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Software Piracy in the Presence of Open Source Alternatives

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Abstract:

We develop a model to investigate the manner in which the pricing, profitability, and protection strategies of a seller of a proprietary digital good respond to changing market conditions. Specifically, we investigate how product piracy and the presence of open source software alternatives (such as Open Office) impact the optimal strategy of a seller of proprietary software (such as Microsoft Office). In contrast to previous literature, we show that firms may make more (rather than less) effort to control piracy when network externalities are strong. In addition, we show that the level of network externalities amplifies losses incurred by an incumbent due to high-quality pirated goods. Therefore, for products characterized by high network externalities (such as software), sellers need to try to maintain a large perceived quality gap between their product and illegal copies. Further, we demonstrate that the appearance of an OSS alternative leads the incumbent to reduce both price and the level of piracy control. Although high-quality pirated goods are detrimental to profits in the absence of OSS, they may actually limit the incumbent's losses and the need to adjust price and protection strategies due to the introduction of an OSS alternative. Thus, an incumbent may find it easier to compete with OSS in the presence of product piracy. Finally, highly correlated intrinsic valuation between an incumbent and OSS products require smaller adjustments to price and piracy controls and leads to muted impact on incumbent profit.

Keywords: Software Piracy, Piracy Protection, Network Externalities, Open Source, Microsoft.

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1 Introduction

Researchers have often depicted the pervasiveness of product piracy as one of the most serious threats to firms that produce digital goods such as software, movies, and music (Chellappa & Shivendu, 2005; Jain, 2008; Prasad & Mahajan, 2003; Waters, 2015). The digital goods industry has tried to fight piracy in various ways, including publicizing its damages, educating the public on copyright law, engaging in legal actions against copyright offenders, and using protective technological systems such as digital rights management (DRM) (Raghu, Sinha, Vinze, & Burton, 2009). Consistent with this view, the academic literature that has incorporated technology-based piracy protection as a firm decision variable has found that profits can increase with higher level of protection (Conner & Rumelt, 1991; Sundararajan, 2004).

However, despite its potentially harmful effects, some producers can also benefit from consumer piracy. For example, Conner and Rumelt (1991) and Jain (2008) demonstrate (in monopoly and duopoly settings, respectively) that producers may benefit from tolerating piracy in the presence of network externalities because piracy increases the externality benefits that accrue to legal buyers and also removes those who have a low willingness to pay from the market, which reduces price competition. Piracy may also help incumbents accelerate product diffusion in markets, especially during early stages of the product lifecycle (Givon, Mahajan, & Muller 1995). Gayer and Shy (2003) analyzed the markets for digital products and concluded that, if network externalities are strong enough, a publisher may gain from distributing a lower-quality version of its product. Accordingly, investing in piracy-control measures may not necessarily be an optimal strategy for digital products.

Another variable that impacts the way in which piracy affects the industry is the quality differential between the original and illegal copies (Geng & Lee, 2013). In some contexts, such as digital music, this differential may be very small, while, in others, such as software, it tends to be significant. Although most of the theoretical models of piracy assume perfect substitutability between copies and the original product, it is clear that the existence of a quality differential impacts sellers' optimal strategies and profit levels. In particular, Sundararajan (2004) has shown that increases in the quality of the pirated good cause the producer to optimally reduce prices.

Moreover, the emergence of open source software (OSS) alternatives creates significant new complications for software producers. Currently, OSS is available in virtually all software categories. Examples include Linux (operating system), Apache (Web server), Mozilla Firefox (Web browser), Mozilla Thunderbird (email), RapidMiner (data mining), Open Office (office package) and ADempiere (ERP Applications). The literature on the topic (see von Krogh & von Hippel, 2006, for a comprehensive review) has analyzed individuals' motivation for producing OSS software, for participating in OSS communities, and the competition between OSS and proprietary software (Lakhani & von Hippel, 2003; Bagozzi & Dholakia, 2006; Lerner & Tirole, 2005; Casadesus-Masanell & Ghemawat, 2006). In particular, Casadesus-Masanell and Ghemawat (2006) considered a dynamic mixed-duopoly model to study the impact of Linux on Microsoft's strategies for Windows and on the market equilibrium. Among other results, they found that the appearance of Linux lowered Microsoft's profits but that Microsoft would likely sustain its leadership position by dropping its prices relative to monopoly levels. Although the authors briefly discuss the introduction of piracy in their model, they assumed the piracy rate to be small and exogenous rather than being endogenously determined by market conditions and/or by Microsoft's piracy control strategy. Powerful incumbents such as Microsoft find themselves caught between zero (or very low) price OSS competitors and digital pirates, which forces them to reconsider the trade-offs between their price setting and copyright protection strategies. Products such as Linux and Open Office have continued to become strong competitors in their markets (Baker, 2009). For example, LibreOffice (a derivative of Open Office) has millions of users (Rubens, 2015). Therefore, the extent to which OSS impacts the strategies of the sellers of proprietary software and market equilibrium in the presence of product piracy remains an open and important question.

Because OSS is either free or available at a cost substantially lower than comparable proprietary software applications, consumers' could have a lower propensity to pirate in an OSS environment. Intuitively, although the availability of OSS may threaten the market share of incumbent software, its presence also allows potential and existing pirates to consider free and legal alternatives to proprietary software. The availability of such free OSS alternatives may, therefore, limit the potential of piracy controls to convert pirates into buyers and, ultimately, reduce the firms' incentives to protect its products.

To address these issues, we develop an analytical model to study how the pricing, profitability, and protection strategies of the seller of a proprietary good respond to changing market conditions. To the best of our knowledge, no theoretical work has thus far investigated how the varying quality of pirate goods affect the optimal strategy of such a seller (in particular, its piracy control strategy) and the market equilibrium in the presence of an OSS alternative.

Table 1 summarizes the main assumptions regarding key variables in the five theoretical papers that relate most closely to our work. By focusing on the assumptions that these papers have in common with our model, we highlight our paper's specific contributions in assessing the impact of piracy on incumbent demand.

Table 1. Assumptions Regarding Key Variables in Relevant Theoretical Work

	Conner & Rumelt (1991)	**Jain (2008)**	**Sundararajan (2004)**	**Shy & Thisse (1999)**	**Casadesus-Masanell & Ghemawat (2006)**	**This Paper**
Piracy protection	Exogenous	**Endogenous**	**Endogenous**	Exogenous	Not Considered	**Endogenous**
Quality of pirated good	Fixed: Perfect Substitute	**Varying: imperfect substitute**	**Varying: imperfect substitute**	Not considered	Not Considered	**Varying: imperfect substitute**
Consumers' pirating costs	Fixed	Fixed	Fixed (free)	Fixed	Not Considered	**Varying**
Network externalities	**Yes**	**Yes**	No	**Yes**	**Yes**	**Yes**
Demand estimation	Exogenous	Exogenous	**Endogenous**	**Endogenous**	**Endogenous**	**Endogenous**
Open source alternatives	No	No	No	No	**Yes**	**Yes**
Market structure	Monopoly	Duopoly	Monopoly	Duopoly	**Mixed oligopoly**	**Mixed oligopoly**
Model dynamics	**Static**	**Static**	**Static**	**Static**	Dynamic	**Static**
Note: **bold items** reflect issues that we incorporate in this paper. The table points out that other papers have address some but not all of these factors.						

Specifically, our contributions stem from examining the strategy of a digital good producer when 1) one treats piracy protection, prices, and the demand for incumbent and pirated goods as endogenous, 2) the quality of the pirated good is not fixed, 3) product demand depends on network externalities, 4) the cost of pirating varies across consumers, and, finally, 5) a viable OSS alternative exists for consumers. In addition, we note that our work represents the first attempt to model the impact of OSS on the demand for both incumbent and pirated goods—an important contribution given the increasing importance, availability, and usage of OSS.

Our main results are as follows. First, in sharp contrast to most of the existing work on piracy and network externalities, we show that there are realistic conditions under which a firm may want to increase piracy controls in response to increasing network externalities. Second, our results indicate that the losses incurred to an incumbent due to high-quality pirated goods are amplified by the level of network externalities. Therefore, the need to maintain a large perceived quality gap between the incumbent product and illegal copies becomes even more pressing for product categories that are characterized by high network externalities (such as software). Third, we find that the appearance of an OSS alternative leads the incumbent to reduce both the price and its level of piracy control. However, the impact of OSS alternative is fully moderated by its quality level and the correlation of its intrinsic valuation with that of the incumbent product. Further, although high-quality pirated goods harm an incumbent's profits, high-quality piracy may actually limit the incumbent's losses that result from the appearance of an OSS alternative in the market and the incumbent's need to respond to the alternative through adjustments to price and piracy control.

This paper proceeds as follows. In Sections 2 to 4, we present the theoretical models for software piracy in the absence and presence of OSS and our main findings based on solving the model analytically and through simulations. In Section 5, we conclude the paper and discuss the implications and directions for future research.

2 Software Piracy Model with Endogenous Demand

We begin our analysis by describing the model in the absence of an OSS alternative (Section 2.1) and investigate how a firm's optimal strategies, demand level, and profits vary with the levels of network externalities and quality of the pirated good (Sections 2.2 and 2.3). In Section 3, we analyze the impact of the appearance of an OSS alternative on the optimal strategy of an incumbent, who now has to deal with both a pirated product and a free (or nearly free) but legal alternative. The complexity of this model necessitated a simulation analysis since we could not obtain closed-form solutions for the optimization problem. We present this analysis in Section 4.

2.1 The Model

Consider a market for an information good where consumers' "intrinsic" valuations for the good (i.e., abstracting from benefits that one may draw from the fact that other consumers also use the same product) is distributed uniformly over $X \in [0, \theta_X]$. One determines the utility from using the information good by the intrinsic value of the product to the consumer (X), the size of the externality benefit from using the product ($\alpha \in [0,1]$), and its price. A consumer who buys an incumbent's software copy or acquiring a pirated copy of it extracts value that depends on the network externality factor, α, and the demands for the information good ($\psi_{leg,}\ \psi_{pir}$).

Consumers can choose to purchase a legal copy of the good at a price (p) or to acquire a pirated copy, in which case the effects of pirating depends on the piracy controls that the producer has imposed (L) and the exogenous quality of the pirated good (q). We consider that piracy control affects users in proportion to their individual cost of pirating (c). That is, the higher the firm sets the piracy control level at, the higher the costs the pirates incur to use the pirated product. Piracy controls imposed by the producer may result in reduced functionalities (such as disabled features, watermark on printouts that signal pirated version, and persistent warning messages), extra effort to acquire or overcome registration requirements, lack of product updates, and the inability to exchange documents with other users. The more severe the piracy controls, more effort and costs the user incurs in ensuring that the pirated software works. The initial model assumes that the cost incurred ($c \epsilon [0,1]$) is constant across all consumers; we relax this assumption in subsequent models. On the other hand, we assume the exogenous quality factor ($q \epsilon [0,1]$) to affect the intrinsic value and the externality value. The exogenous quality factor models the ability of pirates to support the individual consumer. For instance, pirated goods' quality may improve if alternate websites post product updates on an ongoing basis, post replacement registration codes frequently, and maintain an extensive knowledge base for tricks and tips to overcome piracy controls.

Whereas an increase in the quality of a pirated good can benefit the pirate directly, incumbent users benefit indirectly due to the network externality generated by the pirates' demand.

Model 1 describes the utility for a random consumer in this setting:

$$U_i = \begin{cases} X_i + \alpha\left(\psi_{leg} + q\psi_{pir}\right) - p & \textit{Buy a legitimate copy from incumbent} \\ q(X_i + \alpha\psi_{pir}) + \alpha\psi_{leg} - cL & \textit{Acquire a pirated copy} \\ 0 & \textit{Do nothing} \end{cases} \quad (1)$$

Consumers choose to buy, pirate, or do without depending on how they value the good (X) relative to two thresholds (X_1 and X_2). Equation 2 describes the marginal consumer who is indifferent between buying and pirating as:

$$X_1 = \frac{p - cL}{1 - q} \quad (2)$$

Equation 3 describes the marginal consumer who is indifferent between pirating and doing nothing (i.e., neither purchase nor pirate) as:

$$X_2 = \frac{cL - \alpha(\psi_{leg} + q\psi_{pir})}{q} \quad (3)$$

Thus, the demand functions for the three segments (where ψ_{doN} represents consumers who do not pirate or buy the incumbent product; i.e., the "do-nothing" segment) are:

$$\psi_{leg} = 1 - \frac{p - cL}{1 - q}, \qquad \psi_{pir} = \frac{pq - cL(1-\alpha) + \alpha - (p+q)\alpha}{q(1-q)(1-\alpha)},\ \psi_{doN} = \frac{cL(1-\alpha) - \alpha + p\alpha}{1-q} \tag{4}$$

The profit function for the incumbent firm is the revenue generated from the demand for the incumbent's product and the costs incurred in producing the information good. We describe the incumbent's profit with the following equation: $\pi_{leg} = p\psi_{leg} - (Lq)^2$.

The costs associated with piracy control are a function of the level of piracy control and the exogenous quality of the pirated good. We expect higher-quality pirated goods to impact an incumbent's costs in implementing piracy control. For instance, higher-quality pirated goods will require one to expend more development effort to implement more piracy controls. An incumbent producer may have to incur additional costs in bringing down alternate websites that are selling/sharing the pirated good. Piracy controls (such as complex encryption codes, registration requirements, and installation limitations) can cause buyers to more frequently call the organization's support lines. Thus, highe- quality pirated goods can increase costs to support customers due to more stringent piracy controls.

Using the producer's profit equation ($\pi_{leg} = p\psi_{leg} - (Lq)^2$), we can derive the optimal price, p^* and optimal piracy control level, L^*. Apart from the non-negativity constraints on p^* and L^*, from Equation 4, we see that the constraints to ensure that the "do-nothing" and piracy segments are non-negative are $L \geq \frac{pq+\alpha-\alpha(p+q)}{c(1-\alpha)}$ and $L \leq \frac{\alpha(1-p)}{c(1-\alpha)}$, respectively.

Taken together, these constraints lead to four distinct solutions. We discuss each of these cases, which we derived from optimizing four cases (binding or non-binding) associated with the two constraints on L above, below.

Case A (incumbent buyers only): when both constraints are binding, both the pirate and do-nothing segments are eliminated (substituting $L = \frac{pq+\alpha-\alpha(p+q)}{c(1-\alpha)}$ and $L = \frac{\alpha - p\alpha}{c(1-\alpha)}$ in Function 4 above). In this case, $p^* = \alpha$; $L^* = \frac{\alpha}{c}$. Intuitively, the price increases with externality benefits and piracy controls are set such that they nullify all the externality benefits to the pirates. The optimal profit level is given by $\pi_A^* = \alpha - \frac{q^2\alpha^2}{c^2}$, which decreases in the quality of the pirated good (q) and increasing in consumer's piracy cost (c).

Case B (incumbent buyers and pirates only): when the first constraint is binding (i.e., $L^* = \frac{pq+\alpha-\alpha(p+q)}{c(1-\alpha)}$), only the do-nothing segment is eliminated. In this case, the equation $p^* = \frac{c^2(1-q(1-\alpha))(1-\alpha)+2(1-q)q^2\alpha^2}{2c^2(1-\alpha)+2(1-q)q^2\alpha^2}$ describes the optimal value; substituting this optimal value of p in Equation 1 provides optimal profits of $\pi_B^* = \frac{c^2(1+q(1-\alpha))^2-4(1-q)q^3\alpha^2}{4(1-q)(c^2(1-\alpha)+(1-q)q^2\alpha^2)}$.

Profit under case B is strictly higher than that of the case when only legal buyer segment exists (case A). Therefore, case B dominates case A whenever it is a feasible solution (i.e., $\pi_B^* - \pi_A^* = \frac{(c^2(1-q(1-\alpha)-2\alpha)+2(1-q)q^2\alpha^2)^2}{4c^2(1-q)(c^2(1-\alpha)+(1-q)q^2\alpha^2)} \geq 0$), which suggests that the combination of *q*, *c* ,and *α* values determines firms' incentive to tolerate piracy; as externality benefits (α) increase and the cost of pirating (*c*) decreases, the threshold for pirated good quality (*q*) at which the firm will move to eliminate piracy decreases progressively.

Case C (incumbent buyers and do-nothing segment only): when the second constraint is binding (i.e., $L = \frac{\alpha(1-p)}{c(1-\alpha)}$), piracy demand is eliminated. In this case, optimal price and piracy controls are:

$$p^* = \frac{c^2(1-\alpha)-2(1-q)q^2(q-\alpha)\alpha}{2q^2(q-\alpha)^2+2c^2(1-\alpha)},\ L^* = \frac{c(\alpha+q(1-2\alpha))}{2q^2(q-\alpha)^2+2c^2(1-\alpha)} \tag{5}$$

Case D (all three segments exist): when both constraints are non-binding, optimal price and piracy control are as follows:

$$p^* = \frac{2(1-q)^2q^2}{4(1-q)q^2-c^2},\ L^* = \frac{c(1-q)}{4(1-q)q^2-c^2} \tag{6}$$

Note that optimal price and piracy controls are a function of the network effects, α, only in cases A, B, and C (i.e., when the incumbent segment exists with either the do-nothing or the pirate segments—not both). In case D, price and piracy control levels are independent of network externalities, which implies that, when the market is fully covered at equilibrium (i.e., all three segments have non-zero demand), producers are not constrained by effects of network externalities when implementing piracy controls.

2.2 Dominance Regions

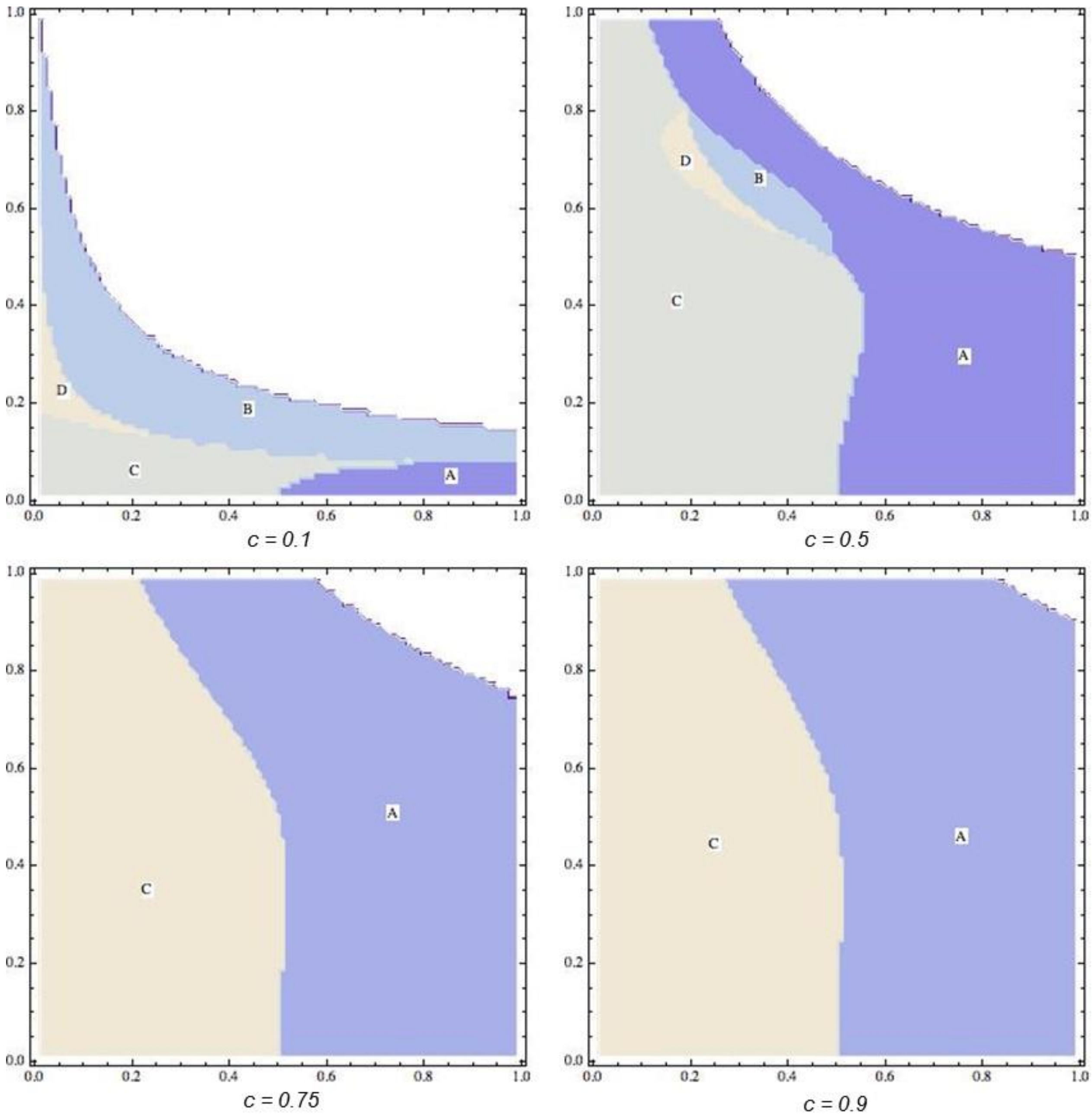


Figure 1. Demand regions Under Different Values of c[1]

In Figure 1, we systematically examine the emergence of the four cases for various values of *c* (customer's cost of pirating). Each graph is a contour plot that involves pirated good quality (*q*) on the x-axis and network externality (α) on the y-axis. First, note that case D (all three segments exist) seldom

[1] Note: the graphs have A, B, C, and D regions (where applicable), which correspond to the four cases of model 1. The four graphs correspond to an increasing value of c in each column. We tested for a range of c between 0.1 to 0.9.

emerges as a dominant solution even over a very large range of parameter values. Specifically, as the consumer's cost of pirating increases, consumers do not engage in pirating and the region pertaining to case D approaches zero. This result arises from the fact that producers have strong incentives to eliminate the pirate segments through price and piracy control manipulations. When the pirated good is high quality, demand for the pirated good is high (case B exists); however, with an increase in network externality, the value for the incumbent good increases and case A prevails. In addition, case C (piracy eliminated) tends to dominate with low network externality (α) and high cost of pirating (c). Finally, when q and α are high enough, case A tends to dominate unless the model has no feasible solution, which the blank regions in the graphs indicate.

Table 2 provides the comparative statics for the four cases (cases A-D). The comparative statics results provide the rationale for the observed dominance regions. If the pirated good is very low quality, it will not pose a significant threat to the firm, and, thus, the firm will tolerate piracy through a low level of protection. If, furthermore, externalities are high enough, then it will be very important for the incumbent to eliminate the do-nothing segment, which one can do via combining a high price and a low to moderate level of protection. When the pirated good (q) is high quality, piracy is a serious threat to the firm, and, therefore, the level of protection will have to be high. However, under a high level of externalities, discouraging piracy will potentially have the very negative effect of driving some pirates out of the market and that, in turn, reduces product value for legal consumers. A firm can avoid this through combining high protection and low to moderate prices, which will be successful in eliminating both the piracy and do-nothing segments unless the model has no feasible solution. Such infeasible cases, which correspond to the blank regions in the graphs, arise mainly when the consumer cost of pirating (c) is low. For example, Figures 1a and 1b (c = 0.1 and c = 0.5, respectively) show that, for products characterized by low network externalities, the producer can participate in the market (i.e., generate positive profits) even in the presence of high-quality pirated good (i.e., high q). However, as network externalities increase, the producer's market participation is eliminated for progressively higher values of q (i.e., the infeasibility region becomes larger). Basically, this result means that, for high levels of q and α, the firm cannot charge a positive price or protect its good, which eliminates it from the market.

Table 2. Comparative Statics for Model 1

Case	Effect of network externality (α)	Effect of quality of pirated good (q)
Case A (incumbent buyers only)	***P***: (+) ***L***: (+) ***Profit***: (+) if $c^2 > 2q^2\alpha$	***P***: 0 ***L***: 0 ***Profit***: (-)
Case B (incumbent buyers and pirates only)	***P***: (+) ***L***: (+) if $c^2 > q^2\alpha^2(1- q^2)/1+q(1-\alpha)^2$ ***Profit***: (+) if $c^2 > 2q^2\alpha\ (1- q2)/1-q(1-\alpha)$ *Incumbent demand*: (+) if $c^2 > q^2\alpha(1- q)(2+q\alpha(2-\alpha))$ *Pirate demand*: (-)	***P***: (+) if $\alpha< 2(1-q^2(1- \alpha)-q)$ ***L***: (-) ***Profit***: (±) *Incumbent demand*: (+) *Pirate demand*: (-)
Case C (incumbent buyers and do-nothing segment only)	***P***: (+) if $c^2 > 2q^3(1- q)(q-\alpha)^2/ q^2+(2-\alpha)(\alpha-2q\ \alpha)$ ***L***: (+) if $c^2 > q^2(\alpha-q)(\alpha-q(-3+2q+2\ \alpha))/1-q$ ***Profit***: (+) if $c^2 > 2q^2(1-q)(q+\alpha)$ *Incumbent demand*: (+) if $q^2>\alpha$	***P***: (-) if $c^2 < q^3\ (q-\alpha)^2/ (3q\ \alpha^2+2\ q^2\ (1-2\alpha)-\alpha^2)$ ***L***: (-) ***Profit***: (-) if $\alpha<1/2$ and $c^2 > 2q^3\ \alpha\ (q-\alpha)/(\alpha+q(2-4\alpha))$ *Incumbent demand*: (+)
Case D (All three segments exist)	***P***: 0 ***L***: 0 ***Profit***: 0 *Incumbent demand*: 0 *Pirate demand*: (+) if $c^2 > 4q^2(1- q)$	***P***: (-) ***L***: (-) if $c^2 <8q(1-q)^2$ ***Profit***: (-) *Incumbent demand*: (+) if $q>2/3$ *Pirate demand*: (+) if $\alpha<c^2(2q^2(6+q(3q-10))-c^2)/ 2q^2(c^2(1-2q)+ 4q^2(1-q)^2)$

2.3 Model Results

Table 2 shows that the sign and magnitude of the effects of *q* and *α* on the endogenous variables vary with the region of dominance, which, in turn, depends on combination of parameter values (*α*, *q*, and *c*). Interestingly, as we note in Section 2.2, our analysis of the dominance regions indicates that case D (where all three segments exist) is almost never dominant. Therefore, we concentrate our discussion on cases A to C. Figure 2 illustrates the joint impact of exogenous parameters on optimal price, piracy control, and profits (lighter shades indicate higher value; all graphs drawn with c = 0.85).

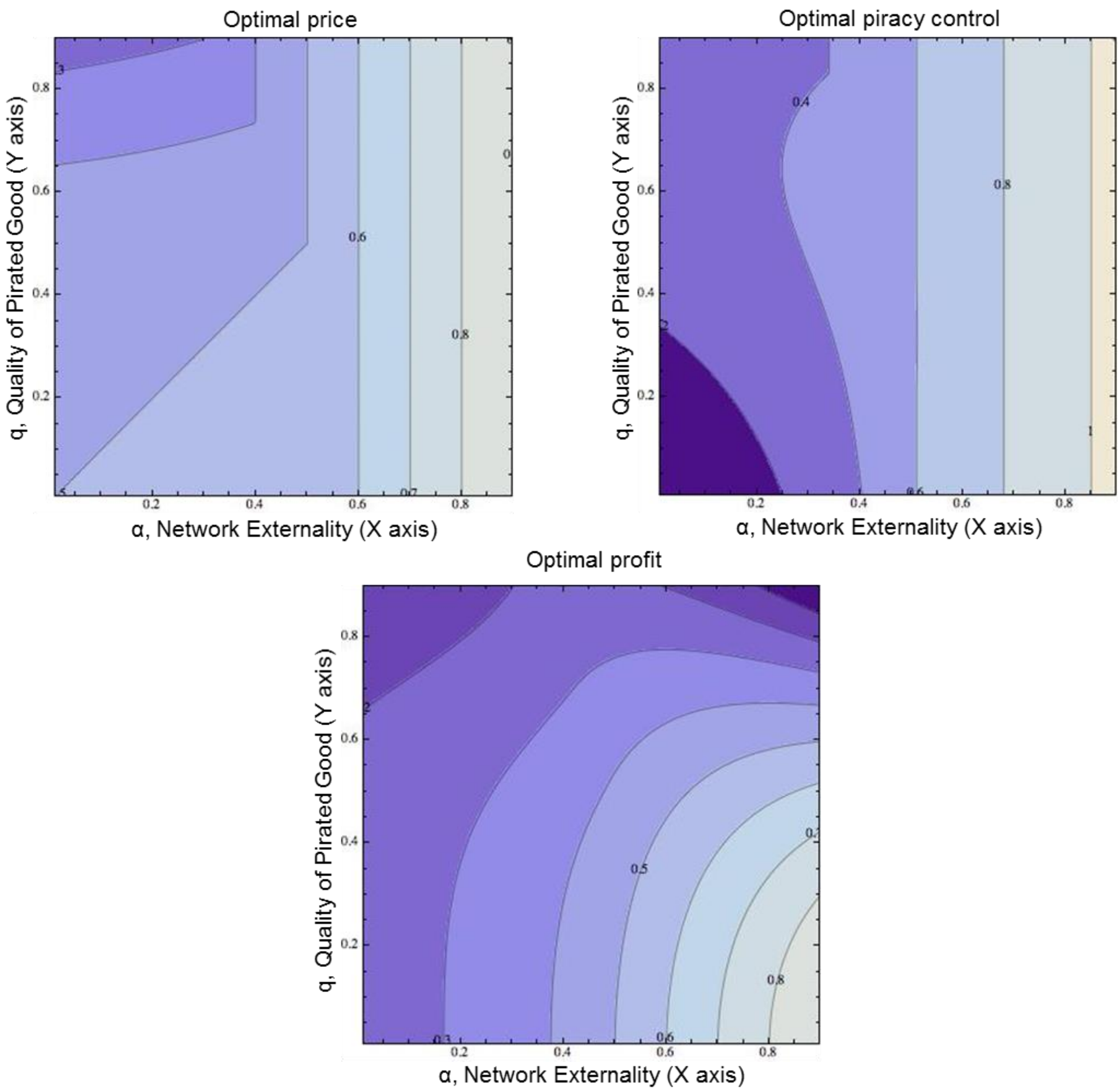


Figure 2. Optimal Price and Piracy Controls

We describe the main implications of our model (as Table 2 and Figure 2 evidence) below.

Implication 1: In response to an increase in the level of externalities, incumbent firms tend to increase both price and piracy control.

Higher network externalities bring added value to legal consumers and pirates. Consequently, the firm captures that value by raising prices. Interestingly, Figure 2 shows that firms find it optimal to do so even when the quality of the pirated good is low. However, such a price rise could have the negative effect of driving some legal buyers out of the market or of transforming them into pirates. One can avoid the former danger by limiting the price increase to the point where the marginal buyer becomes indifferent between buying and doing without it. One can avoid the drawback of a potential increase in piracy, on the other hand, by increasing piracy controls. As a result of such an optimal adjustment, legal demand for a firm's products will tend to increase (or remain constant in case A). As for profits, network externality has an overall positive effect on them because the added revenue fully compensates the increased cost of protection.

Note that our results contrast sharply with those of Conner and Rumelt (1991), who show that a threshold level of network externalities above which profits decrease monotonically with protection exists (implying zero protection with high externalities). They rationalize their model by noting that protection moves some pirates into the buying camp but it also pushes some pirates out of the user base. If externalities are high, the latter effect (i.e., pushing some pirates out of the user base) is very detrimental, and, therefore, the firm chooses not to protect. However, this reasoning requires two very specific conditions: 1) both demand and price are exogenous and 2) all three demand segments exist. In contrast, by treating both price and piracy control as endogenous, our model implies that, at high levels of externalities, firms will choose that combination of these instruments that allows them to eliminate the do-nothing segment and possibly also the pirate segment. In other words, by not assuming the existence of all segments, our results could fall into cases A, B or C, for which the optimal level of piracy control increases with network externalities.

Implication 2: In response to an increase in the quality of pirated goods, incumbent firms tend to decrease both piracy control and price.

An increase in q increases the attractiveness of piracy and, therefore, poses a threat to firms. The comparative statics results of Table 2 show that firms will respond to such a threat by decreasing piracy controls and dropping prices in all cases except Case B where the incumbent product and the pirated good directly compete with each other.

To understand why an incumbent firm lowers piracy controls due to high-quality pirated goods, note that high-quality piracy generates higher externality benefits for legitimate users of the incumbent's product, which causes an incentive to tolerate pirates. In addition, the cost of implementing piracy controls increase with increasing pirate quality[2]. Therefore, increasing piracy controls becomes more costly as pirated goods' quality increases. If incumbent firm attempts to increase piracy-control level, it will have the potentially negative effect of driving some pirates out of the market. Therefore, firms try to avoid converting pirates into do-nothing consumers by dropping prices, which is similar to the effect that Sundararajan (2004) reports. In case B, however, there is no "do-nothing" segment; therefore, the incumbent firm can increase prices to ensure the software is out of the price range of potential pirates. Therefore, in case B, the incumbent firm uses its price and piracy control as two opposing levers to maintain the right balance of pirates in the market.

As Table 2 shows, the quality of pirated goods has a positive overall effect on legal product demand (cases B, C or D) or zero (in case A). In Cases B, C, and D, the added demand counteracts lower prices and higher costs of piracy control, but we show that, for most parameter combinations, profits tend to decline due to an increase in q. This result highlights the importance of maintaining a large quality gap between the legal and illegal copies. As we discuss in Implication 1 above, a larger quality gap is even more crucial with high network externalities. Otherwise, producers face the prospect of lower profits even in the presence of relatively low-quality pirated goods.

3 Introducing Varying Piracy Costs and Open Source Alternatives (OSS)

We enhance model 1 by sequentially introducing two new complications in the analysis. We first model varying piracy costs and next model a scenario with an open source alternative in the choice set.

[2] If incumbent firms' costs to control piracy are independent of pirated good quality, firms will tend to increase the level of piracy control if the pirated good's quality increases. However, as we explain in Section 2.1, it is more reasonable to assume that piracy control costs are likely to increase if pirated good's quality is high.

3.1 Varying Piracy Costs

We now relax the assumption that all consumers have the same cost of pirating (we refer to this as model 2). More specifically, we assume that the cost of pirating per unit of piracy is a uniform random variable with $c \in [0, 1]$. We assume the distribution of c to be independent of the distribution of the consumers' valuation of the good (X). Since c is a random variable, the regions for the different segments differ.

1. A consumer would buy the incumbent product if $x \geq \alpha(\psi_{leg} + q\psi_{pir}) + p$ [Line (1)] AND $x(1-p) \geq p - cL$ [Line (3)] (7)
2. A consumer would pirate if $qx - cL + \alpha(\psi_{leg} + q\psi_{pir}) \geq 0$ [Line (2)] AND $x(1-p) \leq p - cL$ [Line (3)] (8)
3. A consumer would choose to do-nothing if $x \leq \alpha(\psi_{leg} + q\psi_{pir}) + p$ [Line (1)] AND $qx - cL + \alpha(\psi_{leg} + q\psi_{pir}) \leq 0$ [Line (2)] (9)

Figure 3 shows the regions for the three outcomes for the given values of *p* and *L*. The three line segments correspond to the lines identified in the three conditions stated above in Equations 7, 8, and 9. Given the complexity of the demand equations, closed-form solutions to the optimization problem were intractable.

From Figure 3, we observe that one can eliminate the do-nothing segment when *p* = *α*. At this point, the piracy region (blue stripes in Figure 3) increases with *q* and *α*. Thus, the implications of an increased pirated good quality and network externality remain similar to that under Implication 2 in this case.

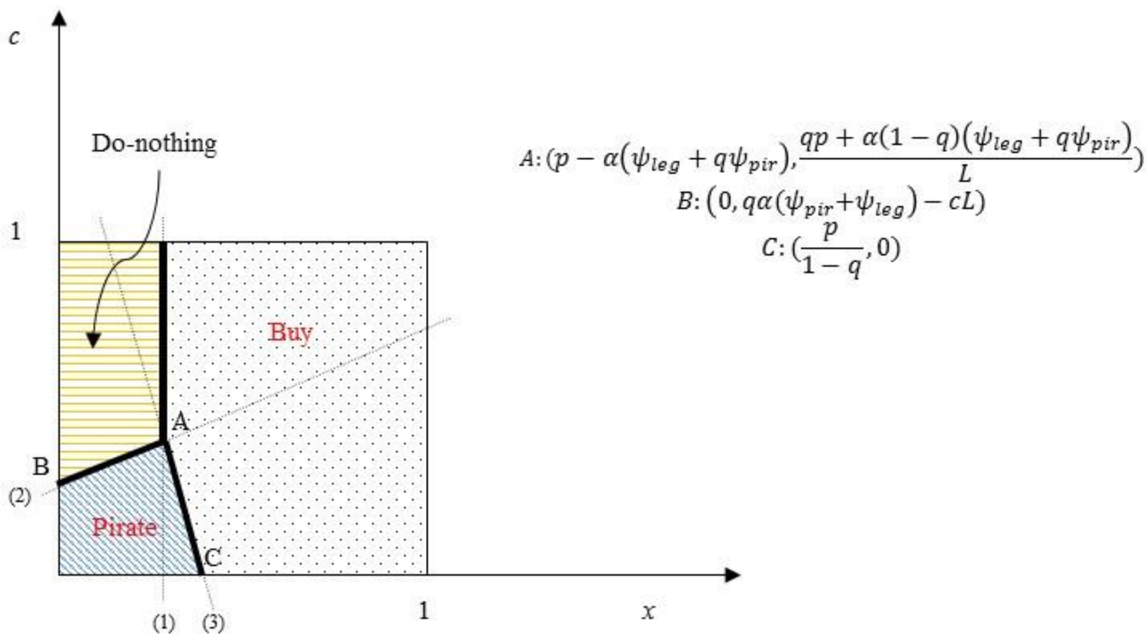


Figure 3. Demand Regions with Consumers Distributed Randomly Over x and c

3.2 Model with Open Source Alternative

We now introduce a non-profit seeking open source alternative (OSS) in the consumers' choice set. We assume that consumers value this new alternative (*Y*) uniformly over $Y \in [0, \theta_Y]$. An Incumbent firm's product quality is assumed to be higher than the quality of the pirated good ($q_P < 1$) and the OSS alternative ($q_O < 1$). In this setting, the OSS sells at a price p_O, which may be zero or a relatively small positive value to reflect service costs that may be associated with its use. The incumbent firm continues to charge its own price (*p*). One may define consumer utility in the presence of OSS as (model 3):

$$U_i = \begin{cases} X_i + \alpha(\psi_{leg} + q_P\psi_{pir}) - p & \textit{Buy a legitimate copy from incumbent} \\ q_O X_i + \alpha q_O \psi_O - p_O & \textit{Buy an OSS copy} \\ q_P X_i + \alpha(\psi_{leg} + q_P\psi_{pir}) - cL & \textit{Buy a pirated copy} \\ 0 & \textit{Do nothing} \end{cases} \quad (10)$$

Open-source consumers also benefit from network externalities (α), and we assume that the overall externality benefit depends on the mean quality of OSS alternatives (q_O). As such, consistent with the assumption we make for pirated copies (see Section 2.1), for any given user-base, a lower-quality product will generate smaller externality benefits for its consumers. We also note that a base level of externality benefit would accrue from using any available product in a software market. However, producers can confer unique externality benefits for users of a specific product. From this perspective, one can consider the externality benefits in our model as the incremental benefit over and above the base level conferred to all users.

To more clearly illustrate the segments, we assume *Yi* = *Xi* (otherwise, one would need a three-dimensional graph to represent the regions).

1. A consumer would opt to do-nothing if $q_O x < p_O - \alpha q_O \psi_O$ [Line (1)] AND $q_P x < cL - \alpha(q_P \psi_{pir} + \psi_{leg})$ [Line (2)] AND $x < p - \alpha(q_P \psi_{pir} + \psi_{leg})$ [Line (3)] (11)
2. A consumer would opt for the open source alternative if $q_O x \geq p_O - \alpha q_O \psi_O$ [Line (1)] AND $(q_O - q_P)x \geq p_O + q_P \alpha \psi_{pir} + \alpha \psi_{leg} - cL - \alpha q_O \psi_O$ [Line (4)] AND $(1 - q_O)x < \alpha q_O \psi_O - p_O + p - (\alpha \psi_{leg} + \alpha q_P \psi_{pir})$ [Line (5)] (12)
3. A consumer would buy the incumbent product if $x \geq p - \alpha(q_P \psi_{pir} + \psi_{leg})$ [Line (3)] AND $(1 - q_O)x \geq \alpha q_O \psi_O - p_O + p - (\alpha \psi_{leg} + \alpha q_P \psi_{pir})$ [Line (5)] AND $x(1 - q_P) \geq p - cL$ [Line (6)] (13)
4. A consumer would pirate if $q_P x \geq cL - \alpha(q_P \psi_{pir} + \psi_{leg})$ [Line (2)] AND $(q_O - q_P)x < p_O + q_P \alpha \psi_{pir} + \alpha \psi_{leg} - cL - \alpha q_O \psi_O$ [Line (4)] AND $x(1 - q_P) < p - cL$ [Line (6)] (14)

For the given values of *p* and *L*, Figure 4 shows a possible arrangement of the regions for the four outcomes. The six lines correspond to the lines we identify in the conditions in Equations 11-14.

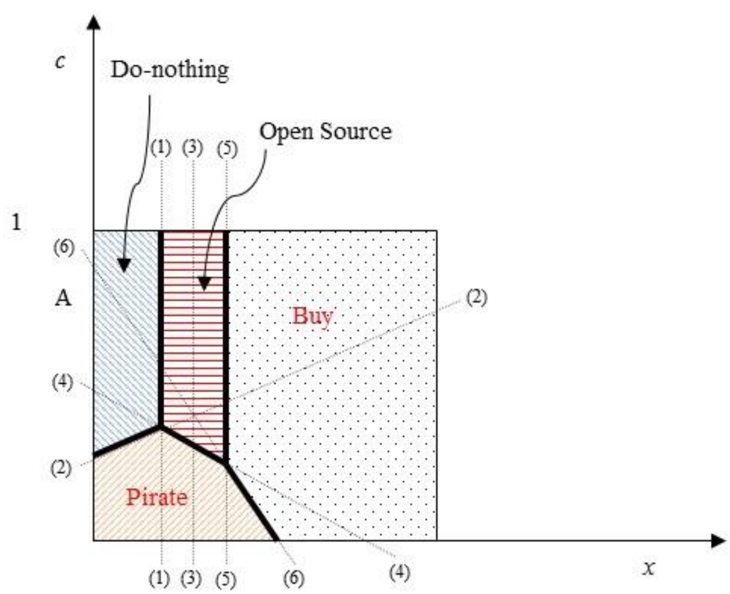


Figure 4. Possible Demand Segments for Model 3

4 Numerical Simulations

Since closed-form solutions to model 2 (varying piracy costs) and model 3 (open source alternative) are intractable, we conducted extensive numerical simulations. More specifically, we simulated a more general specification of model 3 that allowed the correlation between the intrinsic valuations of the incumbent firm's copy (X_i) and the OSS copy (Y_i) to vary. In model 3 (Equation 10) the valuation of OSS is, for every consumer, a fixed proportion of the valuation of the incumbent firm's good ($Y_i = q_0 X_i$), which implies that X and $Y$are perfectly correlated. We generated random samples of 1000 consumers, whose individual values of $X_i$and Y_i (i=1,2,3,…..1000) we randomly sampled from uniform distributions in the [0-1] and [0-θ_Y] intervals, respectively ($\theta_Y < 1$). The mean valuation of OSS ($E(Y) = \theta_Y/2]$) and the correlation with X_i [$Corr(X,Y)$] could vary. One can interpret the ratio $E(Y)/E(X) = \theta_Y$ as the average quality of the open source product (q_0). We also drew the unitary costs of pirating c_i from a uniform distribution in the [0-1.5] interval. Thus, this model has three additional parameters relative to models 1 and 2: $E(Y)$, $Corr(X,Y)$ and p_0. We used the following parameter values in the simulations: α= (0.2, 0.4, 0.6, 0.8, 1); q_P = (0.2, 0.4, 0.6, 0.8, 0.95, 0.99); $E(Y)$ = (0.1, 0.3), which implies q_0 = (0.2, 0.6); $Corr(X,Y)$ = (0, 0.5, 1); and p_0= (0, 0.2). Therefore, we had 360 (5*6*2*3*2) possible combinations of parameter values.

The simulations proceeded as follows:

1. Given the individual values of X_i and c_i drawn from uniform distributions as described above, we began by fixing the values of the model parameters: α, q_P, $E(Y)$, $Corr(X,Y)$, and p_0 .
2. Consistent with the adopted values of $E(Y)$ and $Corr(X,Y)$, we randomly sampled individual values of Y_i from a uniform distribution.
3. Over a pre-specified grid of values of p and L, we solved the model by computing: 1) the utility levels of the four alternatives (proprietary good, pirated good, open-source, and do-nothing) for each consumer through Equation 10 and 2) the proportions of consumers who chose each alternative (demand levels) that resulted from each consumer's choosing the alternative with the highest utility.
4. Given the level of demand for the proprietary good found in the previous step for each combination of p and L, we computed the corresponding level of firm profit through $\pi_{leg} = p\psi_{leg} - (Lq)^2$. We then selected the profit maximizing (*p, L*) combination.
5. We repeated steps 1 to 4 for each combination of model parameters. For each one of those simulations, we tabulated the exogenous parameter values, the profit maximizing levels of p and *L*, the demand levels ψ_{leg}, ψ_{pir}, ψ_{OS} and the producer profit π_{leg}.

We simulated model 2 following a similar procedure, but, since three of the parameters $E(Y)$, $Corr(X,Y)$ and p_0 were absent, the model contained only 30 different combinations of α and q.

To understand the impact of market conditions on firm strategy, demand, and profits, we pooled the data from the two models and regressed the equilibrium values of the endogenous variables on: 1) the levels of quality and network externalities (q and α), 2) a dummy variable (D_{OSS}) that takes the value of 1 when the OSS alternative is present in the market (model 3) and zero otherwise (model 2), 3) an interaction term (q*α) between quality and externalities (since we conclude in Section 2.3 that externalities mediate the effects of pirated goods quality on the seller of the proprietary good), 4) interaction effects between D_{OSS} and all model parameters. We adopted non-linear equations in those regressions as we explain in Section 4.2 below.

4.1 Model Validation

To validate the model, we also simulated model 1 with which we could compare the simulation results to the analytical model solutions (no open source and fixed *c* as in Section 2). We compared the numerical results obtained from the closed-form solutions of the base model (model 1) with that of the simulation program. The results obtained from the simulation program at various parameter values were close to optimal solutions. Table 3 shows a sample of these results. In general, the simulation results align with the analytical results and, more importantly, we observe that the direction of change in optimal values is the same in the two models.

4.2 Model Results

We use regression analysis to examine how the equilibrium variables respond to the model parameters. More specifically, Table 4 reports the main effects of estimating those relationships with a logistic functional form and Table 5 reports the main and interaction effects. We found that the regression estimation fit the data well. Note that $E(Y)$, p_0 and $Corr(X,Y)$ could only enter the estimated equation through such interactions since the simulation program defines them only in the presence of OSS (i.e., when $D_{OSS}=1$).

Table 3. Comparison of Analytical Model and Simulation Results

α	q	p*	p* (sim.)	L*	L* (sim.)	ψ_{Leg}	ψ_{Leg} (sim.)	ψ_{pir}	ψ_{pir} (sim.)	$\psi_{do\text{-}nothing}$	$\psi_{do\text{-}nothing}$ (sim.)	Profit	Profit (sim.)
0.2	0.6	0.421	**0.46**	0.414	**0.44**	0.724	**0.697**	0.000	**0.006**	0.276	**0.297**	0.243	**0.251**
0.2	0.8	0.308	**0.3**	0.375	**0.36**	0.865	**0.873**	0.000	**0.034**	0.135	**0.093**	0.177	**0.179**
0.2	0.99	0.210	**0.24**	0.280	**0.32**	0.987	**0.966**	0.000	**0**	0.013	**0.034**	0.131	**0.131**
0.4	0.2	0.505	**0.52**	0.487	**0.5**	0.825	**0.834**	0.000	**0**	0.175	**0.166**	0.407	**0.424**
0.4	0.4	0.500	**0.5**	0.533	**0.54**	0.833	**0.867**	0.000	**0.015**	0.167	**0.118**	0.371	**0.387**
0.4	0.6	0.447	**0.48**	0.554	**0.58**	0.922	**0.897**	0.000	**0**	0.078	**0.103**	0.301	**0.309**
0.4	0.8	0.400	**0.38**	0.533	**0.5**	1.000	**0.983**	0.000	**0.017**	0.000	**0**	0.218	**0.214**
0.4	0.99	0.400	**0.3**	0.533	**0.4**	1.000	**1**	0.000	**0**	0.000	**0**	0.121	**0.143**
0.6	0.2	0.600	**0.62**	0.800	**0.8**	1.000	**0.98**	0.000	**0**	0.000	**0.02**	0.574	**0.582**
0.6	0.4	0.600	**0.62**	0.800	**0.8**	1.000	**0.979**	0.000	**0.001**	0.000	**0.02**	0.498	**0.505**
0.6	0.6	0.600	**0.6**	0.800	**0.8**	1.000	**1**	0.000	**0**	0.000	**0**	0.370	**0.370**

Table 4. Results of Non-linear Regression Analysis with Main Effects

	P	L	ψ_{leg}	ψ_{pir}	ψ_{OS}	π
q	-2.472*** (.091)	-4.083*** (.247)	-.714*** (.118)	2.435*** (.068)	-2.156*** (.358)	-2.604*** (.134)
α	0.993*** (.068)	2.818*** (.191)	.477*** (.096)	.580*** (.047)	-2.164*** (.319)	0.801*** (.088)
D_{OSS}	-.250*** (.081)	-.399** (.188)	-.121 (.126)	-.143** (.057)	-	-.308*** (.098)
D_{OSS}*p_O#	-	-	-	-	-6.871*** (1.139)	-
D_{OSS}*E(Y)#	-	-	-	-	5.376*** (1.01)	-
D_{OSS}*Corr(X,Y)#	-	-	-	-	-.302 (.209)	-
Const	.445*** (.095)	.617*** (.215)	.856*** (.149)	-2.836*** (.080)	-.619** (.318)	-.258** (.118)
N	390	390	390	390	360	390
R^2	.95	.88	.95	.96	.46	.86

Notes: # the three terms are main effects of price of the OSS product (Po), quality of the OSS product (E(Y)), and the correlation between the incumbent and OSS product (Corr (X,Y)). They are relevant only in the presence of OSS.

*** p< 1% ; ** p< 5% ; * p< 10%

Table 5. Results of Non-linear Regression Analysis with Main Effects

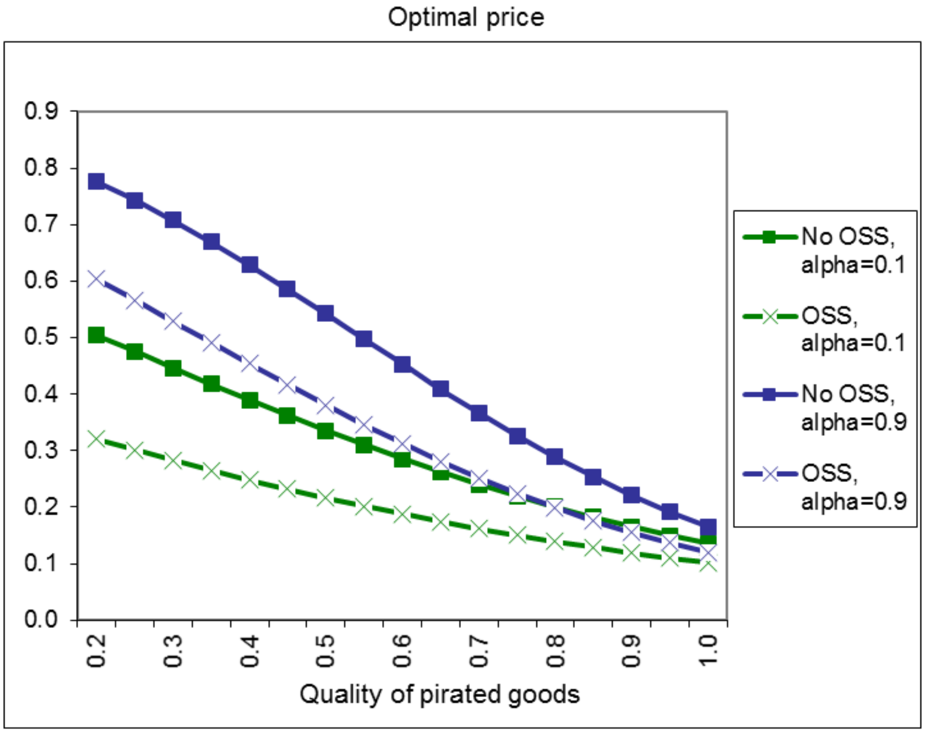
	P	L	ψ_{leg}	ψ_{pir}	ψ_{OS}	π
q	-2.184*** (.287)	-0.818 (.637)	-.334 (.464)	2.502*** (.219)	-1.374*** (.435)	-2.268*** (.422)
α	1.836*** (.225)	6.107*** (.574)	1.292*** (.419)	1.205*** (.194)	-.586 (.579)	1.608*** (.276)
D_{OSS}	-.342* (.182)	-.728* (.406)	-.109 (.356)	-.377** (.188)	-	.139 (.235)
$q*\alpha$	-1.541*** (.216)	-6.905*** (.567)	-1.337*** (.345)	-.878*** (.182)	-3.583** (1.503)	-1.513*** (.333)
$D_{OSS}*q$	.552** (.277)	.825 (.632)	.263 (.454)	.471** (.201)	-	.467 (.398)
$D_{OSS}*\alpha$	-.067 (.202)	.028 (.470)	.045 (.367)	.053 (.148)	-	-.176 (.254)
$D_{OSS}*p_O$	1.497*** (.190)	2.471*** (.417)	.382 (.332)	.761*** (.147)	-6.405*** (1.064)	1.110*** (.260)
$D_{OSS}*E(Y)$	-1.956*** (.193)	-2.689*** (.423)	-1.048*** (.336)	-1.142*** (.149)	5.543*** (.996)	-2.947*** (.273)
$D_{OSS}*Corr(X,Y)$	.116** (.046)	.294*** (.100)	-.047 (.081)	.014 (.036)	-.181 (.203)	-.208*** (.063)
Const	.301* (.177)	-.711* (.391)	.634* (.347)	-2.880*** (.192)	-1.122*** (.342)	-0.487** (.227)
N	390	390	390	390	360	390
R^2	.97	.93	.95	.97	.47	.90

To illustrate our main results, we also show in Figures 5, 6, and 7 how the fitted values of the endogenous variables vary with the quality of the pirated good. We do so for two extreme levels of network externalities ($\alpha = 0.1$, $\alpha = 0.9$) and also for the “OSS absent” and “OSS present” scenarios.

Our results confirmed the overall implications in Section 2.3. For example, Tables 4 and 5 show that price (P), piracy controls (L), legal demand (ψ_{leg}) and profits (π) are positively and significantly related to network externalities (in accordance with Implication 1). Similarly, a higher-quality pirated good has a negative effect on an incumbent firm’s piracy control, price, and profits (consistent with Implication 2). Finally, the negative estimate for $q*\alpha$ in the profit equation confirms that increases in the quality of the pirated good harms the incumbent firm more at high externality levels (consistent with Implications 1 and 2). Next, we investigate the impact of the appearance of an OSS alternative in the market (relative to the “no OSS” case).

Implication 3: The existence of open-source software in the market causes the incumbent firm to not just charge lower prices but also be more tolerant towards piracy.

The significant parameter estimates of D_{OSS} in Table 4 show the main effects of an open source alternative on price and piracy control. We observe the same effects in the more fully specified models in Table 5. The impact of an open source alternative on price is in line with Casadesus-Masanell and Ghemawat’s (2006) findings, and one can regard them as a consequence of lower market power. Lower piracy control results from the fact that, under network externalities, pirates become firms’ allies against the threat that OSS poses. One can clearly see both of these effects in Figures 5, 6, and 7 by comparing the “no OSS” and “OSS” lines. Thus, while price and piracy controls reduce in response to a higher-quality pirated good, these strategic actions mitigate the detrimental effects of OSS. Interestingly, the levels of piracy tend to be lower in the presence of OSS, which suggests that the existence of a zero (or very low) price OSS alternative and the lower price of proprietary software outweigh the stimulus that lower piracy controls provide to privates. Also, the open source alternative had no significant impact on incumbent’s demand. Thus, OSS products are more likely to attract consumers who would have otherwise pirated.



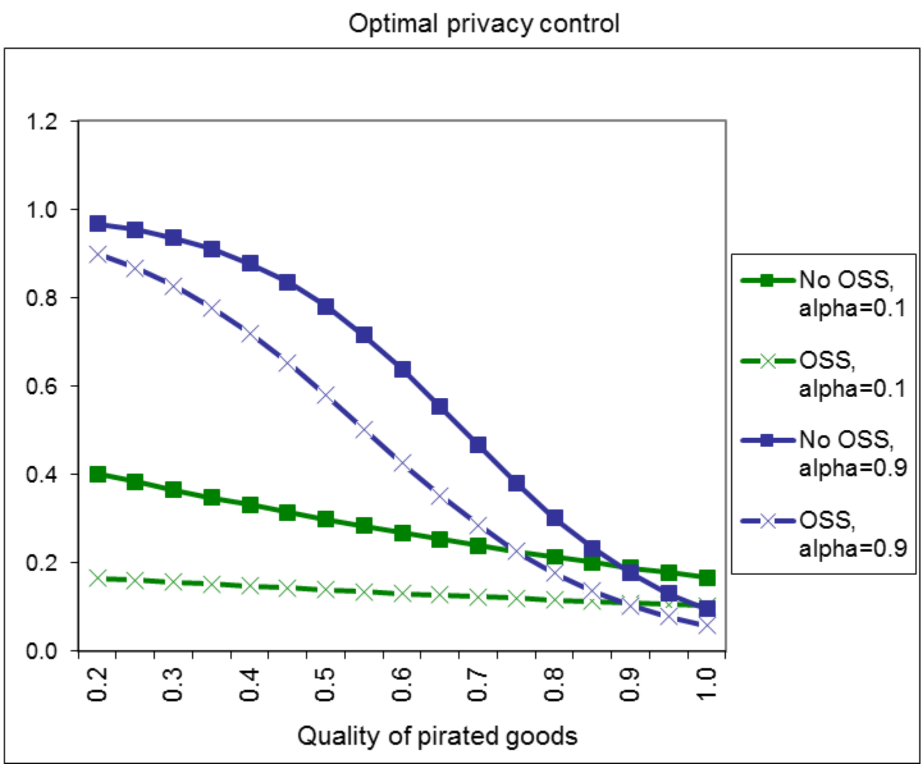


Figure 5. Estimated Levels of Endogenous Variables as a Function of the Quality of Pirated Goods

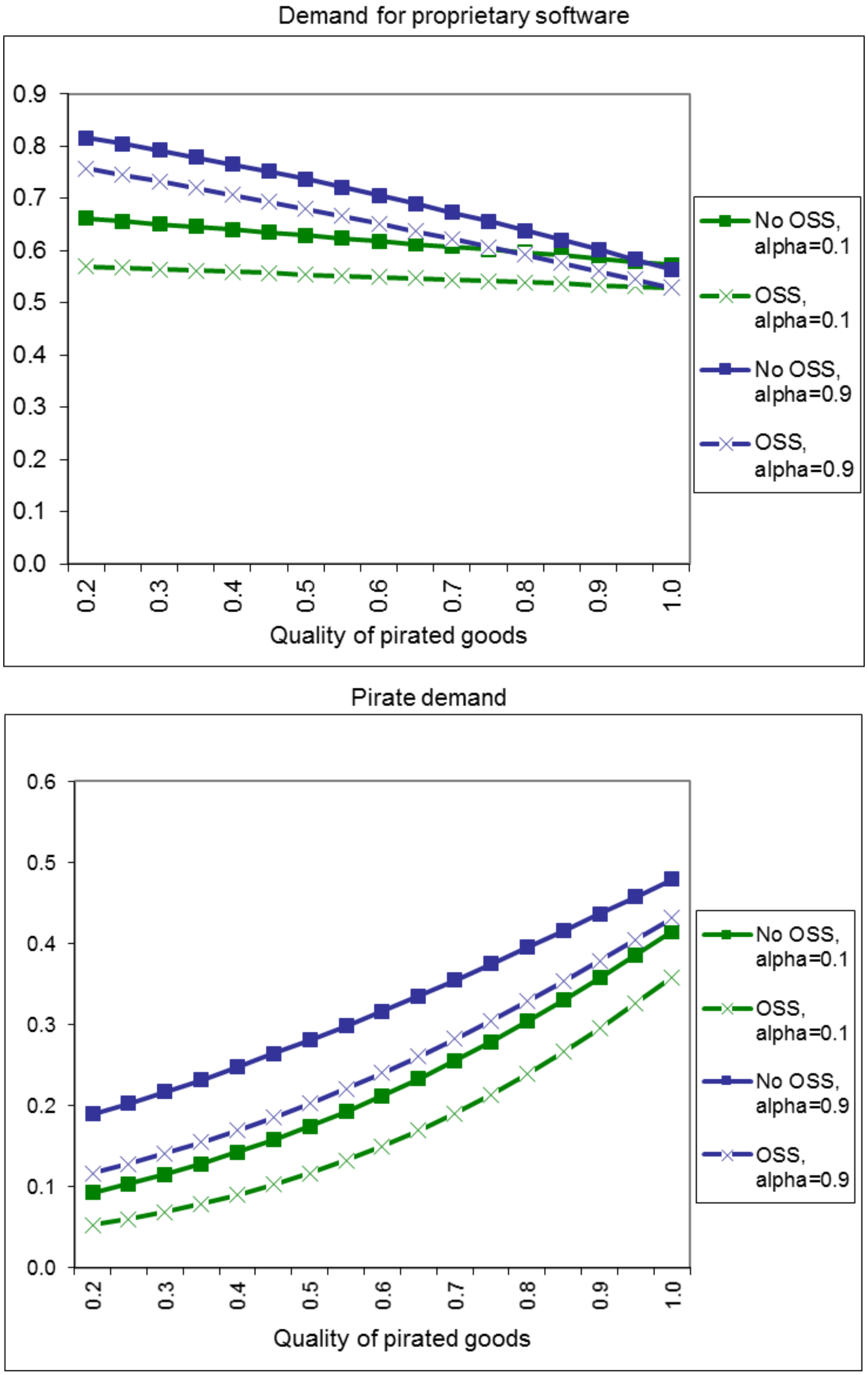


Figure 6. Estimated Levels of Endogenous Variables as a Function of the Quality of Pirated Goods

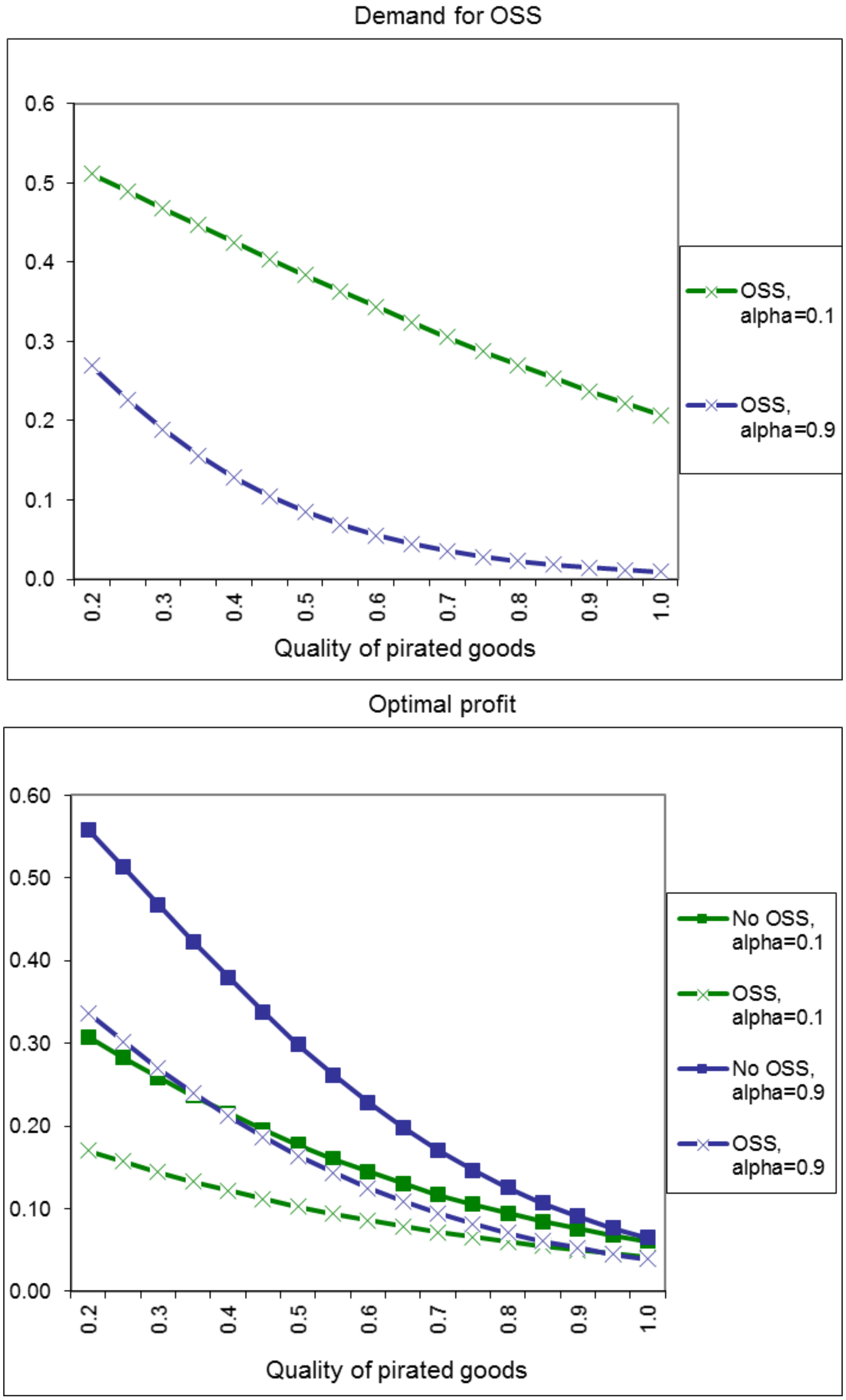


Figure 7. Estimated Levels of Endogenous Variables as a Function of the Quality of Pirated Goods

Implication 4: An incumbent's profit loss due to OSS tends to be smaller in comparison to high-quality pirated alternatives.

In Table 4, the estimated parameters of q and D_{OSS} suggest that high-quality pirated goods more severely affect a firm's profits than the presence of an OSS alternative does. As for why, OSS products mainly cause likely pirates to switch to them (note the lack of significance of D_{OSS} on incumbent demand in Table 4). Further, as the negative effect of D_{OSS} on piracy control indicates, incumbent costs go down as well. The combined effect results in a somewhat muted impact on profits. The joint impact of q and D_{OSS} is also interesting in this context. We observe that the joint impact q and D_{OSS} results in increase in price but not on piracy control and has no impact on profit. The intuition for this is that the joint impact contributes to profit through price increase (note there is no significant impact on incumbent demand) and the higher-quality pirated good also contributes to an increase in the demand for pirated good. In essence, the preservation of externality benefits due to increased pirate demand enables firm to successfully counter negative impacts on the bottom line. Consequently, despite being very detrimental in the absence of OSS, high-quality piracy mitigates the negative effects that the emergence of an open-source competitor imposes on the incumbent. This result is also clearly visible in Figures 5, 6, and 7 (with the distance between the "No OSS" and the "OSS" profit lines declining as q increases).

Implication 5: Higher-quality OSS alternatives force firms to lower their product's prices and piracy controls, which results in lower overall demand for the firm's product and its pirated copies. On the other hand, highly correlated intrinsic valuation may cause firms to increase their product's price and piracy controls.

Higher-quality OSS affects price and piracy controls in a fairly straightforward and expected manner. However, correlated valuation affects them in a more nuanced manner. Consider a fixed ratio between mean consumers' valuations of the two goods. A higher correlation in valuation implies that the two products in the market offer similar intrinsic features and benefits. A side benefit of commonality in features (and the increase in piracy control) is that many pirates may find it beneficial to adopt OSS. However, any consumer switching from pirating incumbent's product to adopting OSS reduces externality benefits for the incumbent group. The extent to which an open source alternative reduces externality benefits depends on the quality of the pirated good (and the magnitude of the externality parameter). Moreover, increase in price may cause some consumers to either pirate (despite higher piracy control) or switch to OSS or do-nothing. As such, the opposing effects of price and piracy controls due to correlation in intrinsic valuation limit the shifts in demand. The significant negative impact on profit will result from the incumbent firm's increased costs of implementing higher-level piracy controls.

5 Discussion and Conclusions

To our knowledge, this study is the first to investigate the strategic options for dealing with product piracy in the presence of an OSS alternative. We propose a theoretical model to discuss the impact of OSS and other market conditions on market equilibrium and the choice of policy instruments. We also perform a simulation analysis of how the quality of pirated software and the presence of an OSS alternative impacts endogenous decision variables (piracy control and price), demand and profit.

Our theoretical model indicates that network externalities contribute to increasing firms' products' price, piracy controls, and the profits they make. Thus, in contrast to most of the existing literature, we show that it may be optimal to increase piracy protection in response to increasing network externalities. However, we also show that, when the quality of the pirated good increases, an incumbent firm chooses to lower piracy control level and price. As such, firms may need to innovate more with their pricing models. In fact, some firms have already begun to do so. Recently, Microsoft shifted to a strategy in which it pre-installs a limited-feature Office version on new computers. When one buys the computer and uses the software, the software prompts consumers to purchase the full version. Such presumably forced sampling can potentially reduce some consumer segments from pirating. One could also offer free or lower-cost upgrades to consumers who may have already used previous versions of a product. For instance, Microsoft and Apple offer free operating systems upgrades to previous users. Besides increasing the overall value of the software product, free upgrades can also be effective in combating OSS competitors. To summarize, our research reveals that the quality differential between a legal good and its pirated version is an important determinant of equilibrium outcomes.

As our results demonstrate, network externalities amplify high-quality piracy's detrimental effect on an incumbent firm's profits. Therefore, our results highlight the importance of maintaining a large quality gap between a product and its illegal substitutes, particularly in markets characterized by high network externalities. One effective approach to lowering pirate good quality is to limit software updates and patches to legitimate copies only. Such an approach is becoming prevalent among most consumer software goods producers.

Our simulations of the theoretical model also yielded important insights regarding the appearance of an OSS alternative in the market. Specifically, we show that OSS reduces the profits of a legitimate firm and causes both its product's price and piracy controls to drop. This finding lends credence to some anecdotal observations made in industry publications. For example, Baker (2009, p. 1) identifies the rise in popularity of OSS as one of the main reasons why Microsoft, "a company known to be almost brutal in its license-protection strategies, softened its approach to piracy.".

The effects of an open source alternative on a firm's strategies, sales, and profits also depend on several other factors. We highlight the role of pirated goods' quality in moderating the impact of OSS alternatives on the demand for an incumbent's product and its profit. Specifically, we demonstrate that, although OSS alternatives reduce profits for an incumbent, the presence of a high-quality pirated good mitigates this impact. Thus, although a wholehearted attempt at fighting pirates is the optimal strategy in the absence of OSS, tolerating the presence of high-quality pirated goods may actually be beneficial in the presence of OSS. This finding suggests that, when a firm has two powerful enemies to contend with (i.e., OSS and pirated software), the presence of the less powerful enemy (i.e., high-quality pirated good) is a blessing in disguise for the incumbent firm.

Several important research questions still remain in this domain. For instance, some consumers may prefer to try multiple alternatives simultaneously, and we did not account for this possibility in our models. The implication of multi-period dynamics of endogenous demand and firms' strategic decisions is also an important open research question. A dynamic model could also explore the strategic interactions between an OSS entrant and an established incumbent firm's product. Further, when an established incumbent firm moves to application (app) markets where piracy is becoming more prevalent, future research could examine using updates as a strategic tool to combat the threat of piracy in the presence of open source (free) apps.

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