Pricing Access Services

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Abstract

Many established industries, such as the online service industry, the telecommunication industry, or the fitness club industry, are access service industries. When using services in these industries, consumers pay for the privilege of accessing the firm's facilities but do not acquire any right to the facility itself. A firm's pricing decisions in access industries frequently come down to a simple choice among *flat fee* pricing, *usage* pricing, or *two-part tariff* pricing. However, it is not so simple for firms in those industries to make this choice. Access service firms typically face a mix of consumers who have intrinsically different usage rates. A key characteristic of access service firms, however, is that the cost of providing an additional minute of usage is typically negligible, as long as the firm has the necessary capacity to serve its customers. Service capacity, which corresponds to the total available time on a firm's system, is often limited.

In this paper, we show that service capacity and consumer usage heterogeneity are two important factors that determine a firm's optimal choice. We develop a model that incorporates these two salient characteristics shared by access industries and study what determines a firm's choice among the three alternative pricing structures (*flat fee* pricing, *usage* pricing, or *two-part tariff* pricing). Our analysis shows that, in the presence of consumer usage heterogeneity, service capacity mediates a firm's optimal choice in a complex, yet predictable way. A firm's choice also hinges on whether heavy or light users are more valuable in terms of their willingness-to-pay on a per-unit-capacity basis. The presence of both consumer usage heterogeneity and capacity constraints prompts a firm to choose its pricing structure to attract a desired customer mix and to price discriminate. As a result, two-part tariff pricing is not always optimal in access industries, and a firm's pricing structure can vary in a complex way with the interaction of those two factors.

Specifically, we show that when light users are more valuable, a firm may use a two-part tariff or a flat fee, depending on whether the firm is constrained by its service capacity, but never charge a usage price alone or offer any signing bonus (a negative flat fee or a flat payment to customers). When heavy users are more valuable, a firm may choose to set a usage price, a signing bonus plus a usage price, or a flat fee. Interestingly, regardless of whether heavy or light users are more valuable in an access service industry, only flat rate pricing is a sustainable pricing structure once the industry has developed sufficient *excess* capacity.

We also show that the optimal pricing strategy in access industries can have some intriguing, nonintuitive implications that have not been explored elsewhere. For instance, when the industry capacity is unevenly distributed between competing firms, the large-capacity firm may well be advised to increase, rather than to decrease, its price to accommodate the small firm. It would be too costly and too tactless for the large firm to do otherwise. In fact, the strategy of accommodation calls on the larger firm to retreat in both light and heavy user markets and leave more of its capacity idle and more of the market demand unmet when the small firm's capacity (hence, the industry capacity) increases. This implies that incremental policy measures that encourage the growth of smaller companies in the presence of a large company can be welfare-decreasing because the growth of a smaller firm can force the retreat of a large company at the expense of market coverage.

Today, services account for two-thirds to three-quarters of the GNP, not only in the United States but also in many industrial countries. Access industries are growing rapidly to exert profound impact on today's economy. However, service pricing in general and pricing access services in particular have not received adequate attention in the literature. In this paper, we take the first step in understanding how capacity constraints and consumer usage heterogeneity mediate the choice of pricing structures in both monopolistic and competitive contexts.
(*Pricing Strategy; Service Pricing; Competitive Strategies; Access Services; Capacity; Equilibrium Models*)

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1. Introduction

"Access industries" are industries in which consumers pay for the privilege to access a facility but do not acquire any right to, or "use up," the facility itself. Companies such as Bloomberg, Reuters, Associated Press, and LexisNexis, for instance, sell access to information content. Internet service providers such as America Online and AT&T WorldNet Service sell access to the World Wide Web as well as to proprietary content. In addition to the information and media industries, firms offer access services in many other industries such as communications, entertainment, and health clubs. In pricing their access services, firms in these diverse industries frequently choose a simple pricing structure of either *flat fee* pricing, *usage* pricing, or a combination of the two, commonly referred to as *two-part tariff* pricing. In this paper, we investigate what a firm in access industries ought to consider in making such a choice.

Access industries share four salient characteristics:

- Capacity constraint: Firms can allow only a limited number of consumers to access the service simultaneously at any time, and this capacity constraint is fairly rigid in the short run.
- Usage heterogeneity: Consumers have different usage rates for the service. For instance, 97% of AT&T Worldnet customers are *light users.* Under the current flat fee pricing schedule, they average 25 hours of online usage per month. The remaining 3% are *heavy users,* or "campers" in Internet parlance, averaging 400 hours and tying up 30% of WorldNet network resources (*Investor's Business Daily* 1998). A similar usage pattern holds for other Internet access service providers.
- Low marginal cost: Provided that capacity is available, the marginal cost of serving a customer is very low and, to a large extent, independent of the consumer's usage rate. For instance, in the telecom industry, PCS carriers' operating costs are essentially unrelated to minutes of usage because of their large empty networks (*PCS Week* 1997).
- Competition: These industries are also competitive and offer differentiated products and services (Stroh 1998).

Despite these common structural characteristics, the choice of pricing structure in access industries is by no means common. Sports clubs, ski resorts, and cable TV companies, for instance, tend to use a flat rate pricing scheme. Long distance phone companies typically adopt usage pricing, charging by the minute of usage. Many Internet service providers and local telephone companies use two-part tariff pricing. In fact, the pricing structure may even vary across firms and over time in the same industry as firms frequently experiment with different pricing schemes at great cost (*PCS Week* 1997). AT&T WorldNet Service, for instance, started out with two-part tariff pricing and then switched to a flat fee, thus initiating the industry-wide move to unlimited Internet access for $19.95 per month. It then reverted back again to its more usage-based pricing strategy (*Investor's Business Daily* 1998). All these variations are rather puzzling in the context of the existing literature, suggesting that a firm's choice of its pricing structure is by no means simple.

The existing literature in economics strongly advocates two-part tariffs as the pricing structure of choice for a profit-maximizing firm with market power. In a classical article, Oi (1971) shows that a nondiscriminating two-part tariff scheme allows a monopolist to be both allocatively efficient, setting its usage price at the marginal cost or close to it, and profit-maximizing, using a flat fee to extract all or most consumer surplus. A number of follow-up studies explore the determinants of the optimal two-part tariff and its welfare implications in different demand and supply conditions (Schmalensee 1981, Calem and Spulber 1984, Hayes 1987, Stole 1995, Armstrong and Vickers 1999). More recently, in the context of nonlinear pricing with random participation constraints, Rochet and Stole (1999) show that the optimal nonlinear pricing schedule takes the simple form of cost-plus-fee schedules, once again affirming the optimality of two-part tariff pricing. However, none of these studies considers capacity constraints and consumer usage heterogeneity. As a result, neither sanctions the choice of usage pricing or flat fee pricing. Access industries need to look elsewhere for guidance in making their choices.

Research on the pricing implications of capacity constraints dates back at least to Edgeworth (1897), when he noted that a firm's pricing strategy is "indeterminant" in a price competition game with capacity constraints. Many economists have subsequently studied this game under different institutional assumptions and establish that capacity constraints underlie strategic interactions among competing firms in the marketplace (Kreps and Scheinkman 1983, Peters 1984, Davidson and Deneckere 1986, Benoit and Krishna 1987, Maggi 1996). However, this line of inquiry does not consider nonlinear pricing or consumer usage heterogeneity and once again cannot address the issue of choosing a pricing structure in access industries. One study that does consider nonlinear pricing and capacity related issues is Scotchmer (1985). She shows that when facilities can be shared and consumers care about the number of sharers, two-tier pricing, e.g., the membership fee plus a usage price, can arise in a symmetrical Nash equilibrium where all competing firms have an identical, fixed size. In our study, two-tier pricing is not motivated by congestion but by a firm's desire to exact the maximum return on its limited capacity when consumer usage intensity differs. As we will show shortly, capacity constraints are entirely different from congestion as a determinant of a firm's optimal pricing structure both in terms of modeling and strategy prescriptions, especially when firms are asymmetrical.

In this paper, we develop a model that incorporates the four salient characteristics shared by access industries and study what determines a firm's choice among the three alternative pricing structures.[1] Our analysis shows that service capacity mediates a firm's optimal choice in a complex yet predictable way. In addition, a firm's choice also hinges on whether heavy or light users are more valuable in terms of their willingness to pay on a per-unit-capacity basis. The presence of both consumer usage heterogeneity and capacity constraints prompts a firm to choose its pricing structure in order to attract a desired customer mix and to price discriminate. As a result, two-part tariff pricing is not always optimal in access industries. Specifically, when light users are more valuable, a firm may use a two-part tariff or a flat fee, depending on whether the firm is constrained by its service capacity, but never charge a usage price alone or offer any signing bonus (a negative flat fee or a flat payment to customers). When heavy users are more valuable, a firm may choose to set a usage price, or a signing bonus plus a usage price, or a flat fee. Interestingly, regardless of whether heavy or light users are more valuable in an access industry, only flat fee pricing is a sustainable pricing structure once the industry has developed sufficient *excess* capacity.

In the following sections, we first analyze a monopolist's choice in a market where light users are more attractive to develop the basic intuition. Then, we incorporate competition into this basic model and extend our analysis to the case where heavy users are more valuable. Finally, we conclude with suggestions for future research.

2. Pricing Monopolistic Access Service

Consider the case of a monopolist service provider. We assume that the firm is located at the left extremity of the Hotelling line bounded between 0 and 1. For its service, the firm can charge an access fee f and a usage price p per capacity unit (e.g., rides at an amusement park or access time). Because the marginal cost of providing access service is, in general, negligible, we set it to zero. The capacity of the firm at a given point in time is fixed at K and the costs for the capacity are sunk. With this setup, we can focus on a firm's short-term pricing decisions.

There are two types of consumers in the market: *heavy users* (h) and *light users* (l). Heavy users, accounting for a fraction α of the market, use d_h units of capacity when accessing the service, while light users, accounting for the rest of the market, use d_l units of capacity with $d_l < d_h$. Both d_h and d_l are as-

[1]We limit our attention to the three pricing schemes not because they are more profitable than some more complex multipart pricing schemes, but because firms frequently focus on these three options for the sake of simplicity, flexibility, and ease of administration (Curle 1998, Wilson 1993, p. 136).

sumed to be inelastic to the changes in price. Although this assumption is made to simplify our analysis, evidence seems to suggest that it is a good first-order approximation of reality in many industries, at least in the short run. In the Internet service industry—where flat fee pricing is common, for instance, despite zero marginal price—an overwhelming majority of users spend an average of only 25 hours online per month. This suggests that consumer usage rate is more a function of individual usage propensity than a function of price. In the concluding section, we will discuss how our conclusions may change if we relax this assumption.

In our basic model, we assume that heavy and light users have the same reservation price V for their ideal access service. We can easily extend this analysis to the case where light users have a higher reservation price with our conclusions essentially intact.[2] Thus, the analysis of our basic model is applicable to those service industries where heavy users are mostly the consumers with a low opportunity cost of time. For instance, a senior citizen who reads *The Wall Street Journal* from cover to cover may not be willing to pay a higher price than an academic scholar who only scans the headlines and browses occasional articles. A college student who spends over five hours a day on the Internet everyday chatting or playing games may not be willing to pay more for the access than a business professional who spends less than an hour a day online.[3] However, when an access service, such as the cellular phone service, is used predominantly for business, heavy users may have a higher willingness to pay for the service. In §4, we will explore a firm's pricing decisions in that case.

Without loss of generality, we normalize the total number of customers in the market to 1. Then, the maximum usage rate in the market is $\bar{d} = \alpha d_h + (1 - \alpha)d_l$, which is also the total capacity required to service the market. To introduce consumer heterogeneity in preference, we follow a well-established modeling convention, assuming that both heavy and light users are located uniformly along the Hotelling line. A consumer located at $0 \leq x \leq 1$ incurs the transportation cost of tx to access the monopolist's service. This cost measures the disutility that the consumer suffers when the service is away from the consumer's ideal point so that the further away the consumer is from the monopolist, the lower is the consumer's preference for the monopolist's service. Since consumers have a reservation price of V, the monopolist can never charge a positive price for its service and still attract a consumer located at a distance greater than. $\gamma = V/t$. We assume $\gamma \geq 3$ to ensure that the monopolist covers the whole market if it is not capacity constrained.

[2]Let $v_h d_h$ and $v_l d_l$ be the reservation prices for heavy and light users, respectively. We can show that our conclusions are not altered, given that $v_h d_h \leq v_h d_h(2 - d_l/d_h)$. The details of analysis are available from the website for *Marketing Science* at http://mktsci.pubs.informs.org.

[3]AT&T classifies those Internet users who spend an average of 150 hours per month online as heavy users. See Investor's Business Daily (1998).

2.1. Monopolist Without Capacity Constraint

Our assumptions about two types of consumers in the market and the firm's ability to use a two-part tariff effectively allow the monopolist to price discriminate between these two segments. For any given f (fee) and p (usage price), light users pay $P_l = f + pd_l$ and heavy users pay $P_h = f + pd_h$. At first blush, one might expect that a segmented pricing based on the usage rate, charging a different type of consumer a different total price, is always optimal for the monopolist. However, this is not the case when the monopolist is not capacity constrained, as the following proposition makes clear.

PROPOSITION 1. *When the monopolist is not capacity constrained ($K > \bar{d}$), it charges only a flat fee and all consumers who purchase the access service pay the same amount, irrespective of their usage rate.*

Proposition 1 is true because in the absence of any capacity constraint, the monopolist is only concerned with penetrating the market profitably, which means in this case covering the entire market since $\gamma \geq 3$. The optimal price for the monopolist is the maximum price it can charge while still attracting all consumers to buy, or $f = P_l = P_h = V - t$. Indeed, Proposition 1 seems hardly surprising, given that both types of consumers have the same reservation price for their ideal service. Intuition would suggest that segmented pricing exploits the difference in consumer willingness to pay at the segment level. Absent of this difference, one would expect that the monopolist has no motivation to use segmented pricing and is inclined to use a flat fee to attract the consumers who are most willing to pay, regardless of their usage rates. However, this intuition is misleading, as it ignores the mediation of capacity and consumer usage heterogeneity in a firm's pricing decision. As we show now, capacity constraint turns on the need for price discrimination: The monopolist will use segmented pricing even when there is no difference in consumer willingness to pay at the segment level, provided that it is capacity constrained.

2.2. Monopolist With Capacity Constraint

For any given capacity $0 \leq K \leq \bar{d}$, the monopolist must decide what pricing structure to use to engage its limited capacity optimally. For any given (f, p), all light users located to the left of x_l who gain positive surplus will make a purchase, where $x_l = (V - f - pd_l)/t$ is the location of the marginal light users who are just indifferent between buying and not buying. Similarly, all heavy users to the left of $x_h = (V - f - pd_h)/t$ will also make a purchase. Given that the total capacity engaged to service these purchases cannot exceed the total capacity available, the monopolist's optimization problem is given below:

$$\max_{(f,p)} (1 - \alpha)x_l(f + pd_l) + \alpha x_h(f + pd_h), \tag{1}$$

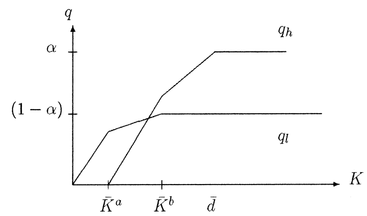
$$\text{s.t.} \quad 0 \leq x_l \leq 1, \tag{2}$$

$$0 \leq x_h \leq 1, \tag{3}$$

$$(1 - \alpha)x_l d_l + \alpha x_h d_h \leq K. \tag{4}$$

The analysis of the monopolist's optimization problem is fully detailed in Appendix 1. The solution is illustrated in Figure 1. There we see that when the monopolist's capacity is sufficiently small, or $K \leq \bar{K}^a = \gamma(d_h - d_l)(1 - \alpha)d_l/2d_h$, it draws only the light users located nearby because they are the least resource-demanding and the most profitable customers. The parameter $\bar{K}^a$ is determined by making sure that the constraint $x_h \geq 0$ is binding. To sell all available capacity to light users, the monopolist simply sets (f, p) so that there are just enough light users to exhaust the capacity, or $(1 - \alpha)x_l d_l = K$. This yields $f + pd_l = V - [K/(1 - \alpha)d_l]t$. To screen out heavy users, the monopolist makes sure $f + pd_h = V$, or $x_h = 0$. The two-part tariff that implements this pricing structure is given by

Figure 1 **Monopolist's Optimal Customer Mix Under Capacity Constraint**



Note: The illustration is for the case where $\gamma \leq 2d_h/(d_h - d_l)$. When $\gamma > 2d_h/(d_h - d_l)$, the only difference is that the monopolist exhausts light users in the market first before it taps into the heavy user segment.

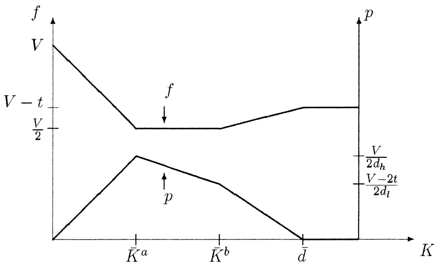
$$f = V - \frac{Kd_h}{(d_h - d_l)(1 - \alpha)d_l}t \quad \text{and}$$

$$p = \frac{K}{(d_h - d_l)(1 - \alpha)d_l}t, \tag{5}$$

where $f > 0$ and $p > 0$.

The fact that the monopolist sets $p > 0$ in this case indicates that it tends to charge heavy users more than it does light users. However, price discrimination arises here not because it allows the monopolist's profit from each segment to rise (the monopolist's profit from the heavy user segment is zero), but because it allows the firm to engage *all* of its capacity in the light user segment to maximize its overall profit. This indicates that the primary motivation for the monopolist to use two-part tariff pricing in this case is not to price discriminate but to attract a desired customer mix to engage its limited capacity. Indeed, this primary motivation prevails throughout our basic model where there exists no difference in willingness to pay for access service at the segment level. This explains why, as illustrated in Figure 2, the monopolist lowers the fixed-fee component of its price as its capacity expands ($K \leq \bar{K}^a$), while simultaneously increasing the usage price. The monopolist simply wants to attract more light users while sifting out

Figure 2 Monopolist's Optimal Pricing Structure



heavy users. This adjustment has the intended effect because a higher usage price hits heavy users harder than it does light users. The combination of these two changes enables the monopolist to deliver more incentives to light users without offering any to heavy users.

As the monopolist's capacity continues to increase beyond $\bar{K}^a$, it pulls in light users who are located further away. Eventually, attracting the heavy users located close to the firm becomes more profitable than attracting additional light users located far away, despite the fact that the former use up more capacity. This is when the monopolist adjusts its pricing structure to serve both light and heavy users, as illustrated in Figure 1 for $\bar{K}^a \le K \le \bar{K}^b$, where $\bar{K}^b = [2\hat{d} - \gamma(d_h - d_l)\alpha d_h]/2d_l$ and $\hat{d} = (1 - \alpha)d_l^2 + \alpha d_h^2$. The optimal mix of light and heavy users, as shown in Appendix 1, is given by the optimal sales in each segment below:

$$q_l = \frac{(1 - \alpha)}{2}\left(\frac{2Kd_l + \gamma(d_h - d_l)\alpha d_h}{\hat{d}}\right), \tag{6}$$

$$q_h = \frac{\alpha}{2}\left(\frac{2Kd_h - \gamma(d_h - d_l)(1 - \alpha)d_l}{\hat{d}}\right). \tag{7}$$

In this case, the monopolist prices its service such that any additional capacity yields the same return whether this incremental capacity is engaged by light users or by heavy users. The two-part tariff that achieves the optimal customer mix is given by

$$f = \frac{V}{2} \quad \text{and} \quad p = \frac{\gamma\bar{d} - 2K}{2\hat{d}}t. \tag{8}$$

By maintaining the level of its fixed fee but decreasing its usage price when it has a larger capacity, the monopolist offers a larger incremental incentive to heavy users to secure more of them.

At an even greater capacity ($\bar{K}^b \le K < \bar{d}$), all light users have already become the monopolist's customers. The incremental units of capacity above and beyond $\bar{K}^b$ are all used to attract additional heavy users that remain unserved. The optimal tariff schedule, as shown in Appendix 1, is given by

$$f = V - \frac{\hat{d} - Kd_l}{(d_h - d_l)\alpha d_h}t \quad \text{and} \quad p = \frac{\bar{d} - K}{(d_h - d_l)\alpha d_h}t. \tag{9}$$

In this case, the monopolist continues to lower its usage price all the way to zero (its marginal cost) as its capacity expands to attract more heavy users. In the meantime, it raises the fixed fee so that light users are not getting a free ride.

Thus, when consumers have different usage rates and preferences, customer mix becomes an important strategic consideration for a firm because of its capacity constraint. Capacity constraint motivates the monopolist to focus on the customer mix it attracts, rather than on the total number of customers, in order to reap the maximum return on its scarce resource. To generate the desired customer mix at a given level of capacity, the monopolist must rely on a two-part tariff because this pricing structure offers the flexibility for the monopolist to deliver differential incentives to heavy and light users. This allocative role of two-part tariff pricing is primarily motivated by the supply factor—capacity. Figure 2 shows that the flat fee component need not be flat because it decreases and then increases with a firm's capacity level. The usage price is also not constant. It increases and then decreases with the firm's capacity. These two components of the pricing structure are negatively correlated to ensure that the desired customer mix is obtained in the most remunerative fashion.

As a managerial insight, this analysis shows that a firm must not only pay customary attention to demand factors but also heed its capacity constraint in using a two-part tariff. When a firm faces capacity constraint, it should not have a limited resource priced in an unlimited fashion and it should use a two-part tariff to pull in the desired mix of customers to optimally engage its limited capacity. An oversight of capacity constraint and the allocative role of two-part tariff pricing can prove costly, as AOL and many other Internet companies have found out not long ago. Our analysis also suggests that the two components of a two-part tariff should be negatively correlated. The flat fee is a relatively more effective way to deliver incentives to, or extract surplus from, light users, whereas heavy users are more sensitive to the changes in the usage price. To prepare for the elimination of usage price, a firm should gradually raise its flat fee. Our analysis further points out that when capacity is plentiful, market penetration should be a firm's main strategic focus and a flat fee is the most efficient way to penetrate a market populated by both light and heavy users indiscriminately.

3. Pricing Competitive Access Service

Our analysis of pricing strategies for a monopolist service provider establishes that with no capacity constraint, the monopolist should simply use a flat fee to pursue market penetration. When capacity constrained, it should use a two-part tariff primarily as an allocative device to attract the desired customer mix in order to maximize its overall profit from the limited capacity. However, this analysis falls short of suggesting whether capacity plays the same role in determining a firm's pricing structure in a competitive context. Competition is, after all, the norm in many access industries.

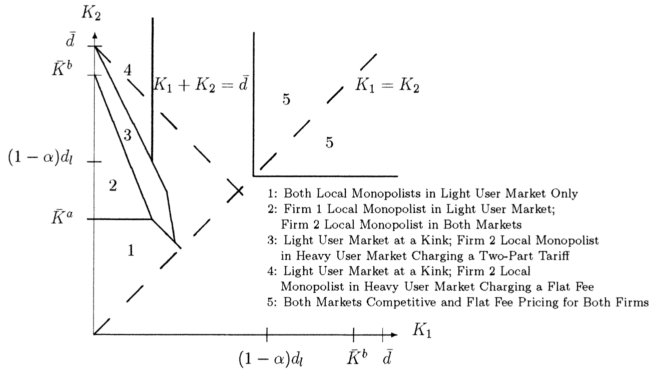
Many questions arise in the presence of competition. Is a flat fee or two-part tariff sustainable? It is not obvious that either pricing scheme can survive competition. A firm that uses a flat fee pricing effectively subsidizes heavy users at the expense of light users and, hence, opens itself up to a rival's attack on light users. A firm that adopts a two-part tariff may be vulnerable to the rival's efforts to peel off either light or heavy users. When a pricing scheme is sustainable, we can ask some further questions. In what ways may service capacity in an industry mediate the optimal pricing structure? Should a firm still pursue either market penetration or the customer mix, depending on whether it faces capacity constraint? If there is a mediating role for capacity, what matters more, the industry capacity or the distribution of industry capacity across firms? How should a firm with a given level of capacity choose its pricing scheme in a competitive context? Our answers to these questions will not only help us understand how to price access services in a competitive environment but also will provide a normative guide for practitioners in setting their prices.

To address these questions, we incorporate competition into our model by introducing a second access service provider at the right extremity of the Hotelling line while maintaining the rest of the assumptions we made in our monopolist model. We refer to the firm located at the left extremity as Firm 1 and at the right as Firm 2. We denote their capacity respectively by K_1 and K_2. Because these two competing firms are symmetric except in capacity, we can focus our analysis on the case where $K_2 \geq K_1$. In addition, we assume that heavy users are sufficiently different from light users in terms of their usage rate, or $d_h \geq 4d_l$.[4]

Competitive strategies for pricing access services are quite complex to analyze. There are a large number of potential equilibria because of competitive interactions with different levels of capacity constraints for both firms. In the light user market, both firms may be local monopolists (the market is uncovered), or secret handshakers (the market is covered but does not overlap), or competitors (they compete for a common subset of light users). When both firms are local monopolists in the light user market, the heavy user market may be uncovered, served by neither, or by a single firm, or by both firms. Moreover, firms may engage in a secret handshake or competition in the heavy user market. The same permutations of the heavy user market also apply to the cases where firms are secret handshakers and competitors in the light user market. Thus, there are altogether 15 potential equilibria. However, all but five of these potential equilibria are ruled out by the six lemmas in

[4]This assumption is sufficient, but not necessary, for our proofs. It greatly simplifies our derivations.

Figure 3 Equilibrium with Two Competing Firms



Appendix 2, so that we only need to focus on the remaining five.

3.1. Local Monopolists

Competition is immaterial if none of the firms has sufficient capacity. Thus, it comes as no surprise that when the industry does not have sufficient capacity to service even the light users, or $K_1 + K_2 < (1 - \alpha)d_l$, and each individual firm's capacity is also small, $K_i \le \bar{K}^a$ for $i = 1, 2$, a pure strategy equilibrium exists where both firms mimic the monopolist behavior in the previous section, serving only light users. We can find each firm's two-part tariff schedule by substituting into Equation (5) the appropriate capacity constraint. This equilibrium is shown in Region 1 of Figure 3.

A pure strategy equilibrium can also exist where both firms are local monopolists in the light user market, but Firm 2, the larger capacity firm, also attracts heavy users when its capacity is larger than $\bar{K}^a$. To see this, note that if $K_2 > \bar{K}^a$, Firm 2 will want to sell to both light and heavy users if it is the monopolist in both markets. In that case, the optimal sales to each segment are given by Equations (6) and (7), substituting in K_2 for K. Similarly, the optimal two-part tariff schedule is given by Equation (8). Then, the sufficient condition for such an equilibrium to exist is that both Firm 1 and Firm 2 are local monopolists in the light user market or that the sum of both firms' capacities engaged in that market is not sufficient to cover the market. This condition is given by

$$K_1 < (1 - \alpha)d_l\left(1 - \frac{2K_2 d_l + \gamma(d_h - d_l)\alpha d_h}{2\hat{d}}\right). \quad (10)$$

We show this equilibrium in Region 2 of Figure 3.

When the latter condition is not satisfied, a similar equilibrium exists where Firm 1 still sells all its capacity to light users, only Firm 2 serves heavy users exhausting all of its capacity, and both firms use a two-part tariff. The difference is that the light user market now becomes just covered. The necessary and sufficient conditions for such an equilibrium are given by

$$K_1 < (1 - \alpha)d_l\left(1 - \frac{K_2}{\bar{d}}\right), \quad (11)$$

$$K_1 \ge (1 - \alpha)d_l\left(1 - \frac{2K_2 d_l + \gamma(d_h - d_l)\alpha d_h}{2\hat{d}}\right), \quad (12)$$

$$K_1 \le (1 - \alpha)d_l\left(1 - \frac{2K_2 d_l + \gamma(d_h - d_l)\alpha d_h}{2\hat{d} + \alpha d_h^2}\right). \quad (13)$$

Condition (11) ensures that the larger capacity firm has a smaller coverage in the heavy user segment than in the light user segment and therefore charges a two-part tariff. Conditions (12) and (13) ensure that Firm 2 will neither raise nor lower its price to light users, while simultaneously reducing or increasing its price to heavy users to keep its capacity fully engaged.[5] We show this equilibrium in Region 3 of Figure 3.

In all three equilibria, two-part tariff pricing is the optimal pricing structure for both firms regardless of their own capacity level. This pricing scheme plays the same role, as in the monopoly case, of attracting the optimal mix of light and heavy users so that each firm gets the most bang for its limited capacity. As we can see from Figure 3, these three equilibria all take place below the line $K_1 + K_2 \le \bar{d}$, or when the industry capacity is inadequate to cover the whole market.

3.2. Secret Handshake and Flat Fee Pricing

When the industry capacity is inadequate to cover the market, the optimal pricing structure for a firm

[5]The derivations for Condition (13) are available from the website for *Marketing Science* at http://mktsci.pubs.informs.org.

varies, depending on the distribution of the industry capacity.

PROPOSITION 2. *In a competitive context, even if the industry capacity is insufficient to cover the whole market ($K_1 + K_2 < \bar{d}$), flat fee pricing can be optimal for a large capacity firm. When the industry has excess capacity ($K_1 + K_2 \geq \bar{d}$), two-part tariff pricing can be optimal for a small capacity firm.*

Proposition 2 arises from the equilibrium where Firm 1 serves light users to its full capacity; Firm 2 pulls in, with a flat fee, the rest of light users and some heavy users without exhausting its capacity. As we show in Appendix 2, as long as $K_1 > (1 - \alpha)d_l(1 - K_2/\bar{d})$ and $K_1 \leq (1 - \alpha)d_l\{1 - [(1 + \alpha)/(3 + \alpha)]\gamma\}$, such an equilibrium exists where

$$f_1 = V - \frac{d_h K_1 t}{(1 - \alpha)(d_h - d_l)d_l},$$

$$p_1 = \frac{K_1 t}{(1 - \alpha)(d_h - d_l)d_l}, \tag{14}$$

$$f_2 = V - t + \frac{K_1 t}{(1 - \alpha)d_l}, \qquad p_2 = 0. \tag{15}$$

This equilibrium is shown in Region 4 of Figure 3.

Proposition 2 is true as Region 4 in Figure 3 spans across the dotted line $K_1 + K_2 = \bar{d}$. In this equilibrium, the small capacity firm plays a niche strategy. Such a niche strategy is viable, even when excess capacity exists in the industry, because the firm with the lion's share of the market has too much to lose if it competes with a nonthreatening, small capacity firm for more light users. Indeed, light users are the most valuable customers from the perspective of the small capacity firm and it can most efficiently deploy its capacity if it concentrates on serving only light users. Furthermore, because of its small capacity and market share, the small firm is also best positioned to compete for light users. As a result, the optimal strategy for the large firm is to accommodate the small firm with a secret handshake: conceding just enough light users to the small firm to keep its capacity fully engaged and leaving some of its own capacity idle even when the market is not fully covered. In this equilibrium, a two-part tariff scheme allows the niche player to choke off the demand from heavy users, while bringing in just enough light users, so that it can most profitably engage its capacity. For the large capacity firm, a flat-fee allows it to expand most effectively in the heavy user segment, and it also helps sustain the secret handshake because any further decrease in the flat fee will generate a large inframarginal loss in both light and heavy user markets. Thus, capacity constraints also inject a strategic motivation into a firm's pricing decision.

In this equilibrium of secret handshake, the total numbers of consumers each firm and the industry as a whole serve are given by

$$N_1 = \frac{K_1}{d_l}, \qquad N_2 = 1 - \frac{K_1}{(1 - \alpha)d_l},$$

$$N_I = 1 - \frac{\alpha K_1}{(1 - \alpha)d_l}.$$

A simple comparative statics analysis on these numbers will lead us to the following proposition:

PROPOSITION 3. *In the equilibrium of secret handshake, the strategy of accommodation calls on the larger firm to retreat in both light and heavy user markets and leave more of its capacity idle and more of the market demand unmet when the small firm's capacity (hence, the industry capacity) increases.*

Proposition 3 has an intriguing, nonintuitive policy implication for access industries, which has not been explored elsewhere. It suggests that incremental policy measures that encourage the growth of smaller companies in the presence of a large company can be welfare-decreasing. This is because the growth of a smaller firm can force the retreat of a large company at the expense of market coverage.

Both Proposition 2 and Proposition 3 have some important managerial implications for pricing access services. Proposition 2 suggests that if the industry capacity is unevenly distributed, it is the large capacity firm, the firm that has excess capacity, that should use the flat fee pricing in an industry. A small capacity firm, the firm that must make every unit of its capacity count, should not follow suit, even when the industry as a whole has excess capacity. Proposition 3 suggests that in response to a small firm's encroachment on its market share, the large capacity firm may well be advised to increase, rather than decrease, its flat fee to accommodate the small firm because it may be too costly and too tactless for the large firm to do otherwise.

3.3. Competitive Flat Fee Pricing

Interestingly, whether or not a firm should use a flat fee pricing does not depend on whether or not it is capacity-constrained or whether or not the opportunity cost of its capacity is zero. This can be shown by analyzing the equilibrium where two firms without capacity constraints compete for both light and heavy users in the market and all use flat fee pricing. The equilibrium is fully characterised in Appendix 3. We show that there exists a pure strategy equilibrium only when both competing firms have sufficient excess capacity relative to the market demand they each serve: specifically, when $K_i \geq \bar{K}^c = (\bar{d}/2)[\sqrt{\gamma^2 - 2} - (\gamma - 2)]$, where $\bar{d}/2 < \bar{K}^c < \bar{d}$, for $i = 1, 2$. In this case, the equilibrium entails the use of a flat fee $f_1 = f_2 = t$ by both competing firms. We summarize the results in the following proposition.

PROPOSITION 4. *Flat fee pricing is optimal for competing firms only when they all have sufficient excess capacity relative to the market demand they each serve.*

Proposition 4 thus suggests that the optimal pricing structure also depends on the excess capacity each firm possesses. When $\gamma = 4$, for instance, each firm must have 74% more capacity than it needs to cover its share of the market to sustain competitive flat fee pricing.[6] Sufficient excess capacity serves two functions in a competitive context. First, it motivates a firm to focus on the number of customers it attracts, rather than the customer mix so that both types of consumers are equally attractive to the firm. A flat fee allows a firm to tap into both light and heavy user markets with equal efficiency, so it is the best choice for the firm.

Second, a firm's excess capacity deters any opportunistic behavior on the part of its rival. A firm can always take advantage of its rival's low price by raising its own price if the rival firm does not have sufficient excess capacity to meet the surge in demand. Then the rival firm wants to set a high price in the first place, which can then be taken advantage of by the firm's setting a low price to expand its market. This opportunistic behavior, along with the possibility that a firm can always redirect its capacity between the two markets through pricing, explains why there exists no pure strategy equilibrium when two large capacity firms do not have sufficient excess capacity, or when two capacity-constrained firms have a similar level of capacity.

Proposition 4 provides an alternative explanation for the popularity of flat fee pricing. Major amusement parks in this country, for instance, all use flat fee pricing (*The New York Times* 1999). One rationale for this pricing scheme is provided by Oi (1971): The firm with market power uses a flat fee to extract as much surplus as possible from those consumers who use a service that can essentially be provided at zero marginal cost. Scotchmer (1985) shows that the membership fee, in addition to a usage price, can arise in a symmetric Nash equilibrium because of congestion, but flat fee pricing *per se* is never optimal for a firm. Our analysis shows that flat fee pricing can be motivated by competitive pressure for market expansion. Such pressure is generated by the firm-level excess capacity. To expand its market, a firm must seek to attract both light and heavy users with a flat fee.

The managerial implication from this analysis is that two-part tariff pricing cannot be sustained in a competitive context when competing firms have developed sufficient excess capacity, but flat fee pricing can. However, only with *sufficient* excess capacity should a firm charge a flat fee for its access service. Thus, a firm is cautioned not to embrace a flat fee pricing when it has only *some* excess capacity. The fee that a firm can charge depends on consumer preference t, indicating the advisability of brand building and service differentiation in an industry where service capacity increases rapidly.

4. Extension

Our analysis thus far identifies three driving forces in a firm's pricing decision when capacity plays an

[6] As γ approaches $+\infty$, $\bar{K}^c$ approaches $\bar{d}$.

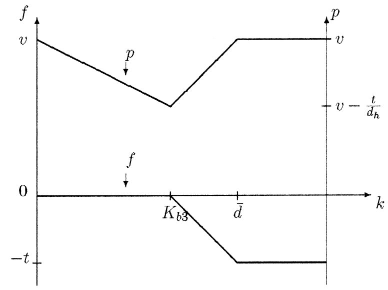
important mediating role. A firm's primary motivation may be to draw a desired mix of customers to deploy its limited capacity optimally, or to engage the rival in a secret handshake, or to pursue market penetration, depending on whether or not all competing firms are capacity-constrained and how industry capacity is distributed. However, these pricing insights are drawn in the context where light users are more ''valuable'' than heavy users because the former have a higher willingness to pay on a per-unit-of-capacity basis. This begs the question of whether these insights carry over to the situation where heavy users are more valuable, and if they are, in what form? In this section, we extend our basic model to address those questions.[7]

4.1. Usage Pricing and Signing Bonus for the Monopolist

We start with the monopoly case to gain some intuition. Consider the case where the reservation prices for heavy and light users are respectively given by vd_h and vd_l, instead of the common V as in our basic model. Analogously, we assume $vd_l/t > 3$ to ensure that the market is always covered when the monopolist does not face any capacity constraint. We also maintain the rest of the assumptions in our basic model. Therefore, at any given $(f + pd_h, f + pd_l)$, all heavy users located to the left of x_h, where $x_h = (vd_h - f - pd_h)/t$, will make a purchase. Similarly, all light users to the left of $x_l = (vd_l - f - pd_l)/t$ will also make a purchase. The monopolist's optimization problem is identical, in form, to that of our basic model as defined by Equations (1)–(4). However, the pricing structure that emerges is quite different.

Figure 4 illustrates the solution to this optimization problem. In this market, the monopolist wants to attract more heavy users than light users and charge heavy users more, too. This is because at any given location $x > 0$, the willingness to pay for one unit of capacity is higher for heavy users ($v - tx/d_h > v - tx/d_l$). The monopolist does so by starting with a high unit price and zero fee and gradually lowers the unit price as its capacity increases. This process continues as long as the monopolist's capacity is not large enough to service all heavy users ($K < K_{b3} = \hat{d}/d_h$). By charging a unit price alone and lowering it with a larger capacity, the monopolist delivers more incentives to heavy users as its capacity increases, thus engaging more of its limited capacity with the more valuable consumers in the market. Once all heavy users are pulled in ($K \geq K_{b3}$), the monopolist must find a way to attract more light users without giving heavy users a free ride. The monopolist does so by simultaneously raising its unit price and offering a ''signing bonus,'' a negative flat fee, to target its incentives at light users. Here, a two-part tariff plays the dual role of helping a firm to attract a desired customer mix and to price discriminate.

Figure 4 Monopolist's Optimal Pricing Structure



In comparison to our basic model, the surprising insight from this analysis is that a flat fee is no longer optimal, even at a high level of capacity when heavy users in a market are more valuable. In its place, the monopolist uses a ''signing bonus'' and a unit price to penetrate the light user market while still taking relatively more surplus away from heavy users.

4.2. Competitive Flat Fee Pricing

In the competitive context, as we show in Appendix 4, when industry capacity is sufficiently small ($K_1 + K_2 < \hat{d}/d_h$), and hence, competition is immaterial, a unit price is all that a firm needs to set, as in the case of monopoly. When $\hat{d}/d_h \leq K_1 + K_2 \leq \hat{d}/d_h + (1 - \alpha)(d_l^2/2d_h)$, both firms will use a two-part tariff that consists of a signing bonus and a unit price. This pricing structure, as in the monopoly case, allows a firm to penetrate the light user segment to fully engage its capacity while taking advantage of the higher willingness to pay on the part of heavy users. Further-

[7]The authors thank an anonymous reviewer for suggesting this analysis.

Table 1 Market Conditions and Optimal Pricing Structure

Optimal Pricing Structure	Market Condition	
	Heavy Users More Valuable	Light Users More Valuable
Flat fee	Sufficient firm excess capacity ($K_i \geq \tilde{K}^c$, $i = 1, 2$)	• Sufficient industry excess capacity ($K_i \geq \bar{K}^c$, $i = 1, 2$) • Noncapacity constrained (competing with a capacity constrained)
Usage price	Industry capacity sufficiently small* ($K_1 + K_2 \leq \hat{d}/d_h$)	Never
Flat fee plus usage price	Never	Capacity constrained firm
Signing bonus plus usage price	Medium industry capacity† ($\hat{d}/d_h < K_1 + K_2 \leq \hat{d}/d_h + (1 - \alpha)\, d_l^2/2d_h$)	Never

*The larger capacity firm charges a smaller usage price.
†The larger capacity firm offers a larger signing bonus and charges a smaller usage price.

more, because of the fact that heavy users are both more valuable and resource consuming, both firms price strategically not to compete for more heavy users at the expense of light users such that the heavy user market is just covered. As each firm's capacity becomes sufficiently large, i.e., $K_i > \tilde{K}^c$ ($\bar{d}/2 < \tilde{K}^c < \bar{d}$), both firms will, surprisingly, charge a flat fee. This is because excess capacity unleashes intense price competition, which in turn drives the prices each firm charges in both segments of the market to be the same.

Thus, the analysis of this extended model offers three interesting new insights, as summarized in Table 1. First, when capacity is a mediating factor, a firm's pricing structure also depends on whether heavy or light users are more valuable in terms of their willingness to pay on a per-unit-capacity basis. When light users are more valuable, a firm may use a flat fee or a flat fee plus a unit price, but never charge a unit price alone or offer any signing bonus. However, when heavy users are valuable, a firm may use a unit price, or a signing bonus plus a unit price, or a flat fee. This perhaps explains why the pricing structure varies across different access industries. Second, regardless of whether heavy or light users are more valuable in an access industry, only flat fee pricing is a sustainable pricing structure once the industry has developed sufficient excess capacity. This may provide useful insights about the future pricing implications in cellular phone or broadband industries as industry capacity continues to increase rapidly. Third, in a market where heavy users are more valuable, the larger capacity firm will charge a lower usage price and offer a larger signing bonus whenever such bonus is required. This is because a larger capacity motivates the firm to pursue heavy users more aggressively.

5. Conclusion

Today, services account for two-thirds to three-quarters of the GNP, not only in the United States but also in many industrial countries (Lovelock 1996). Access industries are growing rapidly to exert profound impact on today's economy (Rifkin 2000). However, service pricing in general and pricing access services in particular have not received adequate attention in the literature. In this paper, we take the first step in understanding how capacity constraints and consumer usage heterogeneity mediate the choice of pricing structures in both monopolistic and competitive contexts.

We show that capacity constraints, along with consumer usage heterogeneity, are an important determinant for pricing access services. Because of these two interacting factors, pricing access services is a delicate decision that requires a firm to balance two frequently conflicting incentives. On one hand, once a firm acquires a certain level of capacity, the firm has incentives to use it to the full extent and in the most efficient way. These incentives can tempt a firm to become as aggressive in pricing as it is consistent with the efficient use of its limited resource. On the other hand, a firm's aggressiveness in pricing is tempered by its desire to price discriminate based on consumer usage heterogeneity and by its strategic motivation to accommodate a capacity-constrained rival. A profit-maximizing firm responds to all these incentives by focusing on customer mix, a driving force in a firm's choice of its pricing structure.

However, there is no simple rule for designing the optimal pricing structure in a competitive context. The past research on nonlinear pricing suggests that two-part tariff pricing is always the pricing structure of a profit-maximizing firm's choice whenever a positive marginal cost is involved, and flat fee pricing is the choice whenever it is not. It is tempting to extend this rule to access industries by replacing the marginal cost with the opportunity cost of capacity: Whenever there exists a positive opportunity cost for a firm's capacity or a firm is capacity-constrained, it should choose a two-part tariff, and otherwise a flat fee. However, such a rule would be misleading. As we have shown in our basic model, competitive flat fee pricing occurs only when there exists sufficient *excess* capacity in an industry. This means that even if the opportunity cost of a firm's capacity is zero, i.e., the shadow price of capacity is zero, it may not be advisable for a firm to use flat fee pricing. In our extended model, usage pricing, rather than two-part tariff pricing, is the pricing structure of a firm's choice even when the opportunity cost of capacity is positive. Choosing a pricing structure is far more complex in access industries because with capacity constraints and hence uncovered market, price discrimination, and surplus extraction are no longer the only motives for a firm.

Nevertheless, aside from the detailed strategic prescriptions uncovered in this study, our analysis does provide a general, managerial guide to narrow down a firm's choice. We show that when light users are more valuable, a firm may use a two-part tariff or a flat fee depending on whether the firm is constrained by its service capacity, but never charge a usage price alone or offer any signing bonus (a negative flat fee or a flat payment to customers). When heavy users are more valuable, a firm may change from a usage price to a signing bonus plus a usage price and then to a flat fee as its capacity increases. Interestingly, regardless of whether heavy or light users are more valuable in an access industry, only flat fee pricing is a sustainable pricing structure once the industry has developed sufficient *excess* capacity.

Our conclusions are based on some important assumptions that warrant further discussion. In our model, the consumer usage rate is inelastic to price changes. Implicitly, what we are saying here is that the consumer usage rate depends largely on individual propensity rather than price. This assumption may seem extreme. However, in the context of service industries, we believe this is a good first-order approximation of reality. Unlike physical goods for which "free disposal" is always an option and more is, in general, always better, service delivery is intrinsically participatory. Participation requires time commitment and physical effort on the part of consumers. Thus, there is no free disposal for service, and time cost and physical efforts limit the effectiveness of price incentives in altering consumer usage habit. This perhaps explains why a vast majority of consumers spend only an average of 25 online hours per month even when they face zero marginal price. However, we acknowledge that this assumption limits the applicability of our conclusions to the service industries where consumer usage propensity is relatively inelastic to price changes.

Implicitly, we also assume that a firm has little room to adjust its "service quality" such that it cannot provide different versions of the same service targeted at consumers of different quality sensitivity with different prices. This assumption rules out any possibility for a firm to offer different versions of access services along with a menu of two-part tariffs to induce consumer self-selection. We make this assumption for two reasons. First, for many access services such as access to ski lift, to Internet, to movie theaters, to sports facilities, or to amusement parks, consumers may care much more about access than about service. In those industries, it is either not feasible or not desirable for firms to offer exclusive services with an elaborate pricing menu. In that case, firms can only tap into usage heterogeneity to charge differential prices. A two-part tariff has the sufficient degree of pricing freedom to allow a firm to do just that. This perhaps explains why we frequently observe the three simple choices we have discussed in the introduction. Thus, our conclusions are applicable to those industries. Of course, our conclusions are also applicable to the industries where the ''service'' dimension is important under a restrictive but plausible condition. The condition is that the distribution of consumer service sensitivity is lumpy, such that the incentive compatibility constraint for each consumer segment is not likely to distort a firm's pricing choice for any specific segment.

Second, as a modeling choice, this assumption allows us to explore how the interactions between capacity constraints and consumer usage heterogeneity determine a firm's choice of its pricing structure. Adding a quality dimension in the context of incomplete market coverage, which the literature has so far deliberately avoided, would have made our analysis much less tractable and transparent without any apparent promise for new insights. The same can be said about extending our model to incorporate more than two usage segments where consumer willingness to pay depends on usage rates.

Future research can extend our analysis in a number of promising directions. For instance, the long-term impact of pricing structures on consumer usage rates and the issue of capacity investment can be discussed in conjunction with pricing decisions. The model can also be extended to include multiple firms with varying sizes to examine the relationship between the market structure and the pricing structure. We hope that this first step we have taken will spark further interest in pricing access services.

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Appendix 1. Analysis of the Capacity Constrained Monopolist

We assume $\gamma \geq 3$ henceforth, so that the monopolist always chooses to cover the market if it has sufficient capacity. Then, for any given capacity $0 \leq K \leq \bar{d}$, the monopolist must decide what pricing structure to use to engage its limited capacity optimally. For any given pricing structure (f, p), all light users located to the left of x_l who gain positive surplus will make a purchase, where

$$x_l = \frac{V - f - pd_l}{t} \tag{A.1}$$

is the location of the marginal light users who are just indifferent between buying and not buying. Similarly, all heavy users to the left of

$$x_h = \frac{V - f - pd_h}{t} \tag{A.2}$$

will also make a purchase. Of course, the total capacity needed to service these purchases cannot exceed the total capacity available. As noted in §2.2, the monopolist optimization problem is therefore

$$\max_{(f,p)} \ (1 - \alpha)x_l(f + pd_l) + \alpha x_h(f + pd_h), \tag{A.3}$$

$$\text{s.t.} \quad 0 \leq x_l, \tag{A.4}$$

$$x_l \leq 1, \tag{A.5}$$

$$0 \leq x_h, \tag{A.6}$$

$$x_h \leq 1, \tag{A.7}$$

$$(1 - \alpha)x_l d_l + \alpha x_h d_h \leq K, \tag{A.8}$$

This optimization problem is considerably simpler to solve if we note that:

- The monopolist capacity will always be fully engaged, given $\gamma \geq 3$, if $K \leq \bar{d}$, i.e., that Constraint (A.8) is always binding.
- As long as $K > 0$, we must have $x_l > 0$, as the monopolist always taps into the light user segment first, i.e., that Constraint (A.4) is never binding.
- When the monopolist capacity is infinitely small, it draws only the light users located nearby because they are the least resource-demanding and the most profitable customers. So for small levels of capacity, Constraint (A.6) is always binding (and therefore (A.7) is not). Also, for small levels of capacity, not all of the light users are served by the monopolist, and therefore Constraint (A.5) is not binding. To determine the boundary conditions of this case, as well as derive the monopolist's optimal pricing structure in this case, we need to solve for the following Lagrangian function:

$$L_1(f, p, u_1, w) = (1 - \alpha)x_l(f + pd_l) + \alpha x_h(f + pd_h) + u_1 x_h - w(K - (1 - \alpha)x_l d_l - \alpha x_h d_h).$$

We use the Mathematica software to maximize the Lagrangian $L_1(f, p, u_1, w)$ (as well as all subsequent Lagrangian functions in this appendix), and solve for f, p, u_1, and w. The optimal pricing structure (f, p) that we obtain in this case is reported in Equations (5) of the paper. The boundary condition of this case (that $x_h = 0$) is given by the condition that the Lagrangian parameter u_1 is positive: We find that constraint (A.6) is binding (i.e., $x_h = 0$) as long as the firm capacity is sufficiently small, i.e., $K \le \bar{K}^a = [\gamma(d_h - d_l)(1 - \alpha)d_l/2d_h$.

- We focus on the case where $\bar{K}^a$ is smaller than $(1 - \alpha)d_l$. This is the case (a) of Figure 1, where $\gamma \le 2d_h/(d_h - d_l)$. In this case, the monopolist will start attracting heavy users before having served all the light users in the market (i.e., $x_l < 1$). So when Constraint (A.6) stops to bind (i.e., $x_h > 0$), Constraint (A.5) does not bind as yet (as $x_l < 1$), nor does Constraint (A.7). The first boundary condition of this case is therefore $\bar{K}^a \le K$, which ensures that $x_h > 0$ (i.e., Constraint (A.6) stops to bind). To determine the other boundary condition of this case, as well as derive the monopolist's optimal pricing structure in this case, we need to solve for the following Lagrangian function:

$$L_2(f, p, w) = (1 - \alpha)x_l(f + pd_l) + \alpha x_h(f + pd_h) - w(K - (1 - \alpha)x_l d_l - \alpha x_h d_h).$$

We maximize $L_2(f, p, w)$ and solve for f, p, and w. The optimal pricing structure (f, p) that we obtain in this case is reported in Equation (8) of the paper. Using this optimal pricing structure and Equations (A.1) and (A.2), we derive the optimal penetration levels x_l and x_h in each of the light and the heavy user segments, respectively. We obtain that $x_l = [2Kd_l + \gamma(d_h - d_l)\alpha d_h]/\hat{d}$ and $x_h = [2Kd_h - \gamma(d_h - d_l)(1 - \alpha)d_l]/\hat{d}$. It is straightforward to check that $x_h < x_l$. We can therefore derive the number of light and heavy users served by the monopolist $q_l = (1 - \alpha)x_l$ and $q_h = \alpha x_h$, respectively. The results are reported in Equations (6) and (7) of the paper. The second boundary condition for this case is given by $x_l < 1$ (i.e., that Constraint (A.5) does not bind, and hence neither does Constraint (A.7): Using the expression for the optimal penetration level $x_l = [2Kd_l + \gamma(d_h - d_l)\alpha d_h]/\hat{d}$ derived above, we find that the condition $x_l < 1$ implies that the firm capacity needs to be lower than the threshold $\bar{K}^b$, where $\bar{K}^b = [2\hat{d} - \gamma(d_h - d_l)\alpha d_h]/2d_l$, and hence the boundary conditions of this case are $\bar{K}^a \le K \le \bar{K}^b$.

- When the monopolist capacity increases beyond $\bar{K}^b$, Constraint (A.5) starts to bind (i.e., $x_l = 1$). As long as the monopolist capacity remains below $\bar{d}$, Constraint (A.7) does not bind (i.e., $x_h < 1$). The boundary conditions of this case are $\bar{K}^b \le K < \bar{d}$, which ensure that $x_h > 0$ (i.e., Constraint (A.6) stops to bind). To derive the monopolist's optimal pricing structure in this case, we need to solve for the following Lagrangian function:

$$L_3(f, p, u_3, w) = (1 - \alpha)(f + pd_l) + \alpha x_h(f + pd_h) - u_3(x_l - 1) - w(K - (1 - \alpha)x_l d_l - \alpha x_h d_h).$$

We maximize $L_3(f, p, u_3, w)$ and solve for f, p, u_3, and w. The optimal pricing structure (f, p) that we obtain in this case is reported in Equation (9) of the paper. We check that the boundary conditions of this case are indeed $\bar{K}^b \le K < \bar{d}$. First, the boundary condition that $x_l = 1$ (i.e., that Constraint (A.5) is binding) is given by the condition that the Lagrangian parameter u_3 is positive, which is equivalent to the firm's capacity being greater than $\bar{K}^b$. Second, using the optimal pricing structure for this case (as reported in Equation (9)) and Equation (A.2), we derive the optimal penetration level x_h in the heavy user segment, and we check that $x_h < 1$ is equivalent to $K < \bar{d}$.

Appendix 2. Equilibrium Analysis of Basic Model

In §3, we noted that there are possibly as many as 15 potential equilibria. We can classify these potential equilibria into three general classes, depending on how light users are served: both firms are local monopolists (the market is uncovered), secret handshakers (the market is covered but does not overlap), or competitors (firms compete for a common subset of light users).

Observe that when the total equilibrium prices in the light user segment are P_{1l} and P_{2l}, the last light user who is willing to buy from firm i is located at a distance $(V - P_{il})/t$ from the firm. One can therefore characterize the three general classes of equilibria in terms of the relative locations of the firms' marginal light users. This yields conditions on the equilibrium prices in the light user market:

Class 1: Equilibria. The light user segment is uncovered (both firms are local monopolists) if and only if $P_{1l} + P_{2l} > 2V - t$.

Class 2: Equilibria. The light user segment is just covered (firms are secret handshakers) if and only if $P_{1l} + P_{2l} = 2V - t$.

Class 3: Equilibria. The light user segment is competitive (firms compete for a common subset of light users) if and only if $P_{1l} + P_{2l} < 2V - t$.

In this appendix, we rule out all but the five equilibria identified in the main text.

Note that the unit price p must be nonnegative for a two-part tariff. This implies that firms must set a light user price $P_l = f + pd_l$ no greater than the heavy user price $P_h = f + pd_h$. However, it is always a *permissible deviation* for a firm to lower its price to light users. In what follows, whenever rationing needs to be invoked for our proofs, we use the efficient rationing rule.

Class 1: Equilibria—Light User Segment Uncovered

If $P_{1l} + P_{2l} > 2V - t$, we must also have $P_{1h} + P_{2h} > 2V - t$, as $P_{ih} \ge P_{il}$ for $i = 1, 2$ under a two-part tariff. This means that in any equilibrium where the light user market is uncovered, the heavy user market must also be uncovered. This, in turn, implies that both firms are capacity constrained. Otherwise, both firms would have incentives to expand their market coverage given $\gamma > 3$.

We can also rule out the case where both firms are local monopolists in the heavy user market when the light user market is uncovered. Note that if an equilibrium exists where both firms are local monopolists in the heavy user market, it must mean that one of the firms, say Firm 1, serves less than half of the light users (i.e., less than $1 - \alpha/2$ users). Otherwise, the light user market would be covered. Then, Firm 1 is a local monopolist in both light and heavy user markets with less than $(1 - \alpha)d_l/2 < \bar{K}^a$ units of capacity engaged in the light user market. However, from our analysis of the monopolist case, we know that this is not possible, as the optimal strategy for a monopolist is to engage its capacity up to $\bar{K}^a$ in the light user market before it attracts any heavy user. Regions 1 and 2 of Figure 3 illustrate the remaining equilibria of this class.

Class 2: Equilibria—Light User Segment Just Covered

In any equilibrium where the light user market is at a kink, we must have $P_{1l} + P_{2l} = 2V - t$. The following five lemmas will establish that the only Class 2 equilibria are those identified in Regions 3 and 4 of Figure 3.

LEMMA 1. *If none of the firms is capacity constrained, the light user market cannot be just covered.*

PROOF. Suppose, to the contrary, that there exists an equilibrium where the light user market is just covered, but none of the firms is capacity constrained. Then, we must have $q_{1l} > (1 - \alpha)(\gamma/3)$, i.e., Firm 1's sales to light users must be sufficiently large that Firm 1 has no incentive to lower its price to light users further to attract more of them. Similarly, we must have $q_{2l} > (1 - \alpha)(\gamma/3)$, so that Firm 2 does not deviate. As $q_{2l} = (1 - \alpha) - q_{1l}$ when the light user market is at a kink, the previous two inequalities then imply $\gamma < 3/2$, a contradiction ($\gamma > 3$ by assumption). □

LEMMA 2. *If only one firm is capacity constrained, there exists no equilibrium in which the light user segment is just covered, both firms are present in the heavy user market and the heavy user market is either uncovered or just covered.*

PROOF. Suppose, to the contrary, that there exists an equilibrium where only one firm is capacity constrained, say Firm 1, the light user segment is just covered, both firms are present in the heavy user market, and the heavy user market is either uncovered or just covered. Firm 2 will not attract new light users (with its unused capacity) only if $q_{1l} < (1 - \alpha)(1 - \gamma/3)$ because the light user market is at a kink. Firm 1 will not release capacity from the heavy user segment and engage the same capacity in the light user segment if

$$q_{1l} \geq \frac{1 - \alpha}{2\hat{d} + \alpha d_h^2}(2K_1 d_l + \gamma(d_h - d_l)\alpha d_h). \tag{A.9}$$

Because $K_1 \geq q_{1l} d_l$, the above inequality implies $q_{1l} > (1 - \alpha)[(d_h - d_l)/d_h](\gamma/3)$. This and the inequality $q_{1l} < (1 - \alpha)(1 - \gamma/3)$ imply $\gamma < 3d_h/(2d_h - d_l)$. Because $d_h > 4d_l$, we must have $3d_h/2(d_h - d_l) < 2$. A contradiction. □

LEMMA 3. *If both firms are capacity constrained, there exists no equilibrium in which both segments are just covered.*

PROOF. Suppose, to the contrary, that there exists an equilibrium where both firms are capacity constrained and both segments are just covered. We then necessarily have $K_1 + K_2 = \bar{d}$.

Firm 1 will not attract additional light users and disconnect the heavy user segment as long as Inequality (A.9) holds. Neither does Firm 2 if

$$q_{2l} > \frac{1 - \alpha}{2\hat{d} + \alpha d_h^2}(2K_2 d_l + \gamma(d_h - d_l)\alpha d_h). \tag{A.10}$$

Because $q_{2l} = (1 - \alpha) - q_{1l}$ and $K_2 = \bar{d} - K_1$, we have from Inequality (A.10)

$$q_{1l} < \frac{1 - \alpha}{2\hat{d} + \alpha d_h^2}(2K_1 d_l - (\gamma - 2)(d_h - d_l)\alpha d_h + \alpha d_h^2). \tag{A.11}$$

Then inequalities (A.9) and (A.11) imply $\gamma < 1 + d_h/2(d_h - d_l)$. As $d_h > 4d_l$ (by assumption), we have $d_h/2(d_h - d_l) < 1$. This implies that $\gamma < 2$, a contradiction. □

LEMMA 4. *If both firms are capacity constrained, there is no equilibrium in which the light user segment is just covered, and both firms serve the heavy user segment as local monopolists.*

PROOF. In any such equilibrium, Firm 1 will not deviate by attracting additional light users and release some heavy users if Inequality (A.9) holds. Neither does Firm 2 if Inequality (A.10) holds. Because $q_{2l} = (1 - \alpha) - q_{1l}$ when the light user market is at a kink, we must have from Inequality (A.10),

$$q_{1l} < (1 - \alpha) - \frac{1 - \alpha}{2\hat{d} + \alpha d_h^2}(2K_2 d_l + \gamma(d_h - d_l)\alpha d_h). \tag{A.12}$$

In this equilibrium, we necessarily have $K_1 + K_2 > (1 - \alpha)d_l$. This, along with Inequality (A.12), implies

$$q_{1l} < (1 - \alpha) - \frac{1 - \alpha}{2\hat{d} + \alpha d_h^2}(2((1 - \alpha)d_l - K_1)d_l + \gamma(d_h - d_l)\alpha d_h), \tag{A.13}$$

which we can simplify as

$$q_{1l} < \frac{1 - \alpha}{2\hat{d} + \alpha d_h^2}(2K_1 d_l + 3\alpha d_h^2 - \gamma(d_h - d_l)\alpha d_h). \tag{A.14}$$

Then, Inequalities (A.9) and (A.14) imply $\gamma < 3d_h/2(d_h - d_l)$. However, because $d_h > 4d_l$, we must have $3d_h/2(d_h - d_l) < 2$. This implies $\gamma < 2$, a contradiction. □

LEMMA 5. *Whenever a firm is not capacity constrained and serves the light user segment in an equilibrium, the firm must also serve the heavy user segment.*

PROOF. Suppose, to the contrary, that an equilibrium exists where the firm serves only the light users. Then, by lowering its price in the heavy user segment to $v - \epsilon$, the firm will use some of its unused capacity to attract some heavy users and increase its profit. A contradiction. □

We can now establish that the only Class 2 equilibria are those identified in Regions 3 and 4. Because the light user market is just covered, at least one of the firms is capacity constrained (Lemma

1), and hence the heavy user segment cannot be just covered as well (Lemma 3). Moreover, the heavy user segment cannot be competitive since $P_{1l} + P_{2l} = 2V - t$, which implies that $P_{1h} + P_{2l} \geq 2V - t$. The heavy users segment is therefore uncovered.

If both firms are capacity constrained, then only one firm can serve the heavy users segment (Lemma 4). This is the local monopolist case discussed in the text and illustrated in Region 3 of Figure 3.

If one firm, say Firm 1, is capacity constrained and Firm 2 is not, Firm 2 must be present in the heavy user segment (Lemma 5), and hence Firm 1 cannot be present in the heavy user segment as well (Lemma 2). Firm 2 is the unique local monopolist in the heavy user market. Therefore, Firm 2 must be charging a flat fee. To see that, note that if Firm 2 were charging a two-part tariff ($p_l^2 < p_h^2$), it would be able to lower its heavy user price and expand in the heavy user market (which is always profitable as $\gamma > 3$). This implies that any Class 2 equilibrium entails that Firm 1 serves only light users to its full capacity, and Firm 2 is not capacity constrained and serves both light and heavy users with a flat fee. This is the case that we now discuss and that is illustrated in Region 4 of Figure 3.

We first derive the necessary conditions for the existence of an equilibrium where Firm 1 serves light users to its full capacity and Firm 2 serves both light users and heavy users with a flat fee. Firm 1, in this proposed equilibrium, serves all light users to the left of x such that its capacity K_1 is exhausted, or $x = K_1/(1 - \alpha)d_l$. In this equilibrium, the light user located at x must be indifferent between buying from Firm 1 and from Firm 2 and has zero surplus. Otherwise, Firm 2 can always raise its flat fee without losing any customer. This necessarily implies $f_1 + p_1 d_l = V - tx$ and $f_2 = V - t(1 - x)$. Because Firm 1 does not sell to any heavy user, we must also have $f_1 + p_1 d_h = V$. Thus, we have

$$f_1 = V - \frac{d_h K_1 t}{(1 - \alpha)(d_h - d_l)d_l}, \qquad p_1 = \frac{K_1 t}{(1 - \alpha)(d_h - d_l)d_l}, \tag{A.15}$$

$$f_2 = V - t + \frac{K_1 t}{(1 - \alpha)d_l}, \qquad p_2 = 0. \tag{A.16}$$

Because Firm 2 does not exhaust its capacity, we must also have in this proposed equilibrium $(1 - \alpha)(1 - x)d_l + \alpha(1 - x)d_h < K_2$, or

$$K_1 > (1 - \alpha)d_l\left(1 - \frac{K_2}{\bar{d}}\right). \tag{A.17}$$

To check the sufficient conditions for this equilibrium, note that Firm 1 will never lower its price to attract more light users because it is already capacity constrained. Neither will it raise its price charged to light users to make room for some heavy users, as $K_1 \leq (1 - \gamma/3)(1 - \alpha)d_l < \bar{K}^a$. Thus, Firm 1 has no incentive to deviate from the proposed equilibrium.

Firm 2, on the other hand, has no incentive to raise its price because it desires to serve the whole market as a monopolist, but it may want to lower its price to either light users or both light and heavy users to gain a larger market share. The most profitable way for Firm 2 to lower its price is to lower its price to both segments of consumers by the same amount, i.e., reducing its flat fee.[8] In that case, if Firm 2 lowers its flat fee by $\epsilon > 0$, it gains $(1 - \alpha)\epsilon/2t$ light users, each of whom pays $(f_2 - \epsilon)$. In addition, it gains $\alpha\epsilon/t$ heavy users, each of whom also pays $(f_2 - \epsilon)$. However, Firm 2 incurs the total loss of $(1 - x)\epsilon$, because it charges a lower price to all those light and heavy users who are currently buying from it. The gain is smaller than the loss if

$$K_1 \leq (1 - \alpha)d_l\left(1 - \frac{1 + \alpha}{3 + \alpha}\gamma\right). \tag{A.18}$$

As long as Condition (A.18) is satisfied, Firm 2 has no incentive to deviate from the proposed equilibrium, either. Thus, the proposed equilibrium is indeed an equilibrium, which we show in Region 4 of Figure 3.

Class 3: Equilibria—The Light Users Segment Competitive

In this case, $P_{1l} + P_{2l} < 2V - t$. We first develop two lemmas (Lemmas 6 and 7) that will help us establish that the only Class 3 equilibria is the competitive equilibrium in Region 5.

LEMMA 6. *In any equilibrium where the light user segment is competitive, if the heavy user segment is not, one of the firms must be capacity constrained while the other is not. The unconstrained firm charges a flat fee only.*

PROOF. In any equilibrium where the light user segment is competitive but not the heavy user segment, we necessarily have $P_{1h} + P_{2h} \geq 2V - t > P_{1l} + P_{2l}$. Therefore, one of the firms' light user price must be *strictly* smaller than its heavy user price, say Firm 2's or $P_{2l} < P_{2h}$. Then, Firm 1 cannot be capacity constrained. Otherwise, Firm 2 can raise its price to light users slightly to $P_{2l} + \epsilon < P_{2h}$ and extract some additional surplus from its light users without losing anyone of them. Given that Firm 1 is not capacity constrained, Firm 2 must be. Otherwise, none of the firms is capacity constrained and the standard Hotelling no-deviation conditions yield $P_{il} = P_{ih} = t$ for both firms ($i = 1, 2$), which then implies $P_{1h} + P_{2h} = 2t < 2V - t$ (the heavy user segment is competitive). A contradiction. If the unconstrained Firm 1 does not charge a flat fee, its light user price would be strictly smaller than its heavy user price ($P_{1l} < P_{1h}$). However, this cannot be an equilibrium because Firm 1 can raise its light user price slightly to $P_{1l} + \epsilon < P_{1h}$ and extract some additional surplus from its light users without losing anyone of them because Firm 2 is capacity constrained. A contradiction again. □

LEMMA 7. *There exists no equilibrium where the light user segment is competitive and the heavy user segment is not.*

PROOF. Suppose, to the contrary, that an equilibrium exists where the light user segment is competitive and the heavy user segment

[8]The alternative is for the firm to use a two-part tariff to deliver a lower price to light users than to heavy users. However, such a deviation can be shown to be less profitable, given that the demand in the light user market is at a kink.

is not. Then, by Lemma 6 we know that in the equilibrium one of the firm must be capacity constrained, say Firm 2, while Firm 1 is not. Moreover, Firm 1 must charge a flat fee only. In this equilibrium, there are only two possibilities in the heavy user market: Either Firm 1 is a local monopolist in the heavy user market, or its demand in the heavy user market is at a kink. We now consider the first case.

Suppose that Firm 1 increases its price by $\epsilon > 0$ in both markets and deviates to $P_{1l} = P_{1h} = f_1 + \epsilon$. Firm 1 will lose $\alpha(\epsilon/t)$ heavy users. Firm 1 does not lose any light users since the light user market is competitive and Firm 2 is capacity constrained. Firm 1's first order gain is $(2q_{1h} + q_{1l} - \alpha\gamma)\epsilon$. Such a deviation is not profitable if

$$\gamma \geq \frac{q_{1l} + q_{1h}}{\alpha} + \frac{q_{1h}}{\alpha}. \tag{A.19}$$

Suppose that Firm 1 lowers its price by $\epsilon > 0$ in both markets and deviates to $P_{1l} = P_{1h} = f_1 - \epsilon$. Firm 1 will attract $(1 - \alpha)(\epsilon/2t)$ light users in the light user market and $\alpha(\epsilon/t)$ in the heavy user market. The first-order gain from the deviation is negative if and only if

$$\gamma \leq \frac{2(q_{1l} + q_{1h})}{1 + \alpha} + \frac{q_{1h}}{\alpha}. \tag{A.20}$$

Inequalities (A.19) and (A.20) imply

$$(1 - \alpha)(q_{1l} + q_{1h}) \leq 0, \tag{A.21}$$

which is not possible. Thus, Firm 1 always has an incentive to deviate.

We now consider the second case, where Firm 1's demand in the heavy user market is at a kink, and show that this equilibrium is also impossible. Suppose, to the contrary, that such an equilibrium exists. Once again, by Lemma 6, one of the firms, say Firm 2, must be capacity-constrained, while Firm 1 is not. In addition, Firm 1 must charge a flat fee. Firm 2 has no incentive to lower its price to light users, while simultaneously increasing its price to heavy users so that all its capacity is still engaged, if

$$\frac{P_{2l}}{t} \leq \frac{2\hat{d}\left(1 - \dfrac{q_{1l}}{1 - \alpha}\right) - 2K_2 d_l + \gamma\alpha d_h d_l}{\alpha d_h^2}. \tag{A.22}$$

Note also that in this equilibrium, we have $P_{1l} + P_{2l} < 2V - t$ (the light user market is competitive) and $P_{1h} + P_{2h} = 2V - t$ (the heavy user market at a kink) so that $P_{1l} + P_{2l} < P_{1h} + P_{2h}$. Because $P_{1l} = P_{1h}$ in this equilibrium, we must have $P_{2l} < P_{2h}$. This means that Firm 2 can also deviate by raising its price to light users, while simultaneously lowering its price to heavy users so that all of its capacity is still engaged. This deviation is not profitable if

$$\frac{P_{2l}}{t} \geq \frac{(4\hat{d} - 2\alpha d_h^2)\left(1 - \dfrac{q_{1l}}{1 - \alpha}\right) - 4K_2 d_l + 2\gamma\alpha d_h d_l}{\alpha d_h^2}. \tag{A.23}$$

Note that in this equilibrium, we have $(1 - \alpha) - q_{1l} = q_{2l}$ and $q_{2l}d_l + q_{2h}d_h = K_2$. Using these two equalities, we have from Inequalities (A.22) and (A.23)

$$\gamma \leq \frac{2q_{2h}}{\alpha}. \tag{A.24}$$

However, Inequality (A.24) and the assumption $\gamma > 3$ imply $q_{2h} > \alpha$, i.e., that Firm 2's sales to heavy users are larger than the heavy user segment. A contradiction. This means that Firm 2 always has an incentive to deviate. □

Appendix 3. Competitive Flat Fee Pricing

To derive the equilibrium of competitive flat fee pricing, we note that if none of the firms is constrained by its capacity, the no-infinitesimal-deviation conditions yield the standard Hotelling result for the price competition game, or $f_l + p_1 d_l = f_l + p_1 d_h = f_2 + p_2 d_l = f_2 + p_2 d_h = t$. This means that in this equilibrium we must have $f_1 = f_2 = t$, while $p_1 = p_2 = 0$. We then have the standard Hotelling payoff for each firm, or $\pi_1^* = \pi_2^* = t/2$. Notice that in such an equilibrium, firms must share the market equally, and each firm uses $\bar{d}/2$ units of its capacity. The condition that none of the firms is capacity constrained therefore implies that both K_1 and K_2 are greater than $\bar{d}/2$.

We now check the sufficiency conditions for such an equilibrium. The no infinitesimal deviation conditions rule out any unilateral deviation by a firm that leaves its competitor with some unused capacity. The only potentially profitable deviation for a firm is to raise its price unilaterally such that its competitor becomes capacity constrained. Firm i's unused capacity under our proposed equilibrium is $K_i - \bar{d}/2$. If each firm's capacity is greater than $\bar{d}$, each has at least $\bar{d}/2$ units of unused capacity under our proposed equilibrium. In this case, there is no deviation by a firm that can leave its competitor capacity constrained, and hence none of the firms wants to deviate unilaterally. Thus, a firm may deviate only if the competitor's capacity is between $\bar{d}/2$ and $\bar{d}$.

Suppose Firm 1's capacity is between $\bar{d}/2$ and $\bar{d}$. Firm 2 deviates by raising its price so much that all of Firm 1's capacity becomes engaged. Here, we assume for simplicity that Firm 1 always sells first to the consumers who value its service the most until it exhausts its capacity. In other words, we use the efficient rationing rule whenever excess demand arises because of capacity constraint. Once Firm 1 becomes capacity constrained, Firm 2 can charge a monopoly price to the remaining customers in the market.

At the point where Firm 1 becomes capacity constrained because of Firm 2's deviation, Firm 1 must be selling at the price t to both light and heavy users to the left of $\hat{x}$ such that it just exhausts its capacity K_1, where $\hat{x} = K_1/\bar{d}$. Then, the optimal deviation for Firm 2 is to sell to the rest of the consumers at a price that leaves zero surplus to the marginal consumers located at $\hat{x}$, or $P_h = P_l = V - (1 - \hat{x})t$. Thus, the optimal deviation profit is given by $\hat{\pi}_2 = [V - (1 - \hat{x})t](1 - \hat{x})$. This deviation payoff is smaller than $\pi_2^* = t/2$ if

$$K_1 \geq \bar{K}^c = \frac{\bar{d}}{2}[\sqrt{\gamma^2 - 2} - (\gamma - 2)], \tag{A.25}$$

where $\bar{d}/2 < \bar{K}^c < \bar{d}$. This means that only when $K_1 \geq \bar{K}^c$, Firm 2 has no incentive to deviate from the proposed equilibrium. Symmetrically, Firm 1 has no incentive to deviate if $K_2 \geq \bar{K}^c$. □

Appendix 4. Equilibrium Analysis of Extended Model

To analyze the competitive case, note that at any given prices (p_h^2, p_h^1) charged respectively by the two competing firms, the heavy users who are indifferent between purchasing from either firm must be located at $\tilde{x}_h = (p_h^2 - p_h^1 + t)/2t$. These indifferent heavy users may derive negative surplus at those prices. In that case, they do not purchase from any firm and the heavy user segment is uncovered, i.e., $p_h^1 + p_h^2 > 2vd_h - t$; or they derive zero surplus from their purchase such that the heavy user segment is just covered (just covered), i.e., $p_h^1 + p_h^2 = 2vd_h - t$; or they enjoy positive surplus such that the heavy user segment is not only covered, but also competitive, i.e., $p_h^1 + p_h^2 < 2vd_h - t$. We now take up each possibility in turn to look for an equilibrium.

Heavy User Segment Uncovered

When the heavy user segment is uncovered, both firms are local monopolies in the heavy user segment. From our analysis of the monopolist case, we know that in any such equilibrium $x_h^i = (d_h/\hat{d})k^i$ is strictly greater than $x_l^i = (d_l/\hat{d})k^i$. Therefore, if the heavy user segment is uncovered, so must be the light user segment. Thus, both firms will price their access services as if they are a monopolist, charging only a per-unit price $p^i = v - (k^i/\hat{d})t$. In this equilibrium, we must have $x_h^1 + x_h^2 < 1$, i.e., $K_1 + K_2 < \hat{d}/d_h$.

Heavy User Segment Just Covered

In any equilibrium where the heavy segment is just covered, the light user segment can be either uncovered, just covered, or competitive. We will first show that there exists no equilibrium where the light user segment is either just covered or competitive and then derive the equilibrium where the light user segment is uncovered. We proceed first by proving a useful lemma.

LEMMA 8. *In any equilibrium where the heavy segment is just covered and the light segment is either just covered or uncovered, if Firm i is present in both markets charging a two-part tariff, we must have* $(2/3)x_l^i d_h \leq x_h^i d_l$.

PROOF. Firm i charging a two-part tariff $(p_l^i < p_h^i)$ in equilibrium can always deviate by raising its price to light users by ϵ and lowering its price to heavy users by ϵ'. Because the light user segment is not competitive, such price changes will drop $(1 - \alpha)\epsilon/t$ light users and free $(1 - \alpha)(\epsilon/t)d_l$ units of capacity. Because the heavy user segment is just covered, the decrease in price to heavy users will attract $\alpha\epsilon'/2t$ heavy users and engage $\alpha(\epsilon'/2t)d_h$ units of additional capacity in that segment. Such simultaneous price changes are always feasible, irrespective of whether or not the firm is capacity constrained, because it can always set $(1 - \alpha)(\epsilon/t)d_l = \alpha(\epsilon'/2t)d_h$. The net gain from these price changes is $(1 - \alpha)(x_l^i - \epsilon/t)\epsilon - (1 - \alpha)(\epsilon/t)p_l^i + \alpha(\epsilon'/2t)(p_h^i - \epsilon') - \alpha x_h^i \epsilon'$. Because none of the user segments are competitive, we must have $p_h^i = vd_h - x_h^i t$ and $p_l^i = vd_l - x_l^i t$. Then, the first-order net gain can be simplified to $\alpha(\epsilon/td_h)(2x_l^i td_h - 3x_h^i td_l)$. To sustain the equilibrium, the first-order gain is necessarily negative, which implies $(2/3)x_l^i d_h \leq x_h^i d_l$. □

We now show that there exists no equilibrium where both the heavy and light segments are just covered. Suppose, to the contrary, that such an equilibrium exists. Then, there must exist a firm, say Firm i, such that $x_l^i \geq x_h^i$, as if otherwise the inequality must apply to the rival firm $(x_l^j < x_h^j)$. Given that $x_l^i \geq x_h^i$, Firm i cannot charge a flat fee in this equilibrium. Otherwise, we must have $p_h^i = p_l^i$, which in turn implies, by the fact that both heavy and light user markets are just covered, $x_l^i < x_h^i$, which contradicts $x_l^i \geq x_h^i$. Therefore, Firm i must be charging a two-part tariff, i.e., $p_h^i > p_l^i$. Then, by Lemma 8, we must have $(2/3)x_l^i d_h \leq x_h^i d_l$ or $x_h^i > 2x_l^i$, because $d_h > 4d_l$ by assumption. A contradiction. □

Now we show that there exists no equilibrium where the heavy user segment is just covered and the light user segment is competitive. Suppose, to the contrary, that such an equilibrium exists. In any such equilibrium, at least one firm is capacity constrained. Otherwise, the standard Hotelling conditions (no-infinitesimal deviations) would yield a flat fee pricing structure for both firms with $f^1 = f^2 = t$. This would further mean that the indifferent heavy user would enjoy positive surplus, which is not possible. Now, let Firm 2 be capacity constrained. Then, Firm 1 must charge a flat fee f^1 in this equilibrium. Otherwise, it can profitably deviate by raising its light user price, extracting additional surplus from its light users without losing any of them to Firm 2 (which is unable to serve them because of its capacity constraint). Furthermore, the capacity constrained Firm 2 necessarily charges a two-part tariff $(p_l^2 < p_h^2)$. Otherwise, if it were to charge a flat fee f^2, the fact that the heavy market is just covered and the light market is competitive implies $2vd_h - t = f^1 + f^2 < 2vd_l - t$, which is impossible because $d_h > d_l$ by assumption.

Firm 1 cannot be capacity constrained in this equilibrium. Or Firm 2 can always profitably deviate by raising its price to light users, extracting additional surplus from its light users without losing any of them to Firm 1 because of the firm's capacity constraint. As the heavy user segment is just covered, we have in equilibrium $p_h^2 = vd_h - (1 - x_h^1)t$ and $f^1 = vd_h - x_h^1 t$. Furthermore, as the light user segment is competitive, we must have $p_l^2 = 2x_l^1 t + f^1 - t$. These three equalities imply $p_h^2 = p_l^2 + 2(x_h^1 - x_l^1)t$. Now, as $p_l^2 < p_h^2$, we must have in equilibrium

$$x_h^1 > x_l^1. \tag{A.26}$$

In the hypothesized equilibrium, Firm 2 has no incentive to drop some light users while simultaneously picking up some heavy users if

$$vd_h(d_h - d_l) > tx_l^2 4d_h - tx_h^2(d_h + 3d_l). \tag{A.27}$$

Given $d_h > d_l$, this inequality implies $vd_h(d_h - d_l) > tx_l^2 4d_h - tx_h^2 4d_h$, which can be simplified to $v(d_h - d_l) > 4t(x_l^2 - x_h^2)$. This inequality, along with $x_l^2 - x_h^2 = x_h^1 - x_l^1$, yields

$$v(d_h - d_l) > 4t(x_h^1 - x_l^1). \tag{A.28}$$

Once again, because the heavy user segment is just covered in the hypothesized equilibrium, Firm 1's marginal heavy users must have zero surplus, i.e., $s_h^1 = vd_h - tx_h^1 - f^1 = 0$. Because the light user segment is competitive, Firm 1's marginal light users must derive a positive surplus, i.e., $s_l^1 = vd_l - tx_l^1 - f^1 > 0$. These two inequalities imply

$$v(d_h - d_l) < t(x_h^1 - x_l^1). \tag{A.29}$$

From Inequalities (A.26), (A.28), and (A.29), we get $0 < 4t(x_h^1 - x_l^1) < t(x_h^1 - x_l^1)$. Because $(x_h^1 - x_l^1) > 0$ from Inequality (A.26), we must have $4t < t$. A contradiction. □

Therefore, the only possible equilibrium we can find is the one where the heavy segment is just covered and the light segment is uncovered. In such an equilibrium, we must have $vd_h - p_h^i - tx_h^i = 0$ for $i = 1, 2$ by definition. Furthermore, both firms' capacity must be binding. Otherwise, the firm whose capacity is not binding can always lower its price to light users to gain more profit, as $\gamma_l \geq 3$ by assumption.

In this equilibrium, we have either $p_h^i = p_l^i$ or $p_h^i > p_l^i$ for any Firm i. However, we cannot have $p_h^i = p_l^i$ in equilibrium. This can be shown as follows. Suppose, to the contrary, that in equilibrium we have $p_h^i = p_l^i$ for Firm i. Then, the fact that the marginal heavy users derive zero surplus at Firm i and the marginal light users gain nonnegative surplus implies

$$\frac{x_h^i - x_l^i}{x_l^i} \geq \frac{(d_h - d_l)v}{tx_l^i}. \tag{A.30}$$

Furthermore, in this equilibrium, Firm i should not have any incentive to deviate by lowering its price to light users and increasing its price to heavy users simultaneously, while keeping its capacity full engaged. This implies $x_h^i d_l \geq x_l^i d_h$, or

$$\frac{x_h^i - x_l^i}{x_l^i} \leq \frac{d_h - d_l}{d_l}. \tag{A.31}$$

Inequalities (A.30) and (A.31), together with $\gamma_l \geq 2$, imply $x_l^i \geq 2$, a contradiction. □

Because we must have $p_h^i > p_l^i$ in equilibrium, we must also have $vd_l - p_l^i - tx_l^i = 0$, i.e., that Firm i's marginal light users derive zero surplus. Otherwise, Firm i can always raise its price to light users slightly to increase its profit. Thus, the necessary conditions for this equilibrium are characterized by the following equalities:

$$vd_h - p_h^i - tx_h^i = 0, \tag{A.32}$$

$$vd_l - p_l^i - tx_l^i = 0, \tag{A.33}$$

$$\alpha x_h^i d_h + (1 - \alpha)x_l^i d_l = K_i, \tag{A.34}$$

$$x_h^1 + x_h^2 = 1, \tag{A.35}$$

where $i = 1, 2$. The sufficient conditions are given by the following two inequalities:

$$\frac{2}{3}x_l^i d_h \leq x_h^i d_l, \tag{A.36}$$

$$x_l^i d_h \geq x_h^i d_l. \tag{A.37}$$

Inequality (A.36) comes from Lemma 8, which ensures that neither firm has an incentive to deviate by simultaneously raising its price to light users and lowering its price to heavy users while still engaging its capacity fully. Inequality (A.37) ensures that neither firm has incentive to make the simultaneous price changes the other way around.

Conditions (A.32)–(A.37) define multiple equilibria. The multiplicity arises from the fact that both firms desire to engage their capacities in the heavy user segment first and they have no incentive to initiate price competition in that market as long as they engage a sufficient amount of capacity in that segment. However, if we impose the condition that the heavy user segment is "equitably" shared, i.e., $x_h^i = K_i/(K_1 + K_2)$, we have a unique equilibrium as long as $\hat{d}/d_h \leq K_1 + K_2 \leq \hat{d}/d_h + (1 - \alpha)d_l^2/2d_h$, where

$$f^1 = \frac{K_1 t[\hat{d} - (K_1 + K_2)d_h]}{(1 - \alpha)(d_h - d_l)d_l(K_1 + K_2)} \leq 0,$$

$$f^2 = \frac{K_2 t[\hat{d} - (K_1 + K_2)d_h]}{(1 - \alpha)(d_h - d_l)d_l(K_1 + K_2)} \leq 0,$$

$$p^1 = v - \frac{[\bar{d} - (K_1 + K_2)]K_1 t}{(1 - \alpha)(d_h - d_l)d_l(K_1 + K_2)} > 0,$$

$$p^2 = v - \frac{[\bar{d} - (K_1 + K_2)]K_2 t}{(1 - \alpha)(d_h - d_l)d_l(K_1 + K_2)} > 0.$$

Heavy User Segment Competitive

In any equilibrium where the heavy user segment is competitive, none of the firms can be capacity constrained. This is because if one of the firms is constrained by its capacity, the rival firm can always profitably deviate by raising its price to heavy users, extracting additional surplus from its heavy users without losing any of them to the capacity-constrained firm. This, in turn, means that the light user segment cannot be uncovered or just covered in equilibrium. The standard Hotelling conditions (no infinitesimal deviations) then yield, as the necessary conditions for a competitive equilibrium, a flat fee pricing structure for both firms with $f^1 = f^2 = t$ and a profit of $t/2$ for each firm. In this equilibrium, each firm's capacity must be large enough to cover half of the market, i.e., $K_i > \bar{d}/2$. We now derive the sufficient conditions for this equilibrium.

The optimal deviation for any firm in this hypothesized equilibrium is to raise its prices such that the rival, charging the flat fee t, becomes capacity constrained. Without the rival being capacity constrained, a firm's best response to the rival's charging the flat fee t is to charge the flat fee t itself. This implies that a firm may deviate only when the rival's capacity is not large enough to cover the whole market, i.e., $K_i < \bar{d}$. Otherwise, the optimal deviation can never make a firm better off. Now, consider, say, Firm 2 unilaterally takes the optimal deviation, given that

$\bar{d}/2 < K_1 < \bar{d}$. In that case, Firm 2's prices will be such that the marginal light and heavy users to Firm 2 will all have zero surplus. As Firm 1's price in both segments is fixed at t, we need to specify a rationing rule to allocate Firm 1's capacity at that low price. For simplicity, we assume that Firm 1's capacity is allocated on the basis of location such that we always have $x_l^1 = x_h^1 = x^1$. This means $x^1 = K_1/\bar{d}$. Here we can also use the efficient rationing rule. Such a rule will not qualitatively alter our conclusion but will yield a far more complex cutoff point in capacity for the competitive equilibrium to be sustained.

Firm 2's optimal deviation prices can be determined from $vd_h - p_h^2 - t(1 - x^1) = 0$ and $vd_l - p_l^2 - t(1 - x^1) = 0$. Then, the optimal deviation profit for Firm 2 is given by $\alpha x^1 p_h^2 + (1 - \alpha)x^1 p_l^2$. Let

$$\tilde{K}^c = \frac{\bar{d}}{2}(\sqrt{\bar{\gamma}^2 - 2} - (\bar{\gamma} - 2)),$$

where $\bar{\gamma} = \bar{d}v/t > 2$ and $\bar{d}/2 < \tilde{K}^c < \bar{d}$. It is straightforward to show that as long as $K_1 > \tilde{K}^c$, Firm 2's optimal deviation profit is strictly less than $t/2$, its profit in the hypothesized equilibrium, so that Firm 2 has no incentive to deviate. The same analysis also applies to Firm 1. □

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