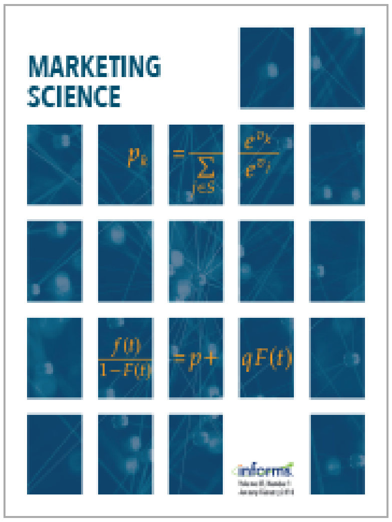

Marketing Science

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MARKETING SCIENCE
Vol. 34, No. 2, March–April 2015, pp. 218–234
ISSN 0732-2399 (print) | ISSN 1526-548X (online)

http://dx.doi.org/10.1287/mksc.2014.0894

Pricing Information Goods: A Strategic Analysis of the Selling and Pay-per-Use Mechanisms

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We analyze two pricing mechanisms for information goods. These mechanisms are selling, where up-front payment allows unrestricted use, and pay-per-use, where payments are tailored to use. We analytically model a market where consumers differ in use frequency and where use on a pay-per-use basis invokes a psychological cost associated with the well known "ticking meter" effect. We demonstrate that pay-per-use yields higher profits in a monopoly provided the associated psychological cost is low. In a duopoly, one firm uses selling and the other uses pay-per-use. Here, in contrast to the monopoly, selling yields higher profits than pay-per-use. We demonstrate that, surprisingly, the profits of both duopolists can increase as the psychological cost associated with pay-per-use increases. Next, we show that uncertainty in consumer use frequency does not affect pay-per-use in a monopoly, but lowers profits from selling. In a duopoly, both the seller and the pay-per-use provider obtain lower profits when use frequency is uncertain. We also analyze how pricing mechanism performance is affected if the firms cannot commit to prices, if the pay-per-use provider offers a two-part tariff, and if consumers are risk-averse.

Keywords: information goods; competitive strategy; pricing; digital marketing; game theory
History: Received: November 21, 2012; accepted: September 16, 2014; Preyas Desai served as the editor-in-chief and Chakravarthi Narasimhan served as associate editor for this article.

1. Introduction

Advances in network technology have enhanced the popularity of pay-per-use pricing for information goods (Altinkemer and Tomak 2001). With the rapid growth of cloud-based computing, the pay-per-use model is now being applied across use settings including gaming and movies (Machrone 2006), data plans (Chavez 2011), information storage (Clark 2011), monetary transactions (Reeve 2011), billing services, software applications that allow payment on a "per-login" basis, and Computer Aided Design (CAD) suites (Machine Design 2000). In this paper, we analyze the performance of conventional selling and pay-per-use pricing for pure information goods in monopoly and duopoly contexts.

Today pay-per-use and flat-fee pricing models frequently co-exist in information-intensive markets. Consider the media streaming industry. Here, consumers can watch content available at online streaming video providers such as Netflix for a flat fee, or watch movies on a pay-per-use basis using providers such as VUDU.com (Carlozo 2012, Hamburger and Lincoln 2012). The VUDU service allows subscribers to watch more than 17,000 HD movies and TV shows on demand. By contrast, Netflix offered consumers the option to rent movies under the Marquee program in 1999, but changed to a flat-fee plan in March 2000 (Hitt et al. 2012). Use of the pay-per-use mechanism has been accelerated by the growth of cloud storage, computing, and service delivery. For example, Amazon Web Services (AWS) offers computing facilities on its Elastic Compute Cloud platform on a pay-per-use basis (Stadil 2013). Yet not all providers have embraced pay-per-use. For example, radius180 delivers cloud-based managed IT services on a fixed-price basis (radius180 2013).

These empirical observations invoke interesting puzzles in the context of information goods. When should a firm offer one, or both, of these pricing mechanisms? Why do competitors offer distinct mechanisms in a single marketplace? How does competition play out between sellers and pay-per-use providers? How can the pricing mechanisms, in and of themselves, serve as platforms for differentiation? Our research provides insights into these questions.

The design of an effective pricing strategy is highly sensitive to the heterogeneity in consumer valuation for the offering and to consumer use patterns (Chen et al. 2001). Consumers with low use frequencies typically prefer pay-per-use (Altman and Chu 2001, Nicolle 2002). However, paying-per-use imposes some disutility on the consumer. The ticking meter effect (also called the taxi meter effect), which is based on the mental accounting of repeated payments, dampens utility from consumption under pay-per-use because the payment is being visually or mentally racked up even as consumption continues (Prelec and Loewenstein 1998, Soman 2001). We model the resulting disutility as a psychological cost associated with pay-per-use. This cost has been shown to dampen consumer enthusiasm for pay-per-use pricing, leading to what has been termed the flat-rate bias (Train et al. 1987). These effects are not associated with selling where payment is separated from consumption. An enduring theme that emerges from our analysis is the influential role of the psychological cost in determining the relative attractiveness of the pricing mechanisms across the modeled contexts.

The paper is structured as follows. In §1.1 we position our findings and discuss contributions relative to the literature. In §2, we contrast the selling and pay-per-use mechanisms and present some exploratory empirical findings that anchor our model assumptions. We detail the base model in §3. In §4, the monopoly outcomes are derived and discussed. In §5, we analyze the competitive setting and extend the model to address four specialized scenarios. Section 6 provides summarizing remarks and a discussion of possible future areas of research.

1.1. Extant Literature and Contribution

Firms can use leasing and selling to coordinate primary and secondary markets for durable goods (Bulow 1982, Desai and Purohit 1999, Shulman and Coughlan 2007). For most pure-information goods, which is the focus of this paper, a significant secondary market does not exist.

A central feature of pure information goods is that they can be conveniently accessed through multiple pricing mechanisms including selling, site licensing, subscriptions, differential pricing, and pay-per-use pricing (Chuang and Sirbu 1997, Varian 2000). Some studies have compared selling (also known as flat-fee or subscription-fee pricing) and pay-per-use pricing (also known as use-based pricing) in the context of information goods. The most relevant literature is summarized in Table 1. A second stream of literature that is relevant to our work relates to competition between vertically differentiated products. Our analysis and contributions can be positioned relative to both of these literatures.

Table 1 Relevant Literature in Information Goods Pricing

Paper	Setting	Backdrop for analysis	Main findings
Choudhary et al. (1998)	Monopoly	Product introduction in period 1 leads to improved product with network externalities in period 2.	• Renting is more profitable than selling in period 1. • Under strong network effects, the firm lowers the period 1 price to increase network size.
Fishburn and Odlyzko (1999)	Duopoly	One firm charges a fixed subscription fee; the other adopts pay-per-use. Prices are revised periodically.	• A price war is the standard outcome. • Stable equilibria exist only in special cases.
Altman and Chu (2001)	Monopoly	Field experiment with flat and per minute/byte pricing for network access.	• Optimal pricing comprises a flat fee for basic access and a use-based fee for higher service quality.
Essegaier et al. (2002)	Monopoly and duopoly	Flat-fee, use-based and two-part tariff-based pricing are offered in a setting with capacity constraints and customers who demand high or low capacity allocation.	• In a monopoly, two part pricing may not always be optimal. When light users are more valuable, the monopolist may charge a flat or two-part fee, but never a use price alone. • To accommodate competition, a large capacity firm may increase price and reduce capacity.
Jain and Kannan (2002)	Monopoly and duopoly	Consumers vary in terms of how they value information units and access time. Firms can price based on connect time or successful search, or use a subscription model.	• Search-based pricing is usually most profitable. • Under competition, one firm serves less (more) sophisticated customers with search/ subscription-based (connect time) pricing.
Sundararajan (2004)	Monopoly	Consumers vary in terms of how they value the information good. A monopolist can offer a fixed fee and/or use-based contracts.	• A combination of a fixed fee and use-based pricing always increases profits. • The optimal use-based pricing schedule is independent of the fixed fee.
Jiang et al. (2007)	Monopoly	Customers have differing valuations for the product.	• Pay-per-use is more profitable in the presence of (a) network effects and (b) piracy.

In a broad sense, the selling mechanism in our model represents the high-end good relative to pay-per-use because it captures high-end consumers who use the good frequently and who, unlike pay-per-use, are not saddled with the psychological cost associated with each use occasion. However, the structure of the consumer utility streams and the payment patterns differ from those in a conventional vertically differentiated product setting. The question that arises is whether those differences lead to qualitatively different insights related to the effectiveness of the pricing mechanisms when compared to the conventional setting. In this context, we first demonstrate that if a monopolist needs to choose one pricing mechanism, it should use pay-per-use if the associated psychological cost is low, and selling mechanism only if that cost is high. If both mechanisms can be used, then pay-per-use captures a larger (lower) share of the market if the associated psychological cost is low (high). These findings can be compared to those in the well known vertical product differentiation model of Shaked and Sutton (1982). While the models across the papers are not identical, if the results from Shaked and Sutton (1982) are extrapolated to a monopoly context, the high-quality product will yield higher profits and will be introduced into the market. By contrast, in our model, provided the psychological cost is sufficiently low, profits from pay-per-use are higher than profits from selling in a monopoly. Therefore, the pricing mechanisms we study have interesting properties that differ from the classic vertical product differentiation context.

Second, we examine the competitive context. Here, our findings can be contrasted with Moorthy (1988), again with the caveat that the compared models are not identical. Moorthy (1988) considers product positioning (or quality) and pricing decisions in the presence of a substitute or outside good, and demonstrates that when firms choose product quality simultaneously, it is better to be a low-end supplier. The intuition is that the low-end supplier can influence the quality choice of the high-end supplier more strongly by leveraging the presence of the outside alternative. If the high-end supplier positions its product too close to the low-end supplier, the latter's margins are compressed owing to the pressure to make the low-end product competitive with the substitute. This, in turn, hurts the margins of the high-end supplier. In contrast, we demonstrate that selling, which represents the high-end mechanism in our model, yields higher profits than the low-end mechanism (i.e., pay-per-use) in a duopoly. The firm that sells can leverage the differential ability of that mechanism to capture the temporally aggregated utility of the best, high-use frequency consumers with a single price, leaving less attractive consumers with a low use frequency to the pay-per-use provider. To summarize, the pricing mechanisms that we use, while being vertically differentiated in one sense, deviate substantially from the notion of vertical quality differentiation that has been extensively studied in the literature. Our topic deserves independent research attention.

Third, in the context of pure information goods, our work addresses specific gaps in the literature (see Table 1). The existing literature has considered competition between a designated seller and a designated pay-per-use provider (Fishburn and Odlyzko 1999). In contrast, we analyze the equilibrium that involves the endogenous choice of selling and/or pay-per-use by a pair of competing firms. We characterize two pure-strategy asymmetric equilibria. In one a firm chooses to sell and the other uses pay-per-use. In our mixed-strategy symmetric equilibrium both firms use either mechanism with some positive probability (e.g., Fay 2009). In contrast to the monopoly setting, we demonstrate that profits from selling dominate profits from pay-per-use in a duopoly. In this context, we derive a "defensive positioning" outcome (Hauser and Shugan 1983, Shaffer and Zhang 1995), wherein a firm may optimally choose pay-per-use in a monopoly, but should protect profits by selling the good if it expects competition. Furthermore, the existing literature has not (to our knowledge) considered the key strategic implications of the psychological cost associated with pay-per-use. In addressing this gap, we highlight the surprising finding that as the psychological cost associated with pay-per-use increases, the profits of both duopolists can increase. In particular, the pay-per-use provider has an inverted U-shaped profit profile with respect to the psychological cost, as that cost increases from zero. The particularly interesting aspect of this finding is that though the psychological cost is borne by the pay-per-use provider (unlike, for example, the transportation cost that affects both competitors in the classic Hotelling model) the profits of both the pay-per-use provider and the seller initially increase in the psychological cost.

Finally, there are some practically relevant and important scenarios related to the pricing of pure information goods that deserve attention, but have not (to our knowledge) been sufficiently analyzed in the literature. We extend the model to address these gaps. First, because the information good is consumed across time, the use frequency may not be perfectly predictable. We demonstrate that such uncertainty hurts selling but not pay-per-use in a monopoly. Uncertainty lowers the profits of both mechanisms in a duopoly. Second, given the multiperiod consumption pattern of the information good, firms may be unable to credibly commit to announced prices. We demonstrate that, in a monopoly, this inability does not affect pay-per-use, but does reduce profits from selling. In a duopoly, the lack of price commitment invokes a competitive effect and a commitment effect that interact to yield some interesting findings. We demonstrate that when the psychological cost is low, surprisingly, both firms benefit from the lack of price commitment. However, this finding is reversed when the psychological cost is high, and both firms have lower profits when they cannot commit to prices. Third, the pay-per-use provider could choose to use a two-part tariff that includes a fixed fee in addition to the payment-per-use. We demonstrate that the use of a two-part tariff is closely tied to the notion of capacity constraints. Interestingly, the issue of capacity constraints in the context of broadband delivery of pure information goods has been in the spotlight recently with the Federal Communication Commission's (FCC's) proposed regulations related to the breakdown of Net Neutrality (Flint 2012). Streaming content provider Netflix, which alone accounts for nearly 35% of downstream Internet bandwidth during peak use hours, has already signed agreements with broadband providers Comcast and Verizon to ensure high-quality consumer access to streamed content. We demonstrate that in a monopoly, the pay-per-use provider can use a two-part tariff to screen out low frequency users when faced with a capacity constraint, and increase profits by focusing on high frequency users. In a duopoly, we demonstrate that a two-part tariff will be used by the pay-per-use provider only when there is both a capacity constraint and a high psychological cost. Therefore, in selected situations, the pay-per-use provider can use two-part tariffs to regulate use and increase profits. Finally, we demonstrate that our findings are impacted in predictable ways when consumers are assumed to be risk averse, with selling becoming relatively more attractive than pay-per-use in both monopoly and duopoly contexts.

2. Contrasting Selling and Pay-per-Use

When consumers are faced with an expected pattern of use for an information good, they tend to favor a flat rate (consistent with selling) over pay-per-use, even when the expected payments under the mechanisms do not differ. This preference is referred to as the flat-rate bias. As Train (1991, p. 211) notes in the context of a communications service: "…consumers seem to value flat-rate service over measured service even when the bill that the consumer would receive under the two services, given the number of calls the consumer places, would be the same."

To anchor our model, we first conducted two studies to gauge the beliefs and preferences of practicing managers and consumers related to the pricing mechanisms. In Study 1, a total of 90 managers randomly chosen from an alumni database were first presented with the following scenario: "A consumer needs to choose between two phone service providers. The first provider charges a flat fee of \$20 a month. The second provider charges a fee of \$0.20 per minute of calling. The consumer has historically called for 100 minutes per month, on average. Which provider do you think the consumer will choose?" Reflecting the flat-rate bias, 38 of the 44 responses received indicated that the consumer would choose the flat fee option over the pay-per-minute option ($\chi^2(1) = 23.27$, $p < 0.0001$). The responding managers were also asked to explain their choice. The offered explanations predominantly focused on eliminating the tension associated with tracking the calling minutes and the associated benefits of a predictable calling budget under flat fee pricing.

Consistent with these findings, a key driver of the flat-rate bias is the ticking meter effect. This effect was described by Prelec and Loewenstein (1998, p. 4): "When people make purchases, they often experience an immediate pain of paying, which can undermine the pleasure derived from consumption. The ticking of the taxi meter, for example, reduces one's pleasure from the ride." The ticking meter effect imposes a psychological cost that lowers the utility derived from the pay-per-use.

More recently, Lambrecht and Skiera (2006) detailed the multiple effects that can lead to the flat-rate bias:

(a) The insurance effect: This relates to the notion that risk-averse consumers who wish to avoid fluctuations in their monthly bill but can predict use only with limited accuracy will prefer a flat-rate over pay-per-use.

(b) The taxi meter (or ticking meter) effect: This relates to the notion that the ticking meter associated with pay-per-use detracts from utility.

(c) The convenience effect: This relates to the notion that the flat-rate is computationally straightforward and efficient. Lambrecht and Skiera (2006) find no empirical support for this effect; this may reflect the fact that with automated billing the physical inconvenience related to tracking and making multiple payments is now lower that it was in the past.

(d) Overestimation effect: This relates to the notion that consumers frequently overestimate projected demand and act to cover that (projected) high level of use by choosing a flat rate. This is related to the insurance effect in the sense that a flat rate can insure against more-than anticipated use, if it occurs.

To gauge the relevance of these effects in the context of information goods, we conducted another study using an online survey platform. By contrast to the managerial focus of Study 1, this study focused on the consumer's perspective. Prospective consumers who were randomly chosen on a survey platform were asked to respond to the following situation: You are in an airport lounge in the middle of an extended trip. You need to leave the lounge to proceed to board your flight about three hours from now. You need to use one hour to do some research using an online database provided by a reputable provider for a personal project (the time spent can vary between 50 minutes to an hour and 10 minutes, and the average time you expect to do your research is an hour). You log into the database on your laptop using the free WiFi system provided in the lounge. Once you proceed to the secure database website, you find that the database provider offers you two payment options. Each option requires you to provide credit card information before you begin to use the database.

Option 1. You are charged \$6 upfront for unlimited use for a day.

Option 2. You pay \$0.10 for every minute of use. If you choose this option, a small counter in one corner of the computer screen will keep track of the number of minutes you have used the database.

Participants were asked to choose between Options 1 and 2 first. After they made their choice, they were asked to indicate which of the following reasons influenced their preference (multiple choices were allowed):

— I like the security that my database access costs will never go above the amount agreed upon.

— I find it hard to work using the database when I have to think about the costs increasing every minute.

— It's too much trouble to compare the prices, so the easier option is what I chose.

— I may use the database for more time than I expected.

— I may use the database for less time than I expected.

— Any other reason (if participants chose this option, they were also asked to detail their reasoning).

Of the 101 responses received, 87 preferred the flat rate option, again demonstrating the flat-rate bias ($\chi^2(1) = 52.76$, $p < 0.0001$). In addition, 51 participants listed the first choice (insurance effect) as one of the underlying causes of their preference, 48 participants listed the second choice (ticking meter effect), 2 participants listed the third choice (convenience effect), 71 participants listed the fourth choice (overestimation effect), 17 participants listed the fifth choice (underestimation effect). Note that the overestimation and insurance effects also feed into the ticking-meter effect. Specifically, ex ante, if consumers are concerned about prolonging use beyond what was planned and are worried about the variance in payments, that would make the ticking meter effect even more salient during consumption.

We incorporate the ticking meter effect into the main model because it is the only effect that directly detracts from consumption utility on each use occasion. As a consequence, and as we will demonstrate, the ticking meter effect drives some interesting and counterintuitive findings, especially in the duopoly context. The insurance and (related) overestimation effects are more in the spirit of additional fixed costs associated with pay-per-use at the mechanism level. For completeness, and as noted in §1, we extend the base model to study the effect of uncertainty in predicted use in §5.1 and the implications of consumer risk aversion in §5.4.

3. The Model

3.1. Assumptions and Notation

Assumption 1. *Consumers purchase the information good, pay for it per use, or abstain from the market.*

Assumption 2. *There are N consumers in the market. Each consumer i is characterized by expected use frequency θ_i. All consumers have the same utility-per-use denoted by ϕ.*

Assumption 3. *The use frequency θ is distributed $U[0, \theta_H]$. The upper limit of the distribution of the use frequency is elastic. This captures multiple market specifications. For example, if $\theta_H > 1$, consumers can use the good multiple times over the time horizon. The situation where θ is distributed $U[0, 1]$ is a special case wherein θ_i represents the probability of use within the time horizon.*

Assumption 4. *Consumers who use pay-per-use incur a psychological cost T per use occasion. This cost captures the ticking meter effect that results when payment is tightly linked to consumption, and is consistent with both the empirical findings described above and with prior findings by other researchers* (*Train* 1991, *Lambrecht and Skiera* 2006). *Furthermore, a similar cost has frequently been associated with pay-per-use in the analytical literature* (*Varian* 2000, *Cheng et al*. 2003, *Sundararajan* 2004).

Assumption 5. *The information good can be reproduced and delivered at negligible marginal cost* (*Essegaier et al*. 2002, *Fishburn and Odlyzko* 1999). *We ignore fixed costs because they do not directly affect optimal pricing decisions.*

Throughout the paper, subscript S (O) denotes a variable pertaining to the seller (pay-per-use provider). Accordingly, p_S, MS_S, and Π_S, respectively, denote the price, market share, and profits related to selling. Similarly, p_O, MS_O, and Π_O denote the payment-per-use, market share, and profits related to pay-per-use.

3.2. Model Set-up

Consumer i will find pay-per-use pricing feasible only when $\phi - T \geq p_O$. This participation constraint requires the net utility-per-use to be greater than the payment-per-use p_O. Similarly, consumer i will find buying feasible only when $\theta_i \phi \geq p_S$, i.e., only when the cumulative utility consumer i gains from using the good is greater than the purchase price. The surplus gained by consumer i under each pricing mechanism is:

$$\text{Pay-per-use:} \quad U_{iO}(p_O) = \theta_i(\phi - T - p_O), \tag{1}$$

$$\text{Selling:} \quad U_{iS}(p_S) = \theta_i \phi - p_S. \tag{2}$$

In computing the surplus under pay-per-use, payments are made each time that the good is used. In contrast, under selling, the upfront price p_S is directly subtracted from the consumer's cumulative use utility. If the monopolist only offers pay-per-use, all consumers potentially use the good if $\phi \geq p_O + T$.

The average frequency of use of the pay-per-use mechanism in each period is $\theta_H/2$, and the monopolist will charge the profit-maximizing payment-per-use of $\phi - T$. The expected profits under pay-per-use are

$$\Pi_O(p_O) = N(\phi - T)\frac{\theta_H}{2}. \tag{3}$$

If the firm sells the good, all consumers with use frequencies in the range $\theta \in [p_S/\phi, \theta_H]$ derive (weakly) positive utility from buying the good. The market share of the monopolist seller and resulting profits are, respectively

$$\begin{aligned} MS_S(p_S) &= \frac{N}{\theta_H}\left[\theta_H - \frac{p_S}{\phi}\right], \\ \Pi_S(p_S) &= MS_S(p_S)p_S = \frac{Np_S}{\theta_H}\left[\theta_H - \frac{p_S}{\phi}\right]. \end{aligned} \tag{4}$$

The model provides a parsimonious representation of the selling and pay-per-use mechanisms.

4. Pricing in Monopoly and Duopoly Contexts

4.1. Monopoly

We first discuss the separate use of each mechanism by a monopolist. The results are tabulated in Table 2 (see Appendix A.1 for the proof).

Proposition 1. *If the monopolist uses only pay-per-use pricing or only selling, the profits from pay-per-use pricing are higher than those from selling if $T < 0.5\phi$. The monopolist obtains the highest profits when selling and pay-per-use are used in combination.*

The proof of Proposition 1 is in Appendix A.1. A monopolist prefers pay-per-use when T is low; this is consistent with Sundararajan (2004). Intuitively, pay-per-use perfectly discriminates across consumers in terms of use frequency. This is because consumers for whom the total cost per use, i.e., the sum of p_O and T, is lower than the utility-per-use will use the good on every occasion when needed. When T is low, the pay-per-use provider can charge a high payment-per-use p_O and yet induce all consumers to adopt pay-per-use. In contrast, if the firm sells, consumers make purchase decisions after comparing their total utility across time, depending on both utility-per-use and use frequency, to the selling price. Therefore, buying the good outright is particularly attractive for consumers with a moderate to high use frequency. A consumer with a low use frequency will not buy the good, but could find pay-per-use feasible. The level of T decides which of these contrasting benefits to consumers translates into higher profits.

The selling and pay-per-use mechanisms for information goods may not be mutually exclusionary; a monopolist can optimally use both mechanisms (Zhang and Seidmann 2010). If the psychological cost is zero, the monopolist uses only pay-per-use. If the psychological cost is equal to or greater than the utility-per-use, the monopolist only sells the good. In all other cases, a monopolist jointly uses selling and pay-per-use to maximize profits.

5. Duopoly with Identical Information Goods

We first analyze the general case wherein each duopolist can use either or both pricing mechanisms. We assume that the firms offer undifferentiated goods. This allows us to focus on the pricing mechanisms themselves as the bases for differentiation and competitive traction. Consumer i derives

Table 2 Optimal Outcomes in a Monopoly

	Pay-per-use	Selling	Pay-per-use + Selling
Payment per-use/selling price	$p_o = \phi - T$	$p_s = \frac{\theta_H \phi}{2}$	$p_o = \phi - T$; $p_s = \frac{\theta_H \phi^2}{\phi + T}$
Market share	$MS_o = 1$	$MS_s = \frac{1}{2}$	$MS_o = \frac{\phi}{\phi + T}$; $MS_s = \frac{T}{\phi + T}$
Profits	$\frac{N\theta_H(\phi - T)}{2}$	$\frac{N\theta_H \phi}{4}$	$\frac{N\theta_H \phi^2}{2(\phi + T)}$

the following net utilities from each firm-mechanism combination:

$$\begin{aligned}
\text{Firm 1: Pay-per-use:}\quad & U_{O1}(p_{O1}) = \theta_i(\phi - T - p_{O1});\\
\text{Buy:}\quad & U_{S1}(p_{S1}) = \phi\theta_i - p_{S1},\\
\text{Firm 2: Pay-per-use:}\quad & U_{O2}(p_{O2}) = \theta_i(\phi - T - p_{O2});\\
\text{Buy:}\quad & U_{S2}(p_{S2}) = \theta\phi_i - p_{S2}.
\end{aligned}$$

The firms first choose their pricing mechanism(s), followed by prices in the second stage (see Coughlan 1985, Gupta and Loulou 1998 for similar two-stage games). Recall that the utility surpluses related to pay-per-use pricing and buying are described in Equations (1) and (2), respectively. Consumer i will prefer buying to pay-per-use only if $U_{iS}(p_S) > U_{iO}(p_O)$. Therefore, consumers who adopt information good i will buy only if their use frequency is higher than a certain critical frequency denoted by $\theta_c = p_{Si}/(p_{Oi} + T)$, and if $U_{iS}(p_S) > 0$. Consumers with $\theta_i < \theta_c$ choose pay-per-use or abstain from the market. The market shares of the mechanisms are described in Figure 1.

Result 1 and Proposition 2 summarize the equilibrium outcomes (see Appendices A.2 and A.3 for the proof):

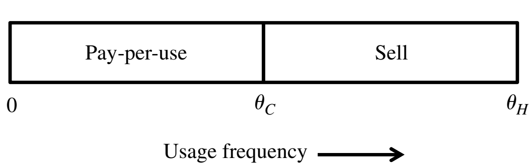
Result 1. There is no Nash equilibrium with positive firm profits where either firm uses both mechanisms, or both firms use the same mechanism.

If both firms use the same mechanism, they compete themselves down to zero profits under Bertrand competition. Each firm can lower its selling price or the payment-per-use to undercut the other. This cycle of undercutting will lead to a zero-profit outcome. On the other hand, each firm committing to a different mechanism yields a stable, mutually profitable equilibrium in the subsequent pricing game, as formally described in Proposition 2.

Proposition 2. (i) *There are two asymmetric pure-strategy Nash equilibria in the game where the two firms offer identical information goods, with one firm using selling and the other using pay-per-use.*

(ii) *If the resulting profit for the firm using the selling mechanism is Π_S and profit for the firm using the pay-per-use mechanism is Π_O, there is also a unique, symmetric, mixed-strategy Nash equilibrium, where each firm chooses the selling mechanism with a probability of $\sigma_S = \Pi_S/(\Pi_S + \Pi_O)$ and the pay-per-use mechanism with a probability of $\sigma_O = \Pi_O/(\Pi_S + \Pi_O)$.*

Figure 1 **Market Shares for Pay-per-Use Pricing and Selling in a Duopoly**



While the pure strategy Nash equilibria can be sustained by one firm being a Stackelberg leader, the mixed-strategy equilibrium will yield nonzero profits for both firms with a probability of $2\sigma_S(1 - \sigma_S)$. Note also that entry using both mechanisms by one firm (the incumbent) is not feasible when a competitor poses a credible threat of entry because entry by that competitor in any one mechanism will drive the profits of the incumbent from both mechanisms to zero. That is, the outcome is robust in the sense that the incumbent would profit from giving up one mechanism following competitive entry, thereby leading to a Nash equilibrium where each firm employs a distinct pricing mechanism. Furthermore, we note that players in the classic "Battle of the Sexes" game that captures such asymmetric equilibria cannot be distinguished on any dimension other than their preferences. In our context, the firms may be differentiated in terms of their ability to work with the selling and pay-per-use mechanisms. This, in turn, can help resolve the coordination challenge because one of the asymmetric equilibria would then be considered more focal by the firms.

The mixed-strategy equilibrium does not rely on the Stackelberg notion for existence (Dixit and Shapiro 1986). A known concern with this equilibrium is the positive likelihood of a symmetric, zero-profit outcome when competitors randomize their strategies. The concern may be addressed by assuming that asymmetric coordination is achieved over the long run as firms learn from their coordination failures in the short run (Farrell 1987). However, in markets with large sunk costs of entry, repeated short-term coordination failures cannot be sustained; therefore, firms have the incentive to learn about the rival's entry plans and to potentially communicate their own (Farrell 1987).

Multiple approaches have been advanced to increase the likelihood of asymmetric coordination in the mixed strategy game. First, firms can use cheap talk, which does not directly affect future payoffs, to coordinate the game. Farrell (1987) assumes that when the firms' announced plans comprise a Nash equilibrium, those plans are followed, i.e., talk is still cheap but not ignored. In that case, the probability of attaining nonzero profits in this equilibrium can be increased by both firms if they have multiple rounds of communication before choosing their strategy (Farrell 1987). In practice, Cooper et al. (1989) find that the mixed-strategy equilibrium yields nonzero profits for both firms with a higher probability if they engage in one-way rather than two-way communication. Firms can also coordinate their strategies when there is a fixed cost of entry that is private information (Levin and Peck 2003), and by agreeing on bonus payments, arbitration or licensing arrangements (Shaffer 2004).

Our findings about the efficacy of the pricing and pay-per-use mechanisms when two firms compete with identical information goods are summarized in Propositions 3 and 4 (proofs are in Appendices A.4 and A.5).

PROPOSITION 3. *In the pure-strategy and mixed-strategy Nash equilibria*: (i) *When* $T \le \phi/2$, *the equilibrium payment per-use and the selling price are* $p_O^* = T$ *and* $p_S^* = \theta_H T$, *respectively. The corresponding profits are* $\Pi_O^* = (N\theta_H T)/8$ *and* $\Pi_S^* = (N\theta_H T)/2$, *respectively.* (ii) *When* $T > \phi/2$, *the equilibrium payment per-use and the selling price are* $p_O^* = \phi - T$ *and* $p_S^* = (\theta_H \phi)/2$, *respectively. The corresponding profits are* $\Pi_O^* = (N\theta_H(\phi - T))/8$ *and* $\Pi_S^* = (N\theta_H \phi)/4$, *respectively.* (iii) *The equilibrium payment-per-use and profits of the pay-per-use provider in the duopoly first increase, and then decrease with the psychological cost* (T).

Proposition 3 is interesting and counterintuitive in several respects. First, note that if $T > \phi/2$, the firms using the pay-per-use mechanism and the selling mechanism price the information good *as if* they were monopolists (note from Proposition 1 that the monopolist pay-per-use provider charges a payment-per-use of $p_O = \phi - T$ and the monopolist seller charges a price of $p_S = (\theta_H \phi)/2$). Intuitively, when T hits the threshold of $\phi/2$, the pay-per-use provider is constrained by the utility surplus of its consumers to charge a maximum of $\phi - T$ (since $U_{iO} = \theta(\phi - p_O - T) \ge 0$). Therefore, this payment-per-use is charged for any value of $T > \phi/2$. Second, the seller in the duopoly makes the same profits from the selling mechanism as it would make in a monopoly (i.e., $\Pi = (N\theta_H \phi)/4$ in both the monopoly and duopoly models). When $T \le \phi/2$, Proposition 3 captures the price suppressing effect of competition.

In addition, there are some subtle and interesting forces at work here (see Figures 2 and 3 for a

Figure 2 Selling Price and Payment-per-Use in the Monopoly and Duopoly Cases

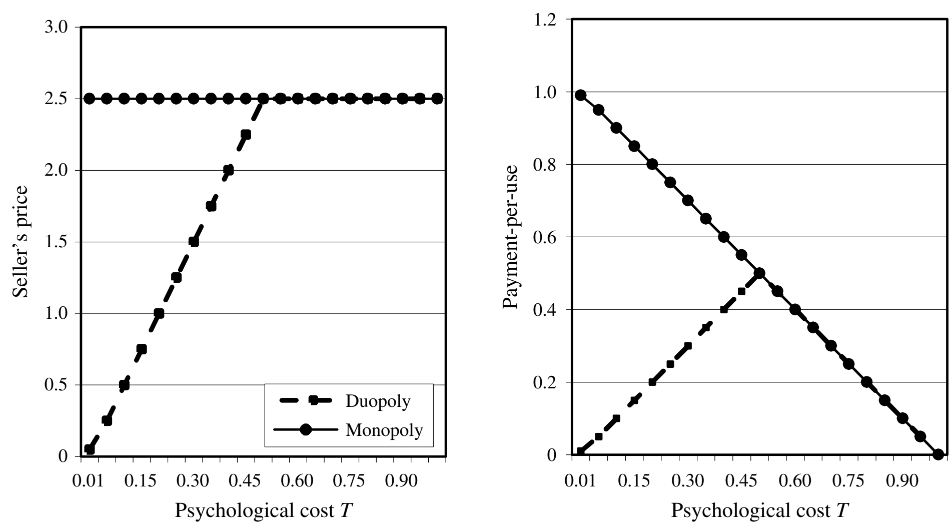
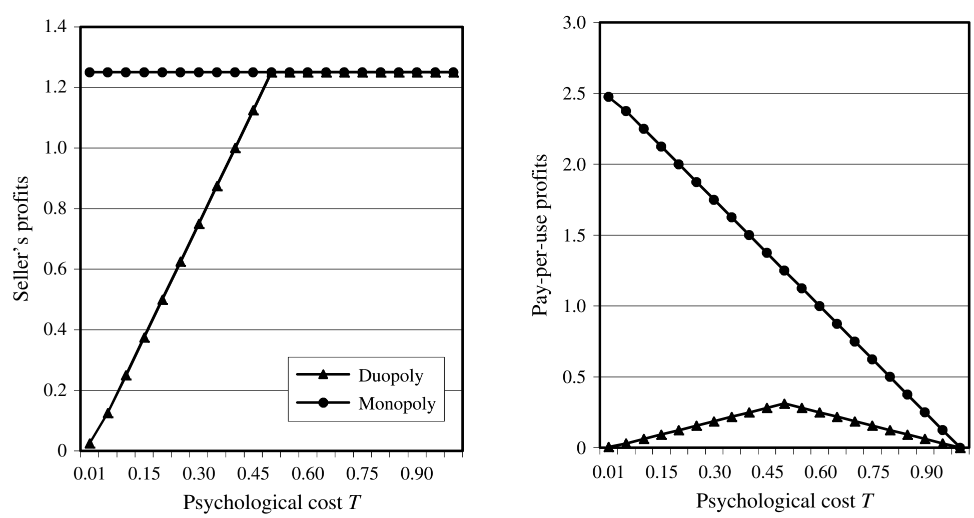


Figure 3 Profits from Selling and Pay-per-Use Pricing in the Monopoly and Duopoly Cases



comparison of prices and profits across the monopoly and duopoly, plotted for $\theta_H = 5, \phi_H = 1$). In our model, the psychological cost is applicable *only* to the pay-per-use provider. One would expect, therefore, that payment-per-use and profits of the pay-per-use provider are high when the associated psychological cost (T), which disadvantages only the offering of this provider, is low. However, we demonstrate that when T is very low, both the payment-per-use and the profits of the pay-per-use provider are low. Both initially increase as T increases, leading to the increasing part of the inverted U-shaped profit function. The intuition is that, when T is very low, the seller must sharply lower prices to attract consumers. This enhances competition and lowers profits across the board. As T increases, this competitive pressure decreases and the profits of both firms increase. However, as T increases yet further, the profits of the pay-per-use provider begin to decrease because that mechanism is ultimately less attractive from the consumer's viewpoint. When T is very low, both the seller and pay-per-use provider have very low profits. As the psychological cost increases, it offers some traction to the competitive engagement between the duopolists, enabling them to differentiate themselves. This results in higher profits at moderate levels of T for both firms.

Proposition 4. *In a duopoly, the profits of the seller are always higher than those of the firm that offers pay-per-use pricing.*

Proposition 4 is interesting in several respects. Recall that when T is low, a monopolist will prefer pay-per-use pricing over selling. However, in a duopoly, the seller's profits are higher even when T is low. The intuition is as follows: The pay-per-use mechanism depends heavily on the frequency of use for its revenues. When the pay-per-use provider increases its payment-per-use, consumers with a moderate to high frequency of use defect to the seller, taking the entire temporal stream of associated revenue with them. Selling therefore captures the best consumers, i.e., those with higher use frequencies in a duopoly, leaving the less attractive fraction of the market to the pay-per-use mechanism (see Figure 1). The ability of pay-per-use to allow consumers to flexibly tailor payments to use is a strength in the monopoly context. The reverse side of the coin, though, is the inability of pay-per-use pricing to lock in consumers at an early stage. This inability has no adverse consequences in a monopoly, but impairs the mechanism in a duopoly.

Propositions 1 and 4 jointly offer some interesting insights into the firm's choice of pricing mechanisms. When T is low, a firm will adopt pay-per-use if it does not expect competition. However, if it expects competition, it will choose to sell instead. That is, the firm will adopt a "defensive positioning" strategy (Hauser and Shugan 1983, Shaffer and Zhang 1995), where it accepts lower profits that are more robust in the face of competition, rather than higher profits that are susceptible to significant erosion on competitive entry.

As briefly noted earlier, the selling mechanism corresponds, at a high level of abstraction, to the "high-quality product" in the well known vertical product differentiation model of Shaked and Sutton (1982). In that model, the high-quality product yields higher profits in the competitive context, and under extrapolation, in the monopoly context as well (Shaked and Sutton 1982). In our case, however, the pay-per-use mechanism that corresponds to the "low-quality product" yields higher profits in the monopoly context. Therefore, the pricing mechanisms we study have interesting properties that differ from the classic vertical product differentiation context.

Our findings can also be compared to those in Moorthy (1988). In Moorthy's model, the high-end (or high quality) product has higher profits in a monopoly, and the low-end product has higher profits in a duopoly when competing firms simultaneously choose quality. Our analysis yields contrasting findings. In particular, pay-per-use, which broadly corresponds to the low-end product, yields higher profits in a monopoly provided the psychological costs associated with it are low, whereas selling, which represents the high-end mechanism, always yields higher profits than pay-per-use in a duopoly. Our findings are differentiated from those in the vertical product differentiation literature because in our model the delivered consumer value and the nature of competitive engagement are driven by the interplay between consumer use frequency and payment patterns, whereas in the product differentiation literature they are driven by differential consumer preferences for quality and variation in unit production costs (for material goods).

We now extend the model to examine how the performance of the pricing mechanisms is affected by (a) uncertainty in consumer use frequency, (b) the lack of price commitment, (c) the ability of the pay-per-use provider to implement a two-part tariff, and (d) consumer risk aversion.

5.1. Uncertainty in Use Frequency

In this section, we consider the impact of uncertainty on use frequency. Let the use frequency be distributed $U(0, \theta_H + v)$ with probability 0.5, and $U(0, \theta_H - v)$ with probability 0.5. Here, v captures the degree of uncertainty, and $v = 0$ implies the absence of uncertainty. We find that (see Appendix A.6 for the proof):

Proposition 5. *If the use frequency is uncertain,* (i) *in a monopoly, the cut-off psychological cost below which pay-per-use is more profitable than selling is higher than in* *the absence of uncertainty, ceteris paribus, this increases the relative attractiveness of pay-per-use*. (ii) *In a duopoly, there are two asymmetric pure-strategy Nash equilibria in the game where firms offer identical information goods, with one firm using selling and the other using pay-per-use, and one mixed-strategy equilibrium. The profits of each firm are lower than the profits obtained in the absence of uncertainty.*

In a monopoly, uncertainty in use frequency increases the relative attractiveness of the pay-per-use mechanism. Recall that, under pay-per-use, a consumer pays for the information good contingent on use. If consumers use the information good more or less frequently compared to the expected use frequency, the (risk neutral) firm still performs as well on average with the payment-per-use set at the same level as in the case with no uncertainty. That is, there is no efficiency loss from such uncertainty. In contrast, under selling, if the firm persists with the same selling price as in the case without uncertainty, then it loses potential margin if the actual distribution of use frequency is at the high end, and loses market share if that distribution is at the low end compared to the case wherein it is priced optimally. The seller prices lower under such uncertainty, thus reducing its profits.

However, in a competitive environment, the pay-per-use mechanism is not insulated from the effect of uncertainty. Owing to the presence of uncertainty, the firm adopting the selling mechanism is forced to lower its price, leading to an equilibrium wherein the firm offering the pay-per-use mechanism is correspondingly forced to lower its price as well. Both firms have lower profits in the presence of uncertainty than when the use frequency is known with certainty.

5.2. Lack of Price Commitment

We next investigate the performance of the two mechanisms when the firms cannot commit to prices. We use a two-period model wherein the firms choose pricing mechanisms at the start but announce prices (and/or the payment-per-use) at the beginning of each period (Web Appendix §1.1 (available as supplemental material at http://dx.doi.org/10.1287/mksc.2014.0894)). Here, in a monopoly, the pay-per-use provider makes the same profits but the seller makes lower profits compared to the case wherein price commitment is possible. Intuitively, because the pay-per-use provider implicitly maximizes profits on a period-by-period basis, commitment makes no difference to the pricing strategy. However, when the monopolist sells, rational consumers expect the firm to lower prices to attract residual consumers in period 2 and are ready to delay buying the good. Consequently, the seller has to lower the price in period 1 to attract consumers, thereby diluting profits.

In a duopoly, the equilibrium again involves one firm selling and the other adopting pay-per-use. Here, when the psychological cost associated with pay-per-use is low, surprisingly, both firms obtain higher equilibrium profits than they would if they could commit to prices. This finding stands in contrast to the existing literature where strategic consumers generally lower the profits of competitors (e.g., Levin et al. 2009). However, when the psychological cost is high, this finding is reversed and both firms obtain lower profits than they would if they could commit to prices.

These findings can be explained by invoking the commitment and competitive effects related to the firms' inability to hold steadfast to announced prices. When the psychological cost is low, the competitive effect dominates. Specifically, when the competitors cannot commit to prices, consumers who buy from the seller in period 1 comprise their installed base in period 2. In period 2, the firms compete only for consumers who adopted pay-per-use in period 1. The knowledge that the seller will compete for consumers again in period 2 reduces the pressure to build market share in period 1. This reduces the competitive intensity, enabling the firms to charge higher prices and lock in higher profits. In contrast, when the psychological cost is high, there is an upper bound on the payment-per-use because the pay-per-use provider has to ensure that consumers obtain positive utility after infliction of the psychological cost. Therefore, the lack of commitment does not support higher prices in this case. Instead, the negative implications related to the lack of commitment lower profits. Specifically, consumers who anticipate lower selling prices in period 2 aim to adopt pay-per-use in period 1 and then switch to the seller in period 2. This induces the seller to lower prices. Competition is sharpened and the profits of both firms decrease.

5.3. Two-Part Tariffs

We also consider the impact of two-part tariffs offered by the pay-per-use provider (Web Appendix §1.2). We demonstrate that a two-part tariff will be invoked in a monopoly only when the pay-per-use provider is constrained by capacity. Intuitively, in the absence of capacity constraints, the payment-per-use extracts all surplus, and there is no need for a fixed fee. When capacity constraints are present, the fixed fee enables the pay-per-use provider to exclude consumers with low use frequencies from the market. The available capacity is allocated to consumers with higher use frequencies, thus increasing profits. As long as the psychological cost associated with pay-per-use is low, the profits under pay-per-use are higher than those under selling. The implications of a two-part tariff in the duopoly context are more nuanced. Irrespective of capacity constraints, when the psychological cost is low, we demonstrate that the inclusion of a two-part tariff by the pay-per-use provider leads to the payment-per-use being set to zero and a complete reliance on the fixed fee. This leads to a lack of differentiation compared to the seller. This, in turn, implies that there is no equilibrium with positive firm profits because of price undercutting. However, when the psychological cost is high and both firms are capacity constrained, the pay-per-use provider optimally charges a two-part tariff. The profits of the seller remain higher than those of the pay-per-use provider at any (symmetric) level of capacity.

5.4. Risk-Averse Consumers

Finally, we consider the impact of consumer risk aversion (Web Appendix §1.3). We obtain the certainty equivalents of the utilities of consumers under risk aversion and demonstrate that in a monopoly, the pay-per-use mechanism dominates the selling mechanism if both the coefficient of absolute risk aversion and the psychological cost are low, while selling dominates if both of those factors are high. The intuition behind this finding is as follows: Risk-averse consumers find that the variability of payment schedules under the pay-per-use mechanism reduces their utility. In a duopoly where both the psychological cost and risk aversion are relevant, we show analytically that the profits from selling are higher than that of the pay-per-use provider. Therefore our findings are consistent with the model that includes just the psychological cost. Furthermore, we show that even with the inclusion of risk aversion, the inverted U-shaped profit profile of the pay-per-use provider, a key finding in the paper, endures, with a predictable shift of the profit profile as the degree of risk aversion changes. The intuition behind this result is that consumer risk aversion disadvantages pay-per-use, as does the psychological cost. The effect of consumer risk aversion is to shift the peak of the profits of the pay-per-use provider to a lower psychological cost than in the risk-neutral case; the seller's profits reach the monopoly level for a lower psychological cost than in the risk-neutral case.

Overall, the effects of risk aversion are more in the spirit of additional fixed costs associated with pay-per-use at the mechanism level and therefore less strategic that those of the psychological cost in driving equilibrium outcomes. Therefore, our key findings endure even if risk aversion, which is linked to the insurance and overestimation effects, drives the flat-rate bias along with the psychological cost (i.e., ticking meter effect).

We conducted other checks to verify the robustness of our results. First, we verified that the dominance of pay-per-use over selling in the monopoly case is robust to the distributional assumptions. We demonstrate this dominance for uniform, upper triangular, and lower triangular distributions of use frequency. We also verified the robustness of the results to the inclusion of a positive unit variable cost for the good and to the inclusion of a fixed cost associated with selling.

6. Conclusions, Discussion, and Future Research

We analyzed the effectiveness of the selling and pay-per-use pricing mechanisms for pure information goods in a market where consumers differ in terms of use frequency. To set up a baseline case, we first considered a monopolist who could use either mechanism. Here, we first showed that as long as the psychological cost associated with pay-per-use is low, profits from that mechanism are higher than those from selling. Intuitively, pay-per-use pricing achieves perfect discrimination along use frequency by allowing consumers to pay only when the good is used. By contrast, selling is attractive only to consumers with high use frequencies.

We next analyzed a duopoly where firms could use either or both pricing mechanisms. We showed that there are two asymmetric pure-strategy Nash equilibria where one firm adopts selling and the other adopts pay-per-use, and a symmetric mixed-strategy Nash equilibrium where both firms choose selling or pay-per-use with a positive probability. Here, in contrast to the monopoly, the seller's profits generally dominated the pay-per-use provider's profits. The key implication is that a monopolist who uses one pricing mechanism is better off using pay-per-use provided the associated psychological cost is not too high. By contrast, a monopolist who expects future competition should pursue a defensive positioning strategy and choose to sell the good instead. While it is difficult to rule out all competing explanations, there are at least two historical instances of firms moving from pay-per-use to the more defensible selling mechanism. In late 1996, AOL moved from an hourly fee for dial-up Internet access to a fixed fee. Likewise, in early 2000, Netflix moved from a movie rental plan to a fixed fee plan. We also demonstrated that the profits of both the seller and pay-per-use provider were low when the psychological cost, which was associated only with the pay-per-use provider, was low. Furthermore, and surprisingly, the profits of the pay-per-use provider were inverted U-shaped with respect to the psychological cost. The intuition was traced back to the key role of the psychological cost in moderating competition.

We extended the model to address some practically relevant cases. First, we showed that when there is uncertainty related to use frequency in a monopoly, profits under pay-per-use are unaffected, but profits under selling are reduced. Such uncertainty reduced profits for both firms in a duopoly. Second, we showed that when it is not possible to commit to prices, profits under pay-per-use are again unaffected in a monopoly whereas the seller's profits are reduced. By contrast, in a duopoly, when the psychological cost associated with pay-per-use is low (high), profits of both firms increase (decrease) when they are unable to commit to prices. Third, we demonstrated how the presence of capacity constraints moderated the use of a two-part tariff by the pay-per-use provider. Fourth, we showed that the relative profitability of selling compared to pay-per-use increases when consumers are risk-averse, both in monopoly and duopoly settings. In sum, our findings have direct implications for managerial decisions related to (a) the choice of the selling mechanisms in monopoly and competitive situations; (b) the leverage of the psychological cost associated with pay-per-use to increase competitive traction and profits; (c) the choice of the pricing mechanism in the face of uncertain consumer demand; (d) the decision to strategically commit to prices; (e) the use of a two-part tariff; and (f) risk-averse consumers.

Our analysis has specific limitations. These limitations, as well as other open issues, can be addressed by future research. First, the role of use frequency-based discounts and other price discrimination mechanisms can be analyzed. Second, future research can examine the optimal pricing strategies for information goods when there is a temporal diffusion of demand (e.g., Krishnan et al. 1999). Third, the scenario wherein consumers endogenously adjust use patterns based on pricing levels and mechanisms can be analyzed. The importance of optimally pricing information goods has rapidly grown with the worldwide dissemination of the Internet and mobile networks, and the advent of new technologies such as cloud-based information dissemination and computing. We hope our analysis and findings catalyze additional research in this domain.

Supplemental Material

Supplemental material to this paper is available at http://dx.doi.org/10.1287/mksc.2014.0894.

Acknowledgments

The authors thank Jessica Sim, Zoe Kinias, and Eliza Bivolaru for their help in this research. The authors also thank the editor-in-chief, the associate editor, and the referees for their feedback during the review of the paper. The authors are grateful to seminar participants at several universities for their feedback on earlier versions of the paper. The second author was supported on this research by INSEAD [Grant 2010241].

Appendix

A.1. Proof of Proposition 1

(i) If the firm charges a payment-per-use of p_O, either all consumers adopt the information good if $\phi \geq p_O + T$, or if this constraint is not satisfied, no one adopts it. The firm solves

$$\max_{p_O} \; Np_O \frac{\theta_H}{2}$$
$$\text{s.t.} \; p_O \leq \phi - T.$$

The Lagrangian of this constrained optimization problem is: $\Lambda = Np_O(\theta_H/2) - \lambda(p_O - \phi - T)$.

The Karush-Kuhn-Tucker (KKT) conditions imply that: $\partial\Lambda/\partial p_O = N(\theta_H/2) + \lambda = 0$; $\lambda(p_O - \phi - T) = 0$. From the first condition, since $\lambda \neq 0$, $p_O = \phi - T$. Therefore, the payment-per-use is given by $\phi - T$. The firm will not charge a lower payment-per-use because it can obtain the same market by increasing the payment-per-use to $p_O = \phi - T$. The average frequency of use for consumers in this fraction in any given period is $\theta_H/2$. The expected profits for the firm are

$$\Pi_O = N\frac{\theta_H}{2}p_O = \frac{N\theta_H(\phi - T)}{2}.$$

(ii) Under selling, if the firm sets a selling price of p_S, then in Figure 1, at any given use utility ϕ, consumers with use frequencies in the range $\theta \in [p_S/(\phi D), \theta_H]$ derive (weakly) positive utility from the purchase. From Figure 1, the market fraction that buys the good and the profits, respectively, are

$$MS_S = \frac{1}{\theta_H}\left[\theta_H - \frac{p_S}{\phi}\right],$$
$$\Pi_S = \frac{Np_S}{\theta_H}\left[\theta_H - \frac{p_S}{\phi}\right].$$

The FOC (first-order conditions) with respect to p_S yields $p_S = \phi\theta_H/2$, which is an interior point. The SOC (second-order conditions) of the seller's profit function shows that the second derivative is negative (with a value of $-2N/(\theta_H\phi)$). Substituting the optimal value for p_S in the expression for the market fraction and profits yields the optimal outcomes. Equating the profits from pay-per-use pricing and selling yields the cut-off psychological cost.

(iii) When the monopolist uses both mechanisms, the condition for a consumer to adopt the selling mechanism in preference to the pay-per-use mechanism is given by: $U_{iS}(p_S) = \theta_i\phi - p_S > U_{iO}(p_O) = \theta_i(\phi - p_O - T)$. Accordingly, the condition for consumers to adopt the selling mechanism is given by: $\theta > p_S/(p_O + T)$. Hence, the market share of the selling mechanism is given by $MS_S = (1/\theta_H)[\theta_H - p_S/(p_O + T)]$ and the market share of the pay-per-use mechanism is given by $MS_O = (1/\theta_H)[p_S/(p_O + T)]$. The profits of the firm are given by $\Pi = \Pi_S + \Pi_O$, where Π_S and Π_O are the profits from the selling and pay-per-use mechanisms, respectively

$$\Pi_S = \frac{Np_S}{\theta_H}\left[\theta_H - \frac{p_S}{p_O + T}\right],$$
$$\Pi_O = \frac{Np_O}{2\theta_H}\left[\frac{p_S}{p_O + T}\right]^2.$$

The profits from the pay-per-use mechanism are given by the product of the market share $(1/\theta_H)[p_S/(p_O+T)]$, the number of consumers in the market (N), and the payment-per-use (p_O) multiplied by the average frequency of consumer use $p_S/(2(P_O+T))$. Hence,

$$\Pi = \Pi_S + \Pi_O = \frac{Np_S}{\theta_H}\left[\theta_H - \frac{p_S}{p_O+T}\right] + \frac{Np_O}{2\theta_H}\left[\frac{p_S}{p_O+T}\right]^2$$
$$= \frac{Np_S}{\theta_H}\left[\theta_H - \frac{p_S}{p_O+T} + \frac{p_S p_O}{2(p_O+T)^2}\right].$$

The FOC w.r.t. p_O of the profit function yields: $\partial\Pi/\partial p_O = N\theta_H(p_O+T)^2/(2(p_O+2T)) > 0$. Hence, $p_O = \phi - T$, which is its upper limit.

The FOC of the profit function w.r.t. p_S yields: $\partial\Pi/\partial p_S = \theta_H - 2p_S[1/(p_O+T) - p_O/(2(p_O+T)^2)] = 0$. Substituting $p_O = \phi - T$ yields $p_S = \theta_H\phi^2/(\phi+T)$.

The profits of the monopolist using both mechanisms can be found by substituting the values of the optimal payment-per-use and selling price into the profit function. □

A.2. Proof of Result 1

Table A.1 summarizes the possible strategies used by both parties in equilibrium.

Case 1. *Firm* 1 *uses only selling, Firm* 2 *uses only pay-per-use mechanism*. Consider a duopoly where firm 1 only uses the selling mechanism, and firm 2 only uses the pay-per-use mechanism to offer the information good. Let the selling price charged by firm 1 be denoted as p_S and the payment-per-use charged by firm 2 be denoted as p_O. Since $U_{iS1}(p_S) = \theta_i\phi - p_S$ and $U_{iO2}(p_O) = \theta_i(\phi - p_O - T)$. The set of consumers who buy the information good are given by $\theta_i\phi - p_S > \theta_i(\phi - p_O - T)$ or characterized by the frequency of use $\theta > \theta_C = p_S^*/(p_O^* + T)$. Consumers with $\theta < \theta_C$ use the information good on a pay-per-use basis. From Figure 1, the expressions for the market shares of the selling and pay-per-use mechanisms are, respectively

$$MS_S(p_S, p_O) = \frac{1}{\theta_H}\left[\theta_H - \frac{p_S}{p_O+T}\right],$$
$$MS_O(p_S, p_O) = \frac{1}{\theta_H}\left[\frac{p_S}{p_O+T}\right].$$

The competing firms maximize their individual profits

$$\text{Seller: } \max_{p_S} \Pi_S(p_S, p_O) = \frac{Np_S}{\theta_H}\left[\theta_H - \frac{p_S}{p_O+T}\right],$$
$$\text{Pay-per-use: } \max_{p_O} \Pi_O(p_S, p_O) = \frac{Np_O}{2\theta_H}\left[\frac{p_S}{p_O+T}\right]^2.$$

Table A.1 Nash Equilibrium Outcomes When Firms Can Use Either or Both Mechanisms

	Firm 1		
	Selling	Pay-per-use	Both
Firm 2			
Selling	No equilibrium	Equilibrium exists	No equilibrium
Pay-per-use	Equilibrium exists	No equilibrium	No equilibrium
Both	No equilibrium	No equilibrium	No equilibrium

The profits of the pay-per-use provider, firm 2, are given by the product of the market size $(N/\theta_H[p_S/(p_O+T)])$, the average frequency of use $(\frac{1}{2}[p_S/(p_O+T)])$, and the payment-per-use (p_O). To see that this game yields a unique asymmetric Nash equilibrium, it is sufficient to check the SOC are satisfied at the Nash equilibrium. The SOC for the seller's profit is easily seen to be satisfied as $\partial^2\Pi/\partial p_S^2 = -N/(\theta_H(p_O+T))$. From the pay-per-use provider's SOC, the equilibrium payment-per-use exists and is unique if $p_O^* < 2T$.

Case 2. *Firm* 1 *uses only selling, Firm* 2 *uses only selling*. If the firms each only use the selling mechanism, let the selling price charged by firm 1 be denoted by p_{S1} and the selling price of firm 2 be denoted by p_{S2}. Let the profits of firm 1 be denoted by $\Pi_{S1}(p_{S1}, p_{S2})$ and the profits of firm 2 be denoted by $\Pi_{S2}(p_{S1}, p_{S2})$. A necessary condition for the Nash equilibrium (with nonzero profits for both firms) to exist is (here p_{S1}^* and p_{S2}^* are the Nash equilibrium prices)

$$\Pi_{S1}(p_{S1}^*, p_{S2}^*) > \Pi_{S1}(p_{S1}^*+\epsilon, p_{S2}^*) \quad \text{and}$$
$$\Pi_{S1}(p_{S1}^*, p_{S2}^*) > \Pi_{S1}(p_{S1}^*-\epsilon, p_{S2}^*),$$
$$\Pi_{S2}(p_{S1}^*, p_{S2}^*) > \Pi_{S2}(p_{S1}^*, p_{S2}^*+\epsilon) \quad \text{and}$$
$$\Pi_{S2}(p_{S1}^*, p_{S2}^*) > \Pi_{S2}(p_{S1}^*, p_{S2}^*-\epsilon).$$

That is, both firms should have no incentive to deviate from the Nash equilibrium prices.

The net surpluses of a consumer who buys the information good from firm 1 and firm 2 are, respectively

$$U_{iS1}(p_{S1}) = \theta_i\phi - p_{S1},$$
$$U_{iS2}(p_{S2}) = \theta_i\phi - p_{S2}.$$

If the information good is not vertically differentiated, it is easy to see that if $p_{S1} \neq p_{S2}$, the entire market share goes to the firm with the lower selling price, and the other firm is left with zero profits. This leads to price undercutting, which can be formally proven as follows.

Without loss of generality, assume that the selling price duo (p_{S1}^*, p_{S2}^*) is a Nash equilibrium and let $p_{S1}^* < p_{S2}^*$, where $p_{S1}^* > 0$ and $p_{S2}^* > 0$. Then,

$$\Pi_{S1}(p_{S1}^*, p_{S2}^*) = \frac{Np_{S1}^*}{\theta_H}\left[\theta_H - \frac{p_{S1}^*}{\phi}\right],$$
$$\Pi_{S2}(p_{S1}^*, p_{S2}^*) = 0.$$

However, for firm 2, $\Pi_{S2}(p_{S1}^*, p_{S2}^*) > \Pi_{S2}(p_{S1}^*, p_{S2}^*-\epsilon)$ is not satisfied, because if $\epsilon = \lim_{h\to 0} p_{S2}^* - p_{S1}^* + h$, then

$$\Pi_{S2}(p_{S1}^*, p_{S2}^*-\epsilon) = \lim_{h\to 0}\frac{N(p_{S1}^*-h)}{\theta_H}\left[\theta_H - \frac{p_{S1}^*-h}{\phi}\right]$$
$$> \Pi_{S2}(p_{S1}^*, p_{S2}^*) = 0 \quad \forall\, p_{S1}^* > 0.$$

Therefore, there is a contradiction, and a nonzero price Nash equilibrium cannot exist if $p_{S1}^* \neq p_{S2}^*$. Since profits are zero if the prices are zero, a nonzero price Nash equilibrium cannot exist if $p_{S1}^* \neq p_{S2}^*$.

Now, let us assume that (p_{S1}^*, p_{S2}^*) is a Nash equilibrium and let $p_{S1}^* = p_{S2}^* = p_S^*$, where $p_{S1}^* = p_{S2}^* > 0$. Because the net consumer surplus for both firms is equal, we can assume that the market shares for both firms are equal (half of that of the monopolist who prices at p_S^*). Then

$$\Pi_{S1}(p_{S1}^*, p_{S2}^*) = \frac{Np_S^*}{2\theta_H}\left[\theta_H - \frac{p_S^*}{\phi}\right] \quad \text{and}$$
$$\Pi_{S2}(p_{S1}^*, p_{S2}^*) = \frac{Np_S^*}{2\theta_H}\left[\theta_H - \frac{p_S^*}{\phi}\right].$$

In this case, the conditions $\Pi_{S1}(p_{S1}^*, p_{S2}^*) > \Pi_{S1}(p_{S1}^* - \epsilon, p_{S2}^*)$ and $\Pi_{S2}(p_{S1}^*, p_{S2}^*) > \Pi_{S2}(p_{S1}^*, p_{S2}^* - \epsilon)$ are not satisfied for all $p_S^* > 0$. If $\epsilon = \lim_{h\to 0} h$, for firm 1, then

$$\Pi_{S1}\left(p_{S1}^* - \lim_{h\to 0} h, p_{S2}^*\right) = \lim_{h\to 0} \frac{N(p_S^* - h)}{\theta_H}\left[\theta_H - \frac{p_S^* - h}{\phi}\right] > \frac{Np_S^*}{2\theta_H}\left[\theta_H - \frac{p_S^*}{\phi}\right].$$

A symmetric condition holds for firm 2. Therefore, there is a contradiction and a Nash equilibrium with nonzero prices and profits do not exist when each firm employs only selling. □

Case 3. *Firm* 1 *and firm* 2 *each use only pay-per-use*. Similar to case 1, each firm can undercut the (positive) payment-per-use of each other to obtain the full market share. Let the payment-per-use charged by firm 1 be denoted by p_{O1} and the payment-per-use of firm 2 be denoted by p_{O2}. Let the profits of firm 1 be denoted by $\Pi_{O1}(p_{O1}, p_{O2})$ and the profits of firm 2 be denoted by $\Pi_{O2}(p_{O1}, p_{O2})$. A necessary condition for the Nash equilibrium (with nonzero profits for both firms) to exist is (here p_{O1}^* and p_{O2}^* are the Nash equilibrium prices)

$$\Pi_{O1}(p_{O1}^*, p_{O2}^*) > \Pi_{O1}(p_{O1}^* + \epsilon, p_{O2}^*) \quad \text{and}$$
$$\Pi_{O1}(p_{O1}^*, p_{O2}^*) > \Pi_{O1}(p_{O1}^* - \epsilon, p_{O2}^*),$$
$$\Pi_{O2}(p_{O1}^*, p_{O2}^*) > \Pi_{O2}(p_{O1}^*, p_{O2}^* + \epsilon) \quad \text{and}$$
$$\Pi_{O2}(p_{O1}^*, p_{O2}^*) > \Pi_{O2}(p_{O1}^*, p_{O2}^* - \epsilon).$$

That is, both firms should have no incentive to deviate from the Nash equilibrium prices.

The net surpluses of a consumer who uses the information good on a pay-per-use basis from firm 1 and firm 2 are, respectively

$$U_{iO1}(p_{O1}) = \theta_i(\phi - p_{O1} - T),$$
$$U_{iO2}(p_{O2}) = \theta_i(\phi - p_{O2} - T).$$

If the information good is not vertically differentiated, it is easy to see that if $p_{O1} \neq p_{O2}$, the entire market share goes to the firm with the lower selling price, and the other firm is left with zero profits. This leads to price undercutting, which can be formally proven in a similar manner as above.

Now, let us assume that (p_{O1}^*, p_{O2}^*) is a Nash equilibrium and let $p_{O1}^* = p_{O2}^* = p_O^*$, where $0 < p_O^* \leq \phi - T$. Because the net consumer surplus for both firms is equal, we can assume that the market shares for both firms are equal (half of that of the monopolist who prices at p_O^*). Then

$$\Pi_{O1}(p_{O1}^*, p_{O2}^*) = \frac{Np_O^*}{2}\frac{\theta_H}{2} \quad \text{and}$$
$$\Pi_{O2}(p_{O1}^*, p_{O2}^*) = \frac{Np_O^*}{2}\frac{\theta_H}{2}.$$

In this case, the conditions $\Pi_{O1}(p_{O1}^*, p_{O2}^*) > \Pi_{O1}(p_{O1}^* - \epsilon, p_{O2}^*)$ and $\Pi_{O2}(p_{O1}^*, p_{O2}^*) > \Pi_{O2}(p_{O1}^*, p_{O2}^* - \epsilon)$ are not satisfied for all $p_O^* > 0$. If $\epsilon = \lim_{h\to 0} h$, for firm 1, then

$$\Pi_{O1}\left(p_{O1}^* - \lim_{h\to 0} h, p_{O2}^*\right) = \lim_{h\to 0} N(p_O^* - h)\frac{\theta_H}{2} > \frac{Np_O^*}{2}\frac{\theta_H}{2}.$$

A symmetric condition holds for firm 2. Therefore, there is a contradiction and a Nash equilibrium with nonzero prices and profits do not exist when each firm employs only the pay-per-use mechanism. □

Case 4. *Firms* 1 *and* 2 *each use both the pay-per-use and selling*. Let the selling price charged by firm 1 be denoted by p_{S1} and the selling price of firm 2 be denoted by p_{S2}. Similarly, let the payments-per-use of firms 1 and 2 be denoted by p_{O1} and p_{O2}, respectively. Let the profits of firm 1 be denoted by $\Pi_1(p_{S1}, p_{S2}, p_{O1}, p_{O2})$ and the profits of firm 2 be denoted by $\Pi_2(p_{S1}, p_{S2}, p_{O1}, p_{O2})$. A necessary condition for the Nash equilibrium (with nonzero profits for both firms) to exist is (here p_{S1}^*, p_{S2}^*, p_{O1}^*, and p_{O2}^* are the Nash equilibrium prices)

$$\Pi_1(p_{S1}^*, p_{S2}^*, p_{O1}^*, p_{O2}^*) > \Pi_1(p_{S1}^* + \epsilon, p_{S2}^*, p_{O1}^*, p_{O2}^*) \quad \text{and}$$
$$\Pi_1(p_{S1}^*, p_{S2}^*, p_{O1}^*, p_{O2}^*) > \Pi_1(p_{S1}^* - \epsilon, p_{S2}^*, p_{O1}^*, p_{O2}^*),$$
$$\Pi_2(p_{S1}^*, p_{S2}^*, p_{O1}^*, p_{O2}^*) > \Pi_2(p_{S1}^*, p_{S2}^* + \epsilon, p_{O1}^*, p_{O2}^*) \quad \text{and}$$
$$\Pi_2(p_{S1}^*, p_{S2}^*, p_{O1}^*, p_{O2}^*) > \Pi_2(p_{S1}^*, p_{S2}^* - \epsilon, p_{O1}^*, p_{O2}^*).$$

That is, both firms should have no incentive to deviate from the Nash equilibrium prices.

The net surpluses of a consumer who buys the information good from firms 1 and 2 are, respectively

$$U_{iS1}(p_{S1}) = \theta_i\phi - p_{S1},$$
$$U_{iS2}(p_{S2}) = \theta_i\phi - p_{S2}.$$

The net surpluses of a consumer who uses the information good on a pay-per-use basis from firm 1 and firm 2 are, respectively

$$U_{iO1}(p_{O1}) = \theta_i(\phi - p_{O1} - T),$$
$$U_{iO2}(p_{O2}) = \theta_i(\phi - p_{O2} - T).$$

If the information good is not vertically differentiated, it is easy to see that if $p_{S1}^* \neq p_{S2}^*$, and $p_{O1}^* \neq p_{O2}^*$, the entire market share for the selling and pay-per-use sections go to the firm with the lower selling price and/or the lower payment-per-use, and the other firm is left with zero profits. Without loss of generality, if $p_{S1}^* < p_{S2}^*$ and if $p_{O1}^* > p_{O2}^*$, then $U_{iS1}(p_{S1}) = \theta_i\phi - p_{S1} > U_{iS2}(p_{S2}) = \theta_i\phi - p_{S2}$, and $U_{iO1}(p_{O1}) = \theta_i(\phi - p_{O1} - T) < U_{iO2}(p_{O2}) = \theta_i(\phi - p_{O2} - T)$. In that case, in equilibrium, firm 1 uses the selling mechanism and firm 2 uses the pay-per-use mechanism only. Hence, if $p_{S1}^* \neq p_{S2}$, and $p_{O1} \neq p_{O2}$, an equilibrium with both firms using both mechanisms cannot exist.

Now, let us assume that $(p_{S1}^*, p_{S2}^*, p_{O1}^*, p_{O2}^*)$ is a Nash equilibrium and let $p_{S1}^* = p_{S2}^* = p_S^*$, where $p_S^* > 0$, and $p_{O1}^* = p_{O2}^* = p_O^*$, where $p_O^* > 0$. In that case, the set of consumers who buy the information good are given by $\theta_i\phi - p_S^* > \theta_i(\phi - p_O^* - T)$ or the frequency of use $\theta > \theta_C = p_S^*/(p_O^* + T)$, and consumers with $\theta < \theta_C$ use the information good on a pay-per-use basis. Because the net consumer surpluses for consumers of both firms are equal, we can assume that the market shares for both firms are equal (half of that of the monopolist who prices at p_S^*, p_O^*). Then

$$\Pi_1(p_{S1}^*, p_{S2}^*, p_{O1}^*, p_{O2}^*) = \frac{Np_S^*}{2\theta_H}\left[\theta_H - \frac{p_S^*}{p_O^*+T}\right] + \frac{Np_O}{4\theta_H}\left[\frac{p_S^*}{p_O^*+T}\right]^2$$

and

$$\Pi_2(p_{S1}^*, p_{S2}^*, p_{O1}^*, p_{O2}^*) = \frac{Np_S^*}{2\theta_H}\left[\theta_H - \frac{p_S^*}{p_O^*+T}\right] + \frac{Np_O}{4\theta_H}\left[\frac{p_S^*}{p_O^*+T}\right]^2.$$

The profits from the pay-per-use mechanism for both firms are given by the product of half the total market size $((N/2\theta_H)[p_S^*/(p_O^*+T)])$, the average frequency of use $(\frac{1}{2}[p_S^*/(p_O^*+T)])$, and the payment-per-use (p_O^*). In this case, the Nash equilibrium conditions $\Pi_1(p_{S1}^*, p_{S2}^*, p_{O1}^*, p_{O2}^*) > \Pi_1(p_{S1}^* - \epsilon,\ p_{S2}^*,\ p_{O1}^*,\ p_{O2}^*)$, $\Pi_2(p_{S1}^*,\ p_{S2}^*,\ p_{O1}^*,\ p_{O2}^*) > \Pi_2(p_{S1}^*,\ p_{S2}^* - \epsilon,\ p_{O1}^*,\ p_{O2}^*)$, $\Pi_1(p_{S1}^*,\ p_{S2}^*,\ p_{O1}^*,\ p_{O2}^*) > \Pi_1(p_{S1}^*,\ p_{S2}^*,\ p_{O1}^* - \epsilon,\ p_{O2}^*)$, and $\Pi_2(p_{S1}^*,\ p_{S2}^*,\ p_{O1}^*,\ p_{O2}^*) > \Pi_{S2}(p_{S1}^*,\ p_{S2}^*,\ p_{O1}^*,\ p_{O2}^* - \epsilon)$, are not satisfied for all $p_S^*, p_O^* > 0$. If $\epsilon = \lim_{h\to 0} h$, for firm 1, then

$$\begin{aligned}\Pi_1\Big(p_{S1}^* - \lim_{h\to 0} h, p_{S2}^*, p_{O1}^*, p_{O2}^*\Big) &= \lim_{h\to 0}\frac{N(p_S^*-h)}{\theta_H}\left[\theta_H - \frac{p_S^*-h}{p_O^*+T}\right] + \frac{Np_O}{4\theta_H}\left[\frac{p_S^*-h}{p_O^*+T}\right]^2 \\ &> \frac{Np_S^*}{2\theta_H}\left[\theta_H - \frac{p_S^*}{p_O^*+T}\right] + \frac{Np_O}{4\theta_H}\left[\frac{p_S^*}{p_O^*+T}\right]^2.\end{aligned}$$

A set of symmetric conditions holds for firm 2's selling price and the payments-per-use of both firms. Therefore, there is a contradiction and a Nash equilibrium with nonzero prices and profits do not exist when each firm employs both the selling and pay-per-use mechanisms. □

The proofs that demonstrate that other pricing combinations in the duopoly wherein one firm uses both pricing mechanisms or each firm uses the same pricing mechanism lead to no-equilibrium outcomes follow along similar lines. Those proofs can be obtained from the authors on request.

A.3. Proof of Proposition 2

To find the mixed-strategy equilibrium profile of the normal game in Table A.2, let the profit of the seller from this asymmetric Nash equilibrium be Π_S and the profit of the firm using the pay-per-use mechanism be Π_O. Then, we have the following payoff matrix for the two firms:

From Dixit and Shapiro (1986), each firm can also adopt a mixed strategy in a Nash equilibrium, in which the probability σ_S of selling makes the other firm indifferent between the selling and pay-per-use mechanisms

$$\sigma_S(0) + (1-\sigma_S)\Pi_S = \sigma_S\Pi_O + (1-\sigma_S)(0),$$
$$\sigma_S = \frac{\Pi_S}{\Pi_S + \Pi_O}.$$

Table A.2 Payoff Matrix if One Firm Uses Selling, Competitor Uses Pay-per-Use

	Sell	Pay-per-use
Sell	$(0, 0)$	(Π_s, Π_o)
Pay-per-use	(Π_o, Π_s)	$(0, 0)$

Therefore, in the unique mixed-strategy equilibrium, each firm chooses the selling mechanism with a probability of $\sigma_S = \Pi_S/(\Pi_S + \Pi_O)$ and the pay-per-use mechanism with a probability of $\sigma_O = \Pi_O/(\Pi_S + \Pi_O)$.

A.4. Proof of Proposition 3

The competing firms maximize their individual profits. The seller's profit function is given by

$$\text{Seller:}\quad \max_{p_S} \Pi_S(p_S, p_O) = \frac{Np_S}{\theta_H}\left[\theta_H - \frac{p_S}{p_O+T}\right].$$

The FOC for the seller with respect to p_s yields $p_S^* = \theta_H(p_O + T)/2$. This is always an interior point solution because $0 \le p_S/(p_O+T) \le \theta_H$. The SOC of the seller's profits are w.r.t. p_S is given by: $\partial^2\Pi_S/\partial p_S^2 = -2N/(\theta_H(p_O+T)) < 0$.

Pay-per-use: The firm adopting the pay-per-use policy solves the following problem:

$$\max_{p_O} \frac{Np_O}{2\theta_H}\left[\frac{p_S}{p_O+T}\right]^2$$
$$\text{s.t.}\quad p_O \le \phi - T.$$

The Lagrangian of this constrained optimization problem is given by: $\Lambda = (Np_O/2\theta_H)[p_S/(p_O+T)]^2 + \lambda(p_O - \phi - T)$.

The KKT conditions imply that

$$\frac{\partial\Lambda}{\partial p_O} = \frac{Np_S^2}{2\theta_H}\left[\frac{(p_O+T)^2 - 2(p_O+T)p_O}{(p_O+T)^4}\right] + \lambda = 0;$$
$$\lambda(p_O - \phi - T) = 0.$$

Case 1. From the KKT conditions, if $\lambda = 0$, $p_O^* = T$, if $T < \phi - T$, or if $T < \phi/2$. The first order condition with respect to p_O satisfies the SOC (as $p_O^* = T < 2T$). Therefore, if $T < \phi/2$, $p_O^* = T$, $p_S^* = \theta_H(p_O + T)/2 = \theta_H T$, and $\Pi_S = N\theta_H T/2$, and $\Pi_O = N\theta_H T/8$.

Case 2. If $T \ge \phi/2$, then $\lambda \ne 0$, and $p_O = \phi - T$. This also satisfies the SOC as $p_O^* = \phi - T < 2T$. Therefore, if $T \ge \phi/2$, $p_O^* = \phi - T$, $p_S^* = \theta_H(p_O+T)/2 = (\phi/2)\theta_H$, and $\Pi_S = N\theta_H\phi/4$, and $\Pi_O = N\theta_H(\phi - T)/8$.

Finally, one can directly see from the expression that (i) if $T < \phi/2$, $p_O = T$, and $\Pi_O = N\theta_H T/8$, the equilibrium payment-per-use and the profits of the firm using the pay-per-use mechanism increase until $T = \phi/2$. (ii) If $T \ge \phi/2$, $p_O = \phi - T$, and $\Pi_O = N\theta_H(\phi - T)/8$, the equilibrium payment-per-use and the profits of the firm using the pay-per-use mechanism decreases after $T = \phi/2$ till $\phi = T$. □

A.5. Proof of Proposition 4

To prove that the seller's profits in the duopoly are always greater than those of the firm that offers pay-per-use pricing, we have to prove that (using expressions from above):

(i) If $T < \phi/2$, $\Pi_O = N\theta_H T/8 < \Pi_S = N\theta_H T/2$, which is obvious.

(ii) If $T \ge \phi/2$, $\Pi_O = N\theta_H(\phi - T)/8 < \Pi_S = N\theta_H\phi/4$, which is obvious. □

A.6. Proof of Proposition 5

Monopoly: If the firm adopts selling and sets a selling price of p_S, the market share of the firm is

$$MS_+(p_S) = \frac{1}{\theta_H + v}\left[(\theta_H + v) - \frac{p_S}{\phi}\right]$$
if the actual frequency of use $\theta \sim U(0, \theta_H + v)$,

$$MS_-(p_S) = \frac{1}{\theta_H - v}\left[(\theta_H - v) - \frac{p_S}{\phi}\right]$$
if the actual frequency of use $\theta \sim U(0, \theta_H - v)$.

The expected profits of the firm are

$$\mathrm{E}[\Pi_S(p_S)] = Np_S \frac{MS_+(p_S) + MS_-(p_S)}{2}.$$

If the firm adopts pay-per-use and sets a payment-per-use of p_O, its profits are

$$\Pi_{O+}(p_O) = N\frac{(\theta_H + v)}{2} \quad \text{if the actual frequency of use } \theta \sim U(0, \theta_H + v).$$

$$\Pi_{O-}(p_O) = N\frac{(\theta_H - v)}{2} \quad \text{if the actual frequency of use } \theta \sim U(0, \theta_H - v).$$

If the firm uses pay-per-use in the presence of uncertainty in use frequency, it prices the information good at $p_O^* = \phi - T$ as before, and its expected profits are: $\mathrm{E}[\Pi_O(p_O)] = (\Pi_{O+}(p_O) + \Pi_{O-}(p_O))/2 = N\theta_H(\phi/2)$, which is the same as the case where the distribution of the frequency of use is known with certainty.

If the firm adopts selling, its expected profits are

$$\begin{aligned}\mathrm{E}[\Pi_S(p_S)] &= Np_S \frac{MS_+(p_S) + MS_-(p_S)}{2}\\ &= Np_S\left[1 - \frac{p_S}{2\phi(\theta_H + v)} - \frac{p_S}{2\phi(\theta_H - v)}\right].\end{aligned}$$

The FOC provide $p_S^* = \phi((\theta_H^2 - v^2)/(2\theta_H))$ and $\mathrm{E}[\Pi_S(p_S)] = (N\phi/4)(\theta_H - v^2/\theta_H)$, which are lower than the profits of the selling firm under certainty $N\phi\theta_H/4$.

The optimal selling price under uncertainty drops compared to the benchmark case without uncertainty. The intuition is that the density of consumers shifts downward when the upper end of use frequency is $\theta_H - v$. Therefore, the losses on account of unserved consumers when the price is not shifted downward in response to a lower realized bound $(\theta_H - v)$ on use frequency loom larger than the loss in profits on accounts of a smaller margin when the price is not shifted upward in response to a higher realized bound $(\theta_H + v)$ on use frequency. Expected profits under selling when there is uncertainty are lower than profits in the absence of uncertainty. In contrast, the profits of the firm under pay-per-use are identical across the cases with and without uncertainty in use frequency. Therefore, the cut-off psychological cost below which pay-use-use yields higher profits than selling is higher in the presence of such uncertainty. Stated simply, such uncertainty makes pay-per-use more attractive from the firm's perspective in the monopoly context.

Duopoly: The existence of the mixed equilibria are proved in a similar fashion to Proposition 2; we omit the proof for brevity. If one firm adopts the selling mechanism and the other firm adopts the pay-per-use mechanism, the market shares of the two firms are given by

$$MS_+(p_S) = \frac{1}{\theta_H + v}\left[\theta_H + v - \frac{p_S}{p_O + T}\right]$$
if the actual frequency of use $\theta \sim U(0, \theta_H + v)$,

$$MS_-(p_S) = \frac{1}{\theta_H - v}\left[\theta_H - v - \frac{p_S}{p_O + T}\right]$$
if the actual frequency of use $\theta \sim U(0, \theta_H - v)$.

The expected profits of the firm are

$$\mathrm{E}[\Pi_S(p_S)] = Np_S \frac{MS_+(p_S) + MS_-(p_S)}{2}.$$

If the firm adopts pay-per-use and sets a payment-per-use of p_O, its profits are

$$\Pi_O(p_O) = N\frac{p_O}{2}\frac{p_S}{(p_O + T)^2}\frac{\theta_H}{\theta_H^2 - v^2}.$$

The FOC of the Nash equilibrium yields

$$p_S^* = \left(\theta_H - \frac{v^2}{\theta_H}\right)\frac{p_O + T}{2},$$

$$p_O^* = T, \text{ if } T < \frac{\phi}{2} \quad \text{and} \quad p_O^* = \phi - T, \text{ if } T \geq \frac{\phi}{2}.$$

This yields

$$\Pi_S = \frac{NT}{2}\left(\theta_H - \frac{v^2}{\theta_H}\right) \quad \text{and} \quad \Pi_O = \frac{NT}{8}\left(\theta_H - \frac{v^2}{\theta_H}\right) \quad \text{if } T < \frac{\phi}{2}.$$

$$\Pi_S = \frac{N\phi}{4}\left(\theta_H - \frac{v^2}{\theta_H}\right) \quad \text{and} \quad \Pi_O = \frac{N(\phi - T)}{8}\left(\theta_H - \frac{v^2}{\theta_H}\right) \quad \text{if } T \geq \frac{\phi}{2}.$$

Comparing the results with those of Proposition 4 (with certainty) yields the results of Proposition 5. □

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