protection. In the case with less quality degradation, marginal incentives to decrease software protection are aligned for a greater range of (low) fixed costs of piracy (see *Figure 1(a)*).

Turning to global incentives, we point out that developers' profits are always U-shaped, i.e., a higher level of protection first decreases profits and then increases profits (see *Figures 1(a)* and *1(b)*). As *Proposition 1* points out, a higher degree of software protection gives platforms an opportunity to levy higher license fees as revenues from software sales go up. Now if protection increases through a higher fixed cost for potential wrongdoers starting from a low level, the immediate positive effect for developers with respect to sales revenues is limited. Nevertheless, they incur higher license costs which leads to a decrease in profits (see *Proposition 3*). Only if protection is increased further, they benefit from a larger amount of legal sales and hence profits increase. Note that developers' profits are always higher with full protection than with no protection. Thus, in this example, developers prefer the highest possible protection.

As far as platforms' profits are concerned, *Figure 1(a)* illustrates the case with a low level of quality degradation $a = 0.05$. In this situation, platforms prefer no software protection whatsoever which is the exact opposite of what developers want from a global perspective. In light of the results presented in *Propositions 1* and *2*, this can be explained as follows: if the level of quality degradation is low, then—independent of the fixed costs of piracy—platforms cannot charge developers high license fees as their revenues from legal sales are low (see *Figure 2* for a comparison of prices). However, an increase in these fixed costs intensifies competition for users which leads to lower profits.

For an intermediate level of quality degradation of the illegal copy ($a = 0.6$

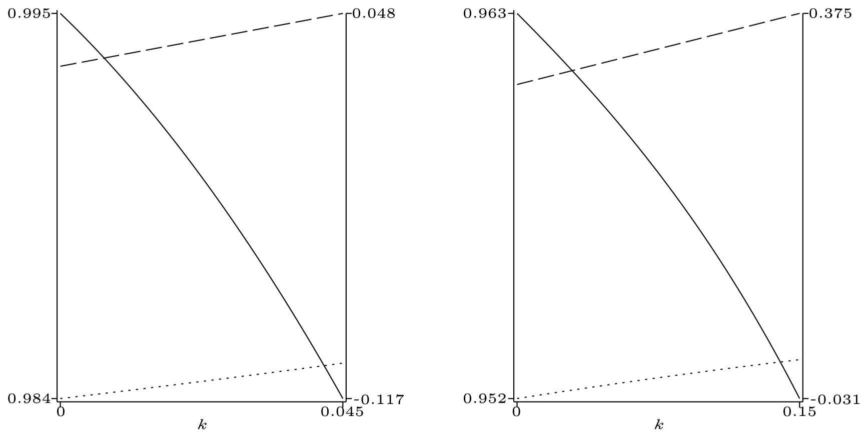
in *Figure 1(b)*), platforms' profits have an inverse U-shaped form so that a higher level of software protection first increases profits and then decreases profits. Hence, platforms would want to achieve an intermediate degree of software protection which yields the highest profits. As a result, platforms first would be willing to invest in software protection that increases users' fixed costs of piracy up to a certain level.



(a) Profits per platform Π^* (solid line) and per developer π_d^* (net of fixed costs, dotted line) for $a = 0.05$ and $\tau = 1/4$.

(b) Profits per platform Π^* (solid line) and per developer π_d^* (net of fixed costs, dotted line) for $a = 0.6$ and $\tau = 1/4$.

Figure 1: Impact of fixed piracy costs on platforms' and developers' profits.



(a) User price p^* (solid line), license fee l^* (dotted line, right axis), and software price p_s (dashed line, right axis) for $a = 0.05$ and $\tau = 1/4$.

(b) User price p^* (solid line), license fee l^* (dotted line, right axis), and software price p_s (dashed line, right axis) for $a = 0.6$ and $\tau = 1/4$.

Figure 2: Impact of fixed piracy costs on prices.

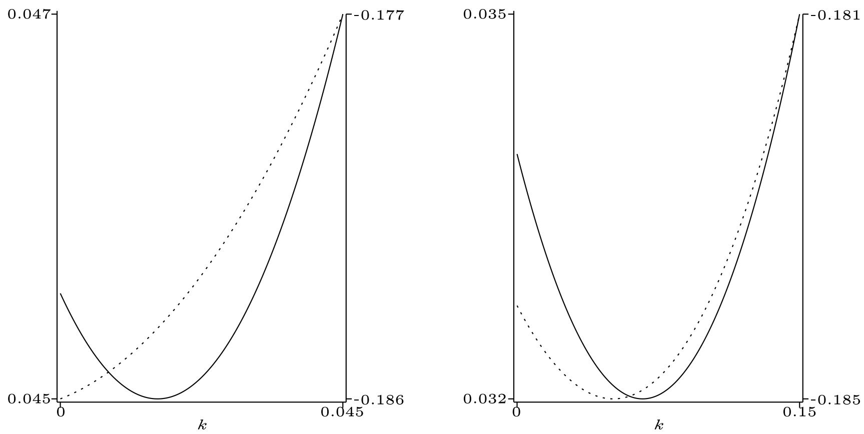
As pointed out before, developers' profits are lowest for an intermediate level of software protection and highest with full protection. As a consequence, from a general perspective, platforms' and developers' incentives regarding software protection diverge: whereas developers favor full protection, platforms would opt for a less strict solution to achieve an intermediate level of software protection. Let us briefly comment on the prices set by the platforms in the two examples: there is a cross-subsidization between the two market sides as license fees are negative. Note, however, that the results derived so far for the case where $a = 0.6$ are qualitatively no different from the ones in a situation without cross-subsidization which is the case for sufficiently large a.

The comparison regarding profits yields somewhat different results than a comparison of user surplus and total welfare. *Figure 3* gives an impression of how user surplus and total welfare react to different levels of software protection. From a global perspective, full software protection through an increase in the fixed costs of piracy is always optimal for consumers and for total welfare. However, this is not necessarily true for marginal changes (see *Figures 3(a)* and *3(b)*). The fact that user surplus can be highest under full protection is quite noteworthy. In a direct effect, consumers are hurt by more protection as the immediate surplus from software consumption is decreased. This negative effect, however, is outweighed by the positive indirect effect of a larger software variety and a (much) lower user price (see *Figure 2*) so that ultimately tough software protection is in the best interest of users.

In light of these insights, we can also comment on the possibility of a Pareto improvement resulting from a (marginal) change in the scope of piracy protection:[23] given a relatively high level of quality degradation (i.e., $a = 0.6$), a reduction of software protection may indeed benefit all three parties involved in the two-sided market: profits for both platforms and developers as well as user surplus increase as piracy protection is reduced (see *Figures 1(b)* and *3(b)*).

Summing up, we highlight two robust insights from this example. Firstly, as far as platforms' and developers' global incentives to better protect their

[23] As Takeyama (1994) points out for the monopoly case, copying may yield a Pareto improvement.



(a) Total welfare W^* (solid line) and user surplus CS^* (dotted line, right axis) for $a = 0.05$ and $\tau = 1/4$.

(b) Total welfare W^* (solid line) and user surplus CS^* (dotted line, right axis) for $a = 0.6$ and $\tau = 1/4$.

Figure 3: Impact of fixed piracy costs on total welfare and user surplus.

software are concerned, it can be concluded that they are never aligned; but this conflict of interest may vanish when it comes to marginal changes of software protection. Secondly, maximizing total welfare and/or user surplus at the same time is feasible for a great range of the quality-degradation parameter a: despite minor misalignments concerning marginal changes, full software protection is always optimal as long as a is not too large. For very high values of a only, total welfare is maximized by abstaining from any software protection at all whereas full protection is still desirable from a user perspective.

5 Compatible platforms

Suppose that in contrast to the base model, platforms are compatible which means that platforms have agreed on a common standard such that software created by any developer can be used on both platforms.[24] As a consequence, the amount of software is no longer a means of vertical differen-

[24]Besides creating a common market for software products, compatibility may also lead to a lower perceived degree of product differentiation between the two platforms. That is, a lower value of τ. Note, however, that this effect of compatibility does not influence platforms' and developers' preferences toward software protection. That is, these preferences are independent of the degree of product differentiation. Hence, in our analysis, we can abstract from this point.

tiation and platforms' user market shares depend only on the price but not on the amount of software available (which is necessarily the same on both platforms):

$$x_m = \frac{1}{2} + \frac{p_2 - p_1}{2\tau}. \tag{21}$$

In equilibrium, user prices then correspond to the ones in a standard Hotelling (1929) setup and are equal to $\bar{p} = \tau$.

Suppose that platforms offer the license to produce software jointly and then divide the revenues in equal shares. The total income from selling licenses is $(\phi - l)l$ which is maximized at

$$\bar{l} = \frac{\phi}{2}. \tag{22}$$

Note that with compatibility platforms never subsidize developers, i.e., the equilibrium license fee is strictly positive. Profits for each platform are then given by

$$\bar{\Pi} = \frac{\tau}{2} + \frac{\phi^2}{8}, \tag{23}$$

where the first term is the income from sales to users and the second term is the income from selling licenses to software developers. As the impact of software protection on ϕ is positive, stricter protection leads to an upward correction of demand for software and in consequence to higher license fees and higher income. With compatible platforms, there is no positive effect of competition for users which could compensate for these losses. Hence, platforms' profits increase with protection. In turn, software developers' profit are also increased when software protection is stronger.

So far, we have assumed that platforms jointly offer licenses. An alternative assumption is that platforms compete for developers, that is, platforms individually offer licenses and cannot coordinate their pricing decision. As both platforms are identical from the developers' point of view, platforms face Bertrand competition for developers and, therefore, the license fee is competed down to zero, $\hat{l} = 0$. Pricing on the user side is not affected by this alternative assumption. Profits of each platform—amounting to $\hat{\Pi} = \tau/2$—only consist of revenues from the user side. The profit of each developer is $\hat{\pi}^d = \phi - f$. In this case, platforms are indifferent with respect to piracy while software developers benefit from stricter software protection.

Proposition 6. i) If compatibility leads to coordinated pricing, both platforms' and software developers' profits increase with the level of software protection. ii) If compatibility leads to non-coordinated pricing, software developers' profits increase with the level of software protection. Platforms are indifferent with respect to the level of software protection.

This extension shows that the effects of piracy depend on the way software platforms are organized. This can be important if overall software protection depends on the efforts of both platforms as well as developers. In this case, choosing compatibility can serve as a means to align incentives in order to fight software piracy more effectively.

6 Conclusions

This paper analyzes the impact of piracy in the software industry. The setting we use is that of a two-sided market perspective. Users of software platforms are interested in a large amount of software. Software developers are interested in offering software for platforms with many users. It is the task of the platform to set prices to users and developers taking the externalities between these two groups into account. Piracy and software protection influence these cross-group externalities. On the one hand, better software protection positively affects immediate legal sales from software developers. On the other hand, software protection decreases the surplus users get from each additional unit of software that is developed.

Our results point to a conflict over software protection strategies between software platforms and software developers. In general, developers benefit from protection if the impact on the developers' immediate legal sales is small and the impact on consumer surplus from software consumption is large. Platforms' profits are affected by these effects in the opposite direction. We point out that by choosing compatibility, the issue of diverging interests can be solved as platforms may align incentives of all players. In this case, developers and platforms are both interested in reducing piracy.

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