# Using Future Access Charges to Soften Network Competition

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**Abstract**

This article analyses network competition in a two-period model in which consumers face costs of switching from a network to another. I show that (even symmetric) networks with consumers' full participation can use reciprocal access charges to soften competition in two-part tariffs. In particular, the total discounted profit increases when the second-period access charge departs (in any direction) from the marginal cost. This result holds both for naive and rational consumer expectations, and has clear policy implications.

**Keywords:** Interconnection, Network Competition, Switching Costs, Telecommunications, Access Charges

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# 1 Introduction

Nowadays, both fixed and mobile network operators still need access to rivals' networks in order to terminate calls to their subscribers. This need for interconnection is one of the most controversial issues of telecoms regulation. Network interconnection involves "two-way" access agreements whereby network operators provide termination services to each other since they operate at the same level of network hierarchy, i.e. they depend on each other to supply the retail service.

With this relationship in mind, the question posed by national competition authorities is: Can network operators undermine retail competition through access charges? The aim of this paper is to answer this question in a model of dynamic competition. The fact is that access charges have remained high in Europe, where the Caller Party Pays regime and termination-based price discrimination are used. These high termination rates are for mobile-to-mobile (MTM) and fixed-to-mobile (FTM) calls, and have become a serious concern in most European countries because of their impact on the off-net prices.

There is no clear consensus within the academic literature on this policy concern, however. As for termination-based price discrimination, Gans and King (2001), building on Laffont, Rey and Tirole (1998b), show that a (reciprocal) access charge below cost raises equilibrium profits. Intuitively, a below-cost access charge makes off-net calls cheaper than on-net calls, so consumers prefer to join the smallest network, all else being equal. Therefore, they are less attracted by lower fixed fees, and as a result network operators bid less aggressively for the marginal customers. This result is somewhat inconsistent with the fact that regulators are normally concerned that access charges are too high. In this sense, Armstrong and Wright (2007) point out the existence of a constraint of "wholesale arbitrage" that explains why mobile operator cannot maintain a high FTM access charge alongside a low MTM access charge. The reason is that the fixed network could then "transit" its calls via another mobile operator. The authors show that mobile operators prefer a uniform access charge for FTM and MTM traffic that lies between the efficient and the monopoly level.[1]

Access charges have decreased over the last years but mainly because of charge controls. Since mobile operators prefer high access charges, it seems that regulation on call termination will not disappear even in the long run.[2] What about banning termination-based price discrimination? Would it neutralize the ability of network operators to undermine retail competition through wholesale agreements?

Some answers to these questions can be found in the seminal papers of Armstrong (1998), Laffont, Rey and Tirole (1998a) and Carter and Wright (1999). Assuming symmetric networks, reciprocal access charges and linear retail prices these papers show that networks can collude in setting retail prices by using the negotiated access charge as a strategic variable.[3] More surprisingly, Laffont, Rey and Tirole (1998a) show that networks cannot use access charges to increase profits when they are allowed to compete in two-part tariffs. Intuitively, an increase in the access charge boosts the usage price and so makes it more profitable for networks to build market share. In the linear pricing case, networks cannot build market share without incurring an access deficit, however when competition is in two-part tariffs they can build market share by lowering their fixed fees while keeping usage prices constant. Dessein (2003) introduces heterogeneity in volume demand, so two-part tariffs can be used for second-degree price discrimination. He shows that in most cases the networks' profit do not depend on the (reciprocal) access charge they agree on, so there is no scope for collusion.[4]

This neutrality result has become the focus of much research;[5] it depends crucially on two assumptions: full participation and symmetry. More specifically, Poletti and Wright

[1] Cherdron (2006) and Gabriel and Vagstad (2007) analyze termination-based price discrimination when consumers' calling patterns are biased towards their peer groups (calling clubs). Both papers find that networks prefer above-cost MTM access charges.

[2] For instance, in UK (Spain) there are planned price caps from 2007 through to 2011 (2009), at which date they will be reviewed again.

[3] The intuition for this result is the following: if a network lowers its retail price, then its subscribers will make more calls, which, in turn, provokes an access deficit provided that the access charge is above the cost. Therefore, by agreeing to high access charges, networks reduce the incentive to undercut each other.

[4] Hahn (2004) models consumer type continuously but still obtains similar conclusions. De Bijl and Peitz (2000, chpt. 7) allow for third-degree price discrimination, and find that equilibrium profits are still independent of access charges when the market is mature.

[5] Excellent surveys can be found in Armstrong (2002) and Vogelsang (2003).

(2004) restore the collusive role of above-cost access charges by modifying Dessein's model and allowing customers' participation constraint to be binding in equilibrium. This paper imposes that network operators wish to service all types of customers (high and low demand customers); however, as the authors point out, if customers are sufficiently heterogenous, networks may find it profitable to exclude low demand customers from the market so as to extract more profit from the high demand users. Therefore, this model may fit better the fixed-line networks than the mobile networks, where one may expect that low demand customers make use of the linear price or prepaid contract instead of the non-linear price or postpaid contract. Carter and Wright (2003) allow asymmetric networks by providing for brand loyalty and show that the incumbent strictly prefers the access charge to be set at marginal cost of terminating a call. The reason is that the large network faces a higher proportion of on-net calls, whereas the small network faces a higher proportion of off-net calls; thus, above-cost access charges boost the average unit cost of the small network. Since networks charge calls at the average unit cost, it follows that the large network will face a net outflow of calls and hence a deficit in the wholesale market.[6]

One may thus conclude that charge controls are not needed when termination-based price discrimination is banned: first, symmetric networks do not gain from high reciprocal access charges, so network should not refuse to coordinate themselves on the socially optimal level, which is pricing access at marginal cost; second, if networks are asymmetric, then a simple policy seems to achieve the welfare maximizing outcome: leave the incumbent free to set the access charge since it always prefer the access charge to be set at marginal cost of terminating a call. Nevertheless, all these papers deal with static competition, while the dynamics of competition in the telecommunications are evident.

The main aim of this paper is to analyze the impact of the access charges on the networks' profit in a model of dynamic competition and check the robustness of the neutrality result

[6] Conversely, if the access charge is below marginal cost the large network will face a net inflow of calls as the small netwok will face a lower average unit cost for calls and hence set a lower call price. Quite obviously, a net inflow of calls alongside a below-cost access charge is not profitable.

in this more general setup. I extend the standard model of static competition in two-part tariffs to a two-period model. For this purpose, I introduce some assumptions regarding the equilibrium concept and the existence of switching costs.

*Subgame Perfect Equilibrium:* De Bijl and Peitz (2000, 2002, 2004) also analyze dynamic competition among network operators but assuming "myopic" networks or, in other words, solving for the per-period profit maximizing equilibria. Starting from an asymmetric situation, they find a similar result to that of Carter and Wright (2003) in the short term, and a result that is very close to profit neutrality in the long term. I will instead consider non-myopic networks and solve for the subgame perfect equilibrium. Another difference is that De Bijl and Peitz make a numerical analysis, while the insights of this paper are drawn from the properties of the model.[7] Another related paper is Valletti and Cambini (2005), here the authors extend the standard setting by introducing an investment stage, prior to competition in two-part tariffs, in which networks can invest to improve the quality of their network. They show that networks favour above-cost access charges since this reduces the incentive to invest and consequently raises networks' profit.[8]

*Switching costs:* The dynamic analysis would be useless if consumers did not face a cost when switching from one operator to other. There is however much evidence suggesting that switching costs are significant. In a standard two-period model, typically switching costs make demand more inelastic in the second period; since second-period profits depend on the customer base, switching costs may then lead to a more competitive behaviour in the initial period (Klemperer, 1987).

Dynamic network competition under consumer switching costs raises several economic issues for network operators and regulators: Are network operators able to undermine retail competition through access charges? Which are the dynamic networks' pricing strategies?

[7] It is worth to remark, however, that they make numerical analyses of a wide range of interesting scenarios as for instance the case of non-reciprocal access charges and the process of entry (De Bijl and Peitz, 2004.)

[8] Intuitively, if the quality of a network has the same impact on on- and off-net calls, then an increase in own quality relative to the rival creates an access deficit when the access charge is above cost.

How are they affected when the access charge departs away from marginal cost? What are the socially optimal access charges across periods? The main result of this paper is that retail competition is softened when future reciprocal access charges depart from marginal cost. More specifically, in equilibrium the total discounted profit is neutral with respect to the first-period access charge but increases when the second-period access charge departs (in any direction) from the marginal cost. This result holds both for naive and rational consumer expectations. Moreover, there is a robust economic argument supporting this non-profit-neutrality result: the model in the second period is similar to the standard static model, thus the profit of the large network decreases when the access charge departs away from the marginal cost; this in turn lowers the incentive to fight for market share in the first period. This result does not rely on asymmetric networks or partial consumer participation, instead it says that networks are able to collude over access charges, even if they are symmetric and there is full participation, as long as they are non-myopic and there is dynamic competition. Moreover, we find that cost-based access charges maximize the social welfare, one may thus conclude that there is scope for regulation in order to prevent potential anti-competitive behaviours.

The rest of the article proceeds as follows. Section 2 describes the model of dynamic network competition. Section 3 analyzes the second period. Section 4 characterizes the equilibrium with naive consumer expectations, obtains and discusses the non-profit-neutrality result, and derives the socially optimal access charges. Sections 5 and 6, look respectively at the cases of general preferences and rational consumer expectations. Finally, Section 7 summarizes the main insights and concludes. All the proofs are given in the appendix.

## 2 The model

Many of the standard assumptions prevail (Laffont, Rey and Tirole, 1998a). There are two operators indexed by $i$ and $j$, $i \neq j = 1, 2$. Each network operator has its own full coverage network and directly competes for consumers. Networks are interconnected, so a consumer who subscribes to one network can call any other consumer on either network. Networks are not allowed to price discriminate between calls that terminate on- and off-net. Thanks to the assumptions of interconnection and non-termination-based price discrimination, there are thus no network externalities.

For off-net calls, the originating network must pay an access charge $a$ to the terminating network. This access fee is reciprocal and is charged per unit of termination. Consumers derive utility from making calls but not from receiving them. Furthermore, consumers make calls according to a balanced calling pattern, in which the percentage of calls originating on a network and completed on the same network is equal to the market share of this network.

As to the cost structure, symmetric costs are assumed for simplicity. Network operators incur a marginal cost per call at the originating end and a marginal cost $c_T$ at the terminating end of the call. The total cost is denoted by $c$. There is a fixed cost of $f \geq 0$ in serving a customer, which reflects the cost of connecting the customer's home to the network and of billing and servicing that customer.

As to the demand structure, the telephone consumption $q(p)$ is $C^k$ (with $k \geq 2$), bounded and has bounded derivatives ($q' < 0$ and $q'' > 0$).[9] Furthermore, $q(p)$ is the same for all consumers; so, networks can do no better than offer a two-part tariff $T^i(q) = F^i + p^i q$, i.e. each network charges a fixed fee $F$ to each customer and a per-unit price for making calls $p$ (called the marginal price or usage fee).

The two networks are differentiated à la Hotelling. A unit mass of consumers is uniformly located on the segment $[0, 1]$, while the network operators are located at the two extremities of the segment. Consumers' tastes for networks are thus represented by their position on the line segment and taken into account through the transportation costs $\tau$. Let $v(p)$ denote the consumers' variable net surplus or indirect utility and $w = v(p) - F$ the net surplus. Then, given income $y$ and the customer demand $q$, a consumer located at $x$ and joining network $i$

[9] Throughout this paper the apostrophe symbol means the first derivative of the considered function. In this case for instance $q' = dq/dp$ and $q'' = d^2q/(dp)^2$.

has utility

$$y + v_0 - \tau |x - x_i| + w^i,$$

where $v_0$ represents a fixed surplus from being connected to either network (it is assumed sufficiently large so that all consumers choose to be connected to a network), and $\tau |x - x_i|$ is the cost of being connected to the network located at $x_i \neq x$.

I follow Klemperer (1987) in adding switching costs to the Hotelling model. In the second period a consumer has a switching cost $s > 0$ of switching network. If $s > \tau$, then at a symmetric equilibrium consumers always choose the same network; instead, I assume throughout that $s < \tau$, so that at least some consumers switch. In addition, I make the following two assumptions:

**A.1.** *Preferences are independent across periods.*

**A.2.** *Consumers have naive expectations.*

Assumption A1 reflects an extreme case in which each consumer's second-period preferences for the networks are independent of his first-period preferences, so consumers' preferences may change over time. A2 imposes a strong condition on the consumer behaviour, namely, consumers do not realize that network operators with higher market shares will charge higher prices in the future. These two assumptions are not essential for the results, but they do simplify the presentation. Sections 5 and 6 relax, respectively, assumptions A1 and A2 and show that they do not affect the main result of this paper.

The timing of the game is as follows. Reciprocal access charges are set by a regulator or negotiated between carriers at stage 0; a flexible regulation allows access charges to differ over time. In the first and second stages, which are indexed by $t \in \{1, 2\}$, network operators compete in retail prices taking as given the first- and second-period access charge. Networks have rational expectations and discount second-period revenues and costs by a factor $\delta$.

From now on and without any loss of generality assume that network 1 (respectively 2) is located at the beginning (respectively at the end) of the segment $[0, 1]$. In the first period consumers have no ties to any particular network, then a consumer located at $x = \alpha_1$ is indifferent between the two networks if and only if

$$w^1_{t=1} - \tau\alpha_1 = w^2_{t=1} - \tau(1-\alpha_1).$$

Therefore, $i's$ first-period market share is

$$\alpha^i_1 = \frac{1}{2} + \sigma\left(w^i_1 - w^j_1\right), \tag{1}$$

where $\sigma \equiv 1/2\tau$ is the index of substitutability between the two networks. At the beginning of the second period there is a fraction $\alpha^i_1$ of consumers initially attached to network $i$. Of these and given assumptions A1 and A2, a consumer located at $x \in [0,1]$ will remain associated with network $i$ if $w^i_2 - \tau x \geq w^j_2 - \tau(1-x) - s$. A consumer initially attached to network $j$ will instead switch to network $i$ if $w^i_2 - \tau x - s \geq w^j_2 - \tau(1-x)$. Therefore, the network $i's$ second-period market share is

$$\begin{aligned} \alpha^i_2 &= \alpha^i_1\left[\frac{1}{2} + \sigma\left(w^i_2 - w^j_2 + s\right)\right] + \alpha^j_1\left[\frac{1}{2} + \sigma\left(w^i_2 - w^j_2 - s\right)\right] \\ &= \frac{1}{2} + (2\alpha^i_1 - 1)\sigma s + \sigma\left(w^i_2 - w^j_2\right). \end{aligned} \tag{2}$$

In period $t$, network $i's$ profit is given by

$$\pi^i_t = \alpha^i_t(p^i_t - c)q(p^i_t) + \alpha^i_t(F^i_t - f) + \alpha^i_t\alpha^j_t m_t(q(p^j_t) - q(p^i_t)), \tag{3}$$

where $m_t \equiv a_t - c_T$ denotes the access mark-up. The first term represents the retail profit originated by the customer usage. The second and third terms represent respectively the profit from line rentals and the net interconnection revenue. Network $i$ originates $\alpha^i_t q(p^i_t)$ calls and from each one of them it gains the margin $p^i_t - c$. In addition, network $i$ incurs a fixed cost $f$ for every customer subscribed to its network $(\alpha^i_t f)$, although it receives from each of them its fixed fee ($\alpha_t^i F_t^i$). Given the balanced calling pattern, a fraction $\alpha_t^j$ of the $\alpha_t^i q(p_t^i)$ calls goes to network $j$, in which case network $i$ pays the reciprocal access charge $a_t$ but saves the marginal cost of terminating the call $c_T$. Moreover, a fraction $\alpha_t^i$ of the calls originated in network $j$, $\alpha_t^j q(p_t^j)$, goes to network $i$, so it obtains from each one of them the reciprocal access charge $a_t$ but incurs the marginal cost $c_T$ of terminating the call.

# 3 The second period

In the first period networks choose prices, which results in profits $\pi_1^i$ and $\pi_1^j$, and market shares $\alpha_1^i$ and $\alpha_1^j$ (with $\alpha_1^i+\alpha_1^j = 1$). Because switching costs exist, these market shares affect the networks' choice of second-period prices and their corresponding second-period profit. In this section we thus analyze the second-period game, taking as given the first-period market shares.

As the seminal work of Laffont, Rey and Tirole (1998a) points out, it is analytically convenient to view network competition as one in which the networks pick usage fees and net surpluses rather than usage fees and fixed fees, since market shares are determined directly by net surpluses. Therefore, networks maximize their profits (3) with respect to $p_2^i$ and $w_2^i$, while taking $p_2^j, w_2^j$ and $\alpha_1^i$ as given:

$$\begin{array}{l} \max\limits_{(p_2^i, w_2^i)} \alpha_2^i(w_2^i, w_2^j)\left[(p_2^i - c)q(p_2^i) + v(p_2^i) - w_2^i - f\right] \\ +\alpha_2^i(w_2^i, w_2^j)(1 - \alpha_2^i(w_2^i, w_2^j))m_2[q(p_2^j) - q(p_2^i)] \end{array}, \tag{4}$$

where $\alpha_2^i$ is given by (2). In equilibrium we have

$$p_2^i = c + \alpha_2^j m_2, \tag{5}$$

$$w_2^i = v(p_2^i) - f - \frac{\alpha_2^i}{\sigma} + (p_2^i - c)q(p_2^i) + (\alpha_2^i - \alpha_2^j)m_2(q(p_2^i) - q(p_2^j)). \tag{6}$$

The equilibrium market shares satisfy (2), (5) and (6), that is,

$$\alpha_2^i = \frac{1}{2} + \left(2\alpha_1^i - 1\right)\frac{\sigma s}{3} + \frac{\sigma}{3}\left[v(p_2^i) - v(p_2^j) + m_2(\alpha_2^j q(p_2^i) - \alpha_2^i q(p_2^j))\right], \tag{7}$$

with $\alpha_2^j = 1 - \alpha_2^i$. Finally, substituting (5) and (6) into (4), we have at equilibrium

$$\widehat{\pi}_2^i = \frac{\left(\alpha_2^i\right)^2}{\sigma} - \left(\alpha_2^i\right)^2 m_2(q(p_2^i) - q(p_2^j)). \tag{8}$$

Together (5), (6), (7) and (8) characterize the equilibrium second-period prices, market shares and profits as functions of the second-period access mark-up $m_2$, the first-period market shares $\alpha_1^i$ and the switching costs $s$.

The model in the second period is similar to the traditional static model in which the symmetric equilibrium profits are independent of the level of the access charge; indeed, in any symmetric equilibrium $\pi_2^i = 1/4\sigma$ whatever the access mark-up $m_2$. The reason for this result is that a second-period access charge above marginal cost boosts usage fees, so it has a positive effect on the revenue per customer; however, as a consequence of this effect, each network operator competes more aggressively for market share by lowering their fixed fee. When there is full participation these two effects cancel each other, and hence in any symmetric equilibrium second-period profits are not affected by the level of $m_2$.

Second-period profits might depend on $m_1$ through $\alpha_1^i$, but in any symmetric equilibrium $\alpha_1^i = 1/2$ whatever the first-period access mark-up, so equilibrium second-period profits are not affected by its level. Next sections show that in the neighborhood of $m_2 = 0$, the first-period market share is a source of benefit; although, the incentive to compete for it decreases when departing away from cost-based access charges, which is the main insight of this paper.

# 4 The first period

In the first period each network $i$ chooses $p_1^i$ and $F_1^i$ to maximize its total discounted profit, while taking $j's$ first-period usage fee and fixed fee as given. Network $i's$ total discounted profit is

$$\Pi^i(p_1^i, p_1^j, w_1^i, w_1^j) = \pi_1^i(p_1^i, p_1^j, w_1^i, w_1^j) + \delta\widehat{\pi}_2^i(m_2, \alpha_1^i(w_1^i, w_1^j)), \tag{9}$$

where $\pi_1^i$ is given by (3) and $\widehat{\pi}_2^i$, as a function of $m_2$ and $\alpha_1^i$, is determined by (5)-(8). The following proposition establishes formally the conditions for the existence of a unique equilibrium:

**Proposition 1** *(existence and uniqueness) If $\delta s^2/9\tau^2 < 1$, then for small enough access markups $m_1$ and $m_2$, the two-period duopoly model has at least one symmetric equilibrium. This equilibrium is moreover the unique equilibrium if $\delta s^2/9\tau^2 < 1/2$. In contrast, there is never a cornered-market equilibrium.*

Small enough access markups is a condition similar to the obtained in the static case (see Laffont, Rey and Tirole, 1998a.) The additional condition $\delta s^2/9\tau^2 < 1/2$ is not too restrictive since $\delta$ is usually assumed lower to one and $s < \tau$ by assumption. For the subsequent analysis we shall assume

**A.3.** *$m_1$ and $m_2$ are close enough to zero, so that a symmetric equilibrium exists, moreover $\delta s^2/9\tau^2 < 1/2$ holds.*

Under A3 the two-period duopoly model has a unique symmetric equilibrium, which is the focus of our analysis. Conditions (5)-(6)-(7) determine second-period market shares and prices as functions of the second-period access mark-up and the first-period market share: $\alpha_2^i(m_2, \alpha_1^i)$, $p_2^i(m_2, \alpha_1^i)$ and $w_2^i(m_2, \alpha_1^i)$. In equilibrium $\partial\Pi^i/\partial p_1^i = \partial\pi_1^i/\partial p_1^i = 0$. It follows that $p_1^i = c + \alpha_1^j m_1$ : networks choose their usage fees in the same way as they do in the second period. Furthermore, in equilibrium (using $\partial\alpha_1^i/\partial w_1^i = \sigma$)

$$0 = \partial\Pi^i/\partial w_1^i = \partial\pi_1^i/\partial w_1^i + \delta\sigma\partial\widehat{\pi}_2^i/\partial\alpha_1^i. \tag{10}$$

Therefore, networks may choose lower or higher first-period net surpluses than those that would maximize first-period profits depending on the sign of $\partial\widehat{\pi}_2^i/\partial\alpha_1^i$. From the previous section we have that profits depend positively on the first-period market share if $m_2 = 0$ : $(\partial\widehat{\pi}_2^i/\partial\alpha_1^i) > 0$. Thus, in this case first-period fixed fees are lower than those that would maximize first-period profits $(\partial\pi_1^i/\partial w_1^i < 0)$ : in order to build a customer base, networks compete more aggressively in the first period than they would do in the absence of switching costs. For $m_2 \neq 0$ the analysis becomes more complex since the level of the second-period access charge may or may not make it profitable to build a customer base in the first period. The first-period access charge may also affect the first-period market share and profits. In summary, since market shares affect the future, each network may compete more or less aggressively for market share than it otherwise would do in the absence of switching costs. Condition (10) can be rewritten as follows

$$0 = \frac{\partial\alpha_1^i}{\partial w_1^i}\overline{\pi}_1^i - \alpha_1^i + \sigma(\alpha_1^j - \alpha_1^i)m_1(q(p_1^j) - q(p_1^i)) + \delta\frac{\partial\widehat{\pi}_2^i}{\partial\alpha_1^i}(m_2, \alpha_1^i)\frac{\partial\alpha_1^i}{\partial w_1^i}. \tag{11}$$

where $\overline{\pi}_1^i = [(p_1^i - c)q(p_1^i) + v(p_1^i) - w_1^i - f]$ is the retail profit obtained by network $i$ from each subscriber. Since $\partial\alpha_1^i/\partial w_1^i = \sigma$, in any symmetric equilibrium:

$$\overline{\pi}_1^i = \frac{1}{2\sigma} - \delta\psi(m_2), \tag{12}$$

where

$$\psi(m_2) \equiv \frac{\partial\widehat{\pi}_2^i}{\partial\alpha_1^i}(m_2, 1/2).$$

Recall that $\widehat{\pi}_2^i(m_2, 1/2) = 1/4\sigma$, so in any symmetric equilibrium the network $i's$ total discounted profit is

$$\widehat{\Pi}(m_2) = \frac{1+\delta}{4\sigma} - \frac{\delta}{2}\psi(m_2). \tag{13}$$

Notice that this profit does not depend on $m_1$, but it can depend on $m_2$ through $\psi(m_2)$. The next proposition establishes formally this relationship.

**Proposition 2** *Under A.1, A.2 and A.3, starting from $m_1 = m_2 = 0$, a small change in $m_1$ has no impact on profits, whereas any small increase or decrease in $m_2$ softens competition in the first period and increases total discounted profits.*

From the previous section we have that neither $m_1$ nor $m_2$ affect the symmetric equilibrium second-period profit. A similar argument to the one that explains the (static or second-period) profit neutrality result with respect to $m_2$, explains also why symmetric first-period profits are neutral with respect to $m_1$. As already noted, the equilibrium second-period profit is increasing in the level of the first-period market share when $m_2$ is close to zero (specifically, $\psi(0) = 2s/3 > 0$). Thus, in the neighborhood of $m_2 = 0$, networks compete more aggressively in the first period than they would do in a market without switching costs.[10] There is however a new insight: $\psi'(0) = 0$ and $\psi''(0) = (2s\sigma/9)q'(c) < 0$, i.e. the equilibrium total discounted profit is strictly convex in $m_2$ at $m_2 = 0$. Therefore, both a (small) increase or decrease in $m_2$ increases networks' equilibrium profits. Since $\psi''(0) < 0$, the benefit of having a higher market share in the second period decreases when the second-period access charge departs away from marginal cost, and so does the incentive to compete for market share in the first period. Note however that the impact of $m_2$ on the total discounted profit depends on the size of sigma.

Figure 1 depicts this situation, where $O = (1/2, z)$ and $z \geq 0$. The dashed lines represent the equilibrium second-period profit when $m_2 = 0$ and $m_2$ is different from (but close enough to) zero.[11] Starting from a symmetric equilibrium, if network $i$ slightly increases its first-period market share then $\widehat{\pi}_2^i$ will increase and network $i$ would move from $O$ to the point $a$. However, if $m_2 \neq 0$ the benefit of having a larger customer base will be lower, so network $i$ would move from the point $a$ to the point $b$. An explanation for this result can be found in the Proposition 1 of Carter and Wright (2003), which proves that the profit of the large network decreases when the access charge is higher or lower than the marginal cost. Therefore, as

[10] Because of the concavity of the $i\prime s$ profit function with respect to $w_t^i$.

[11] It is easy to check that $\partial\widehat{\pi}_2^i(0, \alpha_1^i)/\partial\alpha_1^i > 0$ and $\partial^2\widehat{\pi}_2^i(0, \alpha_1^i)/(\partial\alpha_1^i)^2 > 0$.

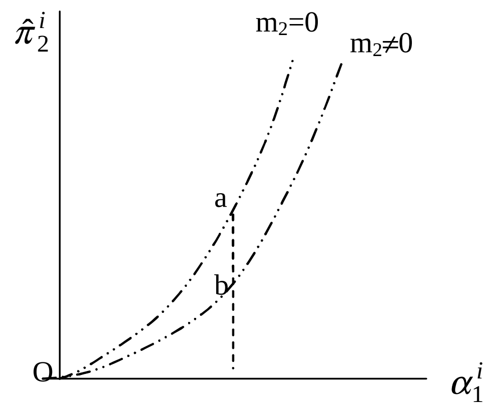


Figure 1: The role of the second-period access mark-up.

higher or lower the second-period access charge is with respect to the marginal cost, lower the second-period profit for the large network will be (though still higher than the profit of the small network), which in turn softens the first-period competition for market share.

It is worth to note that if access charges are cost-based, then symmetric equilibrium total discounted profits are higher in the absence than in the presence of switching costs, so networks are worse off with switching costs. Networks compete aggressively for market share in the first period, as it is valuable in the future, however they do not make any extra profits in the second period because in the symmetric equilibrium prices are the same as if there were no switching costs. This result coincides with the one obtained in Klemperer (1987) when all second-period consumers are either new or have independent preferences across periods. However, here the difference between both equilibrium profits (without and with switching costs) becomes closer as the second-period access mark-up departs away from zero.

From above we may conclude that $m_1 = m_2 = 0$ does not maximize networks' total discounted profits. On the contrary, the next proposition states that cost-based access charges locally maximize consumer surplus and social welfare, measured as the sum of producer and consumer surplus minus transportation and switching costs. Formally,

**Proposition 3** *Under A.1, A.2 and A.3, any small departure from cost-based access charges reduces the consumer surplus and the social welfare.*

This proposition has clear policy implications. Since networks prefer future access charges different from marginal costs, some kind of regulation may be needed to ensure that social welfare is maximized. The next two sections show, respectively, that this result still holds when there exist some consumers that have constant tastes across periods and when they are not myopic.

# 5 General preferences across periods

In the model I have used so far, each consumer's network preferences are independent over time. This section, following Klemperer (1987), considers the general case where a fraction $\nu < 1$ of second-period consumers are new in the market, and a fraction $\mu > 0$ and $1 - \mu - \nu$ of first-period consumers have, respectively, independent and unchanged preferences across periods.

Network $i's$ second-period market share is

$$\alpha_2^i = v\left[\frac{1}{2} + \sigma(w_2^i - w_2^j)\right] + \mu\left[\frac{1}{2} + (2\alpha_1^i - 1)\sigma s + \sigma(w_2^i - w_2^j)\right] + (1 - \mu - v)\alpha_1^i, \qquad (14)$$

provided that

$$s \geq \left|(w_2^i - \tau\alpha_1^i) - (w_2^j - \tau\alpha_1^j)\right|. \qquad (15)$$

This last condition implies that none of the consumers that have unchanged tastes switch of network in the second period.[12] If (15) holds, the first-order conditions, $\partial\pi_2^i/\partial p_2^i =$

[12] The tastes of the fraction $(1 - \mu - \nu)\alpha_1^1$ of network $1's$ consumers are uniformly distributed along the line segment $(0, \alpha_1^1)$; none of these consumers switch of network if $w_2^1 - \tau\alpha_1^1 \geq w_2^2 - \tau\alpha_1^2 - s$. Also, none of the consumers who joined network 2 in the first period and whose tastes are unchanged switch of network if $w_2^1 - \tau\alpha_1^1 \leq w_2^2 - \tau\alpha_1^2 - s$. Hence the network $i's$ second-period market share is given by (14) only if $\left|(w_2^i - \tau\alpha_1^i) - (w_2^j - \tau\alpha_1^j)\right| \leq s$.

$\partial \pi_2^i / \partial w_2^i = 0$, yield $p_2^i = c + \alpha_2^j m$ and

$$w_2^i = v(p_2^i) - f - \frac{\alpha_2^i}{(\mu + v)\sigma} + \alpha_2^j m_2 q(p_2^i) + (\alpha_2^i - \alpha_2^j) m_2 (q(p_2^i) - q(p_2^j)), \qquad (16)$$

where $\alpha_2^i$ is now given by (14). Notice that for a given network $j's$ strategy $(p_2^j, w_2^j \equiv v(p_2^j) - F_2^j)$, network $i's$ best response is

$$\begin{aligned} p_2^i &= \widetilde{p}_2^i(w_2^i, w_2^j) \equiv c + \left[ v\left(\frac{1}{2} + \sigma(w_2^j - w_2^i)\right) + \mu\left(\frac{1}{2} + (2\alpha_1^j - 1)\sigma s + \sigma(w_2^j - w_2^i)\right)\right. \\ &\quad \left. + (1 - \mu - v)\alpha_1^j \right] m_2. \end{aligned}$$

Thus, for given $(p_2^j, w_2^j)$, network $i's$ profit, as a function of $w_2^i$, is $\widetilde{\pi}_2^i(w_2^i) = \alpha_2^i(w_2^i, w_2^j)[v(\widetilde{p}_2^i(w_2^i, w_2^j)) - w_2^i - f + \alpha_2^j(w_2^i, w_2^j) m_2 q(p_2^j)]$. Moreover, for $m_2$ close enough to zero: $\widetilde{\pi}_2^{i\prime\prime} \simeq -2\sigma(\mu + v) < 0$.[13] However, for these first-order conditions to define an equilibrium we still have to show that no network operator has incentive to deviate from our candidate equilibrium by choosing a strategy in which (15) does not hold. In this sense, notice that for $\mu$ or $\nu$ large enough, any network $i's$ deviation so as to capture some of the rival network's consumers that have constant tastes cannot be a global best response provided that switching costs exist.[14]

Therefore, for $\mu + v$ large enough the equations $p_2^i = c + \alpha_2^j m$, (14) and (16) characterize the equilibrium. It follows that in equilibrium the network $i's$ second-period profit is

$$\widehat{\pi}_2^i = \frac{(\alpha_2^i)^2}{(\mu + v)\sigma} - (\alpha_2^i)^2 m_2 (q(p_2^i) - q(p_2^j)).$$

Let me now turn to the first period, in equilibrium, where $\partial \Pi^i / \partial p_1^i = \partial \Pi^i / \partial w_1^i = 0$, we have $p_1^i = c + \alpha_1^j m_1$ and $0 = \partial \pi_1^i / \partial w_1^i + \delta\sigma \partial \widehat{\pi}_2^i / \partial \alpha_1^i$. As in the case of independent preferences across periods, in which $\mu = 1$, this equilibrium exists for $m_1$ and $m_2$ close enough to zero

[13] $\widetilde{\pi}_2^{i\prime\prime} = -2\sigma(\mu + v) + 2\sigma^2(\mu + v)^2 m_2 (q(\widetilde{p}_2^i) - q(p_2^j)) - \sigma^2(\mu + \nu)^2 (m_2)^2 \alpha_2^j q'(\widetilde{p}_2^i)$, where $q$ and $q'$ are bounded functions.

[14] The reason is that any network $i$ has to decrease its fixed fee to capture at least one additional consumer from the fraction $(1 - \mu - \nu)\alpha_1^j$ since $s > 0$. So, necessarily, $w_2^i > \widehat{w}_2^i$, where $\widehat{w}_2^i$ denotes the equilibrium second-period net surplus. Moreover, for a large enough $\mu + v$ we can make $\alpha_2^i(w_2^i, \widehat{w}_2^j)$ close enough to $\alpha_2^i(\widehat{w}_2^i, \widehat{w}_2^j)$ (hence $p_2^i(w_2^i, \widehat{w}_2^j) \simeq p_2^i(\widehat{w}_2^i, \widehat{w}_2^j)$) so that $\pi_2^i(w_2^i, \widehat{w}_2^j) - \pi_2^i(\widehat{w}_2^i, \widehat{w}_2^j) \simeq -\alpha_2^i(w_2^i - \widehat{w}_2^i) < 0$.

provided that $(\delta/9)(s^2/\tau^2) < 1$.[15] Hence, in any symmetric equilibrium

$$\widehat{\Pi}^i(m_2) = \frac{1+\delta}{4\sigma} - \frac{\delta}{2}\psi(m_2),$$

where

$$\psi(m_2) \equiv \frac{\partial \widehat{\pi}_2^i(m_2, 1/2)}{\partial \alpha_1^i} = \left[\frac{1}{(\mu+v)\sigma} + \frac{(m_2)^2}{2} q'\left(c + \frac{m_2}{2}\right)\right]\varphi(m_2),$$

and, using (14),[16]

$$\varphi(m_2) \equiv \frac{\partial \alpha_2^i}{\partial \alpha_1^i}(m_2, 1/2) = \frac{2\sigma s\mu + (1-\mu-v)}{3 + \sigma(\mu+v)(m_2)^2 q'(c + m_2/2)}.$$

Thus, $\varphi'(0) = 0$ and $\varphi''(0) > 0$. It follows therefore that $\psi'(0) = 0$ and $\psi''(0) = [(2\sigma s\mu + (1-\mu-v))/9]q'(c) < 0$, and hence $\widehat{\Pi}^{i\prime}(0) = 0$ and $\widehat{\Pi}^{i\prime\prime}(0) > 0$. So, even though some consumers are new or have constant tastes across periods both a (small) increase or decrease in the second-period access charge still increases the equilibrium total discounted profit. The reason for this result is that as long as $v < 1$, networks find it optimal to compete for market share in the first period. Moreover, the fact that in the second period there are new consumers and consumers that have unchanged preferences does not change the result that the large network prefers cost-based access charges: an access charge above/below cost still boosts/decreases the average unit cost of the small network and so do its usage fee. Therefore, any (small) departure from cost-based access charges still softens first-period competition. Finally, notice that network operators are worse off in the presence of switching costs than in the absence of them when access charges are cost-based. However, again, the difference between equilibrium profits with and without switching costs becomes closer as $m_2$ departs away from zero.

[15] For given rival's prices, network $i's$ total discounted profit, as a function of $w_1^i$, is $\widetilde{\Pi}^i(w_1^i) = \alpha_1^i[v(\widetilde{p}_1^i(w_1^i, w_1^j)) - w_1^i - f + \alpha_1^j m_1 q(p_1^j)] + \delta\widehat{\pi}_2^i(m_2, \alpha_1^i)$. For $m_1$ and $m_2$ close enough to zero we may write $\widetilde{\Pi}^{i\prime\prime} \simeq -2\sigma + \delta(8s^2\sigma^3/9)(\mu^2/(\mu+v))$, so $\widetilde{\Pi}^{i\prime\prime} < 0$ if $(8/9)(s^2/\tau^2) < (\mu+v)/\mu^2$, but $(\mu+v)/\mu^2 > 1$ for any $\mu, v \in (0,1)$.

[16] From the first-order condition we have $\partial p_2^i/\partial \alpha_1^i = -m_2\left(\partial \alpha_2^i/\partial \alpha_1^i\right)$; thus, in any symmetric equilibrium $\partial w_2^i/\partial \alpha_1^i = -\varphi(m_2)/((\mu+v)\sigma) - ((m_2)^2/2)q'(c + m_2/2)\varphi(m_2)$, where $\varphi(m_2) \equiv (\partial \alpha_2^i/\partial \alpha_1^i)(m_2, 1/2)$.

# 6 Rational consumer expectations

So far I have assumed that consumers cannot anticipate the networks' second-period behaviour. In this section I analyze the case in which consumers have rational expectations; formally, I make the following assumption,

**A.2'.** *Consumers have rational expectations.*

Consumers with rational expectations recognize that if a network decreases its first-period fixed fee, it will build market share, which, given the existence of switching costs, it can exploit in the second period by increasing its second-period fixed fee. If a consumer located at $x$ subscribes to network $i$ in period one, he will remain attached to that network in the second period iff $w_2^i - x\tau \geq w_2^j - \tau(1-x) - s$. The second-period total net surplus of a consumer located at $x$ is then

$$Ew^i = \int_0^{\sigma(\tau+\widehat{w}_2^i-\widehat{w}_2^j+s)} \widehat{w}_2^i - \tau x dx + \int_{\sigma(\tau+\widehat{w}_2^i-\widehat{w}_2^j+s)}^1 \widehat{w}_2^j - \tau(1-x) - s dx,$$

where $\widehat{w}_2^i$ is the network $i's$ equilibrium second-period net surplus as a function of $m_2$ and $\alpha_1^i$. The marginal consumer is thus given by

$$\begin{aligned} 0 &= (w_1^i - \tau\overline{x}) - (w_1^j - \tau(1-\overline{x})) + \delta\left[Ew^i - Ew^j\right] \\ &= (w_1^i - w_1^j) + \tau - 2\tau\overline{x} + 2\sigma s\delta\left[\widehat{w}_2^i(m_2,\overline{x}) - \widehat{w}_2^j(m_2,\overline{x})\right]. \end{aligned}$$

So,

$$\alpha_1^i = \frac{1}{2} + \sigma(w_1^i - w_1^j) + 2s\sigma^2\delta\left[\widehat{w}_2^i(m_2,\alpha_1^i) - \widehat{w}_2^j(m_2,\alpha_1^i)\right]. \tag{17}$$

Let me define

$$h(m_2,\alpha_1^i) \equiv \left(\frac{\partial\alpha_1^i}{\partial w_1^i}\right)^{-1},$$

$h$ then measures the inverse of the sensitivity of the first-period market share to the first-period prices. From (17) we may obtain $h$ so that

$$h(m_2, \alpha_1^i) = \frac{1}{\sigma}\left[1 - 2s\sigma^2\delta\frac{\partial \triangle \widehat{w}}{\partial \alpha_1^i}(m_2, \alpha_1^i)\right], \tag{18}$$

where $\triangle\widehat{w}(m_2, \alpha_1^i) \equiv \widehat{w}_2^i(m_2, \alpha_1^i) - \widehat{w}_2^j(m_2, \alpha_1^i)$. When consumers have naive expectations, $h = 1/\sigma$. Here, instead $h$ depends on $m_2$ and $\alpha_1^i$ : consumers recognize that the intensity of competition in the second period depends on the second-period access charge and the first-period market shares. In the first period, network $i$ maximizes (9) with respect to $p_1^i$ and $w_1^i$, which in any symmetric equilibrium yields $p_1^i = c + m_1/2$ and $0 = (\partial\alpha_1^i/\partial w_1^i)\overline{\pi}_1^i - 1/2 + \delta(\partial\widehat{\pi}_2^i/\partial\alpha_1^i)(\partial\alpha_1^i/\partial w_1^i)$, where $\partial\alpha_1^i/\partial w_1^i$ can be obtained from (18). Using these first-order conditions we obtain in a symmetric equilibrium (the existence of which I show for $m_1$ and $m_2$ close enough to zero in the proof of next proposition):

$$F_1(m_1, m_2) = f + \frac{h(m_2, 1/2)}{2} - \frac{m_1}{2}q(c + m_1/2) - \delta\psi(m_2), \tag{19}$$

where recall that $\psi(m_2) \equiv (\partial\widehat{\pi}_2^i/\partial\alpha_1^i)(m_2, 1/2)$. Obviously, in the second period symmetric equilibrium profits are the same as with naive expectations, that is, $1/4\sigma$. Using (19), this gives

$$\widehat{\Pi}(m_2) = \frac{1}{2}\left[\frac{h(m_2, 1/2)}{2} - \delta\psi(m_2)\right] + \frac{\delta}{4\sigma}. \tag{20}$$

When consumers have rational expectations the symmetric equilibrium total discounted profit thus depends on $m_2$ through $h$ and $\psi$, whereas in the case of naive expectations it depends only on $m_2$ through $\psi$. The next proposition establishes formally the relationship between the total discounted profit and $m_2$ when consumers have rational expectations.

**Proposition 4** *Under A.1, A.2' and A.3, starting from $m_1 = m_2 = 0$, a small change in $m_1$ has no impact on profits, whereas any small increase or decrease in $m_2$ softens competition in the first period and increases total profits, although to a lower extent than when consumers have naive expectations.*

In the proof of this last proposition I show that $h(0,1/2) > 1/\sigma$; this result stems from the fact that when consumers have rational expectations they realize that networks with higher market shares will charge higher prices in the future, which in turn makes the demand less elastic. Furthermore, I obtain that $\partial h(0,1/2)/\partial m_2 = 0$ and $\partial^2 h(0,1/2)/(\partial m_2)^2 = (8/9)s^2\sigma^2\delta q'(c) < 0$, which make both the equilibrium total discounted profit and first-period fixed fee strictly convex in $m_2$ at $m_1 = m_2 = 0$ since $s < \tau$.

In addition, using $\psi(0) = 2s/3$ and $h(0,1/2) = 1/\sigma + 8s^2\sigma\delta/3$ we may write $\widehat{\Pi}(0) = (1+\delta)/4\sigma + (s\delta/3)(s/\tau - 1)$, then, as in the case of naive consumer expectations, networks are worse off with switching costs than without them, and the difference between both equilibrium profits becomes smaller as the second-period access charge departs away from the marginal cost level. It remains to note that in the neighborhood $m_1 = m_2 = 0$, the symmetric equilibrium total discounted profit is higher in the rational expectations case than in the naive expectations case; indeed, for $m_1 = m_2 = 0$ we have that $\Pi_{RE} - \Pi_{NE} = (2/3)s^2\sigma\delta$. Therefore, network operators prefer rational consumer expectations to naive consumer expectations, although Proposition 4 gives us the following result

$$\widehat{\Pi}''_{RE} = \left(1 - \frac{s}{\tau}\right)\widehat{\Pi}''_{NE},$$

which says that in equilibrium any departure from cost-based access charges has a lower impact on the total discounted profit when consumers have rational expectations than when they have naive expectations.

# 7 Conclusion

This paper has shown that when there is dynamic competition and network operators are non-myopic, then they can use access charges to lessen competition, even in symmetric markets in which participation is complete. In contrast to what previous research suggests, there is scope for regulation: while cost-based access charges maximize total welfare, networks' equilibrium profits increase when future access charges depart away from marginal costs.

Other insights are derived. Network operators are worse off in the presence than in the absence of switching costs, and even more so when consumers have naive expectations. However, I also show that any departure from cost-based access charges in future periods attenuates this impact of switching costs on competition.

# 8 APPENDIX

Some preliminary lemmas will be useful.

**Lemma 1.** *In equilibrium*

$$\varphi(m_2) \equiv \frac{\partial \alpha_2^i}{\partial \alpha_1^i}(m_2, 1/2) = \frac{2\sigma s}{3 + \sigma (m_2)^2 q'(c + m_2/2)}.$$

*In addition,* $\varphi'(0) = 0$ *and* $\varphi''(0) = -4s\sigma^2 q'(c)/9 > 0$.

**Proof.** In the second period, equilibrium prices and market shares, $w_2^i(m_2, \alpha_1^i)$, $p_2^i(m_2, \alpha_1^i)$ and $\alpha_2^i(m_2, \alpha_1^i)$, are determined by (2) and the first-order conditions (5)-(6), that is:

$$w_2^i = v(p_2^i) - f - \frac{\alpha_2^i}{\sigma} + (p_2^i - c)q(p_2^i) + (\alpha_2^i - \alpha_2^j)m_2(q(p_2^i) - q(p_2^j)), \tag{21}$$

$$p_2^i = c + \alpha_2^j m_2, \tag{22}$$

$$\alpha_2^i = \frac{1}{2} + (2\alpha_1^i - 1)\sigma s + \sigma(w_2^i - w_2^j). \tag{23}$$

Differentiating (21)-(23) with respect to $\alpha_1^i = 1 - \alpha_1^j$ yields in a symmetric equilibrium

$$\frac{\partial w_2^i}{\partial \alpha_1^i} = -\frac{\varphi(m_2)}{\sigma} + \frac{m_2}{2} q'\left(c + \frac{m_2}{2}\right) \frac{\partial p_2^i}{\partial \alpha_1^i},$$

$$\frac{\partial p_2^i}{\partial \alpha_1^i} = -m_2 \varphi(m_2),$$

$$\varphi(m_2) = 2\sigma s + \sigma\left(\frac{\partial w_2^i}{\partial \alpha_1^i} - \frac{\partial w_2^j}{\partial \alpha_1^i}\right),$$

where $\varphi(m_2) \equiv (\partial\alpha_2^i/\partial\alpha_1^i)(m_2, 1/2)$. Using $\partial w_2^j/\partial\alpha_1^i = -\partial w_2^j/\partial\alpha_1^j = -\partial w_2^i/\partial\alpha_1^i$ we thus have that

$$\varphi(m_2) = 2\sigma s + 2\sigma\left(-\frac{1}{\sigma} - \frac{(m_2)^2}{2}q'\left(c + \frac{m_2}{2}\right)\right)\varphi(m_2).$$

It follows that

$$\varphi(m_2) = \frac{2\sigma s}{3 + \sigma(m_2)^2 q'\left(c + m_2/2\right)}.$$

By differentiating this last expression with respect to $m_2$ we may write

$$\varphi'(m_2) = \frac{-2s\sigma\left[2\sigma m_2 q'(c + m_2/2) + \sigma(m_2)^2 q''(c + m_2/2)/2\right]}{\left[3 + \sigma(m_2)^2 q'(c + m_2/2)\right]^2}. \tag{24}$$

Then $\varphi'(0) = 0$ and

$$\varphi''(0) = -\frac{4s\sigma^2 q'(c)}{9} > 0.$$

■

**Lemma 2.** *Under A.1, A.2' and A.3,*

$$h(0, 1/2) = \frac{1}{\sigma} + \frac{8s^2\sigma\delta}{3}.$$

*In addition,* $\partial h(0,1/2)/\partial m_2 = 0$ *and* $\partial^2 h(0,1/2)/(\partial m_2)^2 = (8/9)s^2\sigma^2\delta q'(c) < 0$.

**Proof.** By definition $\triangle\widehat{w}(m_2, \alpha_1^i) = \widehat{w}_2^i(m_2, \alpha_1^i) - \widehat{w}_2^j(m_2, \alpha_1^i)$. Using (21) we may write

$$\begin{aligned}\Delta\widehat{w}(m_2, \alpha_1^i) &= v(p_2^i) - f - \frac{\alpha_2^i}{\sigma} + (p_2^i - c)q(p_2^i) + (\alpha_2^i - \alpha_2^j)m_2(q(p_2^i) - q(p_2^j)) \\ &\quad - \left(v(p_2^j) - f - \frac{\alpha_2^j}{\sigma} + (p_2^j - c)q(p_2^j) + (\alpha_2^j - \alpha_2^i)m_2(q(p_2^j) - q(p_2^i))\right),\end{aligned} \tag{25}$$

where $\alpha_2^i$, $p_2^i$ and $w_2^i$ are functions of $m_2$ and $\alpha_1^i$ and are determined by (21)-(23). By differentiating (25) with respect to $\alpha_1^i$ we may write

$$\frac{\partial \triangle \widehat{w}}{\partial \alpha_1^i}(m_2, 1/2) = -\left(\frac{2}{\sigma} + (m_2)^2 q'\left(c + \frac{m_2}{2}\right)\right)\varphi(m_2). \tag{26}$$

Then, from (18), (26) and Lemma 1 we have that

$$\begin{aligned}
h(m_2, 1/2) &= \frac{1}{\sigma} - 2s\sigma\delta\left(\frac{\partial \triangle \widehat{w}}{\partial \alpha_1^i}(m_2, 1/2)\right) \\
&= \frac{1}{\sigma} + \delta\left(\frac{(2s\sigma)^2}{3 + \sigma(m_2)^2 q'(c + m_2/2)}\right)\left(\frac{2}{\sigma} + (m_2)^2 q'(c + m_2/2)\right) \\
&= \frac{1}{\sigma} + 4s^2\sigma\delta\left(\frac{2 + \sigma(m_2)^2 q'(c + m_2/2)}{3 + \sigma(m_2)^2 q'(c + m_2/2)}\right).
\end{aligned}$$

Define $j(m_2) = u(m_2)/v(m_2)$, where $u(m_2) = 2 + \sigma(m_2)^2 q'(c + m_2/2)$ and $v(m_2) = 3 + \sigma(m_2)^2 q'(c + m_2/2)$. It follows that

$$u'(m_2) = v'(m_2) = 2\sigma(m_2)q'(c + m_2/2) + \sigma\frac{(m_2)^2}{2}q''(c + m_2/2),$$

and

$$u''(m_2) = v''(m_2) = 2\sigma q'(c + m_2/2) + 2\sigma(m_2)q''(c + m_2/2) + \sigma\frac{(m_2)^2}{4}q'''(c + m_2/2),$$

so that $u'(0) = v'(0) = 0$ and $u''(0) = v''(0) = 2\sigma q'(c)$. Hence, $\partial h(0, 1/2)/\partial m_2 = (4s^2\sigma\delta)j'(0) = (4s^2\sigma\delta)(u'(0)v(0) - u(0)v'(0))/v(0)^2 = 0$. In addition,

$$j''(m_2) = \frac{(u''v - uv'')v^2 - (u'v - uv')2vv'}{v^4}.$$

Thus, $j''(0) = 2\sigma q'(c)((v(0) - u(0))/v(0)^2) = 2\sigma q'(c)(1/9)$. Finally, $\partial^2 h(0, 1/2)/(\partial m_2)^2 = (4s^2\sigma\delta)j''(0) = (8/9)s^2\sigma^2\delta q'(c)$. ■

**Proof of Proposition 1.** Let me first show that no cornered-market equilibrium exists in this two-period model. Consider first the second period; if network $i$ corners the market, then $p_2^i = c$ and $\pi_2^i = F_2^i - f \geq 0$, whereas $\pi_2^j = 0$. However, network $j$ could charge $p_2^j = c$ and $F_2^j = F_2^i + \epsilon$, where $\epsilon > 0$. So, $w_2^j = v(c) - F_2^j = v(c) - F_2^i - \epsilon = w_2^i - \epsilon$; thus, $\alpha_2^j = (1/2) + (2\alpha_1^j - 1)\sigma s - \sigma\epsilon = (1/2)[1 - (s/\tau)] + 2\alpha_1^j \sigma s - \epsilon/2\tau$. Then, for $\epsilon$ small enough we have $\alpha_2^j > 0$ (even if $\alpha_1^j = 0$) since $1 - s/\tau > 0$. Hence, $\pi_2^j = \alpha_2^j[F_2^j - f] = \alpha_2^j[F_2^i + \epsilon - f] \geq \alpha_2^j \epsilon > 0$, a contradiction. Consider now the first period and again suppose that network $i$ corners the market. Then, $p_1^i = c$, and $\pi_1^i = F_1^i - f \geq 0$, whereas $\pi_1^j = 0$. Moreover, $\widehat{\Pi}^i = F_1^i - f + \delta\widehat{\pi}_2^i(m_2, 1)$ and $\widehat{\Pi}_{ND}^j = \delta\widehat{\pi}_2^j(m_2, 0)$ (where $ND$ means no deviation.) However, if network $j$ charged $p_1^j = c$ and $F_1^j = F_1^i + \varepsilon$, then for $\varepsilon > 0$ small enough the network $j's$ first-period profit would be $\pi_1^j \simeq (F_1^j - f)/2 \geq \varepsilon/2 > 0$, whereas its total discounted profit would be

$$\widehat{\Pi}_D^j \simeq \frac{F_1^j - f}{2} + \delta\widehat{\pi}_2^j(m_2, 1/2),$$

where $D$ means deviation. Therefore,

$$\widehat{\Pi}_D^j - \widehat{\Pi}_{ND}^j \simeq \frac{F_1^j - f}{2} + \delta\left[\widehat{\pi}_2^j(m_2, 1/2) - \widehat{\pi}_2^j(m_2, 0)\right].$$

From above we have that $(F_1^j - f)/2 \geq \varepsilon/2 > 0$ and, clearly, for $m_2$ small enough $\widehat{\pi}_2^j(m_2, 1/2) - \widehat{\pi}_2^j(m_2, 0) > 0$. Thus, $\widehat{\Pi}_D^j - \widehat{\Pi}_{ND}^j > 0$, a contradiction.

Let me now study the existence and uniqueness of the (shared-market) equilibrium. The second period is similar to the static case but taking into account the presence of a customer base. Nonetheless, we can still use the proof given in the Appendix B of Laffont, Rey and Tirole (1998a) to show the existence and uniqueness of the second-period equilibrium of our model for $m_2$ close enough to zero: given network $j\prime s$ strategy $(p_2^j, w_2^j)$, network $i's$ best response entails $p_2^i(w_2^i, w_2^j) = c + \alpha_2^j(w_2^i, w_2^j)m_2$; thus, for given $(p_2^j, w_2^j)$, network $i$ chooses $w_2^i$ to maximize its second-period profit

$$\overline{\overline{\pi}}_2^i(w_2^i) = \alpha_2^i(w_2^i, w_2^j)\left[v(c + \alpha_2^j(w_2^i, w_2^j)m_2) - w_2^i - f + \alpha_2^j(w_2^i, w_2^j)m_2 q(p_2^j)\right],$$

it follows that for $m_2$ close to zero $d^2\overset{=}{\pi}{}^i_2/(dw^i_2)^2 \simeq -2\sigma < 0$. Consider now the first-period; given network $j's$ strategy $(p^j_1, w^j_1)$, network $i's$ best response again entails $p^i_1(w^i_1, w^j_1) = c + \alpha^j_1(w^i_1, w^j_1)m_1$, now network $i$ chooses $w^i_1$ so as to maximize its total discounted profit:

$$\overset{=}{\Pi}{}^i(w^i_1) = \alpha^i_1(w^i_1, w^j_1)\left[v(c + \alpha^j_1(w^i_1, w^j_1)m_1) - w^i_1 - f + \alpha^j_1(w^i_1, w^j_1)m_1 q(p^j_1)\right] + \delta\widehat{\pi}^i_2(m_2, \alpha^i_1(w^i_1, w^j_1)). \tag{27}$$

First- and second-order derivatives of $\widehat{\pi}^i_2(m_2, \alpha^i_1(w^i_1, w^j_1))$ are

$$\frac{\partial\widehat{\pi}^i_2}{\partial w^i_1} = \left[2\alpha^i_2\left[\frac{1}{\sigma} - m_2\left(q(p^i_2) - q(p^j_2)\right)\right] - (\alpha^i_2)^2 m_2 \frac{\partial}{\partial\alpha^i_2}\left(q(p^i_2) - q(p^j_2)\right)\right]\frac{\partial\alpha^i_2}{\partial\alpha^i_1}(m_2, \alpha^i_1)\sigma,$$

$$\begin{aligned}\frac{\partial^2\widehat{\pi}^i_2}{(\partial w^i_1)^2} &= \left[2\left[\frac{1}{\sigma} - m_2\left(q(p^i_2) - q(p^j_2)\right)\right] - 2\alpha^i_2 m_2 \frac{\partial}{\partial\alpha^i_2}\left(q(p^i_2) - q(p^j_2)\right)\right.\\ &\quad \left. -(\alpha^i_2)^2 m_2 \frac{\partial^2}{(\partial\alpha^i_2)^2}\left(q(p^i_2) - q(p^j_2)\right)\right]\left(\frac{\partial\alpha^i_2}{\partial\alpha^i_1}(m_2, \alpha^i_1)\right)^2\sigma^2 \\ &\quad + \left[2\alpha^i_2\left[\frac{1}{\sigma} - m_2\left(q(p^i_2) - q(p^j_2)\right)\right] - (\alpha^i_2)^2 m_2 \frac{\partial}{\partial\alpha^i_2}\left(q(p^i_2) - q(p^j_2)\right)\right]\frac{\partial^2\alpha^i_2}{(\partial\alpha^i_1)^2}(m_2, \alpha^i_1)\sigma^2.\end{aligned}$$

Moreover, from (7) we have

$$\frac{\partial\alpha^i_2}{\partial\alpha^i_1} = \frac{2\sigma s}{3} + \frac{\sigma}{3}(m_2)^2\left[\alpha^j_2 q'(c + \alpha^j_2 m_2)\frac{\partial\alpha^j_2}{\partial\alpha^i_1} - \alpha^i_2 q'(c + \alpha^i_2 m_2)\frac{\partial\alpha^i_2}{\partial\alpha^i_1}\right].$$

By solving this last couple of equations for $\partial\alpha^i_2/\partial\alpha^i_1$ and $\partial\alpha^j_2/\partial\alpha^j_1$ we obtain

$$\frac{\partial\alpha^i_2}{\partial\alpha^i_1}(m_2, \alpha^i_1) = \left(\frac{1 + \eta^j}{1 + \eta^j\eta^i}\right)\left(\frac{2\sigma s}{3} - \frac{2\sigma^2 s}{9}\frac{\eta^j}{1 + \eta^j}\right),$$

where $\eta^i = (\sigma/3)(m_2)^2\alpha^i_2 q'(c + \alpha^i_2 m_2)$. Thus, for $m_2$ close to zero we may write $\partial\alpha^i_2/\partial\alpha^i_1 \simeq 2\sigma s/3$ (recall that $q'$ is bounded.) Moreover, notice that for $m_2$ close to zero we have that $\partial((1 + \eta^j)/(1 + \eta^j\eta^i))/\partial\alpha^i_1 \simeq 0$ and $\partial(\eta^j/(1 + \eta^j))/\partial\alpha^i_1 \simeq 0$, so $\partial^2\alpha^i_2/(\partial\alpha^i_1)^2 \simeq 0$ and hence $\partial^2\widehat{\pi}^i_2/(\partial w^i_1)^2 \simeq 8\sigma^3 s^2/9$. Therefore, for $m_1$ and $m_2$ close enough to zero we may write

$\partial^2 \overset{=i}{\Pi} / (\partial w_1^i)^2 \simeq -2\sigma + \delta 8 s^2 \sigma^3 / 9$. It follows that network $i's$ total discounted profit is strictly concave in $w_1^i$ for $m_1$ and $m_2$ close enough to zero provided that $(\delta/9)(s^2/\tau^2) < 1$.

Let me now study the uniqueness of the equilibrium. To that end, we can partially follow the proof given in Laffont, Rey and Tirole (1998a, appendix B) for the uniqueness of the equilibrium in the static-symmetric game. Notice that in any (shared-market) equilibrium equations $p_t^i = c + \alpha_t^j m_t$ always hold. By replacing these equations into the first-order conditions with respect to $w_t^i$ we may reduce the set of first-order conditions to a pair of equations for each period $t = 1, 2$ :

$$\frac{\partial \pi_2^i}{\partial w_2^i}(w_2^i, w_2^j) = \sigma[(p_2^i - c)q(p_2^i) + v(p_2^i) - w_2^i - f] - \alpha_2^i + (1 - 2\alpha_2^i)\sigma m_2(q(p_2^j) - q(p_2^i)) = 0, \quad (28)$$

and

$$\begin{aligned} \frac{\partial \Pi^i}{\partial w_1^i}(w_1^i, w_1^j) &= \sigma[(p_1^i - c)q(p_1^i) + v(p_1^i) - w_1^i - f] - \alpha_1^i \\ &\quad + (1 - 2\alpha_1^i)\sigma m_1(q(p_1^j) - q(p_1^i)) + \delta \frac{\partial \widehat{\pi}_2^i}{\partial w_1^i}(m_2, \alpha_1^i(w_1^i, w_1^j)), \end{aligned} \quad (29)$$

where recall that $p_t^i = c + \alpha_t^j m_t$, and $\alpha_1^i$ and $\alpha_2^i$ are, respectively, given by (1) and (2) as functions of net surpluses. (28) and (29) define "pseudo reaction functions" $w_2^i = \widetilde{w}_2^i(w_2^j)$ and $w_1^i = \widetilde{w}_1^i(w_1^j)$, their slopes are given by

$$\begin{aligned} \frac{d\widetilde{w}_t^i}{dw_t^j} &= -\frac{(\partial \phi_t^i / \partial w_t^j) + \sigma m[(\partial \phi_t^i / \partial p_t^i) - (\partial \phi_t^i / \partial p_t^j)]}{(\partial \phi_t^i / \partial w_t^i) + \sigma m[(\partial \phi_t^i / \partial p_t^j) - (\partial \phi_t^i / \partial p_t^i)]} \\ &= -\frac{(\partial \phi_t^i / \partial w_t^j) + \sigma^2 m^2[\alpha_t^i q'(p_t^i) - (\alpha_t^j - \alpha_t^i) q'(p_t^j)]}{(\partial \phi_t^i / \partial w_t^i) + \sigma^2 m^2[(\alpha_t^j - \alpha_t^i) q'(p_t^j) - \alpha_t^i q'(p_t^i)]}, \end{aligned}$$

where $\phi_1^i \equiv \partial \Pi^i / \partial w_1^i$ and $\phi_2^i \equiv \partial \pi_2^i / \partial w_2^i$. For $m_2$ close enough to zero we have $\partial \phi_2^i / \partial w_2^i \simeq -2\sigma$ and $\partial \phi_2^i / \partial w_2^j \simeq \sigma$ (since $q$ and $q'$ are bounded), so we may write $d\widetilde{w}_2^i / dw_2^j \simeq 1/2 < 1$, by which the second-period equilibrium is unique. Moreover, for $m_1$ and $m_2$ close enough to zero we have $\partial \phi_1^i / \partial w_1^i \simeq -2\sigma + \beta$ and $\partial \phi_1^i / \partial w_1^j \simeq \sigma - \beta$ (since $q$ and $q'$ are bounded), where

$\beta \equiv \delta 8 s^2 \sigma^3/9 > 0$, thus we may write $d\widetilde{w}_1^i/dw_1^j \simeq \rho \equiv (-\sigma+\beta)/(-2\sigma+\beta)$. Notice that $0 < \rho < 1$ provided that $\beta < \sigma$, or equivalently, provided that $\delta s^2/(9\tau^2) < 1/2$, in which case the first-period equilibrium is unique. ■

**Proof of Proposition 2.** Rewrite the equilibrium second-period profit as

$$\widehat{\pi}_2^i(m_2, \alpha_1^i) = (\alpha_2^i)^2 \left[ \frac{1}{\sigma} - m_2(q(p_2^i) - q(p_2^j)) \right], \tag{30}$$

where $\alpha_2^i$ and $p_2^i$ are determined as a function of $m_2$ and $\alpha_1^i$ by (21)-(23). By differentiating (30) with respect to $\alpha_1^i$ we may write

$$\begin{aligned} \frac{\partial \widehat{\pi}_2^i}{\partial \alpha_1^i}(m_2, \alpha_1^i) &= [2\alpha_2^i \left( \frac{1}{\sigma} - m_2 \left( q(p_2^i) - q(p_2^j) \right) \right) \\ &\quad + (\alpha_2^i)^2 (m_2)^2 (q'(p_2^i) + q'(p_2^j))] \frac{\partial \alpha_2^i}{\partial \alpha_1^i}(m_2, \alpha_1^i). \end{aligned}$$

Therefore, in a symmetric equilibrium

$$\psi(m_2) = \left[ \frac{1}{\sigma} + \frac{(m_2)^2}{2} q'\left(c + m_2/2\right) \right] \varphi(m_2),$$

where $\psi(m_2) \equiv \partial \widehat{\pi}_2^i(m_2, 1/2)/\partial \alpha_1^i$ and $\varphi(m_2) \equiv \partial \widehat{\alpha}_2^i(m_2, 1/2)/\partial \alpha_1^i$. By Lemma 1 we have that $\varphi(0) = 2s\sigma/3$, $\varphi'(0) = 0$ and $\varphi''(0) = (4s\sigma^2/9)(-q'(c))$. Thus, $\psi'(0) = (1/\sigma)(\varphi'(0)) = 0$ and

$$\psi''(0) = \frac{2s\sigma}{9} q'(c).$$

From (13) we may write $\widehat{\Pi}'(0) = -(\delta/2)\psi'(0) = 0$ and

$$\begin{aligned} \widehat{\Pi}''(0) &= -\frac{\delta}{2}\psi''(0) \\ &= \frac{\delta s \sigma}{9}(-q'(c)) > 0. \end{aligned}$$

Then, starting from $m_1 = m_2 = 0$, any small increase/decrease in $m_2$ increases total discounted profits. Moreover, from (12), at a symmetric equilibrium $\partial F_1^i(0,0)/\partial m_2 = -\delta\psi'(0)$ and $\partial^2 F_1^i(0,0)/(\partial m_2)^2 = -\delta\psi''(0)$. Furthermore, in such an equilibrium $\psi'(0) = 0$ and $\psi''(0) < 0$; hence, $\partial F_1^i(0,0)/\partial m_2 = 0$ and $\partial^2 F_1^i(0,0)/(\partial m_2)^2 > 0$. So, starting from $m_1 = m_2 = 0$, any small increase/decrease in $m_2$ softens competition in the first period. ■

**Proof of Proposition 3.** In any symmetric equilibrium, total transportation costs and switching costs are independent of the access mark-up level since $\alpha_t^i = 1/2\ \forall t, i$. Fixed fees neither have any impact on total welfare because of the full-participation assumption; thus, any small departure from cost-based access charges reduces total welfare since it is maximal when usage prices are cost-based. From above we have that networks increase their profits when the second-period access charge departs away from marginal cost, as a consequence the consumers' surplus must decrease. The first-period access charge does not have any impact on second period surpluses because in equilibrium the market share is always one-half. In a symmetric equilibrium networks' profits are neutral with respect to the first-period access charge; however, notice that the total welfare decreases with any small departure from cost-based access charges, so the consumer surplus must also decrease. ■

**Proof of Proposition 4.** The analysis of the second period is the same under naive and rational consumer expectations, so we can make use of Proposition 1 to show that a unique (shared-market) equilibrium exists for $m_2$ close enough to zero. In the first period, for given $(p_1^j, w_1^j)$, network $i$ chooses $w_1^i$ to maximize (27), where $\alpha_1^i$ is now given by (17). Differentiating this last expression yields

$$\frac{\partial \alpha_1^i}{\partial w_1^i} = \frac{\sigma}{1 - 2s\sigma^2\delta\partial \bigtriangleup \widehat{w}(m_2, \alpha_1^i)},$$

where $\bigtriangleup\widehat{w}(m_2, \alpha_1^i) \equiv \widehat{w}_2^i(m_2, \alpha_1^i) - \widehat{w}_2^j(m_2, \alpha_1^i)$ and $\widehat{w}_2^i$ is characterized by (5), (6) and (7). Differentiating $\bigtriangleup\widehat{w}$ with respect to $\alpha_1^i$ gives after some computations

$$\frac{\partial \bigtriangleup \widehat{w}}{\partial \alpha_1^i}(m_2, \alpha_1^i) = -\left[\frac{2}{\sigma} + (m_2)^2(\alpha_2^j q'(p_2^i) + \alpha_2^i q'(p_2^j)\right]\frac{\partial \alpha_2^i}{\partial \alpha_1^i}.$$

Moreover,

$$\begin{aligned}\frac{\partial^2 \triangle \widehat{w}}{(\partial \alpha_1^i)^2} &= -(m_2)^2\left[q'(p_2^j) - q'(p_2^i) + m_2\left(\alpha_2^i q''(p_2^j) - \alpha_2^j q''(p_2^i)\right)\right]\frac{\partial \alpha_2^i}{\partial \alpha_1^i} \\ &\quad - \left[\frac{2}{\sigma} + (m_2)^2\left(\alpha_2^j q'(p_2^i) + \alpha_2^i q'(p_2^j)\right)\right]\frac{\partial^2 \alpha_2^i}{(\partial \alpha_1^i)^2}.\end{aligned}$$

From the proof of proposition 1 we have that for $m_2$ close to zero $\partial\alpha_2^i/\partial\alpha_1^i \simeq 2\sigma s/3$ and $\partial^2\alpha_2^i/(\partial\alpha_1^i)^2 \simeq 0$. It follows that for $m_2$ close enough to zero $\partial \triangle \widehat{w}/\partial\alpha_1^i \simeq -4s/3$ and $\partial^2 \triangle \widehat{w}/(\partial\alpha_1^i)^2 \simeq 0$, and so $\partial\alpha_1^i/\partial w_1^i \simeq \sigma/(1+(8/3)s^2\sigma^2\delta)$ and $\partial^2\alpha_1^i/(\partial w_1^i)^2 \simeq 0$. Therefore, for $m_1$ and $m_2$ close enough to zero we may write

$$\begin{aligned}\frac{\partial^2 \overset{=i}{\Pi}}{(\partial w_1^i)^2} &\simeq -2\frac{\partial \alpha_1^i}{\partial w_1^i} + \delta\frac{\partial^2\widehat{\pi}_2^i}{(\partial\alpha_1^i)^2}\left(\frac{\partial\alpha_1^i}{\partial w_1^i}\right)^2 \\ &\simeq \left[-2 + \delta\left(\frac{8\sigma s^2}{9}\right)\frac{\sigma}{1+\delta(8/3)s^2\sigma^2}\right]\frac{\sigma}{1+\delta(8/3)s^2\sigma^2} < 0,\end{aligned}$$

since $2 > (\delta(8/9)\sigma s^2)(\sigma/(1+\delta(8/3)s^2\sigma^2))$ if $18/8 > (\delta\sigma^2 s^2)/(1+\delta(8/3)s^2\sigma^2$ holds, which is true since $(\delta\sigma^2 s^2)/(1+\delta(8/3)s^2\sigma^2 < 1 < 18/8$. From Lemma 2 it is easy to characterize both network $i's$ first-period fixed fee and total discounted profit. First, note that from (19)-(20) we have $\widehat{\Pi}'(0) = \partial F_1(0,0)/\partial m_2 = 0$. Furthermore, from the proof of Proposition 2 we have $\psi''(0) = (2s\sigma/9)q'(c)$, thus by Lemma 2 we may write

$$\widehat{\Pi}''(0) = \frac{1}{2}\frac{\partial^2 F_1^i}{(\partial m_2)^2}(0,0) = \frac{\delta s}{18\tau}\left(1 - \frac{s}{\tau}\right)(-q'(c)),$$

where I have used $\sigma \equiv 1/2\tau$. Therefore, in equilibrium both the total discounted profit and the first-period fixed fee are strictly convex in $m_2$ at $m_1 = m_2 = 0$ since $s < \tau$ by assumption. Then, $\widehat{\Pi}''_{RE}(0) = (\delta s\sigma/9)(1 - s/\tau)(-q'(c))$, and from Proposition 2 we have $\widehat{\Pi}''_{NE}(0) = (\delta s\sigma/9)(-q'(c))$, it follows that

$$\widehat{\Pi}''_{RE}(0) = \left(1 - \frac{s}{\tau}\right)\widehat{\Pi}''_{NE}(0).$$

■

# References


[1] ARMSTRONG M. “Network Interconnection in Telecommunications.” *Economic Journal,* Vol. 108 (1998), pp. 545-564.

[2] ARMSTRONG M. "The Theory of Access Pricing and Interconnection." In M.E. Cave, S.K. Majumdar, and I. Vogelsang, eds., *Handbook of Telecommunications Economics.* Amsterdam: North-Holland, 2002.

[3] ARMSTRONG M. AND WRIGHT, J. "Mobile Call Termination." mimeo (2007).

[4] CARTER, M. AND WRIGHT, J. “Interconnection in Network Industries.” *Review of Industrial Organization,* Vol. 14 (1999), pp. 1-25.

[5] CARTER, M. AND WRIGHT, J. “Asymmetric Network Interconnection.” *Review of Industrial Organization,* Vol. 22 (2003), pp. 27-46.

[6] CHERDRON, M. "Interconnection, Termination-Based Price Discrimination, and Network Competition in a Mature Telecommunications Market." mimeo, Mannheim University (2002).

[7] DE BIJL, P. AND M. PEITZ. *Competition and Regulation in Telecommunications Markets.* CPB Netherlands Bureau for Economic Policy Analysis, November 2000.

[8] DE BIJL, P. AND M. PEITZ. *Regulation and Entry into Telecommunications Markets.* Cambridge, UK: Cambridge U. Press, 2002.

[9] DE BIJL, P. AND M. PEITZ. "Dynamic Regulation and Entry in Telecommunications Markets: A Policy Framework." *Information Economics and Policy,* Vol. 16 (2004), pp. 411-437.

[10] DESSEIN, W. "Network Competition in Nonlinear Pricing," *RAND Journal of Economics,* Vol. 34 (2004), pp. 1-19.

[11] GABRIELSEN, T.S. AND S. VAGSTAD. "Why is On-Net Traffic Cheaper than Off-Net Traffic? Access Markup as a Collusive Device." *European Economic Review,* Vol. 52 (2008), pp. 99-115.

[12] GANS, J.S. AND KING, S.P. "Using 'Bill and Keep' Interconnect Arrangements to Soften Network Competition." *Economics Letters,* Vol. 71 (2001), pp. 413-420.

[13] HAHN, J. "Network Competition and Interconnection with Heterogeneous Subscribers." *International Journal of Industrial Organization,* Vol. 22 (2004), pp. 611-631.

[14] KLEMPERER, P.D. " The Competitiveness of Markets with Switching Costs." *RAND Journal of Economics,* Vol. 18 (1987), pp. 138-150.

[15] LAFFONT, J.-J., REY, P. AND TIROLE, J. "Network Competition: I. Overview and Nondiscriminatory Pricing." *RAND Journal of Economics,* Vol. 29 (1998a), pp. 1-37.

[16] LAFFONT, J.-J., REY, P. AND TIROLE, J. "Network Competition II: Price Discrimination." *RAND Journal of Economics.* Vol. 29 (1998b), pp. 38-56.

[17] POLETTI, S. AND WRIGHT, J. "Network Interconnection with Participation Constraints." *Information, Economics and Policy,* Vol. 16 (2004), pp. 347-373.

[18] VALLETTI, T.M., C. CAMBINI. "Investments and Network Competition." *RAND* Journal of Economics. Vol. 36. (2005), pp. 446-468.

[19] VOGELSANG, I. "Price Regulation of Access to Telecommunications Networks." *Journal of Economic Literature.* Vol. 41 (2003), pp. 830-862.