Network Competition and Interconnection with Heterogeneous Subscribers

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Abstract

This paper analyses two-way access pricing in a telecommunications market where consumers are heterogeneous in their demand for calls and firms are allowed to use nonlinear tariffs. We first investigate how the presence of access charges affects the tariffs offered by firms in symmetric equilibrium. Next we show that under certain conditions each firm's profit is independent of the level of (reciprocal) access charge and therefore collusion using access charges is not sustainable. This result suggests that efficient call allocations can be achieved under a minimal regulatory intervention, i.e. recommending firms set access charges equal to call-termination cost.

Keywords: Two-way networks; Interconnection; Competitive nonlinear pricing; Telecommunications policy

JEL classification : D43; L43; L51; L96

1 Introduction

Local telecommunications are no longer considered natural monopolies. Due to technological advances, competition has been (or is being) introduced in local networks in most industrialised countries. The US Telecommunications Act of 1996 sets the ground rules towards competition in all telecommunications markets, and most European countries have removed the legal entry barriers into local telephony. As a result, we often find competing telecommunications operators with their own local networks. In Britain, for example, customers have a choice between BT, Cable and Wireless Communications, cable TV operators, and mobile service providers. Networks have their own subscribers and interconnect with each other to gain access to each other's subscribers. This two-way access (or interconnection) problem differs in many aspects from one-way access situations where a monopolist owns a single local network and provides access to the essential facilities for competitors in complementary segments, such as long-distance telecommunications.[1] First, local networks are not monopolised by one firm. Second, there is head-to-head competition in the retail market. However, each network still has monopoly power at least in providing access to its own local network for rivals and the level of the access charge directly affects retail prices.

An important issue for public policy is how to define the regulatory role in two-way interconnection situations. Current policy regarding interconnection charges varies across countries from almost laissez-faire as in New Zealand to rather strong regulatory involvement as in the US and the UK. In their pioneering work, Armstrong (1998) and Laffont-Rey-Tirole (1998a) (LRT hereafter) have shown that the intensity of competition can be weakened via a collusive high access charge. Under linear pricing, reducing retail prices to expand market shares can be very costly to the price-cutting firm since the price cut causes a net outflow of calls which, for a high access charge, entails large access payments to the rival network. Therefore, access charges can be used as a collusion-facilitating device in order to soften retail market competition and the firms can in fact achieve the joint-profit maximising outcome. However, the validity of the collusion result crucially depends on the assumption of *linear pricing*. As shown by LRT (1998a, section 8), the collusion effect disappears if firms use *two-part tariffs*. Under two-part tariffs, the firms can compete for market shares using fixed fees, leaving marginal prices unchanged, without

[1] The literature on one-way access pricing suggests that regulation of terms of access is necessary to ensure socially desirable outcomes because the monopolist has incentives to set too high a level of access charge. For more details, see Laffont and Tirole (1994) and Armstrong-Doyle-Vickers (1996) among others.

affecting the net outflow of calls. That is, the fixed fee provides the firms with an additional instrument to build market share, making collusion using access charges unsustainable. This is in striking contrast with the linear pricing case implying that results are quite sensitive to the assumptions taken in the model.[2]

This paper examines the two-way access pricing problem in a more general and realistic setting than Armstrong (1998) and LRT (1998a). In particular, we assume that consumers have different tastes for telephone calls and the firms can use general nonlinear tariffs. In reality, consumers are heterogeneous in their demand for calls (say, heavy users and light users) and firms often use various kinds of nonlinear tariffs to screen different consumers. In Britain, for instance, BT offers the 'Premier Line' which discounts the per-call price by a certain fixed lump-sum charge being paid in advance. The main question we wish to investigate is how the equilibrium tariffs are affected by access charges, and whether collusion using access charges can be still sustained in a more general environment with heterogeneous consumers and nonlinear tariffs.[3] The main findings of our analysis are as follows:

- *Equilibrium nonlinear tariff and call allocation*: Provided the (reciprocal) access charge diverges from the call-termination cost, the (symmetric) equilibrium nonlinear tariff involves distortions in call consumption for all types of subscribers. This contrasts with the efficient two-part tariff result obtained by Armstrong-Vickers (2001) and Rochet-Stole (2002) in the context of competitive price discrimination without interconnection between firms.[4] This is mainly because the presence of access charges leads to different intensities of competition at different segments of the market (i.e. different types of consumers), an effect which is not observed in the standard competitive price discrimination model. With access charges different from costs, some market segments produce greater access profits (deficits) relative to other segments and competition is more (less) intense in those profit (deficit)-

[2] There are several variants of the basic model. LRT (1998b) analyse the effect of allowing price discrimination according to the destination network. Carter and Wright (1999) discuss the implications of various forms of interconnection agreements. Wright (2002) considers the issue of call termination charges in mobile networks. For more on this line of research, see two excellent surveys by Laffont and Tirole (2000) and Armstrong (2002) and references therein.

[3] Armstrong (1998) and LRT (1998a) discuss informally on this issue and conjecture that competition in nonlinear pricing with heterogeneous consumers is likely to partially restore the collusive impact of high access charges.

[4] They find that in the Hotelling framework competing firms offer an efficient two-part tariff in equilibrium, provided the market is sufficiently competitive so that every consumer purchases. More recently, however, considering two-part tariff competition with total demands being responsive to prices Yin (2003) has shown that the efficiency result does not hold if there is interaction between the location parameter and the quantity demanded (e.g. transportation costs involve quantity-dependent shipping costs as well as the usual shopping cost.

generating segments. This additional effect leads to call-quantity distortions, unlike in the standard model without interconnection. The nature of distortions depends on consumer calling patterns. For instance, if the calling pattern is such that every subscriber is equally likely to call any other subscriber regardless of the termination network (uniform calling pattern), the equilibrium nonlinear pricing involves distortions in call quantity for all types of subscribers.

• *Profit-neutrality result and light-touch access price regulation*: Even though the firms generally use complicated nonlinear tariffs in equilibrium, each firm's profit does not depend on the level of access charge. Hence, collusion using access charges cannot be sustained in (symmetric) equilibrium. This is because call-quantity allocations are completely separated from market share competition: the firms can compete for market shares using the fixed part of the nonlinear tariff leaving the marginal price schedule unchanged. Since market share competition has no effect on net outflows of calls, there is no room for collusion using access charges.[5] The profit neutrality holds under quite general calling patterns without any restriction on the relationship between consumers' intensities of making and receiving calls. This result suggests a very simple regulatory policy regarding access charge: simply recommend that networks set their access charge equal to the marginal call-termination cost. Provided competing networks are symmetric, the firms have no strict incentive not to follow the recommendation.[6] Then, with access charges being equal to costs the equilibrium tariff is a simple cost-based two-part tariff, resulting in efficient call allocations for all types of consumers.[7]

The rest of the paper is structured as follows. Section 2 introduces a model of network competition and interconnection with heterogeneous subscribers. Section 3 discusses the benchmark case of complete information. In Section 4 we analyse the incomplete information case and characterise symmetric equilibria. In this section, the equilibrium tariff is derived and the profit-neutrality and no-collusion results are established. Section 5 extends the profit-neutrality result to more general calling patterns and discusses its robustness. In Section 6 we conclude with discussions.

[5] Independently, Dessein (2003) has obtained a similar result in a setting with two types of consumers.

[6] This result supports Oftel's prediction that "there may come a point . . . where competition alone is sufficient to restrain prices and formal price controls are not needed" (Oftel, 1996 p.7). Oftel is the current UK regulator for the telecommunications industry, which will be renamed as Ofcom with wide-ranging responsibilities across the UK's communications markets.

[7] Note that, however, this policy implication is valid under a set of assumptions and may not hold in different environments (see section 5.1 for more details).

2 The model

Consider two competing networks located at the two extremities of the unit interval $[0, 1]$. Consumers are uniformly distributed along the interval, and they purchase all services from only a single firm.[8] A consumer's type is represented by a pair of two parameters (θ, x), where θ in $[\underline{\theta}, \overline{\theta}]$ denotes the consumer's preferences for the service and x her location on the unit interval. A consumer's location reflects her preferences for the two horizontally differentiated goods offered by the firms. Let $F(\theta)$ denote the distribution function of θ with density $f(\theta) > 0$, and $t > 0$ transport cost as in the standard Hotelling model. We assume that θ and x are independent (i.e. the distribution of consumers' tastes for the telecommunications service is identical at each location on the unit interval).[9] Also, we assume that subscribers gain no utility from receiving calls (no call externalities) and the firms do not charge incoming calls.[10]

A consumer of type θ, when subscribing to a network and making q calls in return for payment T, obtains the following utility (excluding the transport cost t):

$$\theta U(q) - T,$$

where $U'(\cdot) > 0$ and $U''(\cdot) < 0$. Each network is allowed to offer a general nonlinear tariff denoted $T_i(q)$ for network $i = A, B$. Let

$$v_i(\theta) = \max_q : \theta U(q) - T_i(q) \tag{1}$$

be the type-θ consumer's maximum utility (not including the transport cost) when she subscribes to network i. Utility maximisation requires

$$\theta U'(q(\theta)) = T_i'(q(\theta)) \tag{2}$$

for all $\theta \in [\underline{\theta}, \overline{\theta}]$. Assume that network A is located at $x = 0$ and network B at $x = 1$ without loss of generality. Then a type-(θ, x) consumer obtains net utility of $v_A(\theta) - tx$ when subscribing to network A and $v_B(\theta) - t(1 - x)$ when subscribing to network B. Among those two alternatives, she will choose the one that gives the largest net utility.

[8] This discrete choice approach seems reasonable since an individual usually subscribes to a single local network, mainly because of the large fixed cost incurred in setting up a communication channel, and the bundling or complementary nature of the two services of making and receiving calls from the user's point of view.

[9] It is as if there is a continuum of (identical) Hotelling lines, each of which corresponds to a specific $\theta \in [\underline{\theta}, \overline{\theta}]$.

[10] See Jeon-Laffont-Tirole (2003) for a discussion on access pricing in a situation where there are call externalities and firms are allowed to charge incoming calls.

The competing networks have an identical cost structure. Following the cost specification of LRT (1998a), each network has a constant per-call cost c_o at the originating and terminating ends of a call, a constant per-call switching cost c_s, and a fixed per-customer cost k of installing a subscriber line. Then the total unit cost of a call that is originated and terminated in the same network is given by $c = 2c_o + c_s$. Interconnection is required by regulatory policies and therefore there is no exclusive behaviour around network facilities. Access charges are determined by negotiation between networks but are required to be reciprocal by regulation.[11] We assume that networks are not allowed to charge different prices for calls terminating on the subscriber's network and those terminating on the rival's network.[12] We will focus on cases where $\underline{\theta}$ is large enough for all consumers to prefer to be connected to either network rather than to be not connected at all in equilibrium, and the services of the two networks are sufficiently differentiated so that no firm monopolises the whole market.[13] We initially consider the so-called *uniform calling pattern*, as in Armstrong (1998) and LRT (1998a), where every subscriber is equally likely to call any other subscriber regardless of the termination network and gets the same benefit from an outgoing call regardless of who the recipient is.[14] However, our main result carries over to more general calling patterns as will be shown later in section 5.

As usual in the Hotelling model, market shares are determined solely from the net utility levels offered to customers by the two networks. Network A's market share in the segment consisted of type-θ consumers is

$$\alpha(\theta) = \frac{1}{2} + \sigma(v_A(\theta) - v_B(\theta)) \tag{3}$$

where $\sigma \equiv \frac{1}{2t}$ is an index of substitutability between the two networks. So network A's total market share across all types of consumers is simply given by

$$m = \int_{\underline{\theta}}^{\overline{\theta}} \alpha(\theta) f(\theta) d\theta. \tag{4}$$

[11] The principle of reciprocity is supported in many countries including the United States. Allowing networks to set access charges non-cooperatively would be socially undesirable because of the double-marginalisation problem (see Economides-Lopomo-Woroch (1996), LRT (1998a), and Carter and Wright (1999) for more details).

[12] See LRT (1998b) for an analysis on the effect of allowing price discrimination according to the destination network.

[13] Also, in order to ensure the existence of equilibrium we will restrict our attention to cases where the access charge does not depart too much from the termination costs - see LRT (1998a) for more details on the issue of equilibrium existence.

[14] This assumption is for the sake of analytical convenience, and implies that in equilibrium heavy users make more calls than they receive and light users receive more calls than they make. See Dessein (1999) for an analysis of other types of calling patterns.

We restrict our attention to symmetric equilibria in the proceeding analysis.

3 Complete information about θ

Let us first examine a benchmark case where the firms observe consumer type θ (but not location x). We consider a two-stage game: in the first stage the firms set reciprocal access charge a by negotiation, and then in the second stage they compete in the retail market given the access charge.

We solve the network A's second-stage problem in two steps: first fix network A's total market share m and find the profit-maximising pricing policy to achieve the given market share, and then determine the equilibrium market share of network A. Choosing the profit-maximising tariff is essentially identical to choosing the corresponding utility and quantity schedules. Given firm B's utility and quantity schedules, $v_B(\theta)$ and $q_B(\theta)$, eliminating tariff T using (1) network A's profit as a function of m is given by

$$\begin{aligned} \pi(m) \quad \equiv \quad & \max_{v_A, q_A} : \int_{\underline{\theta}}^{\overline{\theta}} \{\alpha(\theta)[\theta U(q_A(\theta)) - v_A(\theta) - (c + (a - c_o)(1 - m))q_A(\theta) - k] \\ & +(1 - \alpha(\theta))(a - c_o)mq_B(\theta)\}f(\theta)d\theta \end{aligned}$$

subject to the total market share constraint (4). Under the uniform calling pattern, the chance of a call terminating on its originating network depends on the network's total market share m. With complete information on θ, network A can choose its profit-maximising utility and quantity schedules independently as if it were a monopolist. The only constraint it faces is the total market share given by m.

By pointwise maximisation, the optimal q_A and v_A for each θ must satisfy the following first-order conditions:

$$\theta U'(q_A) = c + (a - c_o)(1 - m) \tag{5}$$

and

$$\{\sigma[\theta U(q_A) - v_A - cq_A - k] - \alpha\} - \sigma(a - c_o)(1 - m)q_A - \sigma(a - c_o)mq_B - \sigma\gamma = 0, \tag{6}$$

where γ is the Lagrange multiplier for the total market share constraint given by (4).

Lemma 1 *Given access charge a, network A's optimal marginal and fixed prices are*

$$p_A = c + (a - c_o)(1 - m), \tag{7}$$

$$K_A(\theta) = k + \frac{\alpha(\theta)}{\sigma} \tag{8}$$
$$-(a - c_o)\{\int_{\underline{\theta}}^{\overline{\theta}} [\alpha(\widetilde{\theta})q_A(\widetilde{\theta}) + (1 - \alpha(\widetilde{\theta}))q_B(\widetilde{\theta})]f(\widetilde{\theta})d\widetilde{\theta} - mq_B(\theta)\}.$$

The marginal price is independent of type parameter θ, but the fixed fee *does* depend on taste parameter θ except for the case of $a \neq c_o$. Following LRT (1998a), we define $c + (a - c_o)(1 - m)$ as the *perceived* marginal cost. Given access charge a, network A adjusts its marginal cost based on the rival's market share $1 - m$, which is the probability of a call from its subscribers terminating on the rival's network under the uniform calling pattern. Note that the marginal price is larger (smaller) than the *actual* marginal cost c for $a > c_o$ ($a < c_o$). So, it is optimal for network A to set unit price equal to the perceived marginal cost and demand a personalised fixed premium equal to the individual net surplus at the unit price on top of the fixed cost k, as in the monopoly perfect price discrimination. This result mainly comes from the interaction between consumer heterogeneity in preferences for calls and the presence of access charges, as explained below in more detail.

Proposition 1 *At the symmetric equilibrium, i) the marginal price and the fixed fee are given by*

$$p = c + \frac{a - c_o}{2} \tag{9}$$

and

$$K(\theta) = k + \frac{1}{2\sigma} - (a - c_o)[\int_{\underline{\theta}}^{\overline{\theta}} q(\widetilde{\theta})f(\widetilde{\theta})d\widetilde{\theta} - \frac{q(\theta)}{2}], \tag{10}$$

and ii) each firm's profit is given as $\frac{1}{4\sigma}$ *independent of access charge.*

Since $q(\theta)$ is increasing (see condition (5)), the fixed fee is increasing (decreasing) in θ for $a > c_o$ ($a < c_o$). Under the uniform calling pattern, consumers of a high θ make more calls than they receive, and therefore are induced to pay larger fixed fees as a premium for their access deficits for $a > c_o$ and conversely for $a < c_o$. The per-customer profit, given as $(a - c_o)[q(\theta) - \int_{\underline{\theta}}^{\overline{\theta}} q(\widetilde{\theta})f(\widetilde{\theta})d\widetilde{\theta}] + \frac{1}{2\sigma}$, is also increasing (decreasing) in θ for $a > c_o$ ($a < c_o$), reflecting tougher (looser) competition on the segment of low (high)-θ consumers. This is in contrast with the type-independent efficient two-part tariff result obtained in the standard differentiated products discrimination model à la Armstrong and Vickers (2001) and Rochet and Stole (2002), and clearly shows how the presence of access charges affects the equilibrium tariff.

The average per-firm profit is, however, independent of the access charge and is given as the standard Hotelling profit.[15] At the symmetric equilibrium, the aggregate calls are balanced between the two networks since both firms set the same marginal price given in (9). Because market shares depend only on the utility schedules, the firms can compete effectively for market shares using fixed fees without changing marginal prices and therefore without affecting call-quantity allocations. This confirms that the no-collusion result of LRT (1998a), which has been established with homogeneous consumers, still holds in an environment with consumer heterogeneity in preferences for calls.

4 Incomplete information about θ

Now suppose that consumers have private information about their tastes for the telecommunications service as well as for the firms.

4.1 When $a = c_o$

Suppose that the access charge is set equal to the terminating cost. Then, the tariff given by (9) and (10) is independent of taste parameter θ and in fact reduces to a simple two-part tariff.

Proposition 2 *When $a = c_o$, at the symmetric equilibrium i) the marginal price and the fixed fee are given by*

$$p = c$$

and

$$K = k + \frac{1}{2\sigma},$$

and ii) each firm's profit is given as $\frac{1}{4\sigma}$.

Note that the symmetric equilibrium leads to efficient consumptions of calls.[16] With $a = c_o$ there is no impact of access charges on the equilibrium outcome,

[15] The Hotelling profit result shows up in many other situations, particularly in competition in two-sided markets where one group of consumers interact with those of the other group via intermediaries. Examples include competition between mobile telecommunications networks (Wright, 2002) and media market competition in attracting advertisers and viewers (Anderson and Coate, 2003). See Armstrong (2002) and Rochet and Tirole (2003) for more on competition in two-sided markets. In fact, our model also exhibits a sort of two-sidedness in the sense that the firms make profits not only from callers but also from receivers via access charges.

[16] This result would hold for more general calling patterns as long as access is provided at cost.

and therefore it is natural to see the efficient two-part tariff result discovered by Armstrong and Vickers (2001) and Rochet and Stole (2002) restored.

4.2 When $a \neq c_o$

When the access charge deviates from the terminating cost, the tariff given by (9) and (10) depends on θ and therefore is no longer implementable under incomplete information.[17] Then, the firms will naturally look for a more complicated nonlinear tariff in order to screen different consumers. In choosing the optimal tariff each firm has to consider the following incentive constraints:

$$v'_A(\theta) = U(q_A(\theta)) : \textit{ the envelope condition} \tag{11}$$

and

$$q'_A(\theta) \geq 0 : \textit{ the monotonicity condition,} \tag{12}$$

where primes mean derivatives. Since the utility specification satisfies the single-crossing condition, a necessary and sufficient condition for a quantity schedule to be implementable by means of some tariff reduces to condition (12). The participation constraints are irrelevant because we are assuming full participation in equilibrium.

Again, we solve the problem in two steps. First fix network A's market share m and find the optimal pricing policy, and then determine the equilibrium market share later. Given $v_B(\theta), q_B(\theta), a,$ and m, network A chooses $v_A(\theta)$ and $q_A(\theta)$ to maximise its profit subject to the total market share constraint (4) and the incentive constraints (11) and (12). We use the techniques employed by Rochet and Stole (2002) in their model of nonlinear pricing with random participation. Taking v_A and q_A as state variables and z as a control variable where $z = q'_A(\theta)$, the Hamiltonian-Lagrangian for the network A's problem is

$$\begin{aligned} \mathfrak{L}(v_A, q_A, z, \lambda_1, \lambda_2, \gamma, \mu; m) \quad = \quad & \{\alpha[\theta U(q_A) - v_A - (c + (a - c_o)(1 - m))q_A - k] \\ & +(1 - \alpha)(a - c_o)mq_B - \eta\alpha\}f(\theta) \\ & +\lambda_1 U(q_A) + \lambda_2 z + \eta m + \mu z, \end{aligned}$$

where λ_1 and λ_2 are costate variables, and η and μ are the Lagrange multipliers associated with the total market share constraint and the monotonicity constraint

[17] Given the constant marginal price p in (9), all consumers can be better off (departing from their complete information allocation) by choosing a quantity-price package with a lower fixed fee. This is because the utility loss from changing call quantity is second-order while the gain from saving fixed fees is first-order.

($z \geq 0$). The following proposition characterises the fully separating symmetric equilibrium.[18]

Proposition 3 *When $a \neq c_o$, at the fully separating symmetric equilibrium the optimal tariff is characterised by*

$$\theta U'(q) = \frac{c + \frac{1}{2}(a - c_o)}{1 + \frac{2\lambda_1(\theta)}{\theta f(\theta)}} \tag{13}$$

for a such that $c + \frac{1}{2}(a - c_o) > 0$, which induces

i) *the boundary types to consume the complete information quantity of calls, and*

ii) *all interior types to consume a smaller (larger) quantity of calls than the complete information allocation for $a > c_o$ ($a < c_o$).*

The intuition for the above call-allocation pattern is as follows. Suppose that $a > c_o$ for expositional convenience. There are basically two forces working in the opposite direction. First, all consumers (except those of type $\underline{\theta}$) have incentives to understate their valuation for the service under the complete information tariff. Then, the standard screening policy tends to reduce call quantities offered to consumers except those of type $\overline{\theta}$. Second, given an access charge higher than the call-termination cost and under the uniform calling pattern, the firms have the incentive to expand market shares in the segments consisted of low-θ consumers who produce larger access profits relative to high-θ consumers. This leads the firms to compete more aggressively in the markets for low-θ customers relative to the markets for high-θ customers, resulting in call consumptions closer to the complete information allocations for low-θ consumers. Each firm will try to balance this trade-off by expanding market shares in the segments consisted of low-θ customers while minimising its impact on the effectiveness of consumer screening. Profit losses from deviating from the perfect screening strategy are larger for high-θ customers relative to low-θ customers, while contributions to access revenues are greater from low-θ customers than high-θ customers. This leads to upward shifts in call quantities offered to low-θ customers. In particular, the consumers of type $\underline{\theta}$ are allocated the complete information equilibrium call quantity. So, we obtain the '*complete-information-allocation-on-the-boundaries*' result in this fully separating equilibrium.

[18] See the appendix for the existence of symmetric equilibria. We may have a partially pooling equilibrium where the standard ironing procedure is employed in order to satisfy the monotonicity requirement (see Rochet and Stole (2002) for more details).

The same arguments are applied to the case of $a < c_o$ with the opposite direction and interpretation. The following corollary is then immediate from the condition of efficient call allocation (i.e. $\theta U'(q) = c$) and proposition 3.

Corollary 1 *(Inefficiency of call allocation) At the fully separating symmetric equilibrium, all consumers are allocated inefficiently smaller (larger) call quantities for* $a > c_o$ $(a < c_o)$.

Figure 1 below depicts the typical pattern of equilibrium call-quantity allocations for $a > c_o$ and $a < c_o$ respectively.

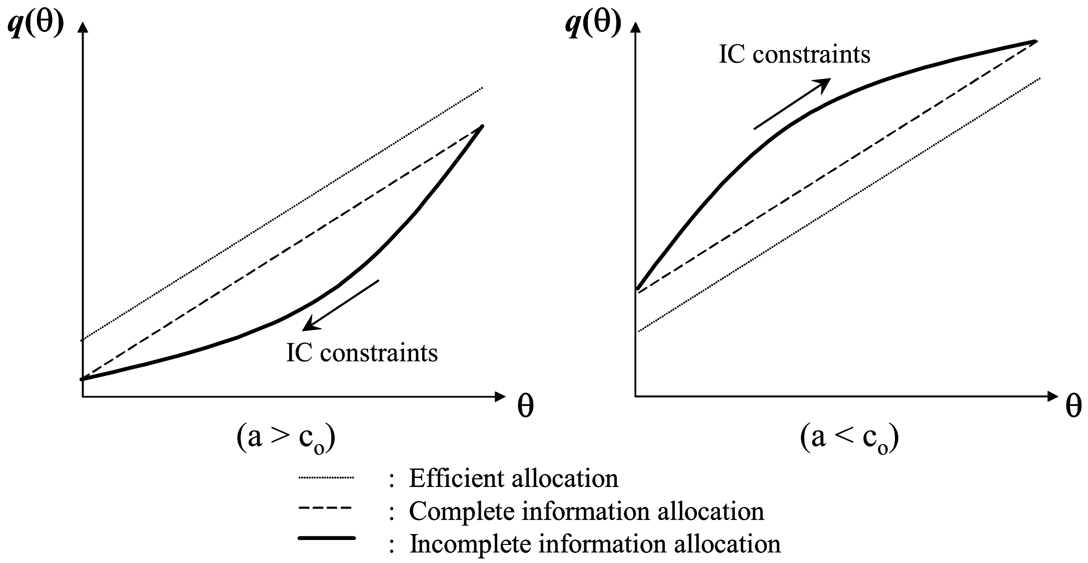

Figure 1: Equilibrium call allocations

It should be noted that the specific call-allocation pattern described above comes from the assumption of the uniform calling pattern. In general, the exact nature of call-quantity distortions depends on consumer calling pattern. Indeed, Dessein (1999) using a simple model with two types of consumers shows that if heavy users receive more calls than they make (relative to the case of the uniform calling pattern) the equilibrium call quantity for heavy users is distorted upward for a positive access mark-up. One important point our analysis clearly makes is that distortion in call quantity is a quite general phenomenon in network competition with interconnection although the distortion pattern may depend on consumer calling patterns. This is in contrast with the prediction of Armstrong and Vickers (2001) and Rochet and Stole (2002). The access charge has different effects on market share competition across different market segments (i.e. different types of consumers): some market segments produce greater access profits (deficits) relative to other segments, and therefore competition is more (less) intense in those profit (deficit)-generating segments. Accordingly, the equilibrium tariff generally involves call-quantity distortions almost everywhere except for the boundary types.

4.3 Neutrality of the access charge on profits

Now we consider the first stage of the game where the firms negotiate over a reciprocal access charge. The following proposition states that access charges have no effect on the firms' profit at any symmetric equilibria (regardless of fully separating or partially pooling) and therefore collusion using access charges cannot be sustained.

Proposition 4 *In any symmetric equilibrium, each firm's profit is independent of access charge and is given as* $\frac{1}{4\sigma}$.

The logic is similar to the previous complete information case. The firms can compete for market shares using the fixed parts of the nonlinear tariff (leaving the marginal price schedule unchanged). So, market share competition does not affect net outflows of calls, which drives each firm's profit down to $\frac{1}{4\sigma}$ regardless of the level of the access charge. This shows that the no-collusion result can be still valid in a more general environment where consumers have heterogeneous tastes for the service and networks compete in nonlinear pricing.

Since each firm's profit is independent of access charge, there exist multiple equilibria. But, given that the firms are essentially indifferent among different levels of (reciprocal) access charge, we can expect they will not be reluctant to choose the access charge equal to the call-termination cost ($a = c_o$) if it is recommended by a policy maker. In this case, we obtain the complete information equilibrium characterised by the simple two-part tariff with marginal price equal to c (the *actual* marginal cost) and fixed fee equal to $k + \frac{1}{2\sigma}$, where all subscribers make efficient amounts of calls.

5 Extension to more general calling patterns

In this section, we show that the profit-neutrality result holds under more general calling patterns, not specific to the uniform calling pattern. Let us introduce parameter β measuring the intensity of calls being made (i.e. how much other consumers wish to make a call) to a specific group of consumers, where $\beta \in (0, 1)$ and the sum of β over all consumers equals to 1. We can interpret β as the proportion of the total calls directed to consumers of type β, i.e. a consumer with high (low) β receives a large (small) amount of calls. Examples of high-β customers include businesses and other institutions (such as hospitals, public enquiry offices, and information centres) which tend to receive a larger number of calls compared with residential customers. The preferences for call destination are assumed to be identical among all potential consumers. The heterogeneity of consumer preferences is then represented by the two taste parameters (θ and β) and the location parameter (x). We do not impose any restriction on the distribution of consumer type except that the taste parameters are independent of the location parameter. So, we allow any kinds of correlation between consumers' intensities of making and receiving calls (θ and β).[19] Note that the uniform calling pattern corresponds to the case where β is identical for all consumers. We continue to focus on symmetric equilibria with full participation of potential consumers.

Definition 1 *A firm is 'unbiased' in the choice of subscriber type if its subscriber base is consisted of the same fraction of all types of consumers.*

Note that in any symmetric equilibrium a sufficient condition for the unbiased type choice is the independence of the taste parameters (θ and β) and the location parameter (x).

Lemma 2 *(Aggregate call balance) Under the unbiased type choice, if both firms offer the same marginal price schedule there is no net outflow of calls from a network regardless of its market share.*

Proposition 5 *Provided the location parameter is independent of other taste parameters, at any symmetric equilibrium each firm's profit is independent of the access charge regardless of consumer calling pattern.*

We obtained the profit-neutrality result without solving for the equilibrium, which seems a much more difficult task since the incentive constraints are no longer

[19] This captures a broad class of calling patterns which have not been treated in the literature. Dessein (1999) considers the two-way access pricing problem under calling patterns different from the uniform calling pattern. His analysis is, however, restricted to the cases where consumers' intensities of making and receiving calls are perfectly correlated. A more desirable way of modelling calling pattern is perhaps to allow each consumer to have her own calling pattern. Also interesting is to consider matching behaviour among consumers or peer-grouping in communications markets.

easily treated as in the case of the uniform calling pattern.[20] Nevertheless, it highlights how the firms compete for market shares in nonlinear pricing without any effect on access deficits or profits, i.e. changing the fixed parts of the nonlinear tariff but leaving the marginal price schedule unchanged. This is in fact the main force leading to the profit-neutrality and no-collusion result.

5.1 Robustness of the profit neutrality

Note that the profit neutrality result has been reached under several simplifying assumptions. In particular, we needed the followings:

- Uniformity (symmetry) in demand[21]
- No call externalities and no reception charge
- Independence of tastes and location
- Invariance of transport cost to consumer type
- Full consumer participation
- No price-discrimination between on-net and off-net calls

The profit-neutrality may hold even if consumers are not uniformly located along the Hotelling line, all the other assumptions being satisfied. As long as the distribution is symmetric, the firms can compete for market shares using only the fixed parts of nonlinear tariff without affecting access deficits or profits. The equilibrium profit may change, but would be equal to the profit under the standard Hotelling competition with the same non-uniform distribution for consumer location, independent of the level of the access charge. Similarly, the result can be extended to other structures of product differentiation, e.g. a more general discrete choice framework. A typical example is the Logit model in which the type-specific valuation of the service offered by network i is ε_i (iid) and $\varepsilon_i - \varepsilon_j$ is distributed according to the logistic function.[22] In this setting, each network's profit will be independent of

[20] Considering the local incentive constraints is not sufficient any longer, and therefore we need to examine whether the constraints are satisfied globally in equilibrium.

[21] Symmetry in marginal cost seems also crucial, whereas fixed costs would not affect the profit-neutrality. With asymmetric marginal costs, equilibrium marginal prices are likely to be different between the two networks, leading to unbalanced aggregate calls. So, one of the networks would naturally have incentives to raise access charge above cost, similar to the case of one-way access.

[22] See Anderson-de Palma-Thisse (1992) for more details on the discrete choice theory of product differentiation.

marginal costs even if we allow for consumer heterogeneity in volume demands, and access charges have no effect on the firms' profit provided they are allowed to use a general nonlinear tariff and the market is fully covered. This relaxes the uniformity assumption taken in our model, and shows that the result may still hold in some asymmetric environments. The same logic can be also applied to cases where subscribers gain utility from receiving calls (call externalities) and firms charge for the reception of calls. In fact, Jeon-Laffont-Tirole (2003) show that the profit neutrality result still holds even in a model with receiver surplus and reception charge.

The other assumptions, however, seem essential to obtain the profit neutrality result. It is fairly easy to see that the profit neutrality fails to hold if the distribution of consumer tastes varies with location: aggregate call balance is likely to break down. Also, if different types of consumers have different transport costs networks have incentives to agree on an access charge below or above the marginal cost. Moreover, the profit neutrality may not hold in situations where participation constraints are binding (e.g. mobile telecommunications). Dessein (2003) shows that limited participation may result in a collusive access charge below marginal cost in equilibrium (see also Poletti and Wright (2003)). Lastly, it is not clear whether the profit neutrality result is still valid when the firms are allowed to price-discriminate between on-net and off-net calls. Analysing this problem looks rather complicated. But, we know that in a homogenous consumer framework the firms' profit does depend on the level of access charge, as shown by LRT (1998b) and Gans and King (2001).

6 Conclusion

This paper has analysed access pricing in a telecommunications market where consumers are heterogeneous in their preferences for calls and firms are allowed to use general nonlinear tariffs. First, we investigated how the presence of access charges affects competition in the retail market and found that the symmetric equilibrium nonlinear tariff generally involves distortions in call allocations for all types of consumers. This implies that the efficient two-part tariff result discovered in the ordinary market cannot be generalised to network markets where competing firms need to interconnect each other and pay access charges.

The profit-neutrality and no-collusion result can, however, be still valid in this more general environment with consumer heterogeneity and nonlinear pricing. The possibility that firms can compete for market shares using fixed parts of tariff without affecting net outflow of calls makes collusion using access charges unsustainable.

Therefore, firms are indifferent among different levels of access charge in equilibrium. This suggests a very simple and light-touch regulatory policy regarding access charges: the policy maker need simply provide firms with a focal point by recommending a reciprocal access charge equal to call-termination cost. This policy leads to efficient call allocations for all consumers.

Given that the profit neutrality result has been obtained under a certain set of assumptions, this policy implication needs to be cautiously applied. We only considered a mature stage of network market where firms are more or less symmetric. In many countries, however, competition in local network is still an undergoing process. In this case, a more plausible description of reality would be a dominant firm competing with one or more small rivals. In this respect it will be useful to develop a two-way access pricing model taking into account possible asymmetries together with consumer heterogeneity, incomplete information, and nonlinear pricing.[23] It should be also noted that in the presence of receiver surplus social efficiency requires access charge to be set below marginal cost (i.e. termination discount) in order to internalise the call externality as shown by Jeon-Laffont-Tirole (2003),[24] and there are arguments supporting bill-and-keep policy (zero access charge) such as DeGraba (2000, 2001).

Finally, even though our analysis and discussion is mainly focused on telecommunications, the basic insight could easily be extended to other network markets with the two-way access feature, such as banking (ATM cash machines) and postal services.

7 Appendix

7.1 Proof of lemma 1

The marginal price in (7) is immediate from conditions (2) and (5). Then, network A's optimal tariff will take the form of $T_A(q) = p_A \cdot q + K_A(\theta)$. The optimal level of

[23] In fact, we have seen some asymmetric interconnection models in the literature (Armstrong, 1998; LRT, 1998a; Carter and Wright, 2003; Peitz, 2003). However, all these models assume homogeneous consumers. One exception is a recent paper by Armstrong (2003) who analyses access pricing in a situation where a regulated incumbent faces a large number of price-taking rivals and subscribers are heterogeneous in their demand for calls. He finds that a reciprocal termination charge above the incumbent's cost of access is optimal if the incumbent is regulated and its retail tariff involves subsidising low volume users at the expense of high volume users.

[24] See Hahn (2003) for a characterisation of the monopoly nonlinear tariff in the presence of call (and network) externalities, which also involves some kind of subsidization.

network A's total market share will be determined to satisfy the first-order condition

$$(a-c_o)\int_{\underline{\theta}}^{\overline{\theta}}\{\alpha(\theta)q_A(\theta)+(1-\alpha(\theta))q_B(\theta)\}f(\theta)d\theta+\gamma=0, \tag{14}$$

where $q_A(\cdot)$ is the utility-maximising call quantity for each type given the marginal price p_A. Eliminating the multiplier γ using (6) and (14), we have

$$\begin{aligned}&\theta U(q_A(\theta))-v_A(\theta)-cq_A(\theta)-k-\frac{\alpha(\theta)}{\sigma}-(a-c_o)(1-m)q_A(\theta)\\ =\ & -(a-c_o)\{\int_{\underline{\theta}}^{\overline{\theta}}[\alpha(\widetilde{\theta})q_A(\widetilde{\theta})+(1-\alpha(\widetilde{\theta}))q_B(\widetilde{\theta})]f(\widetilde{\theta})d\widetilde{\theta}-mq_B(\theta)\}.\end{aligned}$$

Substituting v_A for T_A using (1) and plugging in $T_A(q_A(\theta))=p_A\cdot q_A(\theta)+K_A$ gives the optimal fixed fee in (8).

7.2 Proof of proposition 1

i) Plugging in $\alpha(\theta)=m=\frac{1}{2}$ into (7) and (8) gives (9) and (10).

ii) Using (9) and (10), the total industry profit is given by

$$\begin{aligned}\pi^I &= \int_{\underline{\theta}}^{\overline{\theta}}\{T(q(\theta))-cq(\theta)-k\}f(\theta)d\theta\\ &= \int_{\underline{\theta}}^{\overline{\theta}}\{(c+\frac{a-c_o}{2})q(\theta)-(a-c_o)[\int_{\underline{\theta}}^{\overline{\theta}}q(\widetilde{\theta})f(\widetilde{\theta})d\widetilde{\theta}-\frac{q(\theta)}{2}]+\frac{1}{2\sigma}-cq(\theta)\}f(\theta)d\theta\\ &= \frac{1}{2\sigma}.\end{aligned}$$

So, at the symmetric equilibrium each firm gets profit of $\frac{1}{4\sigma}$.

7.3 Proof of proposition 3

The maximisation of $\mathfrak{L}$ with respect to the control variable z requires that

$$\begin{cases}\lambda_2+\mu=0 \text{ with } z>0\\ \lambda_2+\mu<0 \text{ with } z=0\end{cases}, \tag{15}$$

with the complementary slackness condition

$$\mu\geq 0 \text{ and } \mu z=0. \tag{16}$$

The equations of motion for the two costate variables are

$$\begin{aligned}\lambda_1' &= -\frac{\partial L}{\partial v_A}=-\{\sigma[\theta U(q_A)-v_A-cq_A-k]-\alpha\\ &\quad -\sigma(a-c_o)(1-m))q_A-\sigma(a-c_o)mq_B-\sigma\eta(m)\}f(\theta)\end{aligned} \tag{17}$$

and

$$\lambda_2' = -\frac{\partial L}{\partial q_A} = -\alpha[\theta U'(q_A) - (c + (a - c_o)(1 - m))]f(\theta) - \lambda_1 U'(q_A) \quad (18)$$

with the boundary conditions, $\lambda_1 = \lambda_2 = 0$ at $\theta = \underline{\theta}, \overline{\theta}$. Finally, using the envelope theorem the first-order condition for network A's (interior) optimal total market share is given by

$$(a - c_o) \int_{\underline{\theta}}^{\overline{\theta}} [\alpha(\theta) q_A(\theta) + (1 - \alpha(\theta)) q_B(\theta)] f(\theta) d\theta + \eta(m) = 0. \quad (19)$$

Eliminating η using (17) and (19), λ_1' can be rewritten as

$$\begin{aligned} \lambda_1' &= -\sigma\{\theta U(q_A) - v_A - [c + (a - c_o)(1 - m)]q_A - k - \frac{\alpha}{\sigma} \quad (20) \\ & \quad -(a - c_o) m q_B + (a - c_o) Q\} f(\theta), \end{aligned}$$

where $Q = \int_{\underline{\theta}}^{\overline{\theta}} [\alpha(\theta) q_A(\theta) + (1 - \alpha(\theta)) q_B(\theta)] f(\theta) d\theta$ is the total market demand of calls. Conditions (15), (16), (18) and (20) with the boundary conditions ($\lambda_1 = \lambda_2 = 0$ at $\theta = \underline{\theta}, \overline{\theta}$) constitute necessary conditions for the optimal solution.

We consider only fully separating equilibria. Suppose that $z > 0$ for all θ in $[\underline{\theta}, \overline{\theta}]$, i.e. the equilibrium quantity schedule is strictly increasing. Then, from (15) and (16) it must be that $\mu = 0$ and $\lambda_2 = 0$ for all θ in $[\underline{\theta}, \overline{\theta}]$. The fact that $\lambda_2 = 0$ for all θ immediately means that $\lambda_2' = 0$ for all θ. Now using (18) and (20) we can obtain $v_A(\cdot)$ as the solution of the following second-order boundary-value problem:

$$\begin{aligned} & \frac{d}{d\theta}\left[\frac{\alpha(\theta)}{U'(q_A(\theta))}[\theta U'(q_A(\theta)) - (c + (a - c_o)(1 - m))] f(\theta)\right] \\ = \; & \sigma\{\theta U(q_A) - v_A - [c + (a - c_o)(1 - m)]q_A - k - \frac{\alpha}{\sigma} \\ & -(a - c_o) m q_B + (a - c_o) Q\} f(\theta) \end{aligned}$$

with

$$\frac{\alpha(\theta)}{U'(q_A(\theta))}[\theta U'(q_A(\theta)) - (c + (a - c_o)(1 - m))] f(\theta) = 0 \text{ at } \theta = \underline{\theta}, \overline{\theta}$$

and $q_A(\theta)$ given by (11). Rearranging equation (18), we have

$$(\theta + \frac{\lambda_1}{\alpha(\theta) f(\theta)}) U'(q_A) = c + (a - c_o)(1 - m) \quad (21)$$

with $\lambda_1(\underline{\theta}) = \lambda_1(\overline{\theta}) = 0$. We assume that $\underline{\theta} + \frac{\lambda_1(\underline{\theta})}{\alpha(\underline{\theta}) f(\underline{\theta})} \geq 0$ to guarantee full participation, where λ_1 can be positive or negative depending upon a (see lemma 3 below). Imposing symmetry (i.e., $\alpha(\theta) = m = \frac{1}{2}$) gives equation (13) in proposition 3. The characterisation of the equilibrium call-quantity allocation is immediate from the following lemma. See section 4.2 for some intuition.

Lemma 3 *In any fully separating symmetric equilibrium,* $\lambda_1(\theta) \leq 0$ *for* $a > c_o$ *and* $\lambda_1(\theta) \geq 0$ *for* $a < c_o$ *with equality only at* $\underline{\theta}$ *and* $\overline{\theta}$.

Proof. From the necessary condition for the optimality we know that $\lambda_1(\underline{\theta}) = \lambda_1(\overline{\theta}) = 0$ in equilibrium. Since the complete information allocation cannot be an equilibrium in this case, condition (21) means that $\lambda_1 \neq 0$ except at $\underline{\theta}$ and $\overline{\theta}$. This implies that λ_1 does not cross the θ-axis, and therefore given a it must be that either $\lambda_1 > 0$ or $\lambda_1 < 0$ for all $\theta \in (\underline{\theta}, \overline{\theta})$.

Consider the case where $a > c_o$. Suppose that $\lambda_1 > 0$ for all $\theta \in (\underline{\theta}, \overline{\theta})$. Since λ_1 is continuous, there must exist at least one $\theta^\dagger \in (\underline{\theta}, \overline{\theta})$ such that $\lambda_1'(\theta^\dagger) = 0$ and $\lambda_1''(\theta^\dagger) \leq 0$. Also, $q(\theta^\dagger)$ must be larger than the complete information allocation at $\theta^\dagger$ by the supposition that $\lambda_1 > 0$ for all interior types. Differentiating (20) gives

$$\begin{aligned} \lambda_1'' &= \tfrac{f'}{f}\lambda_1' - f\sigma\{\theta U'(q_A)q_A' - [c + (a - c_o)(1 - m)]q_A' \\ &\quad -(U(q_A) - U(q_B)) - (a - c_o)mq_B'\}, \end{aligned}$$

and imposing symmetry leads to

$$\lambda_1'' = \tfrac{f'}{f}\lambda_1' - f\sigma[\theta U'(q) - (c + \frac{a - c_o}{2})]q' + f\sigma\frac{a - c_o}{2}q'.$$

Evaluating λ_1'' at $\theta^\dagger$ (i.e. $\lambda_1'(\theta^\dagger) = 0$), we have

$$\lambda_1''(\theta^\dagger) = -f\sigma[\theta^\dagger U'(q(\theta^\dagger)) - (c + \frac{a - c_o}{2})]q'(\theta^\dagger) + f\sigma\frac{a - c_o}{2}q'(\theta^\dagger) > 0,$$

where the inequality follows from the monotonicity of $q(\cdot)$, the condition that $a > c_o$, and the supposition that $q(\theta^\dagger)$ is larger than the complete information allocation at $\theta^\dagger$ ($\lambda_1 > 0$ for all interior types), thereby yielding a contradiction. Hence, for $a > c_o$ it must be that $\lambda_1 < 0$ for all $\theta \in (\underline{\theta}, \overline{\theta})$, which implies that the equilibrium call quantity is smaller than the complete information allocation for all $\theta \in (\underline{\theta}, \overline{\theta})$.

We can use the same reasoning in the opposite direction to prove $\lambda_1 > 0$ for interior types for $a < c_o$. Suppose that $\lambda_1 < 0$ for all $\theta \in (\underline{\theta}, \overline{\theta})$. Then there must exist at least one $\theta^{\dagger\dagger} \in (\underline{\theta}, \overline{\theta})$ such that $\lambda_1'(\theta^{\dagger\dagger}) = 0$ and $\lambda_1''(\theta^{\dagger\dagger}) \geq 0$, and $q(\theta^{\dagger\dagger})$ must be smaller than the complete information allocation at $\theta^{\dagger\dagger}$ by the supposition. Evaluating λ_1'' at $\theta^{\dagger\dagger}$ using $\lambda_1'(\theta^{\dagger\dagger}) = 0$, we obtain

$$\lambda_1''(\theta^{\dagger\dagger}) = -f\sigma[\theta^{\dagger\dagger}U'(q(\theta^{\dagger\dagger})) - (c + \frac{a - c_o}{2})]q'(\theta^{\dagger\dagger}) + f\sigma\frac{a - c_o}{2}q'(\theta^{\dagger\dagger}) < 0,$$

where use was made of the monotonicity of $q(\cdot)$, the condition that $a < c_o$, and the supposition that $q(\theta^{\dagger\dagger})$ is smaller than the complete information allocation at $\theta^{\dagger\dagger}$, thereby again yielding a contradiction. Therefore, for $a < c_o$ it must be that $\lambda_1 > 0$ for all $\theta \in (\underline{\theta}, \overline{\theta})$, which implies that the equilibrium call quantity is larger than the complete information allocation for all $\theta \in (\underline{\theta}, \overline{\theta})$. ■

7.4 Existence of fully separating equilibria

The incentive compatibility requires the monotonicity of the call-quantity allocation (the second-order condition of the consumer utility maximisation). Given that $U(\cdot)$ is concave, the symmetric equilibrium call-quantity in the relaxed problem, given by (13), is monotonic in θ if

$$1 + 2[\frac{\lambda_1'(\theta)}{f(\theta)} - \frac{\lambda_1(\theta)f'(\theta)}{f(\theta)^2}] > 0. \tag{22}$$

Given that λ_1 depends on endogenous variables, sufficient conditions for monotonicity are quite difficult to formulate. Substituting λ_1 and λ_1' using (20) and rearranging using (1), condition (22) can be rewritten as

$$1 + \frac{2}{f(\theta)}\Big[\tfrac{1}{2}(1 - \tfrac{f'(\theta)(\theta-\underline{\theta})}{f(\theta)}) + \sigma\{\tfrac{f'(\theta)}{f(\theta)}\textstyle\int_{\underline{\theta}}^{\theta}\pi(\widetilde{\theta})f(\widetilde{\theta})d\widetilde{\theta} - \pi(\theta)f(\theta)\}$$
$$+\sigma(a-c_o)\{q(\theta)f(\theta) - Q - \tfrac{f'(\theta)}{f(\theta)}[\textstyle\int_{\underline{\theta}}^{\theta} q(\widetilde{\theta})f(\widetilde{\theta})d\widetilde{\theta} - QF(\theta)]\}\Big] > 0,$$

where q and v are the equilibrium call-quantity and utility schedule, and $\pi(\theta) \equiv T(q(\theta)) - cq(\theta) - k$ is the per-customer industry profit at the symmetric equilibrium. The sign of the big bracketed term $[\cdot]$ is generally ambiguous. However, we can show that fully separating symmetric equilibria do exist. Suppose that θ is uniformly distributed on $[\underline{\theta}, \overline{\theta}]$. Denote $d = \overline{\theta} - \underline{\theta}$. Condition (22) then reduces to $1 + 2\lambda_1'(\theta)d > 0$. After plugging $f(\theta) = \frac{1}{d}$ into condition (20), imposing symmetry, and taking the limit $a \to c_o$, we obtain

$$1 + 2\lambda_1'(\theta)d = 2\left(1 - \sigma[\theta U(q(\theta)) - v(\theta) - cq(\theta) - k]\right),$$

which is positive when $\sigma \to 0$ for all θ on $[\underline{\theta}, \overline{\theta}]$ regardless of the sign of λ_1'. Therefore, fully separating equilibria occur under a uniform distribution of θ if the access charge is close to the marginal call-termination cost and networks are sufficiently differentiated (a less competitive market).

7.5 Proof of proposition 4

The case of $a = c_o$ has already been proved in lemma 1. Integrating equation (20) from $\underline{\theta}$ to $\overline{\theta}$ and substituting u_A for T_A using (1), at the symmetric equilibrium we have

$$\lambda_1(\overline{\theta}) - \lambda_1(\underline{\theta}) + \sigma\int_{\underline{\theta}}^{\overline{\theta}}[T(q(\theta)) - cq(\theta) - (a-c_o)q(\theta) - k - \frac{1}{2\sigma} + (a-c_o)Q]f(\theta)d\theta = 0.$$

Using the boundary conditions $\lambda_1(\underline{\theta}) = \lambda_1(\overline{\theta}) = 0$ and substituting $Q = \int_{\underline{\theta}}^{\overline{\theta}} q(\theta)f(\theta)d\theta$,

$$\int_{\underline{\theta}}^{\overline{\theta}} [T(q(\theta)) - cq(\theta) - k - \frac{1}{2\sigma}]f(\theta)d\theta - (a - c_o)\int_{\underline{\theta}}^{\overline{\theta}} (q(\theta) - Q)f(\theta)d\theta = 0 \qquad (23)$$

$$\Rightarrow \int_{\underline{\theta}}^{\overline{\theta}} (T(q(\theta)) - cq(\theta) - k)f(\theta)d\theta = \frac{1}{2\sigma}, \qquad (24)$$

where the second integral term of (23) vanishes, i.e. the aggregate calls in the market are exactly balanced between the two networks. Equation (24) implies that the total industry profit is simply given as $\frac{1}{2\sigma}$, exactly the same as in the complete information case. Since the industry profit is equally divided between the two networks at the symmetric equilibrium, the equilibrium per-firm profit is simply given as $\frac{1}{4\sigma}$ independent of access charge.

7.6 Proof of lemma 2

Suppose that network A has total market share s. Then, under the unbiased type choice it has the same fraction s of consumers for all types. Let Q be the total number of calls made in the market when the firms offer the same marginal price schedule. The total number of calls made by subscribers in each network is then given as sQ for network A and $(1-s)Q$ for network B. Consider a group of consumers who are of type β. Given that firms' choice of subscriber type is unbiased, each network has fraction s (for A) and $1-s$ (for B) of those subscribers. Then, the fraction of calls originating from network A and terminating at consumers of type β in network B, given by $sQ\beta(1-s)$, is the same as the fraction of calls originating from network B and terminating at consumers of type β in network A, given by $(1-s)Q\beta s$. This applies to all the other values of β, and does not depend on s. Hence, calls between the two networks are balanced and there is no net outflow of calls from a network.

7.7 Proof of proposition 5

Let $(\widehat{q}(\theta,\beta), \widehat{T}(\theta,\beta))$ be the symmetric equilibrium with per-customer profit $\widehat{\pi}(\theta,\beta)$ and average per-customer profit $\widehat{\pi}$. Suppose that one firm reduces its fixed charges by the same amount ε across all types without any change in its marginal prices. Then, no incentive constraints are affected, and the market shares of the deviating firm are increased by the same amount $\sigma\varepsilon$ for all types (see (3)). Lemma 2 implies that there is no access deficit or surplus for the deviating firm, and therefore its total profit is given by

$$(\frac{1}{2} + \sigma\varepsilon)(\widehat{\pi} - \varepsilon). \qquad (25)$$

For the original contracts to be a true equilibrium, it is required that $\varepsilon = 0$ maximise (25). Therefore, it must be that $\widehat{\pi} = \frac{1}{2\sigma}$ and each firm's equilibrium profit is just given as $\frac{1}{4\sigma}$.

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