DYNAMIC NETWORK INTERCONNECTION UNDER CONSUMER SWITCHING COSTS

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FUNDACIÓN DE LAS CAJAS DE AHORROS
DOCUMENTO DE TRABAJO
Nº 214/2005

De conformidad con la base quinta de la convocatoria del Programa de Estímulo a la Investigación, este trabajo ha sido sometido a evaluación externa anónima de especialistas cualificados a fin de contrastar su nivel técnico.

ISBN: 84-89116-07-5

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September 2005

Abstract

Previous research has argued that telecommunications networks under nonlinear pricing cannot use reciprocal access charges as an instrument of collusion as long as the market is mature and there is either full participation or an exogenous participation rate. This paper shows that (even symmetric) networks with full participation can however use reciprocal access charges to soften competition when they compete in a dynamic framework. This result has clear policy implications, since total welfare is maximized with cost-based access prices.

Key words: Interconnection, networks, switching costs, access pricing

JEL Classifications: D43, D92, K21, L43, L51, L96

* A previous version of this paper was presented at XXIX Simposio Análisis Económico, Pamplona, December 2004. The author thanks Patrick Rey for his guidance and helpful advice, and one referee for helpful suggestions and comments. All remaining errors are my own. E-mail: angel.lopez@univ-tlse1.fr

1 INTRODUCTION

Nowadays, achieving competition in the local telecommunications sector is one of the biggest challenges. While duplication of the local loop is feasible thanks to new technologies, carriers need access to each other's networks in order to compete. This two-way access problem differs clearly from the one-way access situation in which a firm monopolizes the local network and must interconnect with entrants that compete on complementary segments. In the latter case, to the extent that there is a consensus in the literature in that regulation is socially desirable, the main policy concern is how to regulate the access charge. In the two-way access setting there is however retail competition between firms and this may induce to think that regulation is unnecessary. On the face of it, access charges are frequently set cooperatively, while collusion over retail prices is generally illegal for firms. The key issue is thus to determine whether this policy rule is undermining retail competition or on the contrary is socially optimal and hence no-regulation is needed.

This question has been studied in the seminal papers of Armstrong (1998) and Laffont, Rey and Tirole (1998). Assuming symmetric networks, reciprocal access charges and linear retail pricing both papers show that competition in the retail market can be undermined by collusion over the access charge. The intuition for this result stems from the fact that if a firm lowers its retail price, then its subscribers will make more calls, which provokes an access deficit whenever the access charge is above the cost. Then, by agreeing to high access charges, firms reduce the incentive to undercut each other. On the other hand, Laffont et al. (1998) show that under two-part pricing, the collusive power of the access charge disappears and firms' equilibrium profits are neutral with respect to the access charge. Intuitively, nonlinear pricing neutralize the collusive role of the access charge because firms can build market share by lowering their fixed fees while keeping usage prices constant, and hence not incurring an access deficit. It is a striking result that has become the focus of much research. Dessein (2003) introduces heterogeneity in volume demand, in which case two-part tariffs can be used for second-degree price discrimination. He shows that in this situation and under symmetric networks, equilibrium profits remain independent of the reciprocal access charge. Hahn (2004) models consumer type continuously but still obtains similar conclusions. De Bijl and Peitz (2000) allow for third-degree price discrimination, and find that profits are still independent of reciprocal access charges when the market is mature. One may thus conclude that nonregulation is needed in the two-way access setup, as firms are indifferent with respect to the access charge level they are able to coordinate themselves on the socially optimal point.

Nonetheless, this neutrality result depends crucially on the symmetry and the full-participation assumption. In this sense, Poletti and Wright (2000) restore the collusive role of the access charge when it is above cost by modifying Dessein's model and allowing customers' participation constraint to be binding in equilibrium. Yet, Gans and King (2001) allow for price discrimination and find that firms prefer access charges below cost. Schiff (2002) incorporates partial consumer participation in the standard model and show that under some assumptions, as for instance an exogenous participation rate, firms prefer the access charge equal to the marginal cost. However, when these assumptions are dropped out, firms prefer either cost-based or below-cost access prices depending on the case that is under consideration. Dessein (2003) allows for partial participation, although somewhat different to Schiff (2002) since he assumes an elastic subscription demand, such that in the equilibrium some customers drop out of the market. In such a context networks prefer access prices below cost. Carter and Wright (2003) allow asymmetric networks by providing for brand loyalty and show that under reciprocal access prices and two-part pricing the incumbent strictly prefers the access charge to be set at marginal cost, and both firms prefer cost-based access charges when there is a sufficient degree of asymmetry between the two networks.[1]

The main aim of this article is to analyze network competition in a non-static context. We analyze a standard model with reciprocal access charges and non-linear pricing in a two-period game. For this purpose, we shall introduce some assumptions regarding the equilibrium concept and switching costs.

Subgame Perfect Equilibrium: To the best of our knowledge, up to now the only work that has studied network competition in a dynamic context is De Bijl and Peitz (2000, 2002, 2004). They focus, however, on myopic behaviour, that is, per-period profit maximizing equilibria. In such a framework the study of the symmetric case simply consists in the mere repetition of the symmetric equilibrium, which is independent of the access charge level. The authors therefore study the asymmetric case, for which they find in the short term a similar result to that of Carter and Wright (2003),

[1] For a survey of these and other cases see Armstrong (2002).

and in the long-term a result very close to the neutrality. We will instead allow for non-myopic firms and focus on subgame perfect equilibria. Another difference is that they make a numerical analysis, while our insights are drawn from the properties of the model.[2]

Switching costs: The dynamic analysis would be useless if consumers did not face a cost when switching from one carrier to other. There is however much evidence suggesting that switching costs are significant. In a two-period model, typically switching costs make demand more inelastic in the second period, and because of second-period profits depend on customer base, switching costs may then lead to more competitive behavior in the initial period.

Dynamic network competition under consumer switching costs raises several economic issues for carriers and regulators: Are carriers able to undermine retail competition through access charges? Which are the dynamic firms' pricing strategies? How are they affected when the access charge departs from marginal cost? What are the optimal access prices across periods? The main conclusion of our paper is that market competition is softened when future reciprocal access charges depart from marginal cost. Indeed, the firms' overall profits are neutral with respect to the first-period access charge but increase when the second-period access charge is above or below the marginal cost. This result holds both when consumer expectations are naive and when they are rational. 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, and in such a framework the profits of the larger firm decreases when the access charge departs from the marginal cost, thereby lowering the incentives 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 firms are able to collude over access prices, even if being symmetric and under the full participation assumption, whenever they are non-myopic and compete in a dynamic context. Since cost-based access charges maximize

[2] It is worth to say that De Bijl and Peitz (2000, 2002, 2004) make numerical analyses of a wide range of interesting scenarios that are not considered here, as for instance the non-reciprocal access prices case and the process of entry.

the full-period welfare surplus (see section 4), one may conclude that regulation is needed in order to prevent anticompetitive behavior.

The rest of the article proceeds as follows. Section 2 describes the dynamic model of network competition. Section 3 analyzes the dynamic game, characterizes the equilibrium with naive consumer expectations, obtains and discusses the non-profit-neutrality result, and derives the socially optimal access prices. Section 4 looks at the case of rational consumer expectations. Finally, Section 5 summarizes the main insights and concludes. All the proofs are given in the appendix.

2 THE FORMAL REPRESENTATION OF THE GAME

Many of the standard assumptions prevail (Laffont et al 1998). There are two firms indexed by i and j, where $i \neq j$. Each firm has its own full coverage network and directly competes for consumers. It is assumed that every consumer joins one of the networks, that is, there is full participation. Networks are interconnected and hence a consumer who subscribes to one network can call any other consumer on either network.

It is assumed that firms are not able to price discriminate between calls that terminate on- and off-net. Thanks to the assumptions of interconnection and non-discriminatory pricing, 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 get utility from making calls but not from receiving calls. It is also assumed that 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.[3]

With respect to the cost structure, symmetric costs are assumed for simplicity. Firms 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 the customer. With respect to the demand structure

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[3] It is not difficult to find cases in which the calling pattern is unbalanced. The balanced calling pattern must therefore be seen as a first explanation of the problem that needs to be refined in such cases.

it is assumed that the telephone consumption $q(p)$ is C^k (with $k\geq 2$, $q'<0$ and $q''>0$[4]) and has bounded derivatives. Further, $q(p)$ is assumed to be known and the same for all consumers; then firms can do no better than offer two-part tariffs: each firm charges a per-unit price for making calls p (called the marginal price or usage fee) and a fixed fee F to each customer. We denote the consumers' variable net surplus or indirect utility by $v(p)$ and the total net surplus by $w=v(p)-F$. Networks are differentiated à la Hotelling. Consumers are uniformly located on the segment $[0,1]$ and the two networks are located at the two ends of the interval. Then, consumers' tastes for networks are represented by their position on the line segment and taken into account through the transportation costs τ. Given income y and the customer demand q, a consumer located at x and joining network i has utility

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

where v_0 represents a fixed surplus from being connected to either network[5] and $\left|x - x_i\right|$ is the cost of being connected to the network located at $x_i \neq x$. The timing of the game is composed of three stages. In the first stage or period zero, reciprocal access charges are set by a regulator or negotiated between carriers; a flexible regulation is allowed, so that access charges may differ over time. In the first and second periods, which are indexed by $t \in \{1,2\}$, networks compete in retail prices, taking as given the access charges. In addition, every customer incurs a cost $s>0$ when switching networks. If $s>\tau$ every consumer remains with the same network in a symmetric equilibrium. We shall assume instead that $s<\tau$, so that at least some consumers switch. In addition, we shall make the following two assumptions:

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

A.2. *Consumers have naive expectations.*

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

[5] Since only full participation is considered, v_0 is assumend to be large enough such that all consumers choose to be connected to a network in the equilibrium.

The first assumption only says that preferences may change over time[6], while the second one imposes a strong condition on consumers' behavior. This last assumption will be relaxed later on so as to model rational consumer expectations. From now on and without any loss of generality assume firm *i* is located at the beginning of the segment *[0,1]* and firm *j* at the end. Then, a consumer located at $x=\alpha_1$ is indifferent between the two networks in the first period if and only if

$$w_1^i - \tau\alpha_1 = w_1^j - \tau(1-\alpha_1)$$

Therefore, the firm *i's* market share is

$$\alpha_1^i = \frac{1}{2} + \sigma(w_1^i - w_1^j),$$

where $\sigma = 1/2\tau$ is the index of substitutability between the two networks. At the beginning of the second period there is a fraction α_1^i of consumers initially attached to firm *i.* For these and given A.1 and A.2, a consumer located at $x \in [0,1]$ will remain associated with firm *i* if $w_2^i - \tau x \geq w_2^j - \tau(1-x) - s$. A consumer initially attached to firm *j,* namely α_1^j, will instead switch to network *i* if $w_2^i - \tau x - s \geq w_2^j - \tau(1-x)$. Therefore, the firm *i′ s* second-period market share is

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

$$= \frac{1}{2} + (2\alpha_1^i - 1)\sigma s + \sigma(w_2^i - w_2^j),$$

Firms are assumed to have rational expectations and to discount second-period revenues and costs by a factor δ. The firms' profit function is in period *t* given by

$$\pi_t^i = \alpha_t^i(p_t^i - c)q(p_t^i) + \alpha_t^i(F_t^i - f) + \alpha_t^i\alpha_t^j m_t(q(p_t^j) - q(p_t^i)), \tag{2}$$

where $m_t = a_t - c_T$ denotes the access mark-up. The first term represents 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 $\alpha_t^i q(p_t^i)$ calls and from them it gains the margin $p_t^i - c$. In addition, the network *i* incurs a fixed cost *f* for every customer subscribed to its network $(\alpha_t^i f)$ and receives from each of them

[6] This case migh also arise when the customers are different in different periods and second-period customers are exposed to the choice of first-period customers. Actually, asumming constant switching costs over time introduces technical problems when the Hotelling model is used: for some variations in prices, market shares remain constant.

its fixed fee $(\alpha_t^i F_t^i)$. Given the calling pattern, a fraction α_t^j of the calls goes to network j, in which case network i pays the reciprocal access price a_t but saves the marginal cost of terminating the call c_T. Finally, network j originates $\alpha_t^j q(p_t^j)$ calls of which a fraction α_t^i goes to the network i. Network i gets for each of them the reciprocal access price a_t but incurs the marginal cost c_T of terminating the call.

3 THE TWO-PERIOD DYNAMIC GAME

In the first period firms choose prices, which results in profits π_1^i and π_1^j, and market shares α_1^i and α_1^j (with $\alpha_1^i+\alpha_1^j=1$). Because of the switching costs, these market shares affect the firms' choice of second-period prices and their corresponding second-period profits. As usual, we thus start by analyzing the second-period game, taking as given the first-period market shares.

3.1 THE SECOND PERIOD

In this section we analyze the second period of a market with switching costs. We first compute firms' optimal prices as function of first-period market shares. As the seminal work of Laffont et al. (1998) 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, firms maximize their profits (2) with respect to p_2^i and w_2^i, taking as given p_2^j, w_2^j and α_1^i,

$$\max_{(p_2^i, w_2^i)} \quad \alpha_2^i(w_2^i, w_2^j)\left[(p_2^i - c)q(p_2^i) + v(p_2^i) - w_2^i - f\right],$$

$$+\alpha_2^i(w_2^i, w_2^j)(1-\alpha_2^i(w_2^i, w_2^j))m_2\left[q(p_2^j) - q(p_2^i)\right], \tag{3}$$

where α_2^i is given by (1). By solving (3) we obtain

$$p_2^i = c + \alpha_2^j m_2 \tag{4}$$

$$w_2^i = v(p_2^i) - f - \frac{\alpha_2^i}{\sigma} + (p_2^i - c)q(p_2^i) + (\alpha_2^i - \alpha_2^j)m_2(q(p_2^i) - q(p_2^j)) \tag{5}$$

The equilibrium market shares satisfy (1), (4) and (5), that is,

$$\alpha_2^i = \frac{1}{2} + (2\alpha_1^i - 1)\frac{\sigma s}{3} + \frac{\sigma}{3}\left[v(p_2^i) - v(p_2^j) + m_2(\alpha_2^j q(p_2^i) - \alpha_2^i q(p_2^j))\right] \tag{6}$$

and $\alpha_2^j=1-\alpha_2^i$. Finally, substituting (4) and (5) into (3), the equilibrium second-period profits satisfy

$$\pi_2^i = \frac{(\alpha_2^i)^2}{\sigma} - (\alpha_2^i)^2 m_2 (q(p_2^i) - q(p_2^j)) \tag{7}$$

Together (4), (5), (6) and (7) characterize the second-period prices, market shares and profits, as a function of the second-period access markup m_2, the first-period market shares α_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 charge m_2. The intuition for this result is that a second-period access charge above marginal cost boosts final usage prices, since in equilibrium, networks set usage fees equal to the average marginal cost of a call. Hence, a positive access markup has a positive effect on the revenue per customer, which lead firms to compete for market share by lowering the fixed fees. With full participation the two effects cancel and second-period profits are not affected by the second-period access charge level. On the other hand, second-period profits might depend on m_1 through α_1^i. However, in any symmetric equilibrium $\alpha_1^i = 1/2$ whatever the first-period access markup, and hence second-period profits are independent of m_1. Next sections show that in the neighborhood of $m_2=0$, the first-period market share is a source of benefit; however, the incentive to compete for first-period market share decreases when departing from $m_2=0$, which is the main insight of our paper.

3.2 THE FIRST PERIOD

In the first period, each network sets prices taking into account its first-period profitability, but also the effect of its first-period market share on its second-period profitability. Network i chooses p_1^i and F_1^i in order to maximize its total discounted profits, taking j′ s first-period retail price and fixed fee as given. Total discount profits can be written as

$$\Pi^i(p_1^i, p_1^j, w_1^i, w_1^j) = \pi_1^i(p_1^i, p_1^j, w_1^i, w_1^j) + \delta\hat{\pi}_2^i(m_2, \alpha_1^i(w_1^i, w_1^j)), \tag{8}$$

where π_1^i is given by (2) and $\hat{\pi}_2^i$, as a function of m_2 and α_1^i, is determined by (4)-(7). 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 dynamic duopoly has at least one symmetric equilibrium. This equilibrium is moreover the unique equilibrium if* $\delta s^2/9\tau^2 < 3/4$*. In contrast, there is never a cornered-market equilibrium.*

The condition $m_t \approx 0$ is similar to the obtained in the static case (see Laffont, Rey and Tirole, 1998.) The additional condition $\delta s^2/9\tau^2 < 3/4$ is not too restrictive since δ 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 such that symmetric equilibrium exists and* $\delta s^2/9\tau^2 < 3/4$.

Under A.3 the two-period dynamic game has a unique symmetric equilibrium, which is the focus of our analysis. Conditions (4)-(5)-(6) determine second-period market shares and prices as a function of first-period market shares, which we denote as $\hat{\alpha}_2^i(m_2, \alpha_1^i)$, $\hat{p}_2^i(m_2, \alpha_1^i)$ and $\hat{w}_2^i(m_2, \alpha_1^i)$. In equilibrium $0 = \partial \Pi^i / \partial p_1^i = \partial \pi_1^i / \partial p_1^i$. It follows that $p_1^i = c + \alpha_1^j m_1$: networks choose their retail prices in the same way as they do in the second period. Further, in equilibrium (using $\partial \alpha_1^i / \partial w_1^i = \sigma$)

$$0 = \partial \Pi^i / \partial w_1^i = \partial \pi_1^i / \partial w_1^i + \delta\sigma(\partial \hat{\pi}_2^i / \partial \alpha_1^i) \tag{9}$$

Therefore, firms may choose lower or higher first-period net surpluses than those that would maximize first-period profits. In section 3.1 we found that the incumbent profits depend positively on the first-period market share when *m_2=0:* $(\partial \hat{\pi}_2^i / \partial \alpha_1^i)_{m_2=0} > 0$. Then, first-period 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, firms 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, because market shares affect the future, each firm competes more or less aggressively than it otherwise would do in order to capture market share.[7] Condition (9) can be rewritten as follows

$$0=\frac{\partial\alpha_1^i}{\partial w_1^i}\bar{\pi}_1^i-\alpha_1^i+\sigma(\alpha_1^j-\alpha_1^i)m_1(q(p_1^j)-q(p_1^i))+\delta\frac{\partial\hat{\pi}_2^i}{\partial\alpha_1^i}(m_2,\alpha_1^i)\frac{\partial\alpha_1^i}{\partial w_1^i}, \tag{10}$$

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

$$\bar{\pi}_1^i=\frac{1}{2\sigma}-\delta\psi(m_2), \tag{11}$$

where

$$\psi(m_2)=\frac{\partial\hat{\pi}_2^i}{\partial\alpha_1^i}(m_2,1/2)$$

Since $\hat{\pi}_2^i(m_2,1/2)=1/4\sigma$, in a symmetric equilibrium the full-period profits are equal to

$$\hat{\Pi}(m_2)=\frac{1+\delta}{4\sigma}-\frac{\delta}{2}\psi(m_2) \tag{12}$$

Thus these full-period profits do not depend on m_1, but they 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 the total profits.*

From the previous section we know that neither m_1 nor m_2 influence the symmetric equilibrium second-period profits. A similar argument to that explaining the neutrality of the second-period profits with respect to m_2, explains also why first-period profits are neutral with respect to the first-period access markup. There is however a new insight. As already noted, equilibrium second-period profits increase with the level of the first-period market share when $m_2\cong 0$ (specifically, $\psi(0)=2s/3>0$). Thus, in the neighborhood

[7] In the switching costs literature it is usually found that $(\partial\hat{\pi}_2^i/\partial\alpha_1^i)>0$, which implies that firms compete more aggressively in the first period in order to build market share that is profitable in the second period. However, there are also models of switching costs in which a higher market share is harmful to firms (Farrell, 1985 and Summers, 1985).

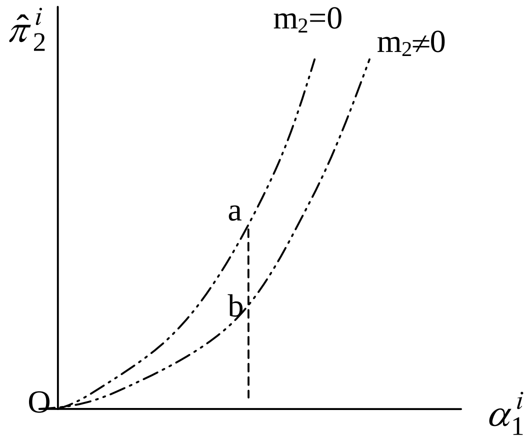

FIG. 1. The role of the second-period access mark-up

of $m_2=0$, firms compete more aggressively in the first period than they would do in a market without switching costs.[8] But here, $\psi'(0)=0$ and $\psi''(0)=(2s\sigma/9)q'(c)<0$, which implies that the equilibrium full-period profits are strictly convex in m_2 at $m_2=0$ and hence both a (small) increase or decrease in m_2 increases the profit of the firms. Note however that this result depends on the size of sigma. Since $\psi''(0)<0$, the benefit of having a higher market share in the second period decreases when the second-period access charge departs from marginal costs. Then, the incentive to compete for market share in the first period decreases with the level of the second-period access charge. Figure 1 depicts this situation, where $O=(1/2,z)$ and $z\geq0$. The dashed lines represent the equilibrium second-period profits when $m_2=0$ and $m_2\neq0$ but close enough to zero.[9] Starting from a symmetric equilibrium, if network i slightly increase its first-period market share then $\hat{\pi}_2^i$ will increase and network i would move from point O to point a. However, if $m_2\neq0$ the benefit of having a higher customer base will be lower and hence network i would move from point a to point b. An explanation for this result can be found in the Proposition 1 of Carter and Wright (2003), which proves that the profits of the larger firm decrease when the access charge is higher or lower than the marginal cost. Therefore, as higher or lower is the second-period access charge with respect to the

[8] Because of the concavity of the $i's$ profit function with respect to w_t^i.

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

marginal costs, lower the second-period profits for the larger firm will be, though still higher than the profits of the smaller one, and consequently the competition for market share in the first period is disincentived.

It is worth to note that in the zero access mark-up, when there are not switching costs the symmetric full-period profits are higher than those when switching costs are positive, that is, firms are worse off with switching costs than without them. Firms 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.[10] Nonetheless, the difference between both equilibrium profits (without and with switching costs) becomes closer as the second-period access markup departs from zero.

Before considering rational consumer expectations let us first derive consumer and total welfare maximizing access pricing. From above we may deduce that $m_1=m_2=0$ do not maximize the total industry profits. In addition, next proposition states that cost-based access prices 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 consumer surplus and social welfare.*

This proposition has clear policy implications. Since firms prefer future access prices departing from marginal cost, some kind of regulation is needed to assure that social welfare is maximized. The next section shows that this still holds when consumers are not myopic.

4 RATIONAL CONSUMER EXPECTATIONS

Up to now we have assumed that consumers have naive expectations and therefore that they cannot anticipate the second-period firms' behavior. In this section we will study the case in which consumers have rational expectations. To that end let us state the following assumption,

[10] This result coincides with the obtained in Klemperer (1987) when all second-period consumers are either new or have independent preferences across periods.

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

Consumers with rational expectations recognize that a firm with lower first-period prices will gain a greater market share and will then charge higher prices in the second period to exploit its customers. If a consumer located at $\bar{x}$ subscribes to network i in period one, he will remain with that network in the second period iff $w_2^i - x\tau \geq w_2^j - \tau(1-x) - s$. The consumer's second-period surplus is then

$$Ew^i = \int_0^{\sigma(\tau + w_2^i - w_2^j + s)} \hat{w}_2^i - \tau x dx + \int_{\sigma(\tau + w_2^i - w_2^j + s)}^1 \hat{w}_2^j - \tau(1-x) - s dx$$

The marginal consumer is thus given by

$$\begin{aligned} 0 &= (w_1^i - \tau\bar{x}) - (w_1^j - \tau(1-\bar{x})) + \delta\left[Ew^i - Ew^j\right] \\ &= (w_1^i - \tau\bar{x}) - (w_1^j - \tau(1-\bar{x})) + \delta\left[\hat{\bar{w}}_2^i(m_2, \bar{x}) - \hat{\bar{w}}_2^j(m_2, \bar{x})\right] \end{aligned}$$

Then,

$$\alpha_1^i = \bar{x} = \frac{1}{2} + \sigma(w_1^i - w_1^j) + 2s\sigma^2\delta\left[\hat{w}_2^i(m_2, \alpha_1^i) - w_2^j(m_2, \alpha_1^i)\right] \tag{13}$$

Let us 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 (13) we may obtain h so that

$$h(m_2, \alpha_1^i) = \frac{1}{\sigma}\left[1 - 2s\sigma^2\delta\frac{\partial \Delta\hat{w}}{\partial \alpha_1^i}(m_2, \alpha_1^i)\right], \tag{14}$$

where $\Delta\hat{w}(m_2, \alpha_1^i) = \hat{w}_2^i(m_2, \alpha_1^i) - \hat{w}_2^j(m_2, \alpha_1^i)$. When consumers have naive expectations, $h=1/\sigma$. Here, instead h depends on m_2 and α_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, firm i maximizes (8) with respect to p_1^i and w_1^i, which in a symmetric equilibrium gives $p_1^i = c + m_1/2$ and $0 = (\partial\alpha_1^i/\partial w_1^i)\bar{\pi}_1^i - 1/2 + \delta(\partial\hat{\pi}_2^i/\partial\alpha_1^i)(\partial\alpha_1^i/\partial w_1^i)$, where

$\partial\alpha_1^i / \partial w_1^i$ is given by (14). Using these first-order conditions we may write the symmetric equilibrium first-period fixed fees as follows

$$\hat{F}_1(m_1, m_2) = f + \frac{h(m_2, 1/2)}{2} - \frac{m_1}{2} q(c + m_1/2) - \delta\psi(m_2), \tag{15}$$

Obviously, in the second-period symmetric equilibrium profits are the same as with naive expectations, that is, $1/4\sigma$. Using (15) this gives

$$\hat{\Pi}(m_2) = \frac{1}{2}\left[\frac{h(m_2, 1/2)}{2} - \delta\psi(m_2)\right] + \frac{\delta}{4\sigma} \tag{16}$$

The symmetric equilibrium full-period profits in the rational expectations case thus depend on m_2 through h and ψ, whereas with naive expectations they depended only on m_2 through ψ. The next proposition establishes formally the relationship between full-period profits and m_2 in the rational expectations case.

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 with naive expectations for consumers.*

From the proof of Proposition (4) we have that $h(0,1/2)>1/\sigma$; this result stems from the fact that rational consumers realize that firms with higher market shares will charge higher prices in the future, which makes the demand less elastic. Further, we 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 full-period profits and first-period fixed fees strictly convex in m_2 at $m_1=m_2=0$, because $s<\tau$ by assumption.

In addition, using $\psi(0) = 2s/3$ and $h(0,1/2) = 1/\sigma + 8s^2\sigma\delta/3$ we may write $\hat{\Pi}(0) = (1+\delta)/4\sigma + (s\delta/3)(s/\tau - 1)$. Because of switching cost are strictly lower than transportation costs by assumption, as with consumers' naive expectations firms 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 from the marginal cost level. It remains to note that in the neighborhood $m_1=m_2=0$, the symmetric equilibrium full-period profits are higher in the rational expectations case than in the naive expectations case; indeed, for $m_1=m_2=0$ we have

$\Pi_{RE} - \Pi_{NE} = (2/3)s^2\sigma\delta$. Firms then prefer rational consumers to consumers with naive expectations, since they then face a less elastic demand on the first period, although Proposition (4) gives us the following result

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

which says that any departure from cost-based access charges has a lower impact on full-period profits in the case of rational expectations than in the naive expectations one.

5 CONCLUDING REMARKS

This paper has shown that when networks are non-myopic and compete in a dynamic framework, they are able to use future access charges to soften competition, even in symmetric markets in which participation is complete. The intuition is simple: in the second period the analysis is similar to the standard static one, and the profits of the larger firm decrease when the access charge departs from the marginal cost, implying that the competition for market share in the first period is disincentived. In contrast to what previous research suggests, regulation is thus needed to prevent anticompetitive behavior, since networks' profits increase when the future access charges departs from the marginal cost, while cost-based access charges mazimize consumer surplus and total welfare.

Other insights are derived. First, as usual (see Klemperer, 1987) networks are worse off with switching costs than without them, and even more so when consumers have naive expectations. However, a departure from cost-based access charges in future periods attenuate this impact of switching costs on competition.

6 APPENDIX

Some preliminary lemmas will be useful.

LEMMA 1. *In a symmetric equilibrium*

$$\varphi(m_2) = \frac{\partial \hat{\alpha}_2^i}{\partial \alpha_1^i}(m_2, 1/2) = \frac{2\sigma s}{3 + \sigma(m_2)^2 q'(c + m_2/2)}$$

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, $\hat{w}_2^i(m_2,\alpha_1^i)$, $\hat{p}_2^i(m_2,\alpha_1^i)$ and $\alpha_2^i(m_2,\alpha_1^i)$, are determined by (1) and the first-order conditions (4)-(5), that is:

$$\hat{w}_2^i = v(\hat{p}_2^i) - f - \frac{\hat{\alpha}_2^i}{\sigma} + (\hat{p}_2^i - c)q(\hat{p}_2^i) + (\hat{\alpha}_2^i - \hat{\alpha}_2^j)m_2(q(\hat{p}_2^i) - q(\hat{p}_2^j)) \tag{17}$$

$$\hat{p}_2^i = c + \hat{\alpha}_2^j m_2 \tag{18}$$

and

$$\hat{\alpha}_2^i = \frac{1}{2} + (2\alpha_1^i - 1)\sigma s + \sigma(\hat{w}_2^i - \hat{w}_2^j) \tag{19}$$

Differentiating (17)-(19) with respect to $\alpha_1^i = 1 - \alpha_1^j$ yields, for a symmetric equilibrium:

$$\frac{\partial \hat{w}_2^i}{\partial \alpha_1^i} = -\frac{\varphi(m_2)}{\sigma} + \frac{m_2}{2} q'\left(c + \frac{m_2}{2}\right)\frac{\partial \hat{p}_2^i}{\partial \alpha_1^i}$$

$$\frac{\partial \hat{p}_2^i}{\partial \alpha_1^i} = -m_2\varphi(m_2)$$

$$\frac{\partial \hat{\alpha}_2^i}{\partial \alpha_1^i} = 2\sigma s + \sigma\left(\frac{\partial \hat{w}_2^i}{\partial \alpha_1^i} - \frac{\partial \hat{w}_2^j}{\partial \alpha_1^i}\right)$$

Using $\partial \hat{w}_2^j / \partial \alpha_1^i = -\partial \hat{w}_2^j / \partial \alpha_1^j = -\partial \hat{w}_2^i / \partial \alpha_1^i$ we thus have that

$$\varphi(m_2) = \frac{\partial \hat{\alpha}_2^i}{\partial \alpha_1^i} = 2\sigma s + 2\sigma\left(-\frac{1}{\sigma} - \frac{(m_2)^2}{2} q'\left(c + \frac{m_2}{2}\right)\right)\varphi(m_2)$$

It follows that

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

By differentiating this expression with respect to m_2 we obtain

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

Then $\varphi'(0)=0$, further

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

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 $\Delta\hat{w}(m_2, \alpha_1^i) = \hat{w}_2^i(m_2, \alpha_1^i) - \hat{w}_2^j(m_2, \alpha_1^i)$. Using (17) we may write

$$\begin{aligned}\Delta\hat{w}(m_2,\alpha_1^i) &= v(\hat{p}_2^i) - f - \frac{\hat{\alpha}_2^i}{\sigma} + (\hat{p}_2^i - c)q(\hat{p}_2^i) + (\hat{\alpha}_2^i - \hat{\alpha}_2^j)m_2(q(\hat{p}_2^i) - q(\hat{p}_2^j)) \\ &- [v(\hat{p}_2^j) - f - \frac{\hat{\alpha}_2^j}{\sigma} + (\hat{p}_2^j - c)q(\hat{p}_2^j) + (\hat{\alpha}_2^j - \hat{\alpha}_2^i)m_2(q(\hat{p}_2^j) - q(\hat{p}_2^i))]\end{aligned} \tag{21}$$

where $\hat{\alpha}_2^i$, $\hat{p}_2^i$ and $\hat{w}_2^i$ are function of m_2 and α_1^i and are determined by (17)-(19). By differentiating (21) with respect to α_1^i, in a symmetric equilibrium it follows that

$$\frac{\partial\Delta\hat{w}}{\partial\alpha_1^i}(m_2,1/2) = -\left(\frac{2}{\sigma} + (m_2)^2 q'\left(c + \frac{m_2}{2}\right)\right)\varphi \tag{22}$$

Finally from (14), (22) and Lemma 1 we have that

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

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

$$v(m_2) = 3 + \sigma(m_2)^2 q'(c+m_2/2)$$

Then,

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

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,

$$\frac{\partial h(0,1/2)}{\partial m_2} = (4s^2\sigma\delta)j'(0) = (4s^2\sigma\delta)\frac{u'(0)v(0) - u(0)v'(0)}{v(0)^2} = 0$$

In addition,

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

It follows that $j''(0) = 2\sigma(q'(c))((v(0)-u(0))/v(0)^2) = 2\sigma(q'(c))(1/9)$. Finally,

$$\frac{\partial^2 h(0,1/2)}{(\partial m_2)^2} = (4s^2\sigma\delta) j''(0) = \frac{8}{9} s^2 \sigma^2 \delta q'(c) .$$

Proof of Proposition 1

We first establish the existence and uniqueness of the equilibrium. Consider first the second-period in which firms take as given previous actions. From the first-order conditions, $p_t^i = c + \alpha_t^j (w_t^i, w_t^j) m_t$. Given network j′ s strategy (p_2^j, w_2^j), firm i chooses w_2^i that maximizes its second-period profits $\overset{=}{\pi}{}_2^i (w_2^i, w_2^j)$:

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

For $m_2=0$, $\overset{=}{\pi}{}_2^i (w_2^i, w_2^j)\Big|_{m_2=0} = \alpha_2^i (w_2^i, w_2^j)\left[v(c) - w_2^i - f\right]$, and thus

$$\left(\frac{\partial \overset{=}{\pi}{}_2^i}{\partial w_2^i}\right)_{m_2=0} = \sigma\left[v(c) - w_2^i - f\right] - \alpha_2^i$$

$$\left(\frac{\partial^2 \overset{=}{\pi}{}_2^i}{(\partial w_2^i)^2}\right)_{m_2=0} = -2\sigma.$$

Therefore, $\overset{=}{\pi}{}_2^i$ is strictly concave in w_2^i when $m_2=0$ and thus also, by continuity, for m_2 close enough to zero (since $q(p)$, $q'(p)$ and $q''(p)$ are bounded). Consider now the first-period; given network *j's* strategy (p_1^j, w_1^j), firm *i* chooses w_1^i such as to maximize its full-period profits $\overset{=}{\pi}{}^i (w_1^i, w_1^j)$.

$$\overset{=}{\pi}{}^i (w_1^i, w_1^j) = \alpha_1^i (w_1^i, w_1^j)\left[v(c+\alpha_1^j (w_1^i, w_1^j) m_1) - w_1^i - f\right] + \alpha_1^i (w_1^i, w_1^j) \alpha_1^j (w_1^i, w_1^j) m_1 q(p_1^j)$$
$$+ \delta \hat{\pi}_2^i (m_2, \alpha_1^i (w_1^i, w_1^j))$$

For $m_1=m_2=0$,

$$\overset{=}{\pi}{}^i (w_1^i, w_1^j)\Big|_{m_1=m_2=0} = \alpha_1^i (w_1^i, w_1^j)\left[v(c) - w_1^i - f\right] + \delta \hat{\pi}_2^i (0, \alpha_1^i (w_1^i, w_1^j))$$

And thus

$$\left(\frac{\partial \bar{\bar{\pi}}^i}{\partial w_1^i}\right)_{m_1=m_2=0} = \sigma\left[v(c)-w_1^i-f\right]-\alpha_1^i+\delta\frac{\partial \hat{\pi}_2^i}{\partial \alpha_1^i}(0,\alpha_1^i)\sigma$$

$$\left(\frac{\partial^2 \bar{\bar{\pi}}^i}{(\partial w_1^i)^2}\right)_{m_1=m_2=0} = -2\sigma+\delta\frac{\partial^2 \hat{\pi}_2^i}{(\partial \alpha_1^i)^2}(0,\alpha_1^i)\sigma^2$$

From (7) we have

$$\hat{\pi}_2^i(0,\alpha_1^i)=\frac{\hat{\alpha}_2^i(0,\alpha_1^i)^2}{\sigma},$$

where $\hat{\alpha}_2^i$ is a function of m_2 and α_1^i determined by (17)-(19). From (17) we have that $\hat{w}_2^i(0,\alpha_1^i)=v(c)-f-\hat{\alpha}_2^i(0,\alpha_1^i)$. Then, by substituting $\hat{w}_2^i(0,\alpha_1^i)$ into (19) we may write

$$\hat{\alpha}_2^i(0,\alpha_1^i)=\frac{1}{2}+(2\alpha_1^i-1)\frac{\sigma s}{3}$$

Thus, $\partial\hat{\alpha}_2^i(0,\alpha_1^i)/\partial\alpha_1^i=2\sigma s/3$ and $\partial^2\hat{\alpha}_2^i(0,\alpha_1^i)/(\partial\alpha_1^i)^2=0$. Therefore,

$$\frac{\partial^2 \hat{\pi}_2^i}{(\partial \alpha_1^i)^2}(0,\alpha_1^i)=\frac{2}{\sigma}\left(\frac{\partial \hat{\alpha}_2^i}{\partial \alpha_1^i}(0,\alpha_1^i)\right)^2=\frac{8\sigma s^2}{9}$$

It follows that,

$$\left(\frac{\partial^2 \bar{\bar{\pi}}^i}{(\partial w_1^i)^2}\right)_{m_1=m_2=0} = -2\sigma+\delta\left(\frac{8s^2\sigma^3}{9}\right)$$

Therefore, network *i's* full-period profits are strictly concave in w_1^i when $m_1=m_2=0$ if and only if $(\delta/9)(s^2/\tau^2)<1$. Moreover, it is then also strictly concave in w_1^i when m_t is close enough to zero because of *q, q′,* and *q′′* are bounded.

Let us now show that no cornered-market equilibrium exists. Consider the first period and 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, $\hat{\Pi}^i=F_1^i-f+\delta\hat{\pi}_2^i(m_2,1)$ and $\hat{\Pi}_{ND}^j=\delta\hat{\pi}_2^j(m_2,0)$ (where *ND* means no deviation.) However, if network *j* charged $p_1^j=c$ and $F_1^j=F_1^i+\varepsilon$, then for ε small enough the first-period profits of network *j* would be $\pi_1^j\cong(F_1^j-f)/2\geq\varepsilon/2>0$, and its full-period profits:

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

where *D* means deviation. Then,

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

From above we know that $(F_1^j - f)/2 \geq \varepsilon/2 > 0$ and from the previous analysis we know that $\partial \hat{\pi}_2^i (0, \alpha_1^i)/\partial \alpha_1^i > 0$, then because of q and q' are bounded we have that $\hat{\pi}_2^j (m_2, 1/2) - \hat{\pi}_2^j (m_2, 0) > 0$ for m_2 small enough, which we assume in order to assure the equilibrium existence. We thus may conclude that $\hat{\Pi}_D^j - \hat{\Pi}_{ND}^j > 0$, a contradiction. Now, suppose network i corners the market in the second period. Then, $p_2^i = c$ and $\pi_2^i = F_2^i - f \geq 0$, whereas $\pi_2^j = 0$. However, if network j charged $p_2^j = c$ and $F_2^j = F_2^i + \varepsilon$, then for ε small enough, j*'s* profits would be $\pi_2^j \cong (F_2^i - f)/2 \geq \varepsilon/2 > 0$, which is a contradiction (the second-period analysis is identical to that of the static case.)

In order to check the uniqueness of the equilibrium we use the Index Condition, which is to the best of our knowledge the weakest criterion to show uniqueness in smooth games. The Index Condition only requires that the determinant of the Jacobian matrix of the gradient of the payoff mapping is positive whenever the payoffs are bounded. In this sense, define the following matrix *J:*

$$J_t = \begin{bmatrix} \dfrac{\partial^2 \pi_t^i (w_t^i, w_t^j)}{(\partial w_t^i)^2} & \dfrac{\partial^2 \pi_t^i (w_t^i, w_t^j)}{\partial w_t^i \partial w_t^j} \\ \dfrac{\partial^2 \pi_t^j (w_t^i, w_t^j)}{\partial w_t^j \partial w_t^i} & \dfrac{\partial^2 \pi_t^j (w_t^i, w_t^j)}{(\partial w_t^j)^2} \end{bmatrix}$$

From the previous analysis if $m_1 = m_2 = 0$ we may write that

$$\frac{\partial^2 \overset{=}{\pi}{}_2^i}{\partial w_2^i \partial w_2^j} = \sigma$$

and,

$$\frac{\partial^2 \overset{=}{\pi}{}^i}{\partial w_1^i \partial w_1^j} = \sigma - \delta \frac{8 s^2 \sigma^3}{9}$$

For a one-period game the uniqueness theorem requires $|J|>0$. Consider first the second period, if m_1 and m_2 are close enough to zero:

$$J_2 = \begin{bmatrix} -2\sigma & \sigma \\ \sigma & -2\sigma \end{bmatrix}$$

Therefore, $|J_2|=3\sigma^2>0$. Consider now the first period, and m_1 and m_2 close enough to zero, then

$$J_1 = \begin{bmatrix} -2\sigma + v & \sigma - v \\ \sigma - v & -2\sigma + v \end{bmatrix},$$

where $v=\delta(8/9)s^2\sigma^3$. Therefore, $|J_1|>0$ if and only if $v<3\sigma/2$, that is, if and only if, $(\delta s^2/9\tau^2)<3/4$. Finally, provided that m_1 and m_2 are close enough to zero and that $(\delta s^2/9\tau^2)<3/4$ the condition of existence and the condition of uniqueness are satisfied in every period, and hence the two-period game has a unique subgame perfect equilibrium (see Brown, Chiang and Yakamoto, 1991).

Proof of Proposition 2

Rewrite the equilibrium second-period profits as

$$\hat{\pi}_2^i(m_2, \alpha_1^i) = (\hat{\alpha}_2^i)^2 \left[\frac{1}{\sigma} - m_2 (q(\hat{p}_2^i) - q(\hat{p}_2^j)) \right], \tag{23}$$

where $\hat{\alpha}_2^i$ and $\hat{p}_2^i$ are determined as a function of m_2 and α_1^i by (17)-(19). By differentiating (23) with respect to α_1^i we can write

$$\frac{\partial \hat{\pi}_2^i}{\partial \alpha_1^i}(m_2, \alpha_1^i) = \left[2\hat{\alpha}_2^i \left(\frac{1}{\sigma} - m_2 \left(q(\hat{p}_2^i) - q(\hat{p}_2^j) \right) \right) + (\hat{\alpha}_2^i)^2 (m_2)^2 (q'(\hat{p}_2^i) + q'(\hat{p}_2^j)) \right] \frac{\partial \hat{\alpha}_2^i}{\partial \alpha_1^i}(m_2, \alpha_1^i)$$

Therefore, in a symmetric equilibrium,

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

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

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

Then, by using (12) we have that

$$\hat{\Pi}''(0) = -\frac{\delta}{2}\psi''(0) = \frac{\delta s\sigma}{9}(-q'(c)) > 0$$

Then, starting from $m_1=m_2=0$, any small increase/decrease in m_2 increases the total profits. On the other hand, from (11) we have that in a symmetric equilibrium $\partial\hat{F}_1^i(0,0)/\partial m_2 = -\delta\psi'(0)$ and that $\partial^2\hat{F}_1^i(0,0)/(\partial m_2)^2 = -\delta\psi''(0)$. Further, from above we know that in such an equilibrium $\psi'(0)=0$ and $\psi''(0)<0$. Then, in a symmetric equilibrium $\partial\hat{F}_1^i(0,0)/\partial m_2 = 0$ and $\partial^2\hat{F}_1^i(0,0)/(\partial m_2)^2 > 0$. Thus, 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 markup level since $\alpha_t^i = 1/2 \;\; \forall t,\, i.$ Fixed fees do not have any impact on total welfare either because of the full-participation assumption; any small departure from cost-based access charges reduces thus total welfare since it is maximal when usage prices are cost-based. From the previous analysis we know that firms increase their profits when the second-period access price departs from the marginal cost. Therefore the consumers' surplus must decrease with any small increase or decrease of the second-period access price with respect to the marginal cost level. The first-period access price does not have any impact on second period surpluses because the market share is always one-half in the equilibrium. Finally, in the symmetric equilibrium the firms' profits are neutral with respect to the first-period access price, but since the total welfare decreases with any small departure from cost-based access charges, the consumer surplus must also decrease.

Proof of Proposition 4

From Lemma 2 it is easy to characterize both the first-period fixed fees and the full-period profits. First, note that from (15)-(16) we have that $\hat{\Pi}'(0) = \partial\hat{F}_1(0,0)/\partial m_2 = 0$. Further, from the proof of Proposition 2 we know that $\psi''(0) = (2s\sigma/9)q'(c)$, thus by Lemma 2 we may write

$$\hat{\Pi}''(0) = \frac{1}{2}\frac{\partial^2\hat{F}_1^i}{(\partial m_2)^2}(0,0) = \frac{\delta s}{18\tau}\left(1-\frac{s}{\tau}\right)(-q'(c)),$$

where we have used the fact that $\sigma=1/2\tau$. Therefore, both full-period profits and first-period fixed fees are strictly convex in m_2 at $m_1=m_2=0$, because $s<\tau$ by assumption. Then, $\hat{\Pi}''_{RE}(0)=(\delta s\sigma/9)(1-s/\tau)(-q'(c))$ and from Proposition 2 we have that $\hat{\Pi}''_{NE}(0)=(\delta s\sigma/9)(-q'(c))$, it follows that

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

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