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# Network Competition in Nonlinear Pricing

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ABSTRACT

## Network Competition in Nonlinear Pricing

by Wouter Dessein

Previous research has argued that, in the mature phase of competition, telecommunications networks may use access charges as an instrument of collusion. We show that this result depends totally on the assumption of linear pricing. Though under nonlinear pricing, the access charge alters the way networks use menus of tariffs to discriminate implicitly among heterogeneous customers, profits are then independent of the access charge, or, if participation constraints are binding, are maximized by the welfare maximizing access charge. In the entry phase, networks often differ in cost structure. An access markup then affects the level playing field between networks. .

*Keywords: Telecommunications, Interconnection, Two-way Access, Competition Policy, Nonlinear Pricing*

ZUSAMMENFASSUNG

## Netzwettbewerb bei nichtlinearer Preispolitik

Die industrieökonomische Forschung hat bisher gezeigt, daß in der Marktphase der Reife, beim Wettbewerb von Telekommunikationsnetzen die Zugangsgebühren als ein Instrument des kollusiven Verhaltens eingesetzt werden können. Es wird gezeigt, daß dieses Ergebnis vollständig von den Annahmen des linearen Preisverhaltens abhängt. Obwohl bei nichtlinearer Preispolitik Zugangsgebühren den Einsatz von Tarifmenüs der Netzwerkbetreiber hinsichtlich einer impliziten Diskriminierung zwischen heterogenen Nachfragern beeinflussen, sind die Gewinne dann aber unabhängig von den Zugangsgebühren oder, wenn Teilnahmebeschränkungen bindend sind, dann werden sie maximiert durch die wohlfahrtmaximierenden Zugangsgebühren. In der Markteintrittsphase sind Netze oft durch Unterschiede in der Kostenstruktur gekennzeichnet. Ein Zugangsgebührenzuschlag beeinflußt dann das Niveau, auf dem der Wettbewerb der Netzanbieter stattfindet.

# 1 Introduction

Most industrialized countries are engaged in a project to create competition in one of the largest noncompetitive industries of modern economies: local telecommunications. Due to technological advances, the local network has ceased to be a natural monopoly and competing operators are starting to develop their own local and interurban networks, often using cable or wireless technologies. This is likely to affect considerably the way the industry operates. As customers of different operators want to get in touch with each other, networks must be interconnected: there is need for *mutual provision of access*. We are thus faced with a two-way access problem in which each competitor owns a bottleneck, its subscriber base: a case which differs considerably in its nature from the more familiar one-way access situation where an (integrated) monopolist controls the local network and is required to interconnect with entrants competing on complementary segments such as long distance, value added services,... Whereas in the latter case, the economic literature[1] and practice has made clear that regulation is necessary, this is less obvious for the two-way bottleneck situation. No consensus has yet been reached on this point and particular rules and principles for the setting of two-way interconnection fees are still to be developed in many countries and are evolving in others. Should access charges be freely negotiated between operators as in New Zealand, or should there be a (strong) regulatory involvement as is currently advocated by the FCC in the US and Oftel in the UK? Should private agreements between local operators be trusted to bring about effective competition?

Up to now, the economic literature on two-way access charges has advocated the regulatory approach or at least taken a very ambivalent position. We limit ourselves to a discussion of the seminal paper of Laffont Rey Tirole (1998a) (LRT hereafter).[2] They present a duopoly model in which customers must decide which network to join and given this choice, how much to call. Per call that terminates off-net, an operator pays a - regulated or negotiated - access charge to its rival. LRT argue that, with linear prices, this access charge may be used as an instrument of collusion due to a *raise-each-other's-cost effect*: for given market shares, the average perceived marginal cost of a call increases with the access charge so that a higher access charge induces the networks to set a higher retail price. Under appropriate conditions, there exists an access charge which implements the monopoly price as a competitive equilibrium. On the other hand, an access charge below marginal cost may off-set the market power of the networks

[1] See, e.g., Laffont-Tirole (1996).

[2] Independently, Armstrong (1998) obtained similar results for the case of linear pricing. Other papers have built on the basic framework of LRT: Laffont-Rey-Tirole (1998b) analyzes how competition is affected when networks can charge a different price for calls terminating off-net, Doganoglu and Tauman (1996) allow the access charge to depend linearly on the retail prices, whereas Carter and Wright (1999) study the effects of brand loyalty.

and implement the Ramsey price which maximizes social welfare subject to the industry breaking even. Nevertheless, LRT indicate some limits on the collusive power of the access charge. First, it is shown that no equilibrium exists when access charges and/or the substitutability between networks are too large. Second, one of the most striking results of LRT is the *dichotomy between competition in linear and nonlinear prices*. The collusionary power of the access charge disappears completely when networks compete in two-part tariffs. An access charge above marginal cost still boosts final usage prices, but the positive effect from this on retail profits is totally neutralized by a lower fixed fee. Intuitively, nonlinear pricing erodes the fat profits generated by a high access charge, as networks then have an instrument to build market share without inflating their outflow. It seems, however, quite extreme that in the end, there is no net effect on profits. As nonlinear prices with known demand and homogeneous customers are very particular, and the literature on nonlinear pricing has shown that once customer heterogeneity is introduced, results in general resemble those obtained with linear prices (e.g., usage fees are set different from marginal cost, some surplus is left to customers...), LRT conjecture that the collusion result is likely to be partially restored if one would generalize the model "so as to allow consumers to differ not only in their relative preference for networks but also in their taste for variable consumption."[3] Given that nonlinear pricing is prevailing in the industry, the main question which the literature tries to answer, whether effective competition between telecommunications networks is possible in a deregulated environment, remains thus open.

The aim of this paper is therefore to investigate more thoroughly competition in nonlinear pricing. We stay as close as possible to the basic framework of LRT, but introduce heterogeneity in volume demand in order to have 'more realistic' nonlinear tariffs, that is to allow for second degree price discrimination in which operators use a menu of tariffs to discriminate implicitly between customers of different types. Such heterogeneity in demand is a very important feature of the telecommunications industry. Operators, for example, have in general at least three customer divisions, respectively focussing on the residential, the business and the corporate sector, and also inside these customer categories, especially the residential segment, customers may differ tremendously in their demand, ranging from those who use the telephone only occasionally and for strictly practical matters to the high volume users for whom the telephone is the principal way of communication with the rest of the world. We model this heterogeneity in a straightforward way by assuming that customers are either *heavy* or *light users*. As in LRT, however, we still assume a balanced calling pattern: for equal usage prices, each customer receives as much calls as he originates. This assumption is particularly strong given that customers differ in their volume demand: heavy users, e.g., often tend to call more than they are called. Our companion paper,

[3] Laffont, Rey and Tirole, 1998a;b p.22; p.53

Dessein 1999, shows how competition is affected in the presence of unbalanced calling pattern. Besides heterogeneity between customers, the paper also analyzes heterogeneity among firms and its impact on competition. Such a heterogeneity is especially relevant during the transition towards competition, when new operators often enter the market with a partial coverage and/or a technology different from the incumbent.

As a benchmark, we first pinpoint why, in a *symmetric equilibrium* and if networks can *discriminate explicitly*, the access charge has no impact on profits. To understand this, it is useful to recall the classic Hotelling model with unit demands. The latter illustrates the typical oligopoly trade-off between maximizing market share, which calls for a low tariff, and maximizing profits per customer, which calls for a high tariff. An important result is that profits only depend on the extent of the differentiation between the firms and thus not on the cost or quality of the good offered. Network competition in nonlinear tariffs can be seen as a variant of the Hotelling model with unit demands, where the good sold is the membership to a network and its quality is determined by the quantity of telecommunications services that will be consumed. In a symmetric equilibrium, the tariff which networks charge has no effect on access payments between networks; its role is thus identical to the one in the standard Hotelling model: trade-off between maximizing profits per customer and maximizing market share. The only impact of an increase in the access charge is thus to lower the utility offered to customers (the access charge raises the perceived marginal cost of a call which makes it optimal to offer a lower quantity). As the standard oligopoly trade-off is not affected by this utility, it follows that profits are independent of the access charge.[4]

Second, we analyze whether this result still holds if networks cannot discriminate explicitly, and *tariffs have a new role in helping discriminate implicitly between heavy and light users.* For an access charge equal to the marginal cost of terminating a call, differences between customers may be overcome with a menu of tariffs and it is as if networks could discriminate explicitly. An increase in the access charge, however, lowers the quantities offered in equilibrium and makes the largest offered quantity, destined to heavy users, more and more attractive to light users. For a high enough access charge, light users then prefer the tariff and quantity offered to the heavy users under explicit discrimination, such that in order to discriminate implicitly, networks have to increase the tariff for heavy users and/or lower the tariff for light users. Since the profit function is concave and symmetric on both segments, networks deviate by the same amount on each segment from their best response (corrected for the size of the segment). As a result, a tariff cut is given to the light users (resulting in lower profits on this segment), which is exactly compensated by higher tariffs and profits on the heavy

[4]A similar intuition for the neutrality on profits of the access charge is given in Laffont et al. (1997).

users: there is no net effect on total profits. Although this 'neutrality' of the access charge with respect to profits probably depends on the specific model, it illustrates very well the fact that the access charge has no clear-cut impact on profits. Intuitively, the principal effect of an access mark-up is that it makes it optimal for both networks to offer lower quantities. Once networks compete in nonlinear pricing, however, there is by definition no link anymore between the quantity offered to customers and the way the resulting surplus is shared with them (which determines final profits). While the need to meet certain incentive constraints makes that a new role for offered quantities and tariffs is to help discriminate between customers of different types, concerns for incentive compatibility never make networks use the quantity instrument to share surplus with customers, as in the case of linear pricing. In this sense, agreeing to offer low quantities to customers (by way of agreeing on a high access charge) cannot soften competition for market share.
That the impact of the access charge on profits is ambiguous in more complex settings, is supported by an extension of the model which supposes that customers of different types, perceive the substitutability of the networks in a different way. These different perceived substitutabilities may correspond to different switching costs, different brand loyalty, a differentiated access to publicity and information... Whether an access markup increases or decreases profits then depends on parameter values: when networks are seen as better substitutes by the heavy users than by the light users, networks always obtain higher profits by agreeing on an access charge *below* marginal cost. In the opposite case, an access charge *above* marginal cost may boost profits.

Third, we look what happens if some customers may not subscribe a network in equilibrium. We show that in a simple model with homogeneous customers, an access charge different from the marginal cost of terminating a call then leads to more exclusion and lower profits, so that networks strictly prefer an access charge equal to marginal cost.

While the latter results suggest that the industry is competitive in the mature phase of the industry, we argue that this is not always the case during the transition towards competition, when heterogeneity among firms may yield opportunities for anti-competitive access pricing by a dominant network. Entrants may be more (less) efficient than the incumbent and often have access to new technologies (e.g. cable) which differ in their cost structure from the one used by the incumbent. Entrants also tend to have only a partial coverage, so that the incumbent does not face competition for all his customers. Both differences in cost structure and coverage yield *asymmetric equilibria*. A major implication of the latter are that access revenues are strictly positive or negative: one network owes net access payments to the other. An increase in the access charge then affects the level playing field between networks: it increases the access deficit (revenue) of the network which sets a lower (higher) usage fee. Concretely, we show that an access markup decreases profits of the network with the smallest variable cost, whereas it increases those of the other network. Our analytical results are calibrated by some simulations which show that even for small differences in cost structure, the impact on profits is substantial. A direct consequence of our results is that the negotiated access charge is likely to reflect the bargaining power of the networks. It is, for example, in the interest of an incumbent with a high variable cost to insist on a high access charge. While ex post, this leads to above marginal cost pricing, ex ante, the prospect of high access charges may deter entry by a low marginal cost entrant. This suggests that even in the absence of collusion, a regulator may play an important role.

This paper is organized as follows. Section 2 and 3 describe our model of heavy and light users under nonlinear pricing. Section 4 discusses the benchmark case of explicit price discrimination in a symmetric equilibrium in which all customers subscribe to a network. Section 5 analyzes implicit price discrimination. Section 6 looks at the impact of limited participation. Section 7, finally, investigates entry and asymmetric equilibria. Section 8 concludes.

# 2 A model of heavy and light users

We consider the competition between two horizontally differentiated networks. The main elements are as follows:

*Cost structure:* The two networks have the same cost structure. Serving a customer involves a fixed cost $f$. Per call, a network also incurs a marginal cost $c_o$ at the originating and terminating ends of the call and a marginal cost $c_1$ in between. The total marginal cost is thus

$$c = 2c_o + c_1$$

*Demand structure:* The networks are differentiated à la Hotelling. Consumers are uniformly located on the segment $[0, 1]$ and networks are located at the two extremities, namely at $x_1 = 0$ and $x_2 = 1$. Given income $y$ and telephone consumption $q$, a type $k-$consumer located at $x$ joining network $i$ has utility:

$$y + u_k(q) + v_o - \tau |x - x_i|$$

where $v_o$ represents a fixed surplus from being connected[5], $\tau |x - x_i|$ denotes the cost of not being connected to its "most preferred" network, and the variable *gross surplus,* $u_k(q)$, is given by:

$$u_k(q) = \frac{k^{\frac{1}{\eta}} q^{1-\frac{1}{\eta}}}{1 - \frac{1}{\eta}}$$

[5]We will assume throughout most of the paper that $v_o$ is "large enough", so that all consumers are connected in equilibrium

Faced with a usage fee $p$, a customer consumes thus a quantity $q_k$ given by

$$u_k'(q_k) = p \Leftrightarrow q_k = kp^{-\eta} \equiv kq(p)$$

Throughout the paper, we will say that the *usage fee is* $p$ *if customers consume a quantity* $q_k = kq(p)$. Given that networks compete in nonlinear tariffs, this does not imply that customers effectively face a tariff of the form $t(q) = F + pq$.
We consider two different customer types or customer segments:

- *light users*, fraction $\mu$ of the market, characterized by $k = k_L$.
- *heavy users*, fraction $1 - \mu$ of the market, characterized by $k = k_H > k_L$.

The distribution of customers on the segment $[0, 1]$ is assumed to be independent of their type $k$.

*Calling patterns:* We suppose that a fraction $\ell$ of the calls terminates on the light user segment. For the purpose of this paper, we assume that $\ell$ is such that the calling pattern is balanced:

**Definition 1** *A calling pattern is balanced whenever for equal usage fees, each customer calls as much as he is being called.*

With homogeneous customers, this is realized very naturally by assuming that customers receive the same amount of calls ($\ell = \mu$). With heterogeneous customers, a different assumption is needed:

**Lemma 1** *A calling pattern is* balanced *if and only if*

$$\ell = \frac{\mu k_L}{\mu k_L + (1 - \mu)k_H}.$$

**Proof.** For equal usage fees, a light user receives the same amount of calls as he originates if and only if

$$\ell \left[\mu k_L q(p) + (1 - \mu)k_H q(p)\right] = \mu k_L q(p) \Leftrightarrow \ell = \frac{\mu k_L}{\mu k_L + (1 - \mu)k_H}$$

By construction, the same holds for heavy users. ■

Given that customers differ in their volume demand, the assumption of a balanced calling pattern is quite strong. Heavy users, for example, often originate more calls than they receive. Our companion paper, Dessein 1999, analyzes the case in which customers of one type tend to call more than they are being called.

# 3 Competition in nonlinear pricing

Competition in optimal nonlinear pricing is investigated, both under the assumption that networks can discriminate explicitly between heavy and light users (third-degree price discrimination) and in the more realistic case in which only implicit discrimination (second-degree price discrimination) is allowed. From the revelation principle, networks cannot do better than offering a quantity $q_L$ for a tariff $t_L$ and a quantity $q_H$ for a tariff $t_H$ where, under implicit discrimination, $\{q_L, t_L, q_H, t_H\}$ must be such that light users opt for $(q_L, t_L)$ and heavy users choose $(q_H, t_H)$. The variable net surplus of respectively a light and a heavy users is thus

$$w_L \equiv u_{k_L}(q_L) - t_L \quad and \quad w_H \equiv u_{k_H}(q_H) - t_H$$

For given net surpluses $(w_L, w_H)$ and $(w'_L, w'_H)$ offered by network 1 and 2, the market shares $\alpha_L$ and $\alpha_H$ of network 1 in respectively the light and the heavy users' segment are determined as in Hotelling's model. A consumer of type $s$ $(s = L, H)$ located at $x = \alpha_s$ is indifferent between the two networks if and only if

$$w_s - \tau\alpha_s = w'_s - \tau(1 - \alpha_s),$$

or

$$\alpha_s = \alpha(w_s, w'_s) \equiv \frac{1}{2} + \sigma\left[w_s - w'_s\right]$$

where

$$\sigma \equiv \frac{1}{2\tau}$$

is an index of substitutability between the two networks. Given our assumptions about the calling pattern, the *share in incoming calls* of network 1 is

$$\hat{\alpha} = \alpha_L\ell + \alpha_H(1 - \ell)$$

Let $a$ denote the unit access charge to be paid for interconnection by a network to its competitor. Network 1's profits are

$$\begin{aligned} \pi \;=\; & \mu\alpha_L\left[t_L - (c + (1 - \hat{\alpha})(a - c_o))\, q_L - f\right] + \\ & (1 - \mu)\alpha_H\left[t_H - (c + (1 - \hat{\alpha})(a - c_o))\, q_H - f\right] + \\ & \left[\mu(1 - \alpha_L)q'_L + (1 - \mu)(1 - \alpha_H)q'_H\right]\hat{\alpha}_1(a - c_o) \end{aligned} \qquad (1)$$

These profits can be decomposed into a *retail profit*

$$\mu\alpha_L\left[t_L - cq_L - f\right] + (1 - \mu)\alpha_H\left[t_H - cq_H - f\right]$$

which would be made if all calls terminated on net, plus an *access revenue*

$$\begin{aligned} A_1 \;=\; & \left[\mu(1 - \alpha_L)q'_L + (1 - \mu)(1 - \alpha_H)q'_H\right]\hat{\alpha}(a - c_o) - \\ & \left[\mu\alpha_L q_L + (1 - \mu)\alpha_H q_H\right](1 - \hat{\alpha})(a - c_o). \end{aligned}$$

From our balanced calling pattern assumption, regardless of $\alpha_L$ and $\alpha_H$, $A_1 = 0$ if all customers face the same usage fee.

# 4 Explicit price discrimination

As a benchmark, we analyze competition when networks can explicitly discriminate customers, so that customers are forced to use the tariff which is destined for their type. As market shares only depend on the variable net surplus, it is convenient to view networks as picking quantities $(q_H, q_L)$ and net surpluses $(w_H, w_L)$ rather than quantities and tariffs $(t_H, t_L)$. Network 1's profits are then

$$\begin{aligned} \pi &= \mu\alpha_L \left[\tfrac{\eta}{\eta-1} k_L^{1/\eta} q_L^{1-1/\eta} - w_L - cq_L - f\right] \\ &\quad +(1-\mu)\alpha_H \left[\tfrac{\eta}{\eta-1} k_H^{1/\eta} q_H^{1-1/\eta} - w_H - cq_H - f\right] + A_1 \end{aligned} \tag{2}$$

From the first order conditions with respect to $q_L$ and $q_H$, the equilibrium usage fees equal the average perceived marginal cost of a call, $c + (1-\hat{\alpha})(a - c_o)$. In a symmetric equilibrium,[6] we have

$$\hat{q}_L = k_L q(c + \frac{a - c_o}{2}) \quad \text{and} \quad \hat{q}_H = k_H q(c + \frac{a - c_o}{2})$$

A higher access charge thus makes it optimal for networks to offer lower quantities and, for $a \geq c_o$, lowers the total surplus created in the industry. Intuitively, a firm offers its customers the quantity which maximizes the sum of its and their surplus, and thus includes the access losses generated by these customers. Whereas the role of the offered quantities is to maximize the joint surplus, the role of the transfers is to share this surplus with customers. Given that all customers face the same usage fee in equilibrium, access revenues are always zero and the joint surplus per customer is independent of market shares and tariffs; hence, when setting $t$, networks face the classic Hotelling trade-off between: (a) maximizing market share, which calls for a low tariff; (b) keeping as much as possible from the per customer surplus, which calls for a high tariff. As in the standard Hotelling model, profits on a customer segment of size $\mu$ can be written as

$$\pi \equiv \mu\alpha(w, w')\bar{\pi} = \mu \left[\frac{1}{2} + \sigma(w - w')\right]\bar{\pi} = \mu \left[\frac{1}{2} + \sigma\left(S - \bar{\pi} - (S - \bar{\pi}')\right)\right]\bar{\pi}$$

where $S = S'$ is the total surplus per customer, $\bar{\pi}$ and $\bar{\pi}'$ are the profits per customer and $w$ and $w'$ are the offered net surpluses of network 1 and 2. It follows that *profits are independent of the total surplus per customer.* Since this total surplus is the only thing which is directly effected by the *access charge* and the *customer type,* profits are thus also independent of $a$ and $k$. Maximizing (1) with respect to $w_L$ and $w_H$, we have

$$\begin{aligned} \hat{t}_L &= 1/2\sigma + f + c\hat{q}_L \\ \hat{t}_H &= 1/2\sigma + f + c\hat{q}_H, \end{aligned}$$

from which profits per firm are $1/4\sigma$, as in the Hotelling model.

[6]Following LRT, it can be shown that for $a$ close to $c_o$, there exists an equilibrium which is unique and symmetric.

**Proposition 1** *If networks discriminate explicitly, profits per customer are independent of the access charge and the customer type. The usage fees are equal to* $p = c + \frac{a-c_o}{2}$ *for both heavy and light users.*

Note that though usage fees equal the perceived marginal cost, the difference in final tariffs for $\hat{q}_H$ and $\hat{q}_L$ reflect the true incremental cost $c(\hat{q}_H - \hat{q}_L)$.

**Remark:** A variant of our model which also comprises the Hotelling model with unit demands as a special case, could let the differentiation of the networks depend on the quantity consumed in equilibrium, so that, for example, a type $k-$consumer located at $x$ joining network $i$ has utility

$$y + u_k(q) + v_o - \tau |x - x_i| q$$

Given that an increase in the access charge makes it optimal for networks to offer lower quantities, it then also increases the substitutability of the networks and thus competition for market share. Profits are therefore likely to decrease with the access charge if the differentiation does not take the form of a fixed benefit which customers receive when joining a particular network.

# 5 Implicit price discrimination

If customers are homogeneous or if explicit price discrimination is possible, price schedules must achieve *two* goals: creating surplus and sharing it with customers. Armstrong (1998) and Laffont, Rey and Tirole (1998a) have shown that when networks have only *one* instrument, a price per unit, a higher access charge then softens competition for market share and can thus be used to boost profits. Under nonlinear pricing, however, networks have two instruments (quantities and tariffs) which allow them to separate the two roles of pricing. As the access charge only has an impact on the optimal quantity to be offered to customers, and not on the competition for market share (how much of the surplus to share with customers), profits are unaffected. If customers are heterogeneous and networks are not allowed to discriminate explicitly, a new, *third*, role of pricing is to discriminate implicitly between customers of different types. The literature on nonlinear pricing has then shown then that results in general resemble those obtained with linear prices (for example, usage fees are set above marginal cost, some surplus is left to customers).[7] Both Armstrong (1998) and Laffont, Rey Tirole (1998a,b) conjecture therefore that the collusion result, obtained under linear pricing, is likely to be partially restored once there are differences in volume demand for consumption which cannot completely be overcome with a menu of tariffs. The central question of this section is thus whether the difference between the number of goals and instruments under implicit price discrimination indeed allows

[7] See, for example, Varian (1989) and Wilson (1992).

networks to use a positive access markup to increase their profits, as is the case under linear pricing.

### 5.1 Standard model

If networks are not allowed to price discriminate explicitly according to whether a customer is a heavy or a light user (that is third-degree price discrimination is ruled out), the proposed menu of tariffs $\{q_L, t_L, q_H, t_H\}$ must be such that heavy users opt for $(q_H, t_H)$ and light users choose $(q_L, t_L)$. The incentive constraints $(IC)$ are

$$\begin{aligned} w_H &= u_{k_H}(q_H) - t_H \geq u_{k_H}(q_L) - t_L && (IC_H) \\ w_L &= u_{k_L}(q_L) - t_L \geq u_{k_L}(q_H) - t_H && (IC_L) \end{aligned}$$

If $a = c_o$, the quantities offered under explicit price discrimination are those generated by usage fees set at marginal cost, while tariffs are so that profits per customer equal $1/2\sigma$. But this tariff structure is incentive compatible; it can for example be implemented by a unique two-part tariff, $t(q) = pq + F$, in which $p = c$ and $F = 1/2\sigma + f$.[8] As $IC_H$ and $IC_L$ are both satisfied with strict inequality whenever $k_L \neq k_H$ and thus $\hat{q}_L \neq \hat{q}_H$, *the explicit discrimination equilibrium is still incentive compatible for a close to* $c_o$.[9]
For $a$ large or $k_L$ close to $k_H$, however, $\left\{\hat{q}_L, \hat{t}_L, \hat{q}_H, \hat{t}_H\right\}$ is no longer incentive compatible. Indeed, the explicit price discrimination equilibrium is given by $\hat{q}_s = k_s\hat{q}$ and $\hat{t}_s = \hat{t}(\hat{q}_s)$, $(s = L, H)$, where

$$\hat{q} = q(c + \tfrac{a - c_o}{2}) \tag{3}$$

$$\hat{t}(q) = 1/2\sigma + f + cq. \tag{4}$$

Given (4), the net utility of a customer of type $k$ is concave in $q$ and reaches a maximum for $q = kq(c)$. From (3), an increase in the access charge lowers both $\hat{q}_L$ and $\hat{q}_H$ and, for large enough an access charge, $\hat{q}_L < \hat{q}_H \leq k_L q(c)$. Light users then strictly prefer $(\hat{q}_H, \hat{t}_H)$ to $(\hat{q}_L, \hat{t}_L)$ and the $IC$ of the *light users* is violated.

[8] This is in line with the results of Armstrong (1998) and Rochet and Stole (1998) which show that simple two-part tariffs often arise in competitive environments where consumers have private information about their tastes. Rochet and Stole (1998) show, however, that this result is highly sensitive to the assumption that the customer's type is uncorrelated with the consumers location on the Hotelling line and that all consumer types are willing to participate with the candidate tariffs.

[9] Notice, however, that the equilibrium contract $\left\{\hat{q}_L, \hat{t}_L, \hat{q}_H, \hat{t}_H\right\}$ then cannot be implemented through two-part tariff(s). In order for customers to chose the optimal quantities $\hat{q}_L$ and $\hat{q}_H$, the usage fee for both types must be set at $p_L = p_H = c + \frac{a - c_o}{2}$; to implement $\hat{t}_L$ and $\hat{t}_H$, however, a different fixed fee is needed for heavy and light users, which, of course, is not incentive compatible.

Similarly, for $a > c_o$, $\hat{q}_L < k_L q(c)$ so that for $k_L$ close enough to $k_H$,

$$\hat{q}_L < \hat{q}_H = \frac{k_H}{k_L}\hat{q}_L \leq k_L q(c),$$

and again the $IC$ of the light users is violated. The polar case is obtained for $a < c_o$ : for $a$ small enough or $k_L$ close enough to $k_H$, $k_H q(c) \leq \hat{q}_L < \hat{q}_H$ and the $IC$ of the *heavy users* is violated. The reason behind the impact of the access charge on incentive compatibility is thus simple: tariffs for - and thus preferences over - $\hat{q}_L$ and $\hat{q}_H$ reflect their true marginal cost $c$, while $\hat{q}_L$ and $\hat{q}_H$ themselves are determined by the perceived marginal cost $c + (a - c_o)/2$.
Intuitively, the $IC$ which is violated under explicit discrimination, will be binding in the equilibrium under implicit discrimination. The next lemma guarantees this for $\delta = k_H - k_L$ small.

**Lemma 2** *If the explicit price discrimination equilibrium,* $\left\{\hat{q}_L, \hat{t}_L, \hat{q}_H, \hat{t}_H\right\}$ *violates the incentive constraint of the light (heavy) users, then for* $\delta = k_H - k_L$ *small, any symmetric equilibrium* $\{t_L^*, q_L^*, t_H^*, q_H^*\}$ *under implicit price discrimination is such that the incentive constraint of the light (heavy) users is binding.*

**Proof.** See appendix 9.1.1 ■

When the $IC$ of the light users is binding, the symmetric equilibrium is characterized by $\{q_L^*, t_L^*, q_H^*, t_H^*\}$ , where

$$\begin{array}{rcl} q_L^* & = & \hat{q}_L; \quad t_L^* < \hat{t}_L \\ q_H^* & > & \hat{q}_H; \quad t_H^* > \hat{t}_H + c(q_H^* - \hat{q}_H). \end{array}$$

By increasing $q_H$ and $(t_H - t_L)$, networks make $\left\{\hat{q}_H, \hat{t}_H\right\}$ less attractive to light users. Note that by providing a larger quantity to heavy users than is optimal given the perceived marginal cost, networks eliminate partly the distortion induced by this inflated perceived marginal cost. This is in contrast with standard results of nonlinear pricing where implicit price discrimination lowers the offered quantity and reduces efficiency. More important, however, compared to the explicit price discrimination equilibrium, a higher surplus is left to the light users. While this lowers profits made on these customers, average profits are nevertheless unaffected, as the loss is exactly compensated by higher profits on the heavy users.

**Proposition 2**
- *In a symmetric equilibrium, profits are equal to* $1/4\sigma$, *irrespective of the access charge.*
- *Fix the average customer type* $k$ *and let the difference* $\delta = k_H - k_L$ *vary. For any* $\delta_o$, *there exists an access charge* $a_o > c_o$ *such that a symmetric equilibrium always exists for* $a \leq a_o$ *and* $\delta \leq \delta_o$. *Moreover,*

– *For any given $\delta \leq \delta_o$, for a close to $c_o$, incentive constraints are non-binding and the equilibrium is the same as if networks could explicitly discriminate between heavy and light users.*

– *For any given $a \in \left]c_o, a'\right]$, for $\delta$ close to 0, the incentive constraint of the light users is binding. Compared to the equilibrium with explicit price discrimination: (1) the quantity (and tariff) offered to heavy users is higher, (2) a lower tariff for an unchanged quantity is charged to light users.*

**Proof.** See appendix 9.1.1 ■

For $\delta$ small enough, an access charge above marginal cost induces the $IC$ of light users to be binding and could thus boost profits if incentive compatibility constraints lead networks to increase their tariffs. We give the intuition for why this does not arise here. Starting from the explicit price discrimination equilibrium, networks must make $(t_H, q_H)$ less attractive and/or $(t_L, q_L)$ more attractive to the light users to meet their $IC$. Besides changes in the offered quantities, networks are obliged to decrease $t_L - t_H$. Neglecting incentive constraints, given the equilibrium quantities $q_H^*$ and $q_L^*$ and given the tariffs $t'_H$ and $t'_L$ charged by network 2, network 1's profits on a segment $s$ $(s = L, H)$ are concave in $t_s$ and reach a maximum for

$$\hat{r}(t'_s) = \frac{\hat{t}(q_s^*) + t'_s}{2} \qquad \text{where } \hat{t}(q_s^*) = 1/2\sigma + f + cq_s^*$$

In order to meet the incentive constraints, it is thus never optimal to decrease only $t_L$ or raise only $t_H$ relative to $\hat{r}(t'_L)$ and $\hat{r}(t'_H)$ : network 1 will spread its losses and deviate least from $\hat{r}(t'_s)$ on the segment $s$ where the profit function is most concave. In our model, the concavity of the profit function on a segment depends only on the substitutability, (the higher $\sigma$, the larger is the impact of changes in $t$ on market shares and thus on profits) and on the size of the segment (the more customers are in a segment the more expensive it is to deviate from the 'optimal' per customer tariff).[10] Hence, if only changes in $t_L - t_H$ matter, network 1 always deviates from its best response in a way that

$$\mu \left[t_H - \hat{r}(t'_H)\right] = (1-\mu)\left[\hat{r}(t'_L) - t_L\right]$$

$$\Leftrightarrow \mu \left[t_H - \frac{\hat{t}(q_H^*) + t'_H}{2}\right] = (1-\mu)\left[\frac{\hat{t}(q_L^*) + t'_L}{2} - t_L\right]$$

[10]Indeed, for given equilibrium quantities, the second derivative of profits with respect to $t_L$ and $t_H$ are

$$\frac{\partial^2 \pi}{\partial t_L^2} = -2\mu\sigma \qquad \frac{\partial^2 \pi}{\partial t_H^2} = -2(1-\mu)\sigma$$

That the second derivative is independent of $t_s$ is specific to our model and stems from the fact that profits are quadratic/market shares are linear in $t$.

In a symmetric equilibrium, $t_L = t'_L$ and $t_H = t'_H$, this yields

$$\mu \left[t_H - \hat{t}(q_H^*)\right] = (1-\mu)\left[\hat{t}(q_L^*) - t_L\right] \tag{5}$$

As for $\left\{q_H^*, \hat{t}(q_H^*), q_L^*, \hat{t}(q_L^*\right\}$, profits equal $1/2\sigma$ per customer, average per customer profits given $\{q_H^*, t_H, q_L^*, t_L\}$ are also $1/2\sigma$. Though the need to discriminate implicitly affect the profits made on each segment, total profits are unaffected.

While this 'neutrality' of the access charge is an extreme result which probably depends on the quadratic profit function, we think its intuition is very robust: the access charge has no clear-cut impact on profits. As a principal effect, the access charge induces networks to offer lower quantities to their customers. Networks who agree on a high access charge thus agree on offering customers low quantities. When the quantity offered to customers is linked to the way the resulting surplus is shared with customers (as with linear pricing), an increase in the access charge may reduce competition for market share and result in higher profits. Once networks compete in nonlinear pricing, however, there is no such clear link. The need to meet certain incentive constraints means that the role of the offered quantity is not just maximizing joint surplus, and the role of tariffs not just to share this surplus optimally with customers, but also to help discriminate between customers of different types. Concerns for incentive compatibility, however, never lead networks to use the quantity instrument to share surplus with customers. In this sense, agreeing on offering low quantities to customers (by way of agreeing on a high access charge) cannot soften competition for market share.

## 5.2 Two-part tariffs

Though sophisticated nonlinear tariffs are more and more common in telecommunications, especially in the mobile sector, two-part tariffs are still very popular. Suppose therefore that for an exogeneous reason, networks are limited to the use of (a menu of) two-part tariffs. As there are only two types, it is optimal to let customers choose between

$$t_L(q) = F_L + p_L q \quad \text{and} \quad t_H(q) = F_H + p_H q$$

where $\{F_L, p_L, F_H, p_H\}$ must be such that heavy users opt for $(F_H, p_H)$ and light users choose $(F_L, F_L)$. Faced with a tariff $t(q) = F + pq$, the net surplus of a customer of type $s$ $(s = L, H)$ is

$$w_s(p, F) \equiv k_s v(p) - F$$

with

$$k_s v(p) \equiv \max_q \{u_k(q) - pq\} = k\left(\frac{p^{-(\eta-1)}}{\eta - 1}\right)$$

Incentive constraints are then

$$w_H(p_H, F_H) \geq w_H(p_L, F_L) \quad \text{and} \quad w_L(p_L, F_L) \geq w_L(p_H, F_H)$$

**Proposition 3** • *In any symmetric equilibrium in two-part tariffs, profits are independent of the access charge and are equal to* $1/4\sigma$

- *For a close to* $c_o$*, a symmetric equilibrium exists and is such that for* $a > c_o$*, the incentive constraint of the light users is binding and*

  – $p_L = c + \frac{a-c_o}{2}, \quad F_L < 1/2\sigma + f - \frac{a-c_o}{2} k_L q(p_L)$

  – $p_H < c + \frac{a-c_o}{2}, \quad F_H > max\{F_L, 1/2\sigma + f - (p_H - c)k_H q(p_H)\}.$

**Proof.** See appendix 9.1.2 ■

Proposition 3 shows that the profit neutrality of the access charge does not depend on our assumption of *optimal* nonlinear pricing. Again, networks have two instruments, a usage fee which directly controls the offered quantity and a fixed fee to share surplus with customers. Though the usage price also partially determines how the surplus is shared, its impact can be corrected in a profit-neutral way by changes in the fixed fee. As in the case of optimal nonlinear pricing, agreeing to offer a low quantity to customers has thus no impact on the way the resulting surplus is shared.

### 5.3 Limits to the neutrality of the access charge on profits.

This section illustrates our claim that, while the access charge may have an impact on profits, this impact is as likely to be positive as negative. Suppose customers of different types perceive the substitutability of the networks in a different way. Such different perceived substitutabilities can correspond to different brand loyalties, different search costs, a differentiated access to product information or publicity, different switching costs, etc. We denote these perceived substitutabilities for light and heavy users respectively by $\sigma_L$ and $\sigma_H$. If networks could discriminate explicitly, they would offer quantities that reflect the perceived marginal cost

$$\hat{q}_L = k_L q(c + \frac{a - c_o}{2}), \quad \hat{q}_H = k_H q(c + \frac{a - c_o}{2}) \tag{6}$$

and charge a tariff $t(q_s)$ such that profits per customer are $1/2\sigma_s$, $(s = L, H)$ :

$$\hat{t}(\hat{q}_L) = 1/2\sigma_L + f + c\hat{q}_L \tag{7}$$

$$\hat{t}(\hat{q}_H) = 1/2\sigma_H + f + c\hat{q}_H \tag{8}$$

Total profits under explicit price discrimination, denoted by $\pi_D^*$, are thus independent of the access charge and are equal to

$$\pi_D^* = \frac{\mu}{4\sigma_L} + \frac{1-\mu}{4\sigma_H}. \tag{9}$$

If explicit price discrimination is not possible, networks still can discriminate implicitly through a menu of tariffs. A first consequence of $\sigma_L \neq \sigma_H$, is that incentive compatibility conditions may affect profits. Denoting profits under implicit price discrimination by $\pi^*$, one has

$$\pi^* < \pi_D^* \text{ when } \sigma_H > \sigma_L \quad \text{and} \quad \pi^* > \pi_D^* \text{ when } \sigma_H < \sigma_L \tag{10}$$

if the $IC$ of the *light users* is binding, and

$$\pi^* > \pi_D^* \text{ when } \sigma_H > \sigma_L \quad \text{and} \quad \pi^* < \pi_D^* \text{ when } \sigma_H < \sigma_L \tag{11}$$

if the $IC$ of the *heavy users* is binding. The intuition of this result is similar to that of the profit neutrality of the access charge in the standard model. Recall that if an $IC$ is binding, networks must deviate from their best responses under explicit discrimination in order to meet incentive constraints. As only the difference between $t_L$ and $t_H$ matters, and profits are concave in $t_L$ and $t_H$, networks deviate most on the segment where profits are least concave. As ceteris paribus, profits are least concave on the segment with the smallest substitutability (market shares react much faster when the substitutability is stronger), networks deviate most on the segment where $\sigma$ is smallest. Depending on whether the needed deviation on that particular segment is a tariff cut or a tariff raise, equilibrium profits are then either lower or higher than under explicit price discrimination. In case, for example, the $IC$ of the light users is binding, networks must decrease $t_H - t_L$. If $\sigma_H > \sigma_L$, networks find it optimal to decrease more $t_L$ than they increase $t_H$ so that profits are lower than under explicit price discrimination. The opposite holds if $\sigma_H < \sigma_L$.

As the *access charge affects incentive compatibility,* a second implication of $\sigma_L \neq \sigma_H$, is that the access charge may also affect profits.

- Suppose first that $a = c_o$. If $\Delta k$ is relatively small compared to $|\sigma_H - \sigma_L|$, then the $IC$ of the customers with the smallest perceived substitutability will be violated in the explicit price discrimination equilibrium: from (6),(7) and (8), the difference in equilibrium quantities is then small relative to the difference in equilibrium tariffs. From lemma 2, if $\Delta k$ is small, the same $IC$ is binding in the implicit price discrimination equilibrium. From (7) and (8), if $\sigma_H > \sigma_L$, the $IC$ of the light users is thus binding for $\Delta k$ small, from which $\pi^* < \pi_D^*$. Similarly, if $\sigma_H < \sigma_L$, the $IC$ of the heavy users is binding for $\Delta k$ small, from which also $\pi^* < \pi_D^*$. Of course, if $\Delta k$ is relatively large, networks can perfectly discriminate and $\pi^* = \pi_D^*$.
- Consider now $a \neq c_o$. In the explicit price discrimination equilibrium, customers of type $k$ are offered a quantity $\hat{q}_k = kq(c + \frac{a-c_o}{2})$ for a tariff $\hat{t}_k = 1/2\sigma_k + f + c\hat{q}_k$. Defining

$$V_k(q) \equiv u_k(q) - cq, \quad \text{and} \quad F_k \equiv 1/2\sigma_k + f,$$

the $IC$ of light and heavy users can be rewritten as

$$V_L(\hat{q}_L) - V_L(\hat{q}_H) \quad > \quad F_L - F_H \qquad (IC_L) \tag{12}$$

$$V_H(\hat{q}_L) - V_H(\hat{q}_H) \quad < \quad F_L - F_H \qquad\qquad (IC_H) \qquad\qquad (13)$$

Note that $V_k(q)$ is strictly concave and reaches a maximum for $q = kq(c)$. We distinguish the impact of a positive and a negative access markup:

(1) A negative access markup ($a < c_o$) has a clear impact on $IC_L$ and $IC_H$. When $c + \frac{a-c_o}{2}$ goes to zero, $\hat{q}_H - \hat{q}_L$ tends to infinity such that $V_s(\hat{q}_L) - V_s(\hat{q}_H)$, $(s = L, H)$ increases without a bound when $a$ gets smaller. For $a$ small enough, $IC_L$ is then always satisfied, while $IC_H$ is violated. A negative access markup thus strengthens the $IC$ of the heavy users and weakens the $IC$ of the light users. Intuitively, the larger the quantities offered in equilibrium (due to the low access charge), the more everybody likes the smallest offered quantity: the incremental gross utility of consuming $\hat{q}_H$ instead of $\hat{q}_L$, given by $u(\hat{q}_H) - u(\hat{q}_L)$, decreases more and more compared to its incremental cost, $F_H - F_L + c(\hat{q}_H - \hat{q}_L)$. It follows that for $\sigma_H > \sigma_L$ and $\Delta k$ small, a sufficiently negative access markup increases profits: the $IC$ of the heavy users is then binding so that $\pi^* > \pi^*_D$, while for $a = c_o$, the $IC$ of the light users is binding and thus $\pi^* < \pi^*_D$.

(2) A positive access markup ($a > c_o$), on the other hand, always decreases $V_s(\hat{q}_L) - V_s(\hat{q}_H)$ $(s = L, H)$, though not without limits: $V_s(\hat{q}_L) - V_s(\hat{q}_H)$ $(s = L, H)$ reaches a negative lowerbound for some $a^*_H > c_o$ and $a^*_L > c_o$. For $|\sigma_H - \sigma_L|$, and thus also $|F_H - F_L|$ small enough, there exists then an $a > c_o$, such that the $IC$ of the light users is violated by the explicit price discrimination equilibrium. If follows that for $\sigma_H < \sigma_L$, the $IC$ of the light users is binding so that $\pi^* > \pi^*_D$.

**Proposition 4** • *Suppose $a = c_o$ :*

*(1) Given $|\sigma_H - \sigma_L|$, for $\Delta k$ sufficiently small, the incentive constraint of customers with the smallest perceived substitutability is binding. Equilibrium profits $\pi^*$ are then smaller than $\pi^*_D$.*

*(2) Given $\Delta k$, for $|\sigma_H - \sigma_L|$ sufficiently small, no incentive constraints are binding and $\pi^* = \pi^*_D$.*

- *The access charge may affect profits:*

  *(1) For a sufficiently negative access markup ($a < c_o$) and $\Delta k$ small, the incentive constraint of the heavy users is binding. If $\sigma_H > \sigma_L$, then $\pi^* > \pi^*_D$ : a sufficiently negative access markup increases profits. If $\sigma_L < \sigma_H$, then $\pi^* < \pi^*_D$.*

  *(2) For a given positive access markup ($a' > c_o$) and $\Delta k$ small, if $|\sigma_H - \sigma_L|$ is sufficiently small, the incentive constraint of the light users is binding. If $\sigma_H < \sigma_L$, then $\pi^* > \pi^*_D$ : $a' > c_o$ boosts profits relative to $a = c_o$. If $\sigma_H > \sigma_L$, $\pi^* < \pi^*_D$ for $a' > c_o$.*

**Proof.** See appendix 9.1.3 ■

# 6 Limited participation

We have assumed so far that the fixed surplus of consuming telephone services, $v_o$, is large enough, so that in equilibrium customers always subscribe to one of the networks, that is participation constraints are always satisfied. This section shows how, in a simple model in which all customers are of the same type ($k_1 = k_2 = 1$), our results are affected if one relaxes this assumption. Intuitively, as in the standard model an access charge above marginal cost reduces the net surplus offered to customers, an access markup is likely to result in more exclusion of customers and thus to lower profits if participation constraints are binding. Denote by $w_i$ the net surplus, including the fixed benefit of subscribing, offered by network $i$ to a customer residing at its location:

$$w_i = v_o + u(q_i) - t_i$$

Given the surplus $w_j$, two regions of network $i's$ demand may be distinguished: a "monopoly" region, where marginal customers' best alternative is not to subscribe and a "competitive" region, where marginal customers are willing to subscribe to the rival network. In the absence of competition of network $j$ (e.g. $w_j = 0$), the demand for network $i$ is

$$\alpha_i = \frac{w_i}{\tau} = 2\sigma w_i$$

This defines the potential market of network $i$. In the competitive region, network $i$'s demand is given by

$$\alpha_i = \frac{1}{2} + \sigma\left(w_i - w_j\right).$$

Intuitively, if $v_o$ is large enough (as we assumed before), the equilibrium always lies in the competitive region. Note that demand is more elastic in the monopoly region than in the competitive region, so that if $0 < w_j < \tau$, the demand curve of network $i$ is kinked; starting from $w_i = 0$, by offering a higher surplus, network $i$ first captures customers who otherwise would not subscribe at all, and finally captures customers who would otherwise subscribe to network $j$.

For simplicity, we assume that calls to different customers are perfect substitutes. This implies that demand for calls is always $q(p) \equiv p^{-\eta}$, even if only a fraction $\phi$ of customers has subscribed a network.[11] Define $s^*$ as the surplus of a subscription by a customer residing at the location of network $i$ or $j$ if the usage fee is equal to $c + \frac{a-c_o}{2}$, then

$$s^* = v_o + u(q(c + \tfrac{a-c_o}{2})) - cq(c + \tfrac{a-c_o}{2}) - f.$$

**Proposition 5** *If a symmetric equilibrium exists, then it is such that*

[11] If calls to different customers were not substitutes, demand would equal $q_\phi(p) \equiv \phi p^{-\eta}$.

- *if* $s^* > \dfrac{3}{4\sigma}$, *then* $\alpha_i = 1/2$ *and* $\pi^* = \dfrac{1}{4\sigma}$
- *if* $s^* \in \left[\dfrac{1}{2\sigma}, \dfrac{3}{4\sigma}\right]$, *then* $\alpha_i = 1/2$ *and* $\pi^* = \dfrac{s^*}{2} - \dfrac{1}{4\sigma} \leq \dfrac{1}{4\sigma}$
- *if* $s^* < \dfrac{1}{2\sigma}$, *then* $\alpha_i < 1/2$ *and* $\pi^* = \dfrac{\sigma\left(s^*\right)^2}{2}$

*As* $s^*$ *is concave in* $a$ *and reaches a maximum for* $a = c_o$, *symmetric equilibrium profits decrease with* $|a - c_o|$ *if* $s^* \leq \dfrac{3}{4\sigma}$.

**Proof.** Competition in quantities and transfers can equivalently be viewed as competition in quantities and net surpluses. As usual, it follows from the FOC with respect to $q$, that offered quantities reflect the perceived marginal cost. In a symmetric equilibrium, we then have

$$q^* = q(c + \frac{a - c_o}{2})$$

The surplus of a subscription of a customer residing at the location of network $i$ or $j$ equals then $s^*$. The rest of the proof is standard. ■

From proposition 5, if participation constraints are binding, profits are decreasing in the net surplus that would have been offered to customers if no participation constraints were binding. As the latter is maximal for $a = c_o$, firms strictly prefer an access charge equal to marginal cost, which is also the access charge which maximizes social welfare. Intuitively, by maximizing the total surplus of a subscription, networks are able to make more profits on more customers.

# 7 Entry and asymmetric equilibria

The previous analysis suggests that there is no need for regulation in the mature phase of the industry. One should be a more cautious, however, in drawing this conclusion during the transition towards competition. Due to asymmetries in cost structure or coverage, the access charge may then have a different impact on the profits of competing networks. This section investigates whether an access charge above marginal cost may give an unfair competitive advantage to one network. For this purpose, we analyze a range of asymmetric equilibria which incorporate the following extensions of our basic model:

*(1) Partial entry:* In contrast with the incumbent (network 1), an entrant (network 2) often covers only part of the market. Denoting the coverage of the entrant by $\mu \leq 1$, its market share is given by:

$$\alpha_2 = \mu\left[\frac{1}{2} + \sigma(w_2 - w_1)\right]$$

where $w_i$ is the variable net surplus offered by network $i$ to his customers.

*(2) Differences in cost structure.* Networks may differ in their variable cost $c_i$ and/or fixed cost $f_i$ $(i = 1, 2)$. Such differences in costs are typical during the transition towards competition, when operators often enter the market with a technology different from the one used by the incumbent. To avoid the issue of nonreciprocal access charges, however, we maintain the assumption that the cost of terminating a call, $c_o$, is identical to both networks.

For simplicity, customers are also assumed to be homogeneous ($k_L = k_H = 1$).

Recall that in a symmetric equilibrium, networks' profits are equal to those of the symmetric Hotelling model with unit demands. Before we proceed with the analysis, we therefore define equilibrium profits and equilibrium market shares in an asymmetric Hotelling model with unit demands. Denoting gross utility minus cost of good $i$ by $s_i$ and network $i's$ per customer profits by $R_i$, then, if $\mu = 1$, total profits of firm $i$ are

$$\alpha_i R_i = \left(\frac{1}{2} + \sigma(w_i - w_j)\right) R_i = \left(\frac{1}{2} + \sigma\left[s_i - R_i - s_j + R_j\right]\right) R_i,$$

yielding equilibrium profits

$$\pi_i^H = \frac{(\alpha_i^*)^2}{\sigma} \tag{14}$$

and equilibrium market shares

$$\alpha_i^* \equiv \alpha_i^H(s_i, s_j) = \frac{1}{2} + \frac{\sigma}{3}\left[s_i - s_j\right] \tag{15}$$

If network 2 covers only $\mu < 1$ of the market, then

$$\alpha_1^H(s_1, s_2) = \frac{1}{2} + \frac{1-\mu}{3} + \frac{\mu\sigma}{3}\left[s_1 - s_2\right] \tag{16}$$

$$\alpha_2^H(s_1, s_2) = \frac{1}{2} - \frac{1-\mu}{3} + \frac{\mu\sigma}{3}\left[s_2 - s_1\right] \tag{17}$$

The following proposition characterizes all asymmetric shared market equilibria and the impact of the access charge on them.

**Proposition 6** • *In any shared market equilibrium, profits of network* 1 *and* 2 *are*

$$\begin{aligned}\pi_1^* &= \pi_1^H + (\alpha_1^*)^2\left(q_2^* - q_1^*\right)(a - c_o)\\ \pi_2^* &= \pi_2^H - (\alpha_2^*)^2\left(q_2^* - q_1^*\right)(a - c_o)\end{aligned} \tag{18}$$

*resulting in total industry profits*

$$\pi_1^H + \pi_2^H + (\alpha_1^* - \alpha_2^*)\left(q_2^* - q_1^*\right)(a - c_o) \tag{19}$$

*where* $q_i^*$ *and* $\alpha_i^*$ *are solutions to*

$$\begin{aligned} q(p_i^*) &= q(c_i + \alpha_j^*(a - c_o)) \\ \alpha_i^* &= \alpha_i^H(s_i(q_i^*), s_j(q_j^*)) \end{aligned}$$

*with* $s_i(q_i^*) \equiv u(q_i^*) - c_i q_i^* - f_i$

- *Suppose* $c_i < c_j$ *and define* $\tilde{\alpha}_i$, $\tilde{\alpha}_j$ *as the equilibrium market shares for* $a = c_o$ :
  - *If* $\tilde{\alpha}_i < \tilde{\alpha}_j$, *then a small access markup* ($a > c_o$), *decreases* $\alpha_i^*$ *and* $\pi_i^*$, *but increases* $\pi_j^*$ *and total industry profits.*
  - *If* $\tilde{\alpha}_i > \tilde{\alpha}_j$, *but*
  $$\left(\frac{\tilde{\alpha}_i}{\tilde{\alpha}_j}\right)^2 < \left(\frac{c_j}{c_i}\right)^{\eta+1}, \tag{20}$$
  *then a small access markups markup decreases* $\alpha_i^*$, $\pi_i^*$ *and total industry profits, but increases* $\pi_j^*$.
  - *If* $\tilde{\alpha}_i > \tilde{\alpha}_j$, *and*
  $$\left(\frac{\tilde{\alpha}_i}{\tilde{\alpha}_j}\right)^2 > \left(\frac{c_j}{c_i}\right)^{\eta+1}, \tag{21}$$
  *then a small access markup increases* $\alpha_i^*$, *but lowers the access revenues of network* $i$. *The impact on total industry profits is ambiguous as* $\pi_1^H + \pi_2^H$ *is increased, but the term* $(\alpha_1^* - \alpha_2^*)(q_2^* - q_1^*)(a - c_o)$ *is negative.*

**Proof.** A formal proof is given in appendix 9.2. In order to show in more detail what drives the results of proposition 6, we give here a sketch of the proof. Profits are the sum of retail revenues

$$\alpha_i [t_i - c_i q_i - f_i] \equiv \alpha_i R_i$$

and access revenues $A_i$

$$A_i = \alpha_i(1 - \alpha_i)(q_j - q_i)(a - c_o)$$

A first difference with symmetric equilibria is that changes in market shares may affect the access revenue. As $A_1 = -A_2$ and $\alpha_1 = 1 - \alpha_2$

$$A' \equiv \frac{\partial A_1}{\partial \alpha_1} = \frac{\partial A_2}{\partial \alpha_2} = (\alpha_1 - \alpha_2)(q_1 - q_2)(a - c_o). \tag{22}$$

The cost to network $i$ of a tariff cut needed to increase its market share by $\varepsilon$ equals $\alpha_i \dfrac{\varepsilon}{\mu\sigma}$. The benefits are the extra retail profits, $\varepsilon R_i$, plus the change in access revenues, $\varepsilon A'$. In equilibrium, retail profits per customer thus satisfy

$$R_1^* = \frac{\alpha_1^*}{\mu\sigma} - A' \qquad \text{and} \qquad R_2^* = \frac{\alpha_2^*}{\mu\sigma} - A'$$

The term $A'$ reflects the incentives of networks to boost access revenues by increasing their market share. If networks can increase access revenues by having a higher market share ($A' > 0$), then competition for market share is tougher and retail profits will be lower. If access revenues are reduced by a higher market share ($A' < 0$), competition is softer and retail profits are higher. As flows between networks - and thus the absolute size of access deficits and revenues - increase when market shares are more equal ($\alpha_1\alpha_2$ is maximal for $\alpha_1 = \alpha_2 = 0.5$), both the largest and the smallest network compete more fiercely for market share if the largest network faces an access deficit. Similarly, if the smallest network incurs an access deficit, an increase in the access charge gives both networks incentives to decrease their market share and thus to raise their tariff. These incentives to lower or increase tariffs in order to boost access revenues, however, do not affect the equilibrium market share, as the latter depends only on $R_2^* - R_1^*$,,

$$\alpha_2 = \mu\left(\frac{1}{2} + \sigma\left[w_2 - w_1\right]\right) = \mu\left(\frac{1}{2} + \sigma\left[s_2(q_i) - R_2^* - s_1(q_j) + R_1^*\right]\right)$$

Given $s_i(q_i)$ and $s_j(q_j)$, $\alpha_i^*$ is thus still identical as in the Hotelling model with unit demands, $\alpha_i^* = \alpha_i^H(s_i(q_i), s_j(q_j))$, but equilibrium profits now equal

$$\pi_i^* = \alpha_i R_i + A_i = \frac{\left(\alpha_i^H\right)^2}{\mu\sigma} - \alpha_i A' + A_i = \pi_i^H - \alpha_i A' + A_i \tag{23}$$

yielding total industry profits of

$$\pi_i^H + \pi_j^H - A' \tag{24}$$

Suppose first that $q_i^*$ and $q_2^*$ are given or determined exogeneous. Total industry profits are then increased by an access markup if and only if the access charge softens competition for market share ($A' < 0$). Nevertheless, even when $A' < 0$, there is no scope for collusion: the absolute size of the access deficit incurred by one network $|A_j|$, is always larger than the gains from softer competition, $-\alpha_i A'$, induced by this access deficit.[12]

Let us now take the impact of $a$ on $q_i^*$ and thus on $\alpha_i$ and $\pi_i^H$ into account. As usual, marginal prices are set at perceived marginal cost

$$q_i^* = q(p_i^*) = q(c_i + \alpha_j(a - c_o)) \tag{25}$$

[12]Suppose $A_j < 0$, then

$$-\alpha_j A' = -\alpha_j \frac{A_j}{\alpha_j} + \alpha_j \frac{A_j}{\alpha_i} = |A_j| - \frac{\alpha_j}{\alpha_i}|A_j| < |A_j|$$

so that profits of network $j$ incurring an access deficit are

$$\pi_j^H - \frac{\alpha_j}{\alpha_i}|A_j|$$

Market shares depend on $s_i(q_i^*) - s_j(q_j^*)$, where $s_i(q_i) = u(q_i) - c_i q_i - f_i$ decreases with $q_i$ for $q_i > q(c)$. From (25), if $c_i \approx c_j$ and $\alpha_i > \alpha_j$ for $a = c_o$, an access markup increases $q_i^* - q_j^*$ and thus $s_i(q_i^*) - s_j(q_j^*)$ : if marginal costs are more or less equal, an access markup increases the largest market share. On the other hand, if $\alpha_i \approx \alpha_j$ for $a = c_o$, and $c_i < c_j$, a small access markup decreases $s_i(q_i^*) - s_j(q_j^*)$ : if market shares are more or less equal, a small access markup lowers the market share of the network with the smallest marginal cost. We distinguish two cases:

(1) If $c_i < c_i$ and $\alpha_i < \alpha_j$ for $a = c_o$, both forces go to decrease $\alpha_i$. As network $i$ then also incurs an access deficit, a small access markup lowers profits of network $i$. On the other hand, since a decrease in $\alpha_i$ increases $\pi_i^H + \pi_j^H$ and from (22), $A' < 0$, total industry profits, given by (24), are increased. This result goes also in the other direction. If for $a > c_o$, $A' < 0$, that is if an access markup softens competition, then the smallest network incurs an access deficit and, from (25), has a smaller marginal cost: *if an access markup softens competition, then it also lowers profits of the smallest network.*

(2) If $c_i < c_i$ and $\alpha_i > \alpha_j$ for $a = c_o$, then an access markup results in an access deficit for the largest network (network $i$) and thus toughens competition for market share ($A' > 0$). Profits of network $i$ are given by

$$\pi_i^* = \pi_i^H - \frac{\alpha_i}{\alpha_j} |A_i| < \pi_i^H - |A_i|$$

where $\pi_i^H = (\alpha_i)^2/\sigma$. If $\alpha_i/\alpha_j$ is relatively small compared to $c_j/c_i$, then an access markup still decreases the market share of the network incurring an access deficit (network $i$) - and thus its profits. The exact condition is given by (20). From (24), also total industry profits are lowered. On the other hand, if $\alpha_i/\alpha_j$ is large relative to $c_j/c_i$, an access markup increases $\alpha_i$, and so that, a priori, its impact on $\pi_i^*$ is ambiguous. ■

Proposition 6 tells us that networks' profits equal the standard Hotelling profits for unit demands, as in a symmetric equilibrium, plus, for $a \neq c_o$, a term specific to network competition. Moreover, the access charge may affect the standard Hotelling profits through its impact on $s_i(q_i) - s_j(q_j)$ (and thus on market shares), whereas the latter are independent of $a$ in a symmetric equilibrium. From (18), the access charge essentially changes the *level playing field* between the two networks: neglecting its impact on market shares, an access markup lowers profits of the network which incurs an access deficit and raises those of the network incurring an access revenue. For small access markups, this is always the network with the lowest marginal cost (which we denote by network $i$). Taking the impact of an access markup on market shares - and thus on $\pi_i^H$ - into account, lowers the profits of network $i$ even more if it also has a smaller market share for $a = c_o$ or, in the opposite case, if $\alpha_i/\alpha_j$ is relative small compared to $c_j/c_i$. This case is typical for entry by a low marginal cost operator. Due to its partial coverage of the market or due to switching costs[13], the entrant tends to have a smaller market share, or, if $c_i \gg c_j$ only a slightly larger market share, than the incumbent. It is then in the interest of the incumbent to insist on a high access charge. While ex post, this leads to above marginal cost pricing (for $a > c_o, q_i^*$ and $q_j^*$ are smaller than $q(c)$), ex ante, the prospect of high access charges may also deter entry by a low marginal cost entrant if there are substantial fixed investments and/or the low marginal cost technology involves a large fixed cost per customer.

If, on the other hand, $\alpha_i/\alpha_j$ is relative large compared to $c_j/c_i$, then an access markup still results in an access deficit for network $i$, but it increases also its market share. A priori, the impact on profits is thus ambiguous. But, as we have shown above, the access charge then also increases competition for market share which lowers profits of both networks, as is reflected by the (negative) term $(a - c_o)(\alpha_1^* - \alpha_2^*)(q_2^* - q_1^*)$ in (19). Intuitively, the impact of the access deficit and this increased competition is likely to dominate the advantages of a possibly larger market share.

To put our analytical results in perspective, we report simulation results on competition between an entrant, $E$, with partial coverage ($\mu = 0.8$) and an incumbent, $I$, which may only differ in marginal costs.[14]

| | | $a = c_o$ | $a - c_o = 0.2$ | $a - c_o = 0.4$ |
|---|---|---|---|---|
| $c_E = 0.9 < c_I = 1$ | $\pi_E =$ | .146 | .134 | .126 |
| | $\pi_I =$ | .105 | .114 | .120 |
| | $\alpha_I =$ | .459 | .459 | .459 |
| $c_E = 1 > c_I = 0.9$ | $\pi_E =$ | .077 | .083 | .088 |
| | $\pi_I =$ | .184 | .168 | .151 |
| | $\alpha_I =$ | .607 | .611 | .618 |
| $c_E = c_I = 1$ | $\pi_E =$ | .1089 | .1091 | .1097 |
| | $\pi_I =$ | .1422 | .1418 | .1407 |
| | $\alpha_I =$ | .533 | .535 | .538 |

[13]Proposition 6 is robust to the case where customers incur a fixed switching cost $S$ when they join the entrant. If the entrant has full coverage, its market share is then

$$\alpha_2 = \frac{1}{2} - \frac{S}{2} + \sigma[w_2 - w_1]$$

such that

$$\alpha_2^* = \alpha_2^H = \frac{1}{2} - \frac{S}{6} + \frac{\sigma}{3}[s(q_1^*) - s(q_2^*)].$$

[14]Other parameter values are $\eta = 2$, $\sigma = 2.5$ and $f_i = f_j = 0$. Simulations where $\mu = 1$, but $f_i < f_j$ would yield similar results: from the expression for $\alpha_i^H$, differences in fixed costs have the same impact on market shares - and thus on profits - as differences in coverage.

- The first case deals with entry by a low marginal cost operator ($c_E < c_I$). Since condition (21) of proposition 6 holds practically at the equality, the access markup has almost no impact on the market shares. Profits, on the other hand, are considerably affected: the entrant's profits fall by ±15% while the incumbent's profits increase by ±15%.
- In the second case, the incumbent has a smaller marginal cost ($c_E < c_I$), and condition (21) is largely satisfied. As predicted, the access markup increases the market share of the incumbent. Nevertheless, the incumbent's profits fall by more than 15%. Also total industry profits falls by some 8%, as the access deficit induces tougher competition for market share. The impact of the access charge on the access deficit and on competition thus by far outweighs the benefits of a larger market share.
- Finally, we look at the case where marginal costs are identical, which is not covered by proposition 6. The impact on profits is then negligeable (less than 0.1% of profits).

# 8 Concluding remarks

Previous research on network interconnection and two-way access has mainly focussed on linear pricing, thereby emphasizing the collusive power of the access charge. Given that competition between telecommunications operators *de facto* is competition in nonlinear pricing, this can only be justified by an implicit assumption that linear prices are a good short cut of nonlinear prices. Though the seminal work of Laffont et al. has shown that in a simple model with homogeneous customers and a symmetric equilibrium, the collusive effect of the access charge then completely disappears, both Laffont et al. (1998a,b) and Armstrong (1998) argued that once customers are heterogeneous in demand and marginal prices differ from marginal cost, results are likely to resemble those under linear pricing more closely. Since subsequent research and policy oriented publications have continued to report results obtained under the assumption of linear pricing, often without mentioning the result on two-part tariffs in Laffont et al., the idea that the access charge is an instrument of collusion has become widespread among policy makers.[15]

This paper has argued that the collusive effect of the access charge totally depends on the - in reality not satisfied - assumption of competition in linear pricing. Our results suggest that once sufficient (network) competition has been developed, regulation of both final prices and access charges can be withdrawn, that is the telecommunication industry is potentially competitive. This, however, is not necessarily true in the entry phase of competition when networks tend to differ in their cost structure and/or coverage. The access charge then has a level-

[15]See e.g. Armstrong (1997), Carter and Wright (1997), Carter and Wright (1999), Doganoglu and Tauman (1996).

playing field effect: it increases profits of one network, and lowers profits of the other. If networks have different marginal costs, this impact on profits may be huge. To the extent that the bargaining power is unequally distributed among networks, the negotiated access charge is likely to differ from the marginal cost of access. A regulatory body which intervenes in case operators do not reach an agreement may then be necessary to restore efficiency. Future research on two-way access should investigate more thoroughly how a high (or low) access charges may give an unfair competitive advantage to a particular network[16] and examine further the (determinants of the) bargaining process.[17] The regulatory framework, that is wether or not access charges must be reciprocal, if there is a mandated access charge in case of no agreement and so on, is likely to affect considerably the efficiency of the bargaining outcome.

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[16] For example, our companion paper Dessein (1999) shows how under certain conditions, the incumbent, by setting an appropriate access charge, can impede entry on a segment wich tends to have a net outflow of calls.

[17] See e.g. Carter and Wright (1997) which analyzes explicitly the bargaining over interconnection, but in case of linear pricing.

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# 9 Appendix

## 9.1 Implicit price discrimination.

### 9.1.1 Standard model

*Proof of lemma 2:*
As we make also use of lemma 2 in the proof of proposition *4,* we provide a proof for the more general case in which $\sigma_H$ may differ from $\sigma_H$, although we restrict ourselves to the case in which $a > c_o$, the case $a < c_o$ being similar. As symmetric equilibria in which networks serve only one segment can easily be ruled out for $k_L$ close to $k_H$, the first order conditions must be satisfied. For $\lambda_L = \lambda_H = 0$, it follows from the FOC that the symmetric equilibrium is uniquely defined and given by $\left\{\hat{q}_L, \hat{t}_L, \hat{q}_H, \hat{t}_H\right\}$. Consequently, if $\left\{\hat{q}_L, \hat{t}_L, \hat{q}_H, \hat{t}_H\right\}$ is not incentive compatible and if a symmetric equilibrium exists, at least one incentive constraint is strictly binding: $\lambda_H > 0$ and/or $\lambda_L > 0$. We characterize

the incentive compatible symmetric equilibrium contract, $\{t_L^*, q_L^*, t_H^*, q_H^*\}$. The first order condition with respect to $q_L$ and $q_H$ yield

$$\begin{aligned} \mu\alpha_L\left[k_L^{1/\eta} q_L^{*\,-1/\eta} - (c + \tfrac{a-c_o}{2})\right] - \lambda_H\left[k_H^{1/\eta} - k_L^{1/\eta}\right] q_L^{*\,-1/\eta} &= 0 \quad (26)\\ (1-\mu)\alpha_H\left[k_H^{1/\eta} q_H^{*\,-1/\eta} - (c + \tfrac{a-c_o}{2})\right] + \lambda_L\left[k_H^{1/\eta} - k_L^{1/\eta}\right] q_H^{*\,-1/\eta} &= 0 \quad (27) \end{aligned}$$

with $\lambda_H$ and/or $\lambda_L$ strictly positive. Incentive constraints can never be binding at the same time: setting both IC's at equality and subtracting yields $q_H^* = q_L^* = q^*$; however, from (26) and (27), one must have then that

$$\left[k_H^{1/\eta} - k_L^{1/\eta}\right](q^*)^{-1/\eta} + \left(\frac{\lambda_L}{(1-\mu)\alpha_H} + \frac{\lambda_H}{\mu\alpha_L}\right)\left[k_H^{1/\eta} - k_L^{1/\eta}\right](q^*)^{-1/\eta} = 0$$

which is impossible if both $\lambda_L$ and $\lambda_H$ are positive. Thus either $(\lambda_H > 0, \lambda_L = 0)$ or $(\lambda_H = 0, \lambda_L > 0)$. The proof can now be constructed by contradiction: $(\lambda_H = 0, \lambda_L > 0)$ holds if $(\lambda_H > 0, \lambda_L = 0)$ is impossible and the other way round. We distinguish two case:

*a) The incentive constraint of the light users is violated in the explicit price discrimination equilibrium.*

Suppose that $\{w_L^*, q_L^*, w_H^*, q_H^*\}$ is then such that the *IC* of the heavy users is binding, thus $\lambda_H > 0$ and $\lambda_L = 0$. We then have

$$w_H^* - w_L^* = \tfrac{\eta}{\eta-1}\left[k_H^{1/\eta} - k_L^{1/\eta}\right] q_L^{*\,1-1/\eta} \quad (28)$$

while from the FOC with respect to $w_L$ and $w_H$,

$$\left[\tfrac{\eta}{\eta-1} k_L^{1/\eta} q_L^{*\,1-1/\eta} - w_L^* - c q_L^* - f\right] + \frac{(a-c_o)}{\mu} S = \lambda_H/\mu\sigma_L + 1/2\sigma_L \quad (29)$$

$$\left[\tfrac{\eta}{\eta-1} k_H^{1/\eta} q_H^{*\,1-1/\eta} - w_H^* - c q_H^* - f\right] - \frac{(a-c_o)}{1-\mu} S = -\lambda_H/(1-\mu)\sigma_H + 1/2\sigma_H \quad (30)$$

where $S$ is the net inflow of calls in the light user's segment:

$$S = S(\lambda_L, \lambda_H) \equiv \left(\ell\left[\mu q_L^* + (1-\mu) q_H^*\right] - \mu q_L^*\right)$$

Subtracting (29) and (30) and substituting (28), we find

$$\tfrac{\eta}{n-1} k_H^{1/\eta}\left[q_H^{*\,1-1/\eta} - q_L^{*\,1-1/\eta}\right] - c(q_H^* - q_L^*) \quad (31)$$

$$= \frac{\sigma_L - \sigma_H}{2\sigma_H\sigma_L} + (a-c_o)\frac{S(\lambda_L, \lambda_H)}{\mu(1-\mu)} - \lambda_H/(1-\mu)\sigma_H - \lambda_H/\mu\sigma_L$$

For $\delta = k_H - k_L$ small, $S(\lambda_L, \lambda_H)$ can be approximated by a Taylor expansion. As for $\lambda_H > 0$ and $\lambda_L = 0$,

$$q_H^* = \hat{q}_H \quad \text{and} \quad q_L^* = \hat{q}_L\left(1 - \frac{2\lambda_H}{\mu}\frac{\left[k_H^{1/\eta} - k_L^{1/\eta}\right]}{k_L^{1/\eta}}\right)^{\eta},$$

we find after some computations that

$$S(\lambda_L,\lambda_H) \cong \delta\left(\frac{\partial S(\lambda_L,\lambda_H)}{\partial \delta}_{|\delta=0,\lambda_H=\lambda_H^*}\right) = 2\delta\lambda_H(1-\mu)(c+\tfrac{a-c_o}{2})^{-\eta}$$

It follows that for $\delta$ or $a-c_o$ small, $\lambda_H/(1-\mu)\sigma_H+\lambda_H/\mu\sigma_L-(a-c_o)\frac{S(\lambda_L,\lambda_H)}{\mu(1-\mu)}>0$, so that

$$\tfrac{\eta}{n-1}k_H^{1/\eta}\left[q_H^{*\,1-1/\eta}-q_L^{*\,1-1/\eta}\right]-c(q_H^*-q_L^*)<\frac{\sigma_L-\sigma_H}{2\sigma_H\sigma_L} \tag{32}$$

On the other hand, the explicit price discrimination outcome $\{\hat{q}_L,\hat{w}_L,\hat{q}_H,\hat{w}_H\}$ satisfies[18]

$$\left[\tfrac{\eta}{\eta-1}k_L^{1/\eta}\hat{q}_L^{1-1/\eta}-\hat{w}_L-c\hat{q}_L-f\right]=1/2\sigma_L \tag{33}$$

$$\left[\tfrac{\eta}{\eta-1}k_H^{1/\eta}\hat{q}_H^{1-1/\eta}-\hat{w}_H-c\hat{q}_H-f\right]=1/2\sigma_H, \tag{34}$$

and

$$\hat{w}_H-\hat{w}_L>\tfrac{\eta}{\eta-1}\left[k_H^{1/\eta}-k_L^{1/\eta}\right]q_L^{1-1/\eta} \tag{35}$$

Subtracting (33) and (34) and taking (35) and $q_H^*=\hat{q}_H$ into account, we find

$$\tfrac{\eta}{n-1}k_H^{1/\eta}\left[q_H^{*\,1-1/\eta}-\hat{q}_L^{1-1/\eta}\right]-c(q_H^*-\hat{q}_L)>\frac{\sigma_L-\sigma_H}{2\sigma_H\sigma_L} \tag{36}$$

But

$$\frac{\partial\left(\tfrac{\eta}{\eta-1}k_H^{1/\eta}q^{1-1/\eta}-cq_L\right)}{\partial q}=k_H^{1/\eta}q^{-1/\eta}-c>0 \Leftrightarrow q<k_Hq(c)$$

As for $\lambda_H>0$, $q_L^*<\hat{q}_L=k_Lq(c+\frac{a-c_o}{2})<k_Hq(c)$, from (36), also

$$\tfrac{\eta}{n-1}k_H^{1/\eta}\left[q_H^{*\,1-1/\eta}-q_L^{*\,1-1/\eta}\right]-c(q_H^*-q_L^*)>\frac{\sigma_L-\sigma_H}{2\sigma_H\sigma_L} \tag{37}$$

which is in contradiction with (31): $\lambda_H>0$ and $\lambda_L=0$ is impossible.

*b) The incentive constraint of the heavy users is violated in the explicit price discrimination equilibrium.*

Suppose that $\{w_L^*,q_L^*,w_H^*,q_H^*\}$ is then such that the $IC$ of the light users is binding, thus $\lambda_L>0$ and $\lambda_H=0$. We then have

$$w_H^*-w_L^*=\tfrac{\eta}{\eta-1}\left[k_H^{1/\eta}-k_L^{1/\eta}\right]q_H^{*\,1-1/\eta}$$

$$\left[\tfrac{\eta}{\eta-1}k_L^{1/\eta}q_L^{*\,1-1/\eta}-w_L^*-cq_L^*-f\right]+\frac{(a-c_o)}{\mu}S=-\lambda_L/\mu\sigma_L+1/2\sigma_L$$

$$\left[\tfrac{\eta}{\eta-1}k_H^{1/\eta}q_H^{*\,1-1/\eta}-w_H^*-cq_H^*-f\right]-\frac{(a-c_o)}{1-\mu}S=\lambda_L/(1-\mu)\sigma_H+1/2\sigma_H,$$

[18]From our balanced calling pattern assumption, $A_L(\hat{q}_L,\hat{q}_H)=A_L(\hat{q}_L,\hat{q}_H)=0$.

from which

$$\tfrac{\eta}{\eta-1}k_L^{1/\eta}\left[q_H^{*\,1-1/\eta}-q_L^{*\,1-1/\eta}\right]-c(q_H^*-q_L^*)$$
$$=\frac{\sigma_L-\sigma_H}{2\sigma_H\sigma_L}+\frac{(a-c_o)}{\mu(1-\mu)}S+\lambda_L/(1-\mu)\sigma_H+\lambda_L/\mu\sigma_L$$

On the other hand, the explicit price discrimination outcome $\{\hat{q}_L,\hat{w}_L,\hat{q}_H,\hat{w}_H\}$ satisfies now

$$\tfrac{\eta}{\eta-1}k_L^{1/\eta}\left[\hat{q}_H^{1-1/\eta}-\hat{q}_L^{1-1/\eta}\right]-c(\hat{q}_H-\hat{q}_L)<\frac{\sigma_L-\sigma_H}{2\sigma_H\sigma_L}$$

Subtracting the previous equations, we find:

$$\tfrac{\eta}{\eta-1}k_L^{1/\eta}\left[q_H^{*\,1-1/\eta}-\hat{q}_H^{1-1/\eta}\right]-c(q_H^*-\hat{q}_H)>\tfrac{\lambda_L}{(1-\mu)\sigma_H}+\tfrac{\lambda_L}{\mu\sigma_L}+\tfrac{(a-c_o)}{\mu(1-\mu)}S \tag{38}$$

For $\delta=k_H-k_L$ small, the LHS of (38) can be approximated by a Taylor expansion. As for $\lambda_L>0$ and $\lambda_H=0$,

$$q_L^*=\hat{q}_L \quad \text{and} \quad q_H^*=\hat{q}_H\left(1+\frac{2\lambda_L}{(1-\mu)}\frac{\left[k_H^{1/\eta}-k_L^{1/\eta}\right]}{k_H^{1/\eta}}\right)^{\eta},$$

we find

$$\tfrac{\eta}{\eta-1}k_L^{1/\eta}\left[q_H^{*\,1-1/\eta}-\hat{q}_H^{1-1/\eta}\right]-c(q_H^*-\hat{q}_H)\cong\delta\frac{\lambda_L}{(1-\mu)}(c+\tfrac{a-c_o}{2})^{-\eta}(a-c_o)$$

On the other hand, as $q_L^*=\hat{q}_L$ while $q_H^*>\hat{q}_H$, we have $S>0$, such that

$$\lambda_L/(1-\mu)\sigma_H+\lambda_L/\mu\sigma_L+\tfrac{(a-c_o)}{\mu(1-\mu)}S>\lambda_L/(1-\mu)\sigma_H+\lambda_L/\mu\sigma_L$$

It follows that for $\delta$ small, (38) is violated: $\lambda_L>0$ and $\lambda_H=0$ is impossible. ■

*Proof of proposition 2.*

*1) Equilibrium profits are independent of the access charge:*

We first show that if a symmetric equilibrium exists, profits per firm are independent of $a$ and equal $1/4\sigma$. We maximize the network's profits, given by (2), subject to the incentive constraints, which can be rewritten as

$$w_H-w_L \geq \tfrac{\eta}{\eta-1}\left[k_H^{1/\eta}-k_L^{1/\eta}\right]q_L^{1-1/\eta} \tag{39}$$
$$w_H-w_L \leq \tfrac{\eta}{\eta-1}\left[k_H^{1/\eta}-k_L^{1/\eta}\right]q_H^{1-1/\eta} \tag{40}$$

With $\lambda_H$ and $\lambda_L$ the lagrange multipliers of the incentive constraint for respectively the heavy users and the light users, the FOC with respect to $w_L$ and $w_H$ yield

$$\lambda_H-\lambda_L+\mu/2 = \mu\sigma\left[\tfrac{\eta}{\eta-1}k_L^{1/\eta}q_L^{1-1/\eta}-w_L-cq_L-f\right]- \sigma\left(\mu q_L-\ell\left[\mu q_L+(1-\mu)q_H\right]\right)(a-c_o) \tag{41}$$

$$-\lambda_H + \lambda_L + (1-\mu)/2 = (1-\mu)\sigma\left[\tfrac{\eta}{\eta-1}k_H^{1/\eta}q_H^{1-1/\eta} - w_H - cq_H - f\right] \quad (42)$$
$$+\sigma\left(\mu q_L - \ell\left[\mu q_L + (1-\mu)q_H\right]\right)(a-c_o)$$

Summing up and substituting $w_L$ and $w_H$, we find

$$\mu\left[t_L - cq_L - f\right] + (1-\mu)\left[t_H - cq_H - f\right] = 1/2\sigma$$

But in a symmetric equilibrium, each operator gets exactly

$$1/2\left[\mu\left(t_L - cq_L - f\right) + (1-\mu)\left(t_H - cq_H - f\right)\right]$$

Hence, equilibrium profits per firm are $1/4\sigma$.

*2) Equilibrium contract:*

For $a = c_o$, network $i'$ s profits on the customer segment $s$ are strictly concave in $\{q_s, w_s\}$.[19] As a result, total profits given $k_L, k_H$ are strictly concave in $\{q_L, w_L, q_H, w_H\}$ for $a = c_o$ and the Hessian matrix $D^2\pi(q_L, w_L, q_H, w_H)$ is negative semidefinite for $a = c_o$. Fix the average customer type $k$. As all terms of $D^2\pi(q_L, w_L, q_H, w_H)$ are continuous in $k_L, k_H$ and $a$, then for any $\delta' = k_H - k_L$, one can find an access charge $a' > c_o$ such that $D^2\pi(q_L, w_L, q_H, w_H)$ is still negative semidefinite and thus profits are strictly concave, for $c_o \leq a \leq a'$ or $0 \leq \delta \leq \delta'$. A candidate equilibrium satisfying the FOC is then effectively an equilibrium. From these FOC, if networks can discriminate explicitly, a unique symmetric equilibrium exists and is given by $\{\hat{q}_L, \hat{u}_L, \hat{q}_H, \hat{u}_H\}$ (cf. section 4). As shown in the text, given $k_H - k_L \in \left]0, \delta'\right]$, for $a$ close enough to $c_o$, $IC$'s are satisfied by $\{\hat{q}_L, \hat{u}_L, \hat{q}_H, \hat{u}_H\}$, which is thus also the equilibrium under implicit price discrimination. On the other hand, given $a \in \left]c_o, a'\right]$, for $k_L$ close to $k_H$, the $IC$ of the light users is violated by $\{\hat{q}_L, \hat{u}_L, \hat{q}_H, \hat{u}_H\}$. From lemma 2, then $\lambda_L > 0$ and $\lambda_H = 0$ and symmetric equilibrium quantities are characterized by

$$q_L^* = \hat{q}_L = k_L q(c + \tfrac{a-c_o}{2}) \quad \text{and} \quad q_H^* = \hat{q}_H\left(1 + \frac{2\lambda_L}{(1-\mu)}\frac{\left[k_H^{1/\eta} - k_L^{1/\eta}\right]}{k_H^{1/\eta}}\right)^{\eta} > \hat{q}_H$$

Similarly from (41) and (42), profits per heavy user, $\pi_H^*$, and light user, $\pi_L^*$, are

$$\pi_H^* = \frac{1}{2\sigma} + \frac{\lambda_L}{\sigma(1-\mu)} \quad \text{and} \quad \pi_L^* = \frac{1}{2\sigma} - \frac{\lambda_L}{\sigma(\mu)}$$

and thus

$$t_L^* = \hat{t}_L - \frac{\lambda_L}{\sigma\mu} < \hat{t}_L \quad \textit{and} \quad t_H^* - cq_H^* = \hat{t}_H - c\hat{q}_H + \frac{\lambda_L}{\sigma(1-\mu)} > \hat{t}_H - c\hat{q}_H.$$

■

[19] See Laffont-Rey-Tirole 1998a, appendix B.

### 9.1.2 Two-part tariffs

*Proof of proposition 3:*
*Equilibrium profits:* Competition can be seen as one in which networks compete in net surpluses $(w_L, w_H)$ and usage fees rather than fixed fees and usage fees, in which case profits are given by (2) with $q_H = k_H q(p_H)$ and $q_L = k_L q(p_L)$. Incentive constraints can be rewritten as

$$w_H - w_L \geq (k_H - k_L)v(p_L) \tag{43}$$
$$w_H - w_L \leq (k_H - k_L)v(p_H) \tag{44}$$

The proof that in any symmetric equilibrium, profits are independent of the access charge and equal $1/4\sigma$, is now identical to the one in the standard model.
*Equilibrium contract:* Profits are strictly concave for $a = c_o$ and thus also for $a$ close to $c_o$. As argued in the text, for $a > c_o$, the equilibrium contract under explicit price discrimination is not implementable in two-part tariffs as then the IC's of the light users would be violated. As the proof of lemma 2 can be applied for competition in two-part tariffs, this $IC$ is then binding in equilibrium. From the FOC with respect to $p_L$ and $p_H$:

$$p_L^* = c + \tfrac{a-c_o}{2} \quad \text{and} \quad p_H^* = \frac{c + \frac{a-c_o}{2}}{1 + \frac{2\lambda_L}{(1-\mu)} \frac{\left[k_H^{1/\eta} - k_L^{1/\eta}\right]}{k_H^{1/\eta}}} < p_L^*$$

From the FOC with respect to $w_L$ and $w_H$, profits per heavy user, $\pi_H^*$, and light user, $\pi_L^*$, are

$$\pi_H^* = \frac{1}{2\sigma} + \frac{\lambda_L}{\sigma(1-\mu)} \quad \text{and} \quad \pi_L^* = \frac{1}{2\sigma} - \frac{\lambda_L}{\sigma\mu}$$

and thus

$$F_L^* = 1/2\sigma + f - \frac{a - c_o}{2} k_L q(p_L) - \frac{\lambda_L}{\sigma\mu}$$
$$F_H^* = 1/2\sigma + f - (p_H - c) k_H q(p_H) + \frac{\lambda_L}{\sigma(1-\mu)}$$

Of course, as $p_L^* > p_H^*$, one must also have $F_H^* > F_L^*$. ∎

### 9.1.3 Limits to the neutrality of the access charge on profits

*Proof of proposition 4.*
**Proof.** From the FOC with respect to $(w_L, q_L)$ and $(w_H, q_H)$, the equilibrium under explicit price discrimination is characterized by (6) and (7) and (8) and profits under explicit price discrimination are $\pi_D^* = \mu/4\sigma_L + (1-\mu)(4\sigma_H)$. From the first order condition with respect to $w_L$ and $w_H$, profits under implicit price

discrimination are given by $\pi^* = \pi_D^* + (\lambda_H - \lambda_L)(1/2\sigma_L - 1/2\sigma_H)$ with $\lambda_H$ and $\lambda_L$ the lagrange multipliers of the $IC$ of respectively heavy users and light users. This proves (11) and (10). From (6) and (7) and (8), the explicit price discrimination equilibrium satisfies the $IC$ of light users and heavy if and only if respectively (12) and (13) are satisfied.

We are now ready to prove the first part of the proposition. As for $a = c_o$, $V_H(\hat{q}_L) - V_H(\hat{q}_H)$ is negative and $V_L(\hat{q}_L) - V_L(\hat{q}_H)$ is positive, for $|\sigma_H - \sigma_L|$ sufficiently small $|F_H - F_L|$ tends to zero and both $IC's$ are satisfied and $\pi^* = \pi_D^*$. On the other hand, both $V_L(\hat{q}_L) - V_L(\hat{q}_H)$ and $V_H(\hat{q}_L) - V_H(\hat{q}_H)$ go to zero as $\Delta k$ goes to zero, such that given $|\sigma_H - \sigma_L|$, the $IC$ of customers with the smallest perceived substitutability are violated for $\Delta k$ sufficiently small. From lemma 2, the same $IC$ then is binding in the equilibrium under implicit discrimination and from (11) and (10), $\pi^* < \pi_D^*$.

The proof of the second part goes as follows. (1) When $c + \frac{a-c_o}{2}$ goes to zero, $\hat{q}_H - \hat{q}_L$ tends to infinity such that $V_s(\hat{q}_L) - V_s(\hat{q}_H)$, $(s = L, H)$ increases without a bound when $a$ gets smaller. For $a$ small enough $IC_L$ is then always satisfied, while $IC_H$ will be violated. From lemma 2, for $\Delta k$ small, the $IC$ of the heavy users is then binding under implicit discrimination such that from (11) and (10), $\pi^* > \pi_D^*$ if $\sigma_H > \sigma_L$ and $\pi^* < \pi_D^*$ if $\sigma_L < \sigma_H$. (2) A negative access markup $(a < c_o)$ always decreases $V_H(\hat{q}_L) - V_H(\hat{q}_H)$ and $V_L(\hat{q}_L) - V_L(\hat{q}_H)$, which reach a minimum respectively for $a_H^* > c_o$ and $a_L^* > c_o$ where

$$\begin{aligned} 1 + (a_H^* - c_o)/2c &= \Delta k / \left(k_H - k_H^{1/\eta} k_L^{1-1/\eta}\right) \\ 1 + (a_H^* - c_o)/2c &= \Delta k / \left(k_H^{1-1/\eta} k_L^{1/\eta} - k_L\right). \end{aligned}$$

Denote this minimum respectively by $-\bar{V}_H$ and $-\bar{V}_L$. As for $a \geq c_o$, $V_H(\hat{q}_L) - V_H(\hat{q}_H)$ is always negative and for $\hat{q}_H \leq k_L q(c)$, $V_L(\hat{q}_L) - V_L(\hat{q}_H)$ is always negative, both $-\bar{V}_H$ and $-\bar{V}_L$ are negative. For $|\sigma_H - \sigma_L|$ - and thus also $|F_H - F_L|$ - small enough, there exists then an $a' > c_o$, such that the $IC$ of the light users is violated by the explicit price discrimination equilibrium. If also $\Delta k$ is small, the $IC$ of the light users is then binding under implicit discrimination and $\pi^* > \pi_D^*$ if $\sigma_H < \sigma_L$, $\pi^* < \pi_D^*$ if $\sigma_L > \sigma_H$. ■

## 9.2 Entry and asymmetric equilibria

*Proof of proposition 6:* Network $i$ solves:

$$\max_{w_i, q_i} \{\pi_i = \alpha_i(w_i, w_j) [s(q_i) - w_i] + A_i\}$$

with

$$\begin{aligned} s(q_i) &= u(q_i) - cq_i - f_i \\ A_i &= \alpha_i(w_i, w_j)(1 - \alpha_i(w_i, w_j))(q_j - q_i)(a - c_o) \end{aligned}$$

*Equilibrium profits*: In any shared market equilibrium, the first order condition with respect to $w_i$ must be satisfied, this yields:

$$\mu\sigma\frac{\pi_i}{\alpha_i} - \alpha_i - \mu\sigma\alpha_i(q_j - q_i)(a - c_o) = 0 \tag{45}$$

and thus

$$\pi_i = \frac{\alpha_i^2}{\mu\sigma} + \alpha_i^2(q_j - q_i)(a - c_o) \equiv \alpha_i R_i + A_i \tag{46}$$

where

$$R_i = \frac{\alpha_i}{\mu\sigma} + (\alpha_i - \alpha_j)(q_j - q_i)(a - c_o)$$

*Industry profits:*

$$\pi_i + \pi_j = \alpha_i R_j + \alpha_i R_j = \frac{(\alpha_i)^2}{\mu\sigma} + \frac{(\alpha_j)^2}{\mu\sigma} + (\alpha_i - \alpha_j)(q_j - q_i)(a - c_o)$$

*Equilibrium quantities:* The first order condition with respect to $q_i$, yields

$$q_i^* = q(p_i^*) = q(c_i + \alpha_j(a - c_o)) \tag{47}$$

*Equilibrium market shares:* Suppose network 1 to be the incumbent in case of entry, $\alpha_1$ is then given by

$$\begin{aligned}
\alpha_1 &= 1 - \mu\frac{1}{2} + \mu\sigma(w_1 - w_2) \\
&= 1 - \mu\frac{1}{2} + \mu\sigma\left[s(q_1) - R_1 - s(q_2) + R_2\right] \\
&= 1 - \mu\frac{1}{2} + \mu\sigma\left[s(q_1) - \frac{\alpha_1}{\mu\sigma} - s(q_2) + \frac{(1 - \alpha_1)}{\mu\sigma}\right]
\end{aligned}$$

which yields

$$\alpha_1^* = \frac{1}{2} + \frac{1 - \mu}{3} + \frac{\mu\sigma}{3}\left[s_1 - s_2\right]$$

*Comparative statics:* The comparative static results are a direct consequence of the following observations:

(1) Impact of $a$ on market shares: We have

$$\frac{d\alpha_i^*}{da} = \frac{\mu\sigma}{3}\left[\frac{ds_i}{da} - \frac{ds_j}{da}\right]$$

As for $a = c_o$, $p_i^* = c_i$, and $\frac{ds_i(q(p_i))}{dp}\mid_{p_i = c_i} = 0$, it follows that $\frac{d\alpha_i^*}{da}\mid_{a = c_o} = 0$. A small access markup increases $s_i - s_j$ and thus $\alpha_i$ if

$$\frac{d^2 s_j(q(p_j))}{da^2}\mid_{a = c_o} < \frac{d^2 s_i(q(p_i))}{da^2}\mid_{a = c_o} \Leftrightarrow$$

$$\frac{\partial^2 s_j(q(p_j))}{\partial p^2}\left(\frac{dp_j}{da}\right)^2 \mid a=c_o < \frac{\partial^2 s_i(q(p_i))}{\partial p^2}\frac{dp_i}{da \mid a=c_o}$$

where $\frac{dp_i}{da \mid a=c_o} = \frac{\partial p_i}{\partial a \mid a=c_o} = \alpha_j$, and

$$\frac{\partial^2 s_i(q(p_i))}{\partial^2 p \quad \mid a=c_o} = \frac{\partial^2\left(\frac{p^{1-\eta}}{1-\frac{1}{\eta}} - c_i p^{-\eta}\right)}{\partial p^2 \quad \mid a=c_o} = -\frac{\eta}{c_i^{\eta+1}},$$

A small access markup thus increases $\alpha_i$ if $(\alpha_i/\alpha_j)^2 > (c_j/c_i)^{\eta+1}$.
Similarly, a small access markup decreases $\alpha_i$ if $(\alpha_i/\alpha_j)^2 < (c_j/c_i)^{\eta+1}$.

(2) Impact of $a$ on the access deficit: As $c_i < c_j$, $q_j^* > q_i^*$ for $a$ small (but positive) and a small access markup results in an access deficit for network $i$. ($A_i < 0$).

(3) Impact of $a$ on total industry profits: A sufficient condition for total industry profits to increase is that a small access markup decreases the smallest market share (as this increases ${\alpha_i}^2 + {\alpha_j}^2$), and results in an access deficit for the network with the smallest market share (as then $(\alpha_i - \alpha_j)(q_j - q_i)(a - c_o) > 0$). A sufficient condition for total industry profits to decrease is that a small access markup decreases the largest market share and results in an access deficit for the network with the largest market share. ■

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