Bilateral monopoly in telecommunications: bargaining over fixed-to-mobile termination rates

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Abstract

It is broadly accepted that mobile network operators are monopolists when they set the termination rate for the calls made to their own network. This is the main rationale under the regulatory activity in most European countries. Indeed, if left unregulated, fixed-to-mobile termination rates would be set too high, mainly because of two reasons: first, the mobile-to-fixed termination rates are usually regulated at cost, and second the fixed network operator has the obligation to terminate the incoming calls. So fixed provider can neither threaten to raise the mobile-to-fixed termination charge, nor to refuse to terminate the call. We propose a policy to overcome this termination bottleneck imposing reciprocity between the mobile-to-fixed and fixed-to-mobile termination rates and relaxing the interconnection obligation. To solve the model we set-up simultaneous negotiations over the termination rates between the network operators. We show that fixed-to-mobile termination rates depend negatively on the mobile-to-mobile termination rate and positively on the intensity of competition in the mobile sector. Moreover, imposing reciprocity on termination rates total welfare increases with respect to the common regulatory setup.

Keywords: Telecommunications, Regulation, Access pricing, Bargaining, Network competition, Two-way access

JEL Classification: L51, L96

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1 Introduction

Call termination can only be supplied by the network provider to which the called party is connected. Since there are no demand nor supply-side substitutes for call termination on an individual network, each network constitutes a separate relevant market and each network has a monopolistic position on the market for terminating calls on its network. Furthermore, a mobile provider can raise its access price without loosing any customers. Indeed, the termination rate is normally passed on to the final customers and under the calling party pays (CPP) principle [1], only the calling party pays the call. Then they are indifferent to the termination charge set by their network provider and they have no incentive to change provider when those charges are raised.[2]

All over Europe the mobile-to-fixed (MTF) termination rate has been always regulated because until few years ago the fixed network operator (FNO) was the monopolist and the only owner of the telephone network and would have been easy to raise the MTF termination rate well above the cost of terminating the call. Moreover, even though nowadays the telephone market seems to be very competitive thanks to the presence of many mobile network operators (MNO) and the frequent entry of new operators (e.g. the recent entry of Hutchinson 3G in the British and Irish market), there are bottlenecks where the mobile operators can exercise their market power and fix monopoly prices. Therefore, when FNO and MNO negotiate the fixed-to-mobile (FTM) termination rate, MNO does not face any countervailing buyer power and can set a monopolistic termination rate. Indeed, FNO cannot threaten to raise its termination rate because it is already regulated and cannot threaten not to purchase termination because of the obligation to terminate all the incoming calls. And since MNO is a monopolist because it is the only network able to reach the receiving party and terminate the call, this gives to MNO the power to fix any access price.

A recent investigation carried out by Ofcom, the British telecom regulator, is a very useful example. When Hutchinson 3G entered the mobile markets in Britain and Ireland, the respective regulatory authorities said that the fixed telephone incumbent operators in Britain and Ireland lacked sufficient countervailing bargaining power to restrain the exercise of monopoly power by Hutchinson 3G. In particular, Ofcom wrote[3]:

> Countervailing buyer power exists when a particular purchaser of a

[1] This principle is prevailing in EU. In US prevails the receivers pays principle.

[2] Though, if positive externalities from receiving calls are taken into account, customers care about incoming calls and thus have an incentive to switch network if termination rates are set too high.

[3] See the report of Ofcom "Wholesale mobile voice call termination" pag. 33, at `http://www.ofcom.org.uk/consult/condocs/mobilecallterm/`

> good or service is sufficiently important to its supplier to influence the price charged for that good or service. In order to constrain the price effectively, the purchaser must be able to bring some pressure to bear on the supplier to prevent a price rise by exerting a credible threat, for example not to purchase [...] In theory, BT might credibly threaten not to purchase termination from an MNO and this would deprive the MNO of the pricing freedom that it derives from its monopoly over termination. In practice, this issue is irrelevant since BT, even if it did have buyer power, has not been able to exert it because of its obligation to complete all calls whatever the terminating network.

Thus, the interconnection obligation deprives the incumbent FNO of all the countervailing power in the negotiation with the entrant.

Currently, there is no common practice in the European countries on how the termination rates are treated. For example, in the UK, alternative fixed-line operators' charges are based on the cost of BT. The Belgian regulatory authority approved asymmetric termination charges. Many countries adopt the principle of reciprocal termination charges as result either of decisions of the national telecom regulatory authority or negotiated agreement between the parties. In France, for example, reciprocal termination charges are imposed.

In this paper we propose a regulatory approach and we relax the interconnection obligation. We let the fixed and the mobile network operators negotiate a reciprocal MTF and FTM termination rate. In some countries telecom authorities allow the parties to negotiate termination charges. For example, the Hong Kong Telecommunications Authority in 2007 allowed "the network operators to negotiate the terms and conditions of mutually acceptable interconnection arrangements".[4] Also in Ireland and Iceland (and in nordic countries before the decision of the national regulatory authorities to regulate industry access prices) FTM charges are freely negotiated between the actors. In this paper we model these negotiations as Nash bargaining and the termination charges are the Nash bargaining solutions.

Related literature In the last years a large literature on two-way access pricing in telecommunications has emerged from the seminal papers of Armstrong (1998) and Laffont et al. (1998b). They build a framework where mobile network operators price discriminate between on-net and off-net calls and agree to a high reciprocal access price for terminating off-net calls. Gans and King (2001) correct their analysis and find that, under price discrimination and non-linear pricing, two networks negotiate an access price below cost. From these papers, many are the extensions that have been considered. Jeon et al. (2004), Berger (2005) and Armstrong and Wright

[4] See the report of (2007), "Deregulation of Fixed-Mobile convergence", available at `www.ofta.gov.hk/en/tas/others/ta20070427.pdf`.

(2009) introduce call externalities in the standard model. The first two assume that the consumers receive some utility when receiving a call; the latter consider the externality linear in the quantity of incoming calls. Jeon et al. (2004) also consider the receiver pays principle and find the optimal prices in this case. Peitz (2005), Hoernig (2007) and Hoernig (2009) find the equilibrium prices in a asymmetric setting.

The literature on telecommunications has captured the lack of countervailing power of FNO with respect to MNO modeling that access price as fix monopolistically by the MNO. And even though many papers have studied the formation of the mobile-to-mobile termination rates and their effect on the intensity of the competition in the market, there are very few papers that focus their attention on the FTM access price. For example, Armstrong and Wright (2009) model the FTM calls and consider a setting with two MNOs and one FNO and they introduce substitutability between FTM and MTM calls. In particular, they assume that the mobile networks operator can set monopolistically the access price to be charged to the fixed network for terminating FTM calls. Valletti and Houpis (2005) analyze the determination of the FTM termination rate and they show that the welfare maximizing access charge depends on the intensity of competition in the mobile sector.

In this paper we consider a similar set-up (two MNOs and one FNO) and we allow the parties to negotiate over the access prices. We consider a two stage model where, first, the network operators negotiate over access prices in the different regulatory scenarios and second, given the access prices previously determined, they compete in the final market and set the optimal retail prices for the costumers. The contribution to the literature is the first stage. We set three different and simultaneous negotiations to determine the termination rate for each call. When a negotiation fails, there is an interconnection breaks down. In this case the subscribers of one network cannot call the subscribers of the other network, then they do not have the utility from making that calls and marginal subscribers will switch provider.

A first attempt to model a negotiation over the termination rates is Binmore and Harbord (2005). They consider a very simple negotiation between the incumbent FNO and an entrant MNO to determine the termination rate, with exogenous market share. They assume that FTM retail prices are regulated, that implies that the quantity of FTM calls is independent of the termination rate. They find that the negotiated access price will lie between the marginal cost and the monopoly price. Their model is not satisfactory because they do not take into account, for example, competition among mobile networks, that is instead, a very important feature in our model.

In section 2 we explain the model; in section 3 we consider the most common regulation situation in Europe and we solve the model. In section 4 we propose a regulation approach and we find again the equilibrium access prices. In section 5 we consider the possibility of re-routing the call via a third network and section 6 concludes.

2 The model

The following model adopts a standard framework of two-way interconnection à la Laffont et al. (1998b) between symmetric networks in which two mobile networks called $i = 1, 2$ offer mobile telephone services. Mobile subscribers are assumed to be identical in term of demand calls to the other subscribers. Under balancing calling pattern, when a subscriber j faces a per-minute charge p for calling a subscriber k, she will choose to make $q(p)$ minutes of calls to k. This means that each subscriber calls any other subscriber with the same probability, independent of which network they belong to. The two mobile telecommunications networks are situated at the extreme points of a Hotelling line, with network 1 at point 0 and network 2 at point 1.

In addition to this framework, and this is a new element in the literature, there is a fixed-line network that generates a demand for fixed-to-fixed and fixed-to-mobile calls.[5]

2.1 Costs

Each mobile network supports a fixed cost per client f and has constant marginal costs of originating a call c_O and of terminating a call c_T. Mobile network i chooses an industry-wide mobile-to-mobile termination charge denoted by a.

The fixed network supports a fixed cost per client F and has constant marginal cost of originating a call C_O and of terminating a call C_T. In order to terminate the MTF calls, MNO i has to pay an access price A_{iF} and FNO has to pay A_{Fi} to terminate FTM calls to a subscriber of MNO i.

2.2 Market shares

Denote the market share of mobile network i by s_i, and assume that the whole market is covered, then $s_1 + s_2 = 1$. Firms set multi-part tariffs and price discriminate between on-net and off-net calls. Mobile network i's prices for on-net, off-net and MTF calls and the fixed fee are respectively p_{ii}, p_{ij}, p_{iF} and r_i, with $i, j \in \{1, 2\}, j \neq i$. A

[5] In the model only one FNO is considered, even though is always more often possible to choose among several alternative fixed operators. We assume only one fixed network because in most of the European countries the incumbent accounts for more than 80% of the market share (and many times more than 90%). See ERG (2007), "Common Position on symmetry of fixed call termination rates and symmetry of mobile call termination rates" available at http://erg.ec.europa.eu/doc/publications/erg_07_83_mtr_ftr_cp_12_03_08.pdf.

mass 1 of consumers is distributed uniformly along the Hotelling line. Consumers receive utility by making and receiving calls. These externatilities are linear in the quantity of received calls. In particular, we assume that consumers only obtain utility from receiving fixed-to-fixed, FTM and MTF calls.

There are two main reasons to consider only the externalities for these calls. First, with mobile-to-mobile externalities we can't find an explicit solution of the market share in the asymmetric case. For example, Hoernig (2009) considers a economy with n asymmetric mobile networks and finds an implicit condition for the market share in equilibrium. In our model we need an explicit expression of the market share in order to maximize the product of the profits in the determination of the access price for the FTM calls.

Second, the existence of the externalities in the FTM and MTF calls explains some very important and interesting features of the model (an interconnectivity break down changes the utility subscribers obtain because they do not receive fixed calls anymore and this makes switch provider to the marginal subscribers). And furthermore, the presence of mobile-to-mobile externalities does not add anything either to the analysis of the FTM access prices or to the results about the mobile-to-mobile access price present in the literature.

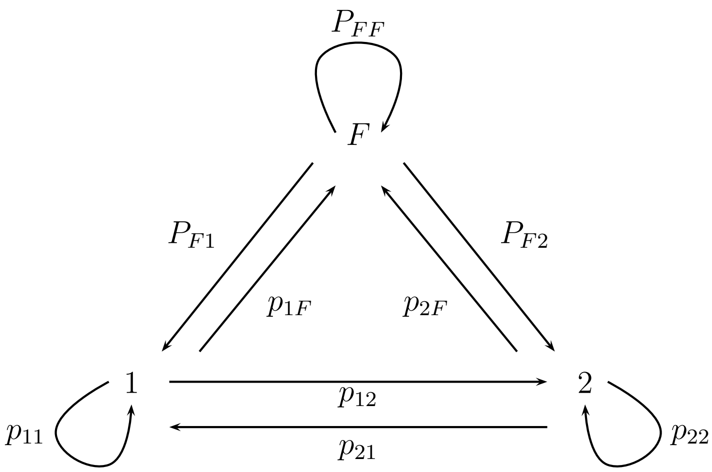


Figure 1: Mobile and fixed calls

Consumers' utility of calls is $u(q)$, with indirect utility $v(p) = \max_p u(q) - pq$, so that $v(p) = -q(p)$. Let v_{ij}, v_{iF}, q_{ij}, u_{ij} be defined as $v(p_{ij})$, $q(p_{ij})$, $u(p_{ij})$. The utility of receiving mobile calls is bq, where $b \in [0, 1]$. Let v_{iF} and q_{iF} denote the indirect utility and the quantity of calls from mobile network i to the fixed network. The utility of receiving fixed calls is BQ, where $B \in [0, 1]$. Finally, let V_{FF}, V_{Fi}, Q_{FF}, Q_{Fi} be defined as $V(P_{FF})$, $V(P_{Fi})$, $Q(P_{FF})$, $Q(P_{Fi})$. These denote the indirect utility from making fixed on-net calls, indirect utility from making fixed calls to mobile network i, quantity of on-net fixed calls and quantity of off-net fixed calls to network i, respectively. Figure 1 depicts the retail prices in the industry.

The utility from joining network i w_i is given by

$$w_i = s_i v_{ii} + (1 - s_i) v_{ij} + v_{iF} + BQ_{Fi} - r_i, \tag{2.1}$$

The indifferent consumer is located at s_i such that:

$$w_i - ts_i = w_j - t(1 - s_i), \tag{2.2}$$

where t represents the degree of product differentiation in the market for mobile subscribers.

2.3 Timing

A two stage game is considered, where first networks bargain over the access prices. The MNOs negotiate a reciprocal access price denoted by a and the FNO negotiates an access price A_{Fi} with MNO i, in order to terminate FTM calls. These three negotiations are simultaneous. In subsection 3.3 we will explain in details the characteristics of the negotiations. Formally, each pair of networks delegates the choice of the access price to an agent. Each pair of agent chooses the access price that maximizes the product of the net profits of the parties, taking as given the results of the other negotiations. In other words, this is a Nash equilibrium in Nash bargaining solutions, introduced by Davidson (1988) and Horn and Wolinsky (1988).

Second, once the access prices are set, each network decides a multi-part tariff that includes a fixed fee, a price for on-net calls and a price for the off-net calls to the two other networks. Once the prices are set, the consumers join the MNO that gives them the higher utility.

We look for the subgame perfect equilibrium of the game and we solve the game by backward induction. Hence, we will start computing the equilibrium retail prices and the equilibrium profits of both MNOs and FNO, in order to be able to build the negotiation processes. Afterwords, we will compute the outside options and find the equilibrium access prices.

2.4 Profits functions

The profits of the MNO i are given by retail profit from supplying service to its subscribers, the profit from providing termination for the rival mobile network, and the profit from providing termination for the fixed network. In particular:

$$\begin{aligned}
\pi_i = s_i\Big[& r_i - f && \text{fixed fee minus fixed cost}\\
& + s_i(p_{ii} - c_O - c_T)q_{ii} && \text{profits from on-net calls}\\
& + (1 - s_i)(p_{ij} - c_O - a)q_{ij} && \text{profits from mobile off-net calls}\\
& + (1 - s_i)(a - c_T)q_{ji} && \text{profits from terminating mobile calls}\\
& + (A_{Fi} - c_T)Q_{Fi} && \text{profits from terminating FTM calls}\\
& + (p_{iF} - c_O - A_{iF})q_{iF}\Big] && \text{profits from MTF calls}
\end{aligned}$$

or, following the notation of Hoernig (2009):

$$\pi_i = s_i\Big[\sum_{j=1,2} s_j R_{ij} + r_i - f + F_i\Big], \tag{2.3}$$

where $R_{ij} = (p_{ij} - c_O - a)q_{ij} + (a - c_T)q_{ji}$ are the profits from calls between networks i and j. When $j = i$ it simplifies to $R_{ii} = (p_{ii} - c_O - c_T)q_{ii}$. Furthermore, $F_i = (p_{iF} - c_O - A_{iF})q_{iF} + (A_{Fi} - c_T)Q_{Fi}$.

The profits of the FNO are given by retail profit from supplying service to its subscribers and the profit from providing termination for the mobile networks:

$$\begin{aligned}
\pi_F = & R - F && \text{fixed charge - fixed charge}\\
& + (P_{FF} - C_O - C_T)Q_{FF} && \text{profits from FTF calls}\\
& + s_1(P_{F1} - C_O - A_{1F})Q_{F1} && \text{profits from FTM calls to MNO 1}\\
& + s_2(P_{F2} - C_O - A_{2F})Q_{F2} && \text{profits from FTM calls to MNO 2}\\
& + s_1(A_{1F} - C_T)q_{1F} && \text{profits from terminating MTF calls of MNO 1}\\
& + s_2(A_{2F} - C_T)q_{2F} && \text{profits from terminating MTF calls of MNO 2}
\end{aligned}$$

or:

$$\pi_F = R - F + R_{FF} + s_1 M_1 + s_2 M_2, \tag{2.4}$$

where $R_{FF} = (P_{FF} - C_O - C_T)Q_{FF}$ are the profits from fixed-to-fixed calls and $M_i = (P_{Fi} - C_O - A_{Fi})Q_{Fi} + (A_{iF} - C_T)q_{iF}$ are the profits from fixed-to-mobile calls plus the mobile-to-fixed termination profits.

2.5 Regulation

In this paper we will consider several different regulation set-ups. First, we will consider the most common situation in Europe in which the MTF termination rates are regulated at the cost of terminating a MTF call and the MTM termination rate is reciprocal.

Second, we will propose a new regulatory approach. We will consider reciprocity where each pair of networks fix a unique access price to terminate the respective calls. We will extend the model including the possibility of re-routing the call.

3 Benchmark

In this section we consider the most common situation in Europe where MTF termination rates are regulated at the cost of terminating a MTF call and the MTM termination rate is reciprocal, as depicted in Figure 2.

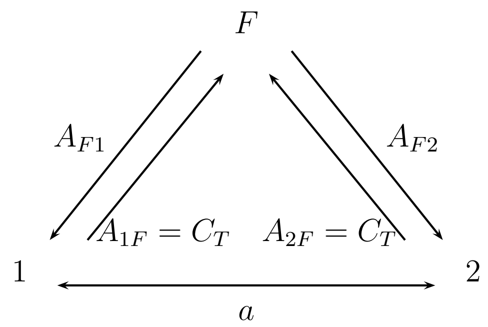


Figure 2: Access prices

3.1 Mobile network operator

First we look for the equilibrium prices in the retail market for the MNO.

3.1.1 Equilibrium retail prices of MNO

In order to determine the equilibrium call prices, we follow the standard procedure of first keeping market shares s_i constant and solving (2.2) for r_i and substitute this into the profits in (2.3). Maximizing the latter with respect to the prices we derive the optimal retail prices. Second, taking the call prices and the fixed fee of the rival networks as given, we maximize (2.3) taking s_i as a function of the rental charge r_i.

Proposition 3.1. *The equilibrium retail prices for MNO i are:*

$$\begin{aligned} p_{ii} &= c_O + c_T, \\ p_{ij} &= c_O + a, \\ p_{iF} &= c_O + A_{iF}. \end{aligned}$$

Proof. See Appendix. □

With multi-part tariff the mobile networks set prices equal to the perceived marginal cost. In such way consumers' surplus is maximized and the networks extract it through the fixed fees according to the intensity of competition. Indeed, when the firm is a monopolist, it is able to extract all the rent through the fixed fee; in a oligopoly the firms compete on the fixed fee and are able to extract just a part of the surplus generated.

3.1.2 Equilibrium fixed fee of MNO

Now we determine the equilibrium fixed fees. We take the call prices and the fixed fees of the rival network as given and we maximize the profits in (2.3) considering s_i as a function of the rental charge r_i.

Proposition 3.2. *The equilibrium rental charge of MNO i is:*

$$r_i = f - (1 - 2s_i)(a - c_T)\hat{q} - (A_{Fi} - c_T)Q_{Fi} + 2s_i(t + \hat{v} - v). \tag{3.1}$$

Furthermore, the equilibrium profits and market shares of MNO i are:

$$\pi_i = s_i^2\Big[(a - c_T)\hat{q} + 2(t + \hat{v} - v)\Big], \tag{3.2}$$

$$s_i = \frac{1}{2} + \frac{(A_{Fi} - c_T + B)Q_{Fi} - (A_{Fj} - c_T + B)Q_{Fj}}{2[2(a - c_T)\hat{q} + 3(t + \hat{v} - v)]}. \tag{3.3}$$

Proof. See Appendix. □

Notice that when $A_{Fi} = A_{Fj}$ it follows that $Q_{Fi} = Q_{Fj}$ and consequently the market share is equal to 1/2. If the market share is equal to 1/2, the equilibrium rental charge simplifies to [6]

$$r_i = f - (A_{Fi} - c_T)Q_{Fi} + (t + \hat{v} - v)$$

and the profits to

$$\pi_i = \frac{(a - c_T)\hat{q} + 2(t + \hat{v} - v)}{4}.$$

The higher are the profits from terminating a fixed-to-mobile call $(A_{Fi} - c_T + B)Q_{Fi}$, the lower is the rental charge. Indeed, if MNO i reaches a better deal with the FNO over A_{Fi}, it makes more profits and it can subsidize the consumer in the mobile market reducing the fixed fee and, de facto, increasing competition in the mobile market. This waterbed effect (i.e. the phenomenon according to which termination profits accruing from interconnection to the fixed network lead to reductions in prices for mobile retail customers.) is complete because all the termination profits are passed on to the customers.

[6] The rental charge is very similar to the one found in Armstrong and Wright (2009) in equation (12). In my expression there is also the externality. The profits are exactly the same as in Armstrong and Wright (2009) because even though the externalities affect the market share, in the symmetric equilibrium the effects cancel out.

3.2 Fixed network operator

The FNO sets a multi-part tariff. Following the same procedure explained above, first we maximize (2.4) with respect to the optimal retail prices P_{FF}, P_{F1} and P_{F2}. In the second step, since it is monopolist, FNO chooses the profit-maximizing fixed fee extracting all the rent from the subscribers.

The utility from joining the fixed network is:

$$W = V_{FF} + \sum_{j=1,2} s_j V_{Fj} + BQ_{FF} + \sum_{j=1,2} s_j bq_{jF} - R, \tag{3.4}$$

where V_{FF} is the utility derived from making fixed to fixed calls, V_{Fi} is the utility derived from making FTM calls to MNO i, q_{iF} are the MTF calls from MNO i and R is the subscription fee. First, we compute the equilibrium retail prices for the FNO.

Proposition 3.3. *The equilibrium retail prices of the FNO are:*

$$\begin{aligned} P_{FF} &= C_O + C_T - B, \\ P_{F1} &= C_O + A_{F1}, \\ P_{F2} &= C_O + A_{F2}. \end{aligned}$$

Proof. See appendix. □

Second, in order to determine the rental charge, notice that the FNO is monopolist and extracts all the surplus from its subscribers. Then the rental charge to join the FNO is:

$$R = V_{FF} + s_1 V_{F1} + s_2 V_{F2} + BQ_{FF} + s_1 bq_{1F} + s_2 bq_{2F} - W. \tag{3.5}$$

Substituting the equilibrium rental charge in (3.5) and the retail prices into the profits in (2.4), and recalling that A_{iF} is regulated at the cost $A_{iF} = C_T$, it follows:

$$\pi_F = V_{FF} + \sum_{j=1,2} s_j V_{Fj} + bq_F - W - F. \tag{3.6}$$

3.3 Bargaining

I model the negotiation between the network operators as a Nash bargaining problem, and we characterize its equilibrium using the Nash solution. When two operators bargain, they take into account that the other access prices are determined in bargaining between the other network operators and that the three bargaining problems are interdependent.

In particular, if A^*_{Fi} and A^*_{Fj} are the FTM termination rates, the bargaining problem between the two mobile network operators over the MTM access price is described by the following set of payoff pairs:

$$B^{MTM} = \{[\pi_i(a, A^*_{Fi}, A^*_{Fj}), \pi_j(a, A^*_{Fj}, A^*_{Fi})] | a \geq 0, \},$$

and the disagreement point are defined by $d = \{\underline{\pi}_i, \underline{\pi}_j\}$, where $\underline{\pi}_i$ are the profits of MNO i when is not possible to make MTM calls. The Nash bargaining solution to this problem is given by:

$$a^* = \arg\max_a [\pi_i(a, A^*_{Fi}, A^*_{Fj}) - \underline{\pi}_i(A^*_{Fi}, A^*_{Fj})][\pi_j(a, A^*_{Fj}, A^*_{Fi}) - \underline{\pi}_j(A^*_{Fi}, A^*_{Fj})].$$

Note that the two mobile networks are symmetric.

Similarly, the bargaining problem for the determination of the FTM termination rate between MNO i and FNO is described by the following set of payoff pairs:

$$B_i^{FTM} = \{[\pi_i(a^*, A_{Fi}, A^*_{Fj}), \pi_F(a^*, A_{Fi}, A^*_{Fi})] | A_{Fi} \geq 0, \}$$

and the disagreement point are defined by $d = \{\underline{\pi}_i, \underline{\pi}_F\}$, that are the profits of MNO and FNO, respectively, when is not possible to make FTM calls.
The Nash bargaining solution to this problem is given by:

$$A^*_{Fi} = \arg\max_{A_{Fi}} [\pi_i(a^*, A_{Fi}, A^*_{Fj}) - \overline{\pi}_i(a^*, A^*_{Fj})]^{\alpha} [\pi_F(a^*, A_{Fi}, A^*_{Fj}) - \overline{\pi}_F(a^*, A^*_{Fj})]^{1-\alpha}.$$

Following Binmore et al. (1986), we interpret the axiomatic Nash bargaining game as the reduced form of a suitably specified dynamic bargaining game of the type that is studied by Rubinstein (1982).

Besides, we assume that when two networks do not reach an agreement, all the networks know that that negotiation failed and set prices consequently. This means that when the negotiation between FNO and MNO i fails and FTM calls to MNO i are not possible, MNO j changes its four-part tariff according to this.

3.4 Negotiation for a

The MNOs negotiate a reciprocal access price to terminate the mobile-to-mobile calls. To find the reciprocal MTM access price we consider the Nash bargaining solution. Then, they choose the price that maximizes the product of their net profits. Since the MNOs are symmetric, the objective function can be written as follows:

$$\max_a \, [\pi_i(a) - \underline{\pi}_i]^2$$

Denote by π_i the profits that MNO i makes when the an agreement on the access price is reached and off-net calls are possible. Denote by $\underline{\pi}_i$ the profits that MNO i makes when the negotiation fails, there is not agreement about the access prices and consequently is not possible to make MTM calls.

In the next subsection we compute the outside option of MNO i.

3.4.1 Outside options of MNO

When the negotiation breaks down there are not mobile-to-mobile calls. The utility of joining network i now is:

$$\underline{w}_i = \underline{s}_i v_{ii} + v_{iF} + BQ_{iF} - \underline{r}_i.$$

Using the same procedure as above first we solve the new indifference condition for $\underline{r_i}$ and we substitute this into the profits in (3.7). We maximize the latter expression to find the retail prices taking the market share constant. Second, we maximize (3.7) with respect to $\underline{r}_i$. The profits of the MNO can be written as:

$$\underline{\pi}_i = \underline{s}_i \Big[\underline{s}_i R_{ii} + \underline{r}_i - f + F_i \Big], \tag{3.7}$$

where $\underline{x}$ represents the variable x when the interconnection breaks down. In fact, the utility a subscriber obtains joining a network, the fixed part of the multi-part tariff and the profits of the MNOs change. The quantity of minutes of calls depends on the retail prices and we show later that these prices remain constant when one negotiation breaks down.

Proposition 3.4. *When negotiation for a breaks down, the equilibrium retail prices of MNO i are:*

$$p_{ii} = c_O + c_T, \qquad p_{iF} = c_O + c_{iF}.$$

Notice that in the interconnection break down the equilibrium retail prices are equal to the case where the negotiation is successful. This is because these prices still maximize the surplus from on-net calls and MTF calls.
Now we derive the equilibrium rental fee.

Proposition 3.5. *The equilibrium rental charge of MNO i is:*

$$\underline{r}_i = f - (A_{Fi} - c_T + B)Q_{Fi} + 2\underline{s}_i(t - v) \tag{3.8}$$

Furthermore, the equilibrium profits and market shares of MNO i are:

$$\begin{aligned} \underline{\pi}_i &= 2\underline{s}_i^2(t - v), \\ \underline{s}_i &= \frac{1}{2} + \frac{(A_{Fi} - c_T + B)Q_{Fi} - (A_{Fj} - c_T + B)Q_{Fj}}{6(t - v)}. \end{aligned} \tag{3.9}$$

Notice that also in the outside option, when the access prices for the fixed to mobile calls are equal, the market share are symmetric and equal to 1/2.

3.4.2 Bargaining solution

Now is possible to solve the bargaining problem:

$$\max_{a} [\pi_i(a) - \underline{\pi}_i]^2$$

Proposition 3.6. *When the MNOs negotiate the reciprocal access price, the equilibrium access charge is:*

$$a = c_T + \frac{\hat{q}}{\hat{q}'}.$$

Proof. See Appendix. $\square$

Notice that since the first order condition in the symmetric equilibrium does not depend on A, we can solve the negotiation independently from the negotiation for A. This is because in the symmetric case, both MNOs make the same profits from terminating fixed calls and both can lower the fixed fee of the same quantity. The interconnection with the fixed network gives some extra utility to the customers of MNOs and, in the symmetric equilibrium, this extra utility is equal for both MNOs. And since it is equal it does not affect the intensity of competition in the mobile market. Then, whatever will be the FTM termination rate, MNOs determine MTM termination rate independently.

As it is easy to see, the MNOs prefer a access price below cost. This result has been found by Gans and King (2001). They say that low MTM access prices soften competition. Indeed, when MTM access price is below cost off-net calls are cheaper than on-net calls and networks make losses when terminating a call. Besides, the profits of attracting a new consumer are reduced and this makes MNOs more reluctant to compete aggressively for the market share. Then competition is softened and MNOs can increase their profits raising the fix fee.

3.5 Negotiation for A

Each MNO negotiates with the FNO a FTM termination rate. In order to find that access price we consider the Nash bargaining solution. They look for the price that maximizes the product of the net profits:

$$\max_{A_{Fi}} [\pi_i(A_{Fi}) - \overline{\pi}_i]^{\alpha} [\pi_F(A_{Fi}) - \overline{\pi}_f]^{1-\alpha},$$

where $\pi_i(A_{Fi})$ denotes the profits of the MNO when the negotiation is successful, and $\overline{\pi}_i$ denotes the profits of MNO when the negotiation breaks down and is not possible to make FTM calls.

3.5.1 Outside option of the MNO

When the negotiation breaks down, the subscribers of MNO i can not receive any call from the subscribers of the fixed network. Then the subscribers do not obtain the utility from receiving that calls and the networks do not make profits from originating and terminating that calls. The utility from joining MNO i when the negotiation for A_{Fi} breaks down changes and the utility from joining MNO j remains as before. The expressions are:

$$\begin{aligned}\overline{w}_i &= s_i v_{ii} + (1 - s_i) v_{ij} + v_{iF} - \overline{r}_i,\\ \overline{w}_j &= (1 - s_i) v_{jj} + s_i v_{ji} + v_{jF} + BQ_{Fj} - \overline{r}_j.\end{aligned}$$

Notice that the subscribers of both mobile networks may still call the subscribers of the fixed network but subscribers of MNO i can not receive any call from them.
The profits of MNOs modify as follow:

$$\begin{aligned}\overline{\pi}_i &= \overline{s}_i \Big[\overline{s}_i R_{ii} + \overline{s}_j R_{ij} + \overline{r}_i - f + (p_{iF} - c_O - A_{iF}) q_{iF}\Big], \qquad (3.10)\\ \overline{\pi}_j &= \overline{s}_j \Big[\overline{s}_j R_{jj} + \overline{s}_i R_{ji} + \overline{r}_j - f + (p_{jF} - c_O - A_{jF}) q_{jF} + (A_{Fj} - c_T) Q_{Fj}\Big].\end{aligned}$$

Notice that since the negotiation breaks down A_{Fi} does not exist anymore.
Further, $\overline{x}$ represents the variable x in the case of connection breaks down. In fact, the utility a subscriber obtains joining a network, the fixed part of the multi-part tariff and the profits of the MNOs change. The quantity of minutes of calls depends on the retail prices and we show later that these prices remain constant when one negotiation breaks down.
When the negotiation for A breaks down MNOs still set retail prices equal to the perceived marginal cost:

$$p_{ii} = c_O + c_T, \qquad p_{ij} = c_O + a, \qquad p_{iF} = c_O + A_{iF}.$$

The equilibrium fixed fee, profits and market share are the following:

Proposition 3.7. *When the negotiation for A breaks down, the equilibrium rental charges, the profits and the market shares are:*

$$\begin{aligned}\overline{r}_i &= f - (1 - 2\overline{s}_i)(a - c_T)\hat{q} + 2\overline{s}_i (t + \hat{v} - v),\\ \overline{r}_j &= f - (2\overline{s}_i - 1)(a - c_T)\hat{q} - (A_{Fj} - c_T) Q_{Fj} + 2(1 - \overline{s}_i)(t + \hat{v} - v),\\ \overline{\pi}_i &= \overline{s}_i^2 \Big[(a - c_T)\hat{q} + 2(t + \hat{v} - v)\Big],\\ \overline{s}_i &= \frac{1}{2} + \frac{-(A_{Fj} - c_T + B) Q_{Fj}}{2[2(a - c_T)\hat{q} + 3(t + \hat{v} - v)]}.\end{aligned}$$

Note that when the negotiation breaks down $\overline{r}_i > \overline{r}_j$. Indeed, MNO i does not make any termination profits from FNO and cannot subsidize its subscribers. Furthermore, note that the market share of MNO i is smaller than or equal to 1/2. The market share is equal to 1/2 only if $A_{Fj} = c_T - B$. This is the access price that gives zero profits to MNO j. Indeed is equal to the marginal cost minus the externality that the customers obtain from receiving FTM calls and that MNO extract with the fixed fee. Only giving zero profits to MNO j the market shares are equal to 1/2.

3.5.2 Outside option of the FNO

When the negotiation breaks down, the subscribers of FNO cannot make neither receive any call to or from MNO i. Then the subscribers do not have the utility from making and receiving that calls and the fixed network does not make profits from originating and terminating that calls. The profits of the FNO are:

$$\overline{\pi}_F = \overline{R} - F + R_{FF} + \overline{s}_2 \overline{M}_2, \tag{3.11}$$

where where $R_{FF} = (P_{FF} - C_O - C_T)Q_{FF}$ are the profits from fixed-to-fixed calls and $\overline{M}_2 = (P_{F2} - C_O - A_{F2})Q_{F2} + (A_{2F} - C_T)q_{2F}$. Notice that in this case the element M_1 does not appear in (3.11).

The FNO sets a multi-part tariff and extract all the rent from its subscribers. The retail prices are equal to the perceived marginal cost

$$P_{FF} = C_O + C_T - B, \qquad P_{F2} = C_O + A_{F2}.$$

FNO extracts all the rent from its subscribers and, using the fact that A_{iF} is regulated at the cost $A_{iF} = C_T$, its profits are:

$$\overline{\pi}_F = V_{FF} + \overline{s}_2 V_{F2} + bq_F - W - F. \tag{3.12}$$

3.5.3 Bargaining solution

Now is possible to find the access price A_{Fi} that maximizes the product of the net profits of MNO i and FNO:

$$\max_{A_{Fi}} \, [\pi_i(A_{Fi}) - \overline{\pi}_i]^{\alpha} [\pi_F(A_{Fi}) - \overline{\pi}_F]^{1-\alpha}$$

where α is the bargaining power of MNO.

Proposition 3.8. *When MTF termination rate is regulated at cost $A_{iF} = C_T$ and FNO and MNO i negotiate over the FTM termination rate A_{Fi} we obtain:*

$$A_{Fi} = c_T - B \qquad \text{when } \alpha = 0,$$

$$A_{Fi} = c_T - B - \frac{Q_{Fi}}{Q'_{Fi}} \qquad \text{when } \alpha = 1.$$

Proof. See Appendix. □

This means that on the one hand, when the MNO can set arbitrarily the access price, it will choose the monopoly price minus the externality that the subscribers of its network obtain receiving fixed calls. Indeed, a too high access price would reduce below the optimum level the FTM calls, and then MNO takes into account this extra utility and fix a price below the monopoly price. On the other hand, when FNO can make take-it-or-leave-it offers (i.e. $\alpha = 0$), it set the access price such that MNO makes zero profits.

3.6 Comparative statics

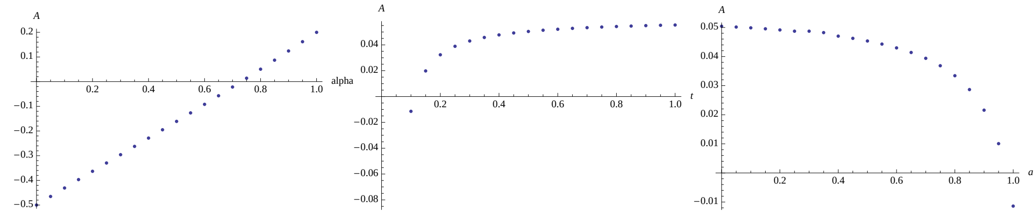
In this subsection we see how the access price varies, changing the differentiation parameters t and the MTM access price a.
Using the implicit function theorem, the derivatives of A with respect to t and a are the following:

$$\frac{dA^*}{dt} = -6\frac{\alpha V_{Fi}[(A_{Fi} - c_T + B)Q'_{Fi} + Q_{Fi}] - (1-\alpha)Q^2_{Fi}(A_{Fi} - c_T + B)}{\frac{\partial F}{\partial A^*}},$$

$$\frac{dA^*}{da}\bigg|_{a=c_T} = 2\hat{q}\frac{\alpha V_{Fi}[(A_{Fi} - c_T + B)Q'_{Fi} + Q_{Fi}] - (1-\alpha)Q^2_{Fi}(A_{Fi} - c_T + B)}{\frac{\partial F}{\partial A^*}}.$$

Numerical example To see the sign of these derivatives and give an intuition of them, it is useful to illustrate them with a specific numerical example. Suppose costs are $c_O = c_T = C_O = C_T = 0.1$, the MTM access price is below cost $a = 0$, the externality from receiving a FTM calls is $B = 0.6$, the degree of differentiation product $t = 0,5$ and the demand functions are $Q_F = 1 - P_F$ and $q_F = 1 - p_F$.[7] We obtain that the derivative of the FTM access price with respect to the network differentiation parameter is positive (Figure 3b) and the derivative with respect to the MTM access price is negative (Figure 3c).
First, let us consider the derivative of A with respect to the degree of product differentiation t. The higher is t, the less willing are consumers to change network. Then, when there is not interconnection with the FNO and the networks are very differentiated (high t), just few customers will change provider. On the contrary, when the networks are homogeneous (small t), if there is not interconnection, almost all costumers want to switch provider. In the latter case, FNO has little incentive to reach an agreement because most of the customers would go to the other network and the subscribers of FNO can keep calling them on the other network (remember

[7] I consider a linear demand function as in Armstrong and Wright (2009). The cost parameters are positive in order to consider MTM access price below cost.



(a) Derivative wrt α (b) Derivative wrt t (c) Derivative wrt a

Figure 3: Comparative statics on FTM access price

that when the two parts are negotiating the access price they assume that the other negotiations succeed). Hence, when t is high, all the consumers remain in their network and FNO's subscribers can not call them anymore. Then, reaching the agreement on the access price greatly increases FNO's profits. In other words, we can say that (increasing t) the marginal contribution of the agreement to the profits of FNO increases (with high t is more important to reach the agreement for FNO), then it is willing even to pay more to have the interconnection. Besides, with high t, MNO looses less consumers when the negotiation breaks down, then it can ask for a higher access price. Hence, the higher is t, the higher is A.
Second, let us consider how A changes when mobile providers raise MTM access price above marginal cost. As we saw in subsection 3.4, since mobile networks prefer a low MTM access price because competition is softened, customers prefer to belong to small networks. When there is not FTM interconnection, some customers will switch provider. If a is high, clients prefer to belong to large networks, then there is more people willing to switch provider in order to belong to the large one.[8] Hence, if, because of regulation or other reasons, the MTM access price increases, MNO is less powerful in the negotiation over A (in case of break down it would loose more customers) and it must charge a smaller price to FNO.
Finally, note that the access price is always increasing on α. Indeed, the more powerful is MNO, the higher will be the access price. The maximum price it can ask is the monopoly price when $\alpha = 1$.

3.7 Welfare

Let us compute the welfare maximizing access price. Let us define it as the sum the utility the consumers obtain making and receiving FTM and MTF calls and the profits of originating and terminating that calls. Hence, the welfare generated by

[8]Analytically, notice that the market share lost in case of break down is increasing in a. Then reaching the agreement is more important when MTM access price is high. Hence the access price decreases.

FTM and MTF calls between MNO i and FNO is:

$$\begin{aligned}W_i =& s_i(P_{Fi} - C_O - A_{Fi})Q_{Fi} + s_i V_{Fi} + s_i B Q_{Fi} + s_i(A_{Fi} - c_T)Q_{Fi} \\ &+ s_i(p_{iF} - c_O - A_{iF})q_{iF} + s_i v_{iF} + s_i b q_{iF} + s_i(A_{iF} - C_T)q_{Fi}.\end{aligned}$$

When A_{iF} is regulated at cost C_T, welfare is maximized when $A_{Fi} = c_T - B$, that is the take-it-or-leave-it offer of FNO.

4 Reciprocity

One of the possible regulatory approaches[9] is to require that interconnecting network operators negotiate termination rates subject to the obligation that these rates are reciprocal. In this section we consider a setting where FNO and MNO have to find an agreement about a reciprocal FTM and MTF termination rate. Figure 4 depicts the regulation approach.

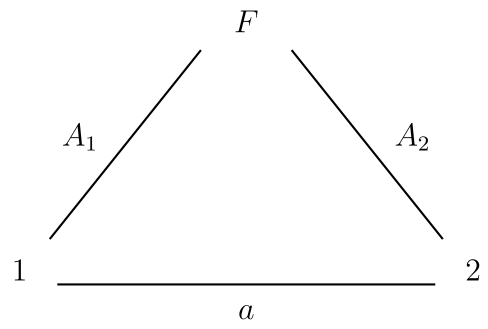


Figure 4: Reciprocal access prices

4.1 Mobile network operator

As before, the profits of MNO i are:

$$\pi_i = s_i \Big[\sum_{j=1,2} s_j R_{ij} + r_i - f + F_i \Big], \tag{4.1}$$

[9]Other arrangements that will not be considered in this paper are uniformity (a network set a termination charge equal for all the others networks), "Bill and Keep" (the termination rates is reciprocal and equal to zero).

In this case, the retail prices are the same as in the case considered in proposition 3.1. Indeed, the equilibrium retail prices are:

$$p_{ii} = c_O + c_T, \qquad p_{ij} = c_O + a, \qquad p_{iF} = c_O + A_i.$$

With reciprocity, the equilibrium fix fee chosen by MNO i is:

$$r_i = f - (1 - 2s_i)(a - c_T)\hat{q} - (A_i - c_T)Q_{Fi} + 2s_i(t + \hat{v} - v). \tag{4.2}$$

Furthermore, the equilibrium profits and the market share are:

$$\pi_i = s_i^2\Big[(a - c_T)\hat{q} + 2(t + \hat{v} - v)\Big], \tag{4.3}$$

$$s_i = \frac{1}{2} + \frac{(A_i - c_T + B)Q_{Fi} - (A_j - c_T + B)Q_{Fj} + (v_{iF} - v_{jF})}{2[2(a - c_T)\hat{q} + 3(t + \hat{v} - v)]}. \tag{4.4}$$

Note that now both indirect utilities v_{iF} and v_{jF} depend on the termination rate and are not necessarily equal.
When $A_i = A_j$, consequently $v_{iF} = v_{jF}$ and $Q_{iF} = Q_{jF}$ and the market share is equal to 1/2. The bigger are the FTM termination profits for MNO i, the bigger will be its market share.
Finally, note that also with reciprocity the waterbed effect is complete.

4.2 Fixed network operator

The profits of the FNO are, as before:

$$\pi_F = R - F + R_{FF} + s_1 M_1 + s_2 M_2, \tag{4.5}$$

The FNO sets a multi-part tariff $(P_{FF}, P_{F1}, P_{F1}, R)$. The equilibrium retail prices are equal to the previous section because these prices maximize the total surplus:

$$P_{FF} = C_O + C_T - B, \qquad P_{F1} = C_O + A_1, \qquad P_{F2} = C_O + A_2.$$

Substituting the equilibrium rental charge and the retail prices into the profits in (4.5) one obtains:

$$\pi_F = V_{FF} + \sum_{j=1,2} s_j V_{Fj} + \sum_{i=1,2} s_j b q_{jF} - W - F + \sum_{i=1,2} s_i(A_i - C_T)q_{iF}. \tag{4.6}$$

Notice that now the MTF termination rate is not regulated and FNO can make profits raising that access price. The difference from the previous case is the last element $\sum_{i=1,2} s_i(A_{iF} - C_T)q_{iF}$ that previously was equal to zero.

4.3 Negotiation for a

The mobile network operators negotiate a reciprocal access price to terminate the MTM calls. To find it we consider the Nash bargaining solution. They maximize the product of their net profits:

$$\max_{a} \, [\pi_i(a) - \overline{\pi}_i]^2$$

In this case the negotiation is similar to the one described in the previous section where the MTF termination rates are regulated at cost. We obtain again a reciprocal MTM access price below cost.

4.4 Negotiation for A

The mobile network operators negotiate a reciprocal access price to terminate the MTF and the FTM calls. To find the reciprocal FTM and MTF access price we consider the Nash bargaining solution. The parts maximize the product of the net profits over the reciprocal access price A_i:

$$\max_{A_i} \, [\pi_i(a^*, A_i, A_j^*) - \overline{\pi}_i(a^*, A_j^*)]^{\alpha}[\pi_F(a^*, A_i, A_j^*) - \overline{\pi}_F(a^*, A_j^*)]^{1-\alpha}$$

4.4.1 Outside option of the MNO

When the negotiation breaks down, the subscribers of MNO i can not make any call to the fixed network operator and the subscribers of the FNO can not call the subscribers of the MNO i. Then the subscribers do not have the utility from making and receiving that calls and the networks do not make profits from originating and terminating that calls. The utility from joining mobile network i and network j are:

$$\begin{aligned} \overline{w}_i &= s_i v_{ii} + (1 - s_i) v_{ij} - \overline{r}_i, \\ \overline{w}_j &= (1 - s_i) v_{jj} + s_i v_{ji} + v_{jF} + BQ_{Fj} - \overline{r}_j. \end{aligned} \tag{4.7}$$

The profits of MNO i modify as follow:

$$\overline{\pi}_i = \overline{s}_i \Big[\sum_{j=1,2} \overline{s}_j R_{ij} + \overline{r}_i - f \Big], \tag{4.8}$$

where $\overline{x}$ represents the variable x in the case of interconnection breaks down. The optimal retail prices are:

$$p_{ii} = c_O + c_T, \qquad p_{ij} = c_O + a.$$

Notice that when the negotiation for A_i fails, is not possible to make MTF calls, then p_{iF} does not exist. The equilibrium fix fees are:

Proposition 4.1. *With reciprocity, when the negotiation for A_i breaks down, the equilibrium fix fees are:*

$$\overline{r}_i = f - (1 - 2s_i)(a - c_T)\hat{q} + 2s_i(t + \hat{v} - v), \tag{4.9}$$
$$\overline{r}_j = f - (2s_i - 1)(a - c_T)\hat{q} - (A_j - c_T)Q_{Fj} + 2(1 - s_i)(t + \hat{v} - v). \tag{4.10}$$

Moreover, the equilibrium profits and market share are:

$$\begin{aligned} \overline{\pi}_i &= \overline{s}_i^2\Big[(a - c_T)\hat{q} + 2(t + \hat{v} - v)\Big], \\ \overline{s}_i &= \frac{1}{2} + \frac{-(A_j - c_T + B)Q_{Fj} - v_{jF}}{2[2(a - c_T)\hat{q} + 3(t + \hat{v} - v)]}. \end{aligned} \tag{4.11}$$

Proof. The proof is very similar to the one of Proposition 3.2. □

Notice that the market share of MNO i is smaller than 1/2. The market share in the outside option is equal to 1/2 only when $A = c_T - B - \frac{v_{iF}}{Q_{Fi}}$, that makes MNO i indifferent between accept or reject the agreement. Then this will be the lowest possible access price that the mobile network will accept.

4.4.2 Outside option of the FNO

When the negotiation breaks down, the subscribers of FNO can not make neither receive any call to or from MNO i. Then the subscribers do not have the utility from making and receiving that calls and the FNO does not make profits from originating and terminating that calls. The profits of the FNO are:

$$\overline{\pi}_F = \overline{R} - F + R_{FF} + \overline{s}_2\overline{M}_2, \tag{4.12}$$

In this case the element M_1 does not appear in (4.12).
The retail prices are equal to the perceived marginal cost and extracts all the rent from the subscribers. Substituting the multi-part tariff in the profits we obtain:

$$\overline{\pi}_F = V_{FF} + \overline{s}_2 V_{F2} + \overline{s}_2 b q_{2F} - W - F + \overline{s}_2(A_2 - C_T)q_{2F}. \tag{4.13}$$

4.4.3 Bargaining solution

Now is possible to solve the bargaining problem and find the reciprocal access price A_i:

$$\max_{A_i} \, [\pi_i(a^*, A_i, A_j^*) - \overline{\pi}_i(a^*, A_j^*)]^\alpha [\pi_F(a^*, A_i, A_j^*) - \overline{\pi}_F(a^*, A_j^*)]^{1-\alpha}$$

With reciprocity, the negotiated FTM and MTF termination rates come from the following first order condition:

$$\alpha\frac{\partial \pi_i}{\partial A_i}(\pi_F - \overline{\pi}_F) + (1 - \alpha)\frac{\partial \pi_F}{\partial A_i}(\pi_i - \overline{\pi}_i) = 0.$$

In order to understand the meaning of this expression, we consider the extreme cases with $\alpha = 0$ (i.e. FNO has all the bargaining power) and $\alpha = 1$ (i.e. MNO has all the bargaining power).

First, let us consider the case $\alpha = 0$. This means that FNO can make a take-it-or-leave-it offer that MNO will accept only if it makes non-negative profits. Hence, FNO solves the following problem:

$$\max_{A_i} \ \pi_F \qquad \text{s.t.} \quad \pi_i - \overline{\pi}_i \geq 0.$$

Evaluating the expression at the symmetric equilibrium, the later expression gives as solutions:

$$A = C_T - b + \frac{Q_F - q_F}{q'_F} \qquad \text{if} \quad \left[(C_T - c_T) + (B - b) + \frac{Q_F - q_F}{q'_F}\right] Q_F + v_F \geq 0 \tag{4.14}$$

$$A = c_T - B - \frac{v_F}{Q_F} \qquad \text{otherwise} \tag{4.15}$$

Notice that if we assume that the cost of terminating a call are similar for MNO and FNO and the externalities of receiving a fixed or a mobile call are the same (i.e. $c_T \approxeq C_T$ and $b \approxeq B$), when $q_F - Q_F > 0$ the condition in (4.14) is always satisfied. Hence, the meaning of the solution is the following. Remember that we are in the case where FNO decides unilaterally the access price. When there are more MTF than FTM calls,FNO has to terminate more calls than MNO. Hence, A is a source of revenue for FNO. Then FNO will prefer a high access price. Indeed, If we consider the extreme case in which there are not FTM calls, $Q_F = 0$ and FNO sets the monopoly price $A = C_T - b - \frac{q_F}{q'_F}$.
In the other case, when there are more FTM than MTF calls, FNO will prefer a low access price in order to pay less for terminating FTM calls. In this case he will fix the lowest possible price that makes MNO indifferent between accepting or refusing the agreement.

Let us consider now the case $\alpha = 1$. This means that MNO can make a take-it-or-leave-it offer that FNO will accept only if it makes non-negative profits. Hence, MNO solves the following problem:

$$\max_{A_i} \ \pi_i \qquad \text{s.t.} \quad \pi_F - \overline{\pi}_F \geq 0.$$

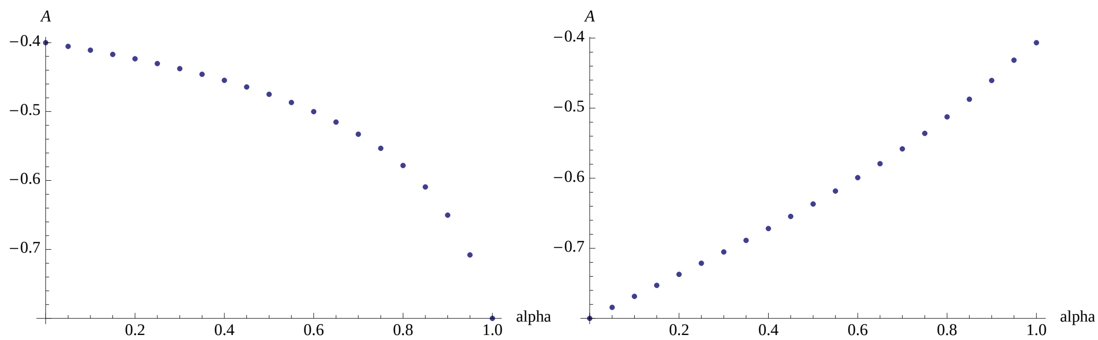
At the symmetric equilibrium we have:

$$A = c_T - B + \frac{q_F - Q_F}{Q'_F} \qquad \text{if} \quad \left[(c_T - C_T) + (b - B) + \frac{q_F - Q_F}{Q'_F}\right] q_F + V_F \geq 0$$

$$A = C_T - b - \frac{V_F}{q_F} \qquad \text{otherwise}$$

This is the analogous to the previous case. When there are more FTM than MTF calls, MNO prefers a high access price in order to increase profits from termination. When, otherwise, there are more MTF than FTM calls, MNO prefers a low access price to allow its subscribers to make cheap MTF calls.

Numerical example: equilibrium reciprocal access prices It is useful to illustrate the results with a specific numerical example. Suppose the MTM access price is $a = 0$, the externality from receiving a FTM calls is $B = 0,6$ and from receiving MTF calls is $b = 0,6$, the network differentiation parameter $t = 0,5$, termination costs $c_T = C_T = 0,1$, and the demand functions are $Q_F = 1 - P_F$ and $q_F = 1 - p_F$. As we explained before, since the access price can be either a cost or a source of revenues, when the MNO has all the bargaining power and makes take-it-or-leave-it offers, may set either a high or a low price. The access price is a cost when MNO originates more MTF calls than the received FTM calls. To capture this feature of the results, we consider two cases. One with low costs of originating a MTF call and high costs of originating a FTM call, and another with high costs of originating a MTF call and low costs of originating a FTM call. In the former case we have fewer FTM calls and then for MNO the access price is a cost. In the latter case, there are many FTM (with respect to MTF calls) and the access price is a source of revenues.



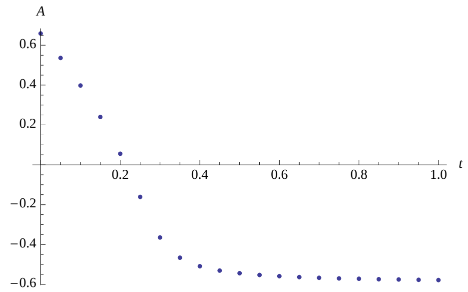
(a) $c_O = 0,1$ and $C_O = 0,3$ (b) $c_O = 0,3$ and $C_O = 0,1$

Figure 5: Reciprocal FTM access price

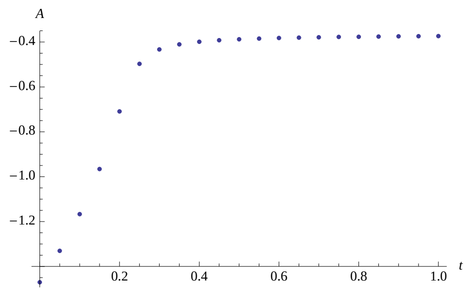
In Figure 5a we consider the first case. Suppose (in addition to the previous assumptions) that $c_O = 0,1$ and $C_O = 0,3$. In this case, there are less FTM than MTF calls. Then, since the access price is a cost for MNO, it will set the lowest possible price. Hence, the access price is decreasing in α, because the more powerful MNO is, the lower is the price is willing to pay.
In Figure 5b we suppose that $c_O = 0,3$ and $C_O = 0,1$. In this case, the access price is a source of revenue for MNO and it will set the highest possible price. Hence, the

access price is increasing in α, because the more powerful MNO is, the higher is the price it may charge to FNO.

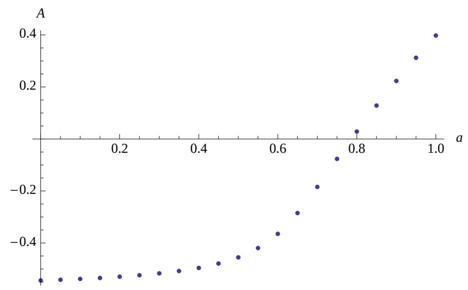
Numerical example: comparative statics The effect of an increase of the degree of network differentiation t depends on whether the access price is seen by MNO as a cost or as a source of revenues. When there are more MTF than FTM calls and then A is a cost for MNO, the higher is t the lower is the reciprocal access price A. Indeed, when t is high, few mobile consumers would change provider in case of interconnection break down. Then, when t is high the agreement increases more the profits of FNO. Hence, FNO charges a lower access price. This is illustrated in Figure 6a. When there are more FTM than MTF calls and A is a source of revenue for MNO, the higher is t the higher is A. The reason is the same as before. Since competition is softened and consumers are locked-in with MNO i, it is more powerful, in the negotiation and can raise the access price. This is illustrated in Figure 6a. Consider now the derivative of A with respect to a. Also in this case



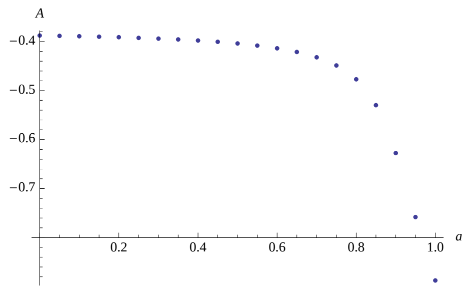
(a) $\frac{dA}{dt}$ when $c_O = 0,1$ and $C_O = 0,3$



(b) $\frac{dA}{dt}$ when $c_O = 0,3$ and $C_O = 0,1$



(c) $\frac{dA}{da}$ when $c_O = 0,1$ and $C_O = 0,3$



(d) $\frac{dA}{da}$ when $c_O = 0,3$ and $C_O = 0,1$

Figure 6: Derivative of A wrt to t

the sign depends on the differential between FTM and MTF calls. On the one had, when there are more FTM than MTF calls, an increase of the MTM access price above cost increases the MTF access price A. This is illustrated in Figure 6c. On the other hand, when there are more MTF than FTM calls, an increase of a provokes a decrease of A as we can see in Figure 6d.

4.5 Welfare

Denote the welfare as the sum of the utilities the consumers obtain making and receiving FTM and MTF calls plus the origination and termination profits for that calls. It can be written as follows:

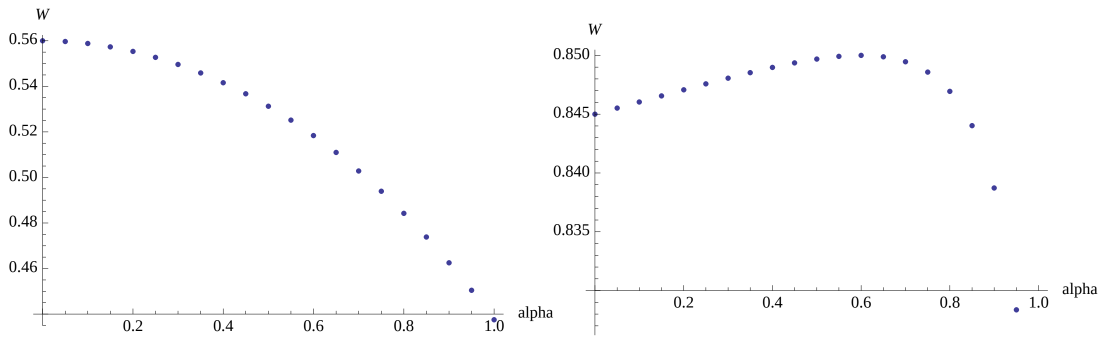
$$
\begin{aligned}
W_i = & s_i(P_{Fi} - C_O - A_i)Q_{Fi} + s_i V_{Fi} + s_i B Q_{Fi} + s_i(A_i - c_T)Q_{Fi} \\
& + s_i(p_{iF} - c_O - A_i)q_{iF} + s_i v_{iF} + s_i b q_{iF} + s_i(A_i - C_T)q_{Fi}.
\end{aligned}
$$

The welfare maximizing reciprocal termination rate is

$$
A = \frac{(c_T - B)Q' + (C_T - b)q'}{Q' + q'}.
$$

This is the sum of the marginal cost (corrected by the externality) weighted for the marginal quantity of MTF and FTM calls. If A has a larger impact of FTM calls, than the welfare maximizing termination rate will be closer to the cost of terminating such call. It means that if an increase of A_i induces a large decrease of FTM calls (and then a decrease of the profits of FNO), then A_i will move towards $c_T - B$ so FNO pays a cheaper (for him) access price and recovers some of the losses.

Numerical example: welfare comparison Is very useful to consider a numerical example to see under which regulatory setting the total welfare is higher. Let us consider again the linear demand functions $Q_F = 1 - P_F$ and $q_F = 1 - p_F$, $t = 0,5$, externalities $B = 0,6$ and $b = 0,6$. We suppose the termination costs are $c_T = C_T = 0,1$, and the origination costs are $c_O = 0,1$ and $C_O = 0,3$. We compute



(a) Welfare with regulated MTF termination rate

(b) Welfare with reciprocal termination rate

Figure 7: Reciprocal FTM access price

the welfare for different values of α. In Figure 7a is plotted the welfare when the MTF termination rate is regulated at cost ($A_{iF} = C_T$) and in Figure 7b is plotted the welfare with reciprocal MTF access price. As we can see, for every value of α the welfare is higher with reciprocal access price. This is because A_{iF} is regulated well above the price the networks would like to pay, because the externalities of receiving a call are not taken into account. If we just impose reciprocity, the networks adjust the price taking into account the externalities the consumers obtain when receiving calls.

5 Re-routing

In this section let us introduce the possibility of re-routing traffic from one provider to the other via the network of the third operator. This feature of the model strongly modify the outside options of the network operator when bargaining the access prices. Indeed, a network, in order to terminate its calls, will not accept an access price greater than the sum of the access prices it should pay to siphon off the calls via the other network.

As in section 3, we consider that the networks negotiate over FTM termination charges and MTF ones are regulated at cost. Then, the profits when the negotiations succeed are the ones calculated the section 3. We compute the outside options and the equilibrium termination rates.

5.1 Negotiation for a

5.1.1 Outside option of MNOs

The profits of the mobile network operator i are:

$$\pi_i = s_i\Big[\sum_{j=1,2} s_j R_{ij} + r_i - f + F_i\Big]. \tag{5.1}$$

Now $R_{ii} = (p_{ii} - c_O - c_T)q_{ii}$, and the profits from off-net calls modify. Let us define $R_{ij} = (p_{ij} - c_O - A_i - A_j)q_{ij} + (A_i - c_T)q_{ji}$. Note that when the negotiation fails, the subscribers of MNO i can still make MTM calls, but their provider has to route the call via the FNO, and then it has to pay the access price to the FNO and to MNO j. Summing up, MNO i supports the cost of originating the call c_O, the MTF access price A_i and the FTM access price in order to reach MNO j A_j.
The retail prices are:

$$\begin{aligned}
p_{ii} &= c_O + c_T,\\
p_{ij} &= c_O + C_T + A_j,\\
p_{iF} &= c_O + C_T.
\end{aligned}$$

Notice that now the off-net price depends on FTM access price A_j. The equilibrium fix fees are:

$$r_i = f - (1-2s_i)(A_i - c_T)\hat{q} - (A_i - c_T)Q_{Fi} + 2s_i(t + \hat{v} - v) = 0. \tag{5.2}$$

Furthermore, the equilibrium profits and the market share are:

$$\pi_i = s_i^2\Big[(A_i - c_T)\hat{q} + 2(t + \hat{v} - v)\Big], \tag{5.3}$$

$$s_i = \frac{1}{2} + \frac{(A_i - c_T + B)Q_{Fi} - (A_j - c_T + B)Q_{Fj}}{2[2(A_i - c_T)\hat{q} + 3(t + \hat{v} - v)]}. \tag{5.4}$$

Note that without the possibility of re-routing we do not have neither MTM calls ($\hat{q}$) nor utility from making MTM calls ($\hat{v}$). Now these elements exist and depend on the FTM access prices A_i and A_j. Also in this case it is easy to note that when $A_i = A_j$, consequently $v_{iF} = v_{jF}$ and $Q_{iF} = Q_{jF}$ and the market share is equal to 1/2.

5.1.2 Bargaining solution

The negotiation can be written as:

$$\max_a \text{ s.t. } \quad [\pi_i(a) - \underline{\pi}_i]^2$$

The first order condition becomes:

$$2s_i\frac{\partial s_i}{\partial a}[(a - c_T)\hat{q} + 2(t + \hat{v} + v)] + s_i^2[(a - c_T)\hat{q}' + \hat{q} - 2\hat{q}] = 0$$

Evaluating the latter expression at the symmetric equilibrium we obtain again that the MNOs choose a MTM termination rate below cost.

5.2 Negotiation for A

5.2.1 Outside option of MNO

The profits of MNOs modify as follow:

$$\overline{\pi}_i = \overline{s}_i\Big[\overline{s}_i R_{ii} + \overline{s}_j R_{ij} + F_i + \overline{r}_i - f\Big]$$

$$\overline{\pi}_j = \overline{s}_j\Big[\overline{s}_j R_{jj} + \overline{s}_i R_{ji} + F_j + \overline{r}_j - f\Big]$$

where

$$
\begin{aligned}
R_{ij} &= (p_{ij} - c - a)q_{ij} + (a - c_T)q_{ji} + (a - c_T)Q_{Fi}, \\
F_i &= (p_{iF} - c_O - C_T)q_{iF}, \\
R_{ji} &= (p_{ji} - c - a)q_{ji} + (a - c_T)q_{ij} + (a - c_T)q_{iF}, \\
F_j &= (p_{jF} - c_O - C_T)q_{jF} + (A_j - c_T)Q_{Fj} + (A_j - c_T)Q_{Fi},
\end{aligned}
$$

Note that now when a subscriber of MNO i calls a FNO's subscriber, MNO i has to siphon off the call via MNO j. Hence, it has to pay an access price in order to transfer the calls to the other mobile network and this latter has to pay an access price to send the call to FNO. The equilibrium retail prices are:

$$
\begin{aligned}
p_{ii} &= c_O + c_T, & & & p_{jj} &= c_O + c_T, \\
p_{ij} &= c_O + a, & &\text{and} & p_{ji} &= c_O + a, \\
p_{iF} &= c_O + C_T & & & p_{jF} &= c_O + C_T
\end{aligned}
$$

The equilibrium fix fees are:

$$
\overline{r}_i = f - (1 - 2s_i)(a - c_T)(\hat{q} + Q_{Fi}) + 2s_i(t + \hat{v} - v) \tag{5.5}
$$

$$
\begin{aligned}
\overline{r}_j = f - (2s_i - 1)(a - c_T)\hat{q} - (A_j - c_T)(Q_{Fj} + Q_{Fj}) \\
+ 2(1 - s_i)(t + \hat{v} - v)
\end{aligned} \tag{5.6}
$$

Notice that now the fixed-to-mobile waterbed effect changes. On the one hand, the termination profits for MNO i accruing from interconnection with FNO are $(1 - 2s_i)(a - c_T)Q_{Fi}$. Since s_i in equilibrium will be smaller or equal than 1/2 (since the MTF and FTM calls will be more expensive), this quantity still affect negatively the fix fee but now the effect is partial because an increase of one unit in the termination profits makes decrease r_i of $(1 - 2s_i) \leq 1$ units. On the other hand, r_j depends negatively on its termination profits and on the termination profits accruing from transferring the fixed calls to MNO i. Without the possibility of re-routing (as in the previous section) the waterbed effect is absent.
Furthermore, the equilibrium profits and market shares are:

$$
\overline{\pi}_i = \overline{s}_i^2 \Big[(a - c_T)(\hat{q} + Q_{Fi}) + 2(t + \hat{v} - v)\Big] \tag{5.7}
$$

$$
\overline{\pi}_j = \overline{s}_j^2 \Big[(a - c_T)\hat{q} + 2(t + \hat{v} - v)\Big]
$$

$$
\overline{s}_i = \frac{1}{2} + \frac{B(Q_{Fi} - Q_{Fj}) - (A_j - c_T)(Q_{Fi} + Q_{Fj})}{2[(a - c_T)(2\hat{q} + Q_{Fi}) + +3(t + \hat{v} - v)]} \tag{5.8}
$$

Note that, since in equilibrium $P_{Fi} \geq P_{Fj}$, then there will be less FTM calls to MNO i than to MNO j (i.e. $Q_{Fi} \leq Q_{Fj}$). This means that the market share s_i will be always smaller than 1/2.

5.2.2 Outside option of FNO

The profits of FNO are:

$$\overline{\pi}_F = \overline{R} - F + R_{FF} + \overline{s}_1\overline{M}_1 + \overline{s}_2\overline{M}_2, \tag{5.9}$$

where $R_{FF} = (P_{FF} - C_O - C_T)Q_{FF}$ are the profits from fixed-to-fixed calls; $\overline{M}_1 = (P_{F1} - C_O - a - A_2)Q_{F1}$ are the profits from making calls to MNO i. Note that the total cost of a call is the sum of the originating cost, the access price to the network of MNO j and the access price to the network of MNO i.
Finally, $\overline{M}_2 = (P_{F2} - C_O - A_2)Q_{F2}$are the profits from making calls to MNO j.The retail prices are:

$$\begin{aligned} P_{FF} &= C_O + C_T - B, \\ P_{F1} &= C_O + a + A_2, \\ P_{F2} &= C_O + A_2. \end{aligned}$$

The FNO extracts all the rent from the customers and the profits are:

$$\overline{\pi}_F = V_{FF} + \sum_{j=1,2} \overline{s}_j V_{Fj} + \sum_{j=1,2} \overline{s}_j b q_{jF} - W - F.$$

5.2.3 Bargaining solution

The bargaining problem is:

$$\max_{A_i} \quad \text{s.t.} \quad [\pi_i(A_i) - \overline{\pi}_i]^\alpha [\pi_F(A_i) - \overline{\pi}_F]^{1-\alpha}.$$

Proposition 5.1. *With re-routing and $a = c_T$, the FTM termination rate lies between the following values:*

$$\begin{aligned} A_{Fi} &= c_T - B\frac{Q_{Fi} - Q_{Fj}}{Q_{Fi} + Q_{Fj}} && \textit{when} \quad \alpha = 0, \\ A_{Fi} &= c_T - B - \frac{Q_{Fi}}{Q'_{Fi}} && \textit{when} \quad \alpha = 1. \end{aligned}$$

Proof. See appendix. □

5.2.4 Discussion

The FTM termination rate is increasing on α and goes from $c_T - B\frac{Q_{Fi}-Q_{Fj}}{Q_{Fi}+Q_{Fj}}$ to $c_T - B - \frac{Q_{Fi}}{Q'_{Fi}}$. Let us compare these extreme prices with the ones found in Section 3. First, notice that the upper bound is the monopoly price (as in Section 3): indeed, when MNO can make a take-it-or-leave-it-offer it will choose always the price that maximizes its profits. Second, the lower bound is greater than in Section 3 (when B is strictly positive). The access price with re-routing can be smaller or greater than the price without re-routing depending on the size of the externality. On the one hand, when $B = 0$, MNO accepts only a price equal or above marginal cost. When the interconnection breaks down, MNO looses all the termination profits (as in the case without re-routing) but FNO can still make fixed calls via the other MNO. In this case, the value of the outside option of FNO is always greater than the one without re-routing. Then the access price decreases.

On the other hand, when B is strictly positive, MNO may accept prices below cost depending on the bargaining power α. In this case, MNO looses money every time it terminates a fixed call, but can extract more rent from the subscribers that receive the calls. If the interconnection breaks down, MNO does not loose money terminating call and receive the fixed calls via the other MNO (if the MTM access price is positive, there will be less FTM calls). Hence, the value of its outside option increases (with respect as section 3), then, for large B, the access price increases. We can see this effect in the following numerical example.

Numerical example In Figure 8 we can see that the termination rate with re-routing is always above the termination rate found in the benchmark. In particular suppose costs are $c_O = c_T = C_O = C_T = 0.1$, the MTM access price is $a = 1$, the bargaining power is $\alpha = 1/2$ and the demand functions are $Q_F = 1 - P_F$ and $q_F = 1 - p_F$. In Figure 8 the access price with re-routing is the dotted line and the continued line represents the access price without re-routing. We can see that exists a $\bar{B}$ such that for $B < \bar{B}$ the access price with re-routing is greater than the access price without re-routing, and for $B > \bar{B}$ the result is inverted.

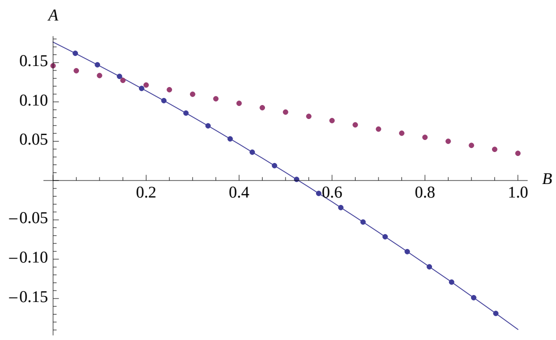


Figure 8: Re-routing

6 Conclusions

In this paper we propose a policy to overcome the bottleneck present in mobile termination. We propose to impose reciprocity between FTM and MTF termination rate. To do so, we take the standard setting à la Laffont et al. (1998b) with mobile network competition, and we introduce a fixed network operator that sets a multi-part tariff. We relax the interconnection obligation and we set-up a two stage model where the network operators bargain over the termination rates in different regulation environments.

In the common regulatory setting where MTF access charges are regulated at cost, we saw that the FTM termination rate depends negatively on the MTM termination rate. Indeed, when MTM access price increases the market share lost in case of interconnectivity break down increases. Then is more important for MNO to reach an agreement over FTM termination rate and is willing to lower the charge. Moreover, we consider the reciprocity policy where MTF and FTM termination rates have to be equal. In equilibrium this termination rate depends on the differentials of FTM and MTF calls. Thus, even if FNO (or MNO) can set arbitrarily the access price, it chooses a charge depending on how many calls has to terminate and how many calls sends to the other network. This eliminate the possibility for MNO to exercise its market power and fix excessively high access prices. Indeed, the termination rate can be a cost or a source of revenues. In the first case MNO would like to set a low access price and in the second will set a high price. Using a particular demand function we saw that with reciprocity the total welfare is greater than in the current regulatory set-up.

We also considered the possibility to call the other network re-routing the call via a third provider. In this case, the result depends on the intensity of the externalities. Low externalities imply smaller (with respect to the benchmark) termination charges because FNO has now the possibility to redirect the calls via the third network. On the other hand, high externalities imply low termination charges that discourage a network to terminate a call that can be terminated by another one. Then equilibrium the possibility of re-routing a call increases the FTM access price.

A Appendix

Proof of Proposition 3.1 Following the procedure explained before, first we solve (2.2) for r_i:

$$\begin{aligned} w_i - ts_i &= w_j - t(1-s_i) \\ w_i &= w_j - t(1-2s_i) \\ r_i &= s_i v_{ii} + (1-s_i)v_{ij} + v_{iF} + \text{const} \end{aligned} \tag{A.1}$$

where "const" denotes the terms that do not depend on the prices of network i. Substitute (A.1) into the profits in (2.3):

$$\pi_i = s_i\Big[\sum_{j=1,2} s_j R_{ij} + s_i v_{ii} + (1-s_i)v_{ij} + v_{iF} + F_i\Big] + \text{const.}$$

The latter expression can be maximized over the prices. MNO i finds the on-net and off-net prices and MTF call prices solving:

$$\max_{p_{ii},p_{ij},p_{iF}} \pi_i.$$

The first order conditions are:

$$\begin{aligned}
p_{ii}: \quad & s_i^2 v'_{ii} + s_i^2 q_{ii} + s_i^2(p_{ii} - c_O - c_T)q'_{ii} = 0\\
& -q_{ii} + q_{ii} + (p_{ii} - c_O - c_T)q'_{ii} = 0\\
& p_{ii} = c_O + c_T.
\end{aligned}$$

$$\begin{aligned}
p_{ij}: \quad & s_i(1-s_i)v'_{ij} + s_i(1-s_i)q_{ij} + s_i(1-s_i)(p_{ij} - c_O - a)q'_{ij} = 0\\
& p_{ij} = c_O + a.
\end{aligned}$$

$$\begin{aligned}
p_{iF}: \quad & s_i v'_{iF} + s_i q'_{iF} + s_i(p_{iF} - c_O - A_i F)q'_{iF} = 0\\
& p_{iF} = c_O + A_{iF}.
\end{aligned}$$

Proof of Proposition 3.2 Following the procedure just explained, we derive the profits with respect to r_i considering s_i as a function of r_i. The first order condition is:

$$\frac{\partial \pi_i}{\partial r_i} = \frac{\partial s_i}{\partial r_i}\Big[r_i - f + \sum_{j=1,2} s_j R_{ij} + F_i\Big] + s_i\Big[1 + \sum_{j=1,2}\frac{\partial s_i}{\partial r_i}R_{ij}\Big] \tag{A.2}$$

From the indifference condition in (2.2) is possible to derive the expression of the market share:

$$s_i = \frac{t + (r_j - r_i) + [v_{iF} - v_{jF}] + [v_{ij} - v_{jj}] + B[Q_{Fi} - Q_{Fj}]}{2t + [v_{ji} - v_{ii}] + [v_{ij} - v_{jj}]} \tag{A.3}$$

The derivative of the market share with respect to the fix fee r_i is:

$$\frac{\partial s_i}{\partial r_i} = -\frac{1}{2t + [v_{ji} - v_{ii}] + [v_{ij} - v_{jj}]}.$$

The first order condition in (A.2) becomes:

$$
\begin{aligned}
&\frac{\partial s_i}{\partial r_i}\Big[r_i - f + \sum_{j=1,2} s_j R_{ij} + F_i\Big] + s_i\Big[1 + \sum_{j=1,2} \frac{\partial s_i}{\partial r_i} R_{ij}\Big] = 0 \\
&r_i = f - 2s_i R_{ii} - (1-2s_i)R_{ij} - F_i + s_i\Big[2t + [v_{ji} - v_{ii}] + [v_{ij} - v_{jj}]\Big] \qquad \text{(A.4)}
\end{aligned}
$$

Using the equilibrium retail prices it is easy to notice that:

$$
\begin{aligned}
p_{ii} &= p_{jj} = p \\
p_{ji} &= p_{ji} = \hat{p} \\
v_{ii} &= v_{jj} = v \\
v_{ij} &= v_{ji} = \hat{v} \\
R_{ii} &= R_{jj} = 0 \\
R_{ij} &= R_{ji} = (a - c_T)\hat{q},
\end{aligned}
$$

where $\hat{q}$ represents the quantity of mobile-to-mobile off-net calls. Hence the equilibrium rental charge can be written as follows:

$$
r_i = f - (1-2s_i)(a-c_T)\hat{q} - F_i + 2s_i[t + \hat{v} - v]
$$

Substituting the equilibrium rental charge r_i^* in (A.4) into profits in (2.3) one can derive the equilibrium profits:

$$
\begin{aligned}
\pi_i &= s_i\Big[\sum_{j=1,2} s_j R_{ij} + r_i - f_i + F_i\Big] \\
\pi_i &= s_i^2\Big[-R_{ii} + R_{ij} + 2t + (v_{ji} - v_{ii}) + (v_{ij} - v_{jj})\Big] \qquad \text{(A.5)}
\end{aligned}
$$

Using the equilibrium retail prices, the equilibrium profits can be written as:

$$
\pi_i = s_i^2\Big[(a - c_T)\hat{q} + 2(t + \hat{v} - v)\Big]
$$

Substituting the equilibrium rental charge in (A.4) into the market share in (A.3) we obtain the equilibrium market share:

$$
\begin{aligned}
s_i &= \frac{t + (r_j - r_i) + [v_{iF} - v_{jF}] + [v_{ij} - v_{jj}] + B[Q_{Fi} - Q_{Fj}]}{2t + [v_{ji} - v_{ii}] + [v_{ij} - v_{jj}]} \\
s_i &= \frac{1}{2} + \frac{(r_j - r_i) + (v_{iF} - v_{jF}) + B(Q_{Fi} - Q_{Fj})}{2(t + \hat{v} - v)} \qquad \text{(A.6)}
\end{aligned}
$$

Since

$$r_j - r_i = -2(2s_i - 1)(a - c_T)\hat{q} + F_i - F_j + 2(1 - 2s_i)(t + \hat{v} - v) \tag{A.7}$$

Substituting (A.7) into the market share in (A.6) and solving for s_i:

$$s_i = \frac{(r_j - r_i) + (v_{iF} - v_{jF}) + (t + \hat{v} - v) + B(Q_{iF} - Q_{jF})}{2(t + \hat{v} - v)}$$
$$s_i = \frac{1}{2} + \frac{(r_j - r_i) + (v_{iF} - v_{jF}) + B(Q_{iF} - Q_{jF})}{2(t + \hat{v} - v)}$$
$$s_i = \frac{1}{2} + \frac{2(1 - 2s_i)(a - c_T)\hat{q} + F_i - F_j + 2(1 - 2s_i)(t + \hat{v} - v) + (v_{iF} - v_{jF}) + B(Q_{iF} - Q_{jF})}{2(t + \hat{v} - v)}$$
$$s_i = \frac{1}{2} + \frac{2(a - c_T)\hat{q} + 2(t + \hat{v} - v) - 4s_i[(a - c_T)\hat{q} + (t + \hat{v} - v)] + F_i - F_j + v_{iF} - v_{jF} + B(Q_{iF} - Q_{jF})}{2(t + \hat{v} - v)}$$
$$\frac{s_i[4(a - c_T)\hat{q} + 6(t + \hat{v} - v)]}{2(t + \hat{v} - v)} = \frac{2(a - c_T)\hat{q} + 3(t + \hat{v} - v) + (F_i - F_j) + (v_{iF} - v_{jF}) + B(Q_{iF} - Q_{jF})}{2(t + \hat{v} - v)}$$
$$s_i[4(a - c_T)\hat{q} + 6(t + \hat{v} - v)] = 2(a - c_T)\hat{q} + 3(t + \hat{v} - v) + (F_i - F_j) + (v_{iF} - v_{jF}) + B(Q_{iF} - Q_{jF})$$
$$s_i = \frac{2(a - c_T)\hat{q} + 3(t + \hat{v} - v) + (F_i - F_j) + (v_{iF} - v_{jF}) + B(Q_{iF} - Q_{jF})}{2[2(a - c_T)\hat{q} + 3(t + \hat{v} - v)]}$$
$$s_i = \frac{1}{2} + \frac{(F_i - F_j) + (v_{iF} - v_{jF}) + B(Q_{Fi} - Q_{Fj})}{2[2(a - c_T)\hat{q} + 3(t + \hat{v} - v)]}$$
$$s_i = \frac{1}{2} + \frac{(A_{Fi} - c_T)Q_{Fi} - (A_{Fi} - c_T)Q_{Fj} + B(Q_{Fi} - Q_{Fj})}{2[2(a - c_T)\hat{q} + 3(t + \hat{v} - v)]}$$
$$s_i = \frac{1}{2} + \frac{(A_{Fi} - c_T + B)Q_{Fi} - (A_{Fi} - c_T + B)Q_{Fj}}{2[2(a - c_T)\hat{q} + 3(t + \hat{v} - v)]}$$

Proof of Proposition 3.3 Substitute (3.4) in the profits of FNO in (2.4) and maximizing with respect to the prices we have:

$$\begin{aligned}
P_{FF}: &\quad V'_{FF} + BQ'_{FF} + (P_{FF} - C_O - C_T)Q'_{FF} + Q_{FF} = 0 &\rightarrow\quad & P_{FF} = C_O + C_T - B \\
P_{F1}: &\quad V'_{F1} + (P_{F1} - C_O - A_{F1})Q'_{F1} + Q_{F1} = 0 &\rightarrow\quad & P_{F1} = C_O + A_{F1} \\
P_{F2}: &\quad V'_{F2} + (P_{F2} - C_O - A_{F2})Q'_{F2} + Q_{F2} = 0 &\rightarrow\quad & P_{F2} = C_O + A_{F2}
\end{aligned}$$

Proof of Proposition 3.4 The indifference condition is:

$$\begin{aligned}
\underline{w}_i - t\underline{s}_i &= \underline{w}_j - t(1 - \underline{s}_i) \\
\underline{r}_i &= \underline{s}_i v_{ii} + v_{iF} + \text{const}
\end{aligned} \tag{A.8}$$

Substituting the latter into (3.7):

$$\underline{\pi}_i = \underline{s}_i\left[\underline{s}_i R_{ii} + \underline{s}_i v_{ii} + v_{iF}\right] + \text{const.}$$

MNO i finds the on-net price and MTF price solving:

$$\max_{p_{ii}, p_{iF}} \underline{\pi}_i.$$

The optimal retail prices are

$$p_{ii} = c_O + c_T$$
$$p_{iF} = c_O + A_{iF}.$$

Proof of Proposition 3.5 I maximize the profits w.r.t. $\underline{r}_i$. The first order condition is:

$$\frac{\partial \underline{\pi}_i}{\partial \underline{r}_i} = \frac{\partial \underline{s}_i}{\partial \underline{r}_i}\Big[\underline{r}_i - f + \underline{s}_i R_{ii} + F_i\Big] + \underline{s}_i\Big[1 + \frac{\partial \underline{s}_i}{\partial \underline{r}_i} R_{ii}\Big] \tag{A.9}$$

From the indifference condition in (A.8) is possible to derive (as before) the expression of the market share:

$$\underline{s}_i = \frac{t + (\underline{r}_j - \underline{r}_i) + (v_{iF} - v_{jF}) - v_{jj} - Q_{jF}}{2t - v_{ii} - v_{jj}} \tag{A.10}$$

The derivative of the market share with respect to the fix fee $\underline{r}_i$ is:

$$\frac{\partial \underline{s}_i}{\partial \underline{r}_i} = -\frac{1}{2t - v_{ii} - v_{jj}}$$

.From the first order condition in (A.9) is possible to find the following expression for $\underline{r}_i$:

$$\underline{r}_i = f - 2s_i R_{ii} - F_i + s_i\Big[2t - v_{ii} - v_{jj}\Big]$$

or, using the equilibrium rental prices:

$$\underline{r}_i = f - (A_{Fi} - c_T + B)Q_{Fi} + 2\underline{s}_i(t - v) \tag{A.11}$$

Substituting the equilibrium rental charge $\underline{r}_i^*$ into profits in (3.7) and using the equilibrium rental prices, is possible to derive the equilibrium profits:

$$\underline{\pi}_i = 2\underline{s}_i^2\Big[t - v\Big]$$

Substituting the equilibrium rental charge (A.11) into the market share in (A.10) we obtain the equilibrium market share:

$$\underline{s}_i = \frac{1}{2} + \frac{(\underline{r}_j - \underline{r}_i) + v_{iF} - v_{jF} + BQ_{iF} - BQ_{jF}}{2(t - v)}. \tag{A.12}$$

Since

$$\underline{r}_j - \underline{r}_i = F_i - F_j + 2(1 - 2s_i)(t - v). \tag{A.13}$$

Substituting (A.13) into the market share in (A.12) and solving for $\underline{s}_i$:

$$\underline{s}_i = \frac{1}{2} + \frac{F_i - F_j + v_{iF} - v_{jF} + BQ_{iF} - BQ_{jF}}{6(t-v)}$$

Using the equilibrium rental prices the equilibrium market share is:

$$\underline{s}_i = \frac{1}{2} + \frac{(A_{Fi} - c_T + B)Q_{Fi} - (A_{Fj} - c_T + B)Q_{Fj}}{6(t-v)}$$

Proof of Proposition 3.6 Using the expression of the profits found before, we can rewrite the maximization problem as follows:

$$\begin{aligned}&\max_a \, [\pi_i(a) - \underline{\pi}_i]^2\\ &\qquad [s_i(a)[(a-c_T)\hat{q} + 2(t+\hat{v}-v)] - 2\underline{s}_i(t-v)]^2\end{aligned}$$

that is analogous to maximize the following:

$$s_i(a)[(a-c_T)\hat{q} + 2(t+\hat{v}-v)]$$

The first order condition is:

$$2s_i\frac{\partial s_i}{\partial a}[(a-c_T)\hat{q} + 2(t+\hat{v}-v)] + s_i^2[\hat{q} + (a-c_T)\hat{q}' - 2\hat{q}'] = 0$$

Now we compute the solution in the symmetric equilibrium when $A_{iF} = A_{jF}$. As noticed before, the numerator of s_i is equal to 0, then the first order condition reduces to:

$$\begin{aligned}&(a-c_T)\hat{q}' + \hat{q} + 2\hat{v}' = 0\\ &a = c_T + \frac{\hat{q}}{\hat{q}'}.\end{aligned}$$

Proof of Proposition 3.8 The first order condition is:

$$\alpha\frac{\partial \pi_i}{\partial A_{Fi}}\frac{\pi_F - \overline{\pi}_F}{\pi_i - \overline{\pi}_i} + (1-\alpha)\frac{\partial \pi_F}{\partial A_{Fi}} = 0 \tag{A.14}$$

Remember that $\pi_i = s_i^2\Delta$ and $\overline{\pi}_i = \overline{s}_i^2\Delta$ where $\Delta \equiv (a-c_T)\hat{q} + 2(t+\hat{v}-v)$. Furthermore $\pi_F = V_{FF} + s_1V_{F1} + s_2V_{F2} + s_1bq_{1F} + s_2bq_{2F} - W - F$ and $\overline{\pi}_F = V_{FF} + \overline{s}_2V_{F2} + bq_F - W - F$. Then:

$$\begin{aligned}\pi_i - \overline{\pi}_i =& (s_i^2 - \overline{s}_i^2)\Delta\\ \pi_F - \overline{\pi}_F =& s_1V_{F1} + s_2V_{F2} - \overline{s}_2V_{F2},\end{aligned}$$

and in the symmetric equilibrium the latter can be written as $\pi_F - \overline{\pi}_F = \overline{s}_1 V_F$. Again, in the symmetric equilibrium the derivative of the profits with respect to the access price can be written as:

$$\begin{aligned}
\frac{\partial \pi_i}{\partial A_{Fi}} =& 2s_i \frac{\partial s_i}{\partial A_{Fi}}\Delta \\
\frac{\partial \pi_F}{\partial A_{Fi}} =& \frac{\partial s_i}{\partial A_{Fi}} V_{Fi} + s_i \frac{\partial V_{Fi}}{\partial A_{Fi}} - \frac{\partial s_i}{\partial A_i} V_{Fj} = s_i \frac{\partial V_{Fi}}{\partial A_{Fi}} = -\frac{1}{2} V'_{Fi}.
\end{aligned}$$

Substituting into the first order condition in (A.14):

$$\begin{aligned}
&\alpha \frac{\partial \pi_i}{\partial A_{Fi}} \frac{\overline{s}_i V_F}{(s_i^2 - \overline{s}_i^2)\Delta} + (1-\alpha)\frac{\partial \pi_F}{\partial A_{Fi}} = 0 \\
&\alpha 2 s_i \frac{\partial s_i}{\partial A_{Fi}} \Delta \overline{s}_i V_{Fi} + \frac{(1-\alpha)}{2} V'_{Fi}[(s_i - \overline{s}_i)(s_i + \overline{s}_i)\Delta] = 0 \\
&\alpha \frac{\partial s_i}{\partial A_{Fi}} \overline{s}_i V_{Fi} - \frac{(1-\alpha)}{2} Q_{Fi}(s_i - \overline{s}_i)(s_i + \overline{s}_i) = 0 \qquad \text{(A.15)}
\end{aligned}$$

Let us consider the two extreme cases when MNO has all the bargaining power and decides the access price (i.e. $\alpha = 0$) and when FNO has all the bargaining power (i.e. $\alpha = 1$).

If $\alpha = 0$ we find two conditions:

$$\begin{aligned}
s_i - \overline{s}_i &= 0 \\
s_i + \overline{s}_i &= 0
\end{aligned}$$

The second condition is never satisfied because the market shares have to be strictly positive. From the first we have:

$$s_i - \overline{s}_i = 0 \quad \rightarrow \quad (A_{Fi} - c_T + B)Q_{Fi} = 0 \quad \rightarrow \quad A_{Fi} = c_T - B$$

If $\alpha = 1$ we find two conditions:

$$\begin{aligned}
\frac{\partial s_i}{\partial A_{Fi}} &= 0 \\
\overline{s}_i &= 0
\end{aligned}$$

The second condition is never satisfied because the market shares are strictly positive. From the first we have:

$$\frac{\partial s_i}{\partial A_{Fi}} = 0 \quad \rightarrow \quad (A_{Fi} - c_T + B)Q'_{Fi} + Q_{Fi} = 0 \quad \rightarrow \quad A_{Fi} = c_T - B - \frac{Q_{Fi}}{Q'_{Fi}}$$

Proof of Proposition 5.1 The first order condition is:

$$\alpha \frac{\partial \pi_i}{\partial A_{Fi}}(\pi_F - \overline{\pi}_F) + (1-\alpha)\frac{\partial \pi_F}{\partial A_{Fi}}(\pi_i - \overline{\pi}_i) = 0 \tag{A.16}$$

Remember that $\pi_i = s_i^2\Delta$ and $\overline{\pi}_i = \overline{s}_i^2\overline{\Delta}$ where $\Delta \equiv (a - c_T)\hat{q} + 2(t + \hat{v} - v)$ and $\overline{\Delta} \equiv (a - c_T)(\hat{q} + Q_{Fi}) + 2(t + \hat{v} - v)$. Furthermore $\pi_F = V_{FF} + s_1 V_{F1} + s_2 V_{F2} + s_1 b q_{1F} + s_2 b q_{2F} - W - F$ and $\overline{\pi}_F = V_{FF} + \overline{s}_1 \overline{V}_{F1} + \overline{s}_2 V_{F2} + b q_F - W - F$. Thenin the symmetric equilibrium, it can be written as $\pi_F - \overline{\pi}_F = \overline{s}_1(V_F - \overline{V}_{Fi})$. Again, in the symmetric equilibrium the derivatives of the profits with respect to the access price can be written as:

$$\begin{aligned}
\frac{\partial \pi_i}{\partial A_{Fi}} =& 2 s_i \frac{\partial s_i}{\partial A_{Fi}}\Delta \\
\frac{\partial \pi_F}{\partial A_{Fi}} =& \frac{\partial s_i}{\partial A_{Fi}} V_{Fi} + s_i \frac{\partial V_{Fi}}{\partial A_{Fi}} - \frac{\partial s_i}{\partial A_i} V_{Fj} = s_i \frac{\partial V_{Fi}}{\partial A_{Fi}} = \frac{1}{2}V'_{Fi}.
\end{aligned}$$

Substituting into the first order condition in (A.16) we obtain:

$$\begin{aligned}
&\alpha \frac{\partial \pi_i}{\partial A_{Fi}} \overline{s}_i V_F + (1-\alpha)\frac{\partial \pi_F}{\partial A_{Fi}}(s_i^2 - \overline{s}_i^2)\Delta = 0 \\
&\alpha 2 s_i \frac{\partial s_i}{\partial A_{Fi}} \Delta \overline{s}_i V_{Fi} + \frac{(1-\alpha)}{2} V'_{Fi}[(s_i - \overline{s}_i)(s_i + \overline{s}_i)\Delta] = 0 \\
&\alpha \frac{\partial s_i}{\partial A_{Fi}} \overline{s}_i V_{Fi} - \frac{(1-\alpha)}{2} Q_{Fi}(s_i - \overline{s}_i)(s_i + \overline{s}_i) = 0
\end{aligned}$$

Let us consider the two extreme cases when MNO has all the bargaining power and decides the access price (i.e. $\alpha = 0$) and when FNO has all the bargaining power (i.e. $\alpha = 1$).
If $\alpha = 0$ we find two conditions:

$$\begin{aligned}
s_i - \overline{s}_i &= 0 \\
s_i + \overline{s}_i &= 0
\end{aligned}$$

The second condition is never satisfied because the market shares have to be strictly positive. From the first we have:

$$s_i - \overline{s}_i = 0 \quad \rightarrow \quad -(A_{Fi} - c_T)(Q_{Fi} + Q_{Fj}) + B(Q_{Fi} - Q_{Fj}) = 0 \quad \rightarrow \quad A_{Fi} = c_T - B\frac{Q_{Fi} - Q_{Fj}}{Q_{Fi} + Q_{Fj}}$$

If $\alpha = 1$ we find two conditions:

$$\begin{aligned}
\frac{\partial s_i}{\partial A_{Fi}} &= 0 \\
\overline{s}_i &= 0
\end{aligned}$$

The second condition is never satisfied because the market shares are strictly positive. From the first we have:

$$\frac{\partial s_i}{\partial A_{Fi}} = 0 \quad \rightarrow \quad (A_{Fi} - c_T + B)Q'_{Fi} + Q_{Fi} = 0 \quad \rightarrow \quad A_{Fi} = c_T - B - \frac{Q_{Fi}}{Q'_{Fi}}$$

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