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ABSTRACT

On-Net and Off-Net Pricing on Asymmetric Telecommunications Networks*

The differential between on-net and off-net prices, for example on mobile telephony networks, is an issue that is hotly debated between telecoms operators and regulators. Small operators contend that their competitors' high off-net prices are anticompetitive. We show that if the utility of receiving calls is taken into account, the equilibrium pricing structures will indeed depend on firms' market shares. Larger firms will charge higher off-net prices even without anticompetitive intent, both under linear and two-part tariffs. Predative behaviour would be accompanied by even larger on-net / off-net differentials even if access charges are set at cost.

JEL Classification: L51
Keywords: asymmetry, call externality, on/off-net pricing and telecommunications network competition

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1 Introduction

This is not a paper about access prices. It is centered on the setting of *retail prices* when networks price discriminate between on-net and off-net calls. While this problem has already been touched upon several times in the literature, we take the additional steps of allowing for call externalities and for asymmetric networks, both of which have significant effects on the market outcome.

The markets that we are trying to model are the retail markets of mobile telephony in the European Union. Retail prices are not regulated, only the caller pays for the call (if he is not roaming), price discrimination between on-net and off-net calls is the rule rather than the exception, both linear and two-part tariffs are on offer, market shares of networks vary widely, and consumers care about being called. The "termination-based network externality" created by the on-net / off-net price differential has led small networks to complain that it puts them at a disadvantage, or even that large networks can use this price differential strategically to induce their exit.

In the following we will analyze Nash equilibria in the presence of price discrimination between on-net and off-net calls, and also "predatory pricing" where the large network tries to leverage the termination-based network externality to reduce the small network's profits. This is done for both for linear and two-part tariffs, and we will check whether on the one hand predation is successful, and on the other whether it is detectable (distinguishable from the Nash equilibrium). In other words, we will provide some evidence as to whether the claim of "predatory on-net / off-net price discrimination" makes sense or not.

So what about access prices? Since here we are not interested in the question of anti-competitive or collusive access prices we assume for simplicity that they are set by an industry regulator. This assumption corresponds to regulatory reality in the European Union, where following the introduction of the telecommunications directives of 2002 regulators are implementing price controls for termination (i.e. access charges) on all mobile networks.

Our results are as follows: We find that both asymmetry and the call externality have strong effects on the equilibrium on-net and off-net prices, and the resulting on-net / off-net differentials: Large firms charge significantly higher off-net prices, and allow for a higher on-net / off-net differential. As a result even with a balanced calling pattern the traffic between the two networks will not be balanced: The small network incurs an access deficit if reciprocal access prices are set above cost. These results hold under both linear and two-part tariffs. Furthermore, under linear tariffs the large network also charges a higher on-net price, while with two-part tariffs both firms set the on-net price at the efficient level.

We present a series of comparative statics results, with respect to the level of asymmetry in market share, the size of the call externality, product differentiation and a reciprocal access charge. These are derived from numerical simulations since under the assumptions of asymmetry and the existence of a call externality the equilibrium market share cannot be determined analytically.

As concerns predatory pricing, we find that its hallmark is a large on-net / off-net differential, but the reasons for this large differential are rather different depending on the type of tariffs. While with linear tariffs it is caused by a low on-net price, with two-part tariffs it is the off-net price that is very high (accompanied by a low fixed fee).

The following Section 2 contains a short overview of the literature, and Section 3 introduces the model. Section 4 considers the profit-maximizing on-net / off-net pricing structures for given market shares, while Section 5 discusses the Nash equilibrium of the pricing game. Finally, Section 6 discusses anti-competitive behavior by the large firm, while Section 7 concludes. Figures 1 - 11 are found at the end of the paper.

2 Overview of the Literature

Work published in this area has considered several of the aspects and assumptions central to this paper. The seminal paper in the literature on price discrimination between on-net and off-net calls is Laffont, Rey and Tirole (1998, LRT), which was later followed by Gans and King (2001). Both papers only consider symmetric equilibria, which leads to simple and elegant expressions for equilibrium values.

There is a budding literature on competition between asymmetric networks. Carter and Wright (1999, 2003) introduce asymmetry through an additive component in consumers' utility function. Cambini and Valletti (2004) endogenize the value of this parameter in a game of quality choice by networks. Yet, these articles do not consider termination-based price discrimination.

De Bijl and Peitz (2002, ch. 6.4) present the equilibrium pricing structure with two-part tariffs and termination-based price discrimination, but in the absence of a call externality. In this case both the on-net and off-net prices are equal to cost, and therefore the differential is completely determined by the access charge. As we will see below, if the call externality is taken into account then strategic considerations change this result. Dewenter and

Haucap (2003) consider asymmetric networks and the setting of termination charges when consumers are not aware of their level (comparable to what happens under roaming), but do not consider on-net calls.

The model of call externality used in the following has been introduced by Kim and Lim (2001) and Jeon, Laffont and Tirole (2004, JLT). While both papers are mainly concerned with the "receiver pays principle", JLT consider on pp. 104-105 the equilibrium pricing structure in two-part tariffs with asymmetric networks, and show that on-net and off-net prices can differ significantly from the underlying cost level. They do not solve for the equilibrium market shares, and therefore do not consider the equilibrium differential. Berger (2004) uses their model with only the caller paying and on-net / off-net price discrimination, while being principally interested in the role of a reciprocally set access charge.

Lastly, to our knowledge there is no analysis of the on-net / off-net differential in the presence of predatory pricing. This is true even at the basic level of analysis presented below, where we only consider what some limited form of predatory pricing would look like, and not whether predation as such is rational. In particular, the question we tackle here is fundamentally different from foreclosure through high access prices, see e.g. Gabrielsen and Vagstad (2004) or Calzada and Valletti (2005).

3 The Model

The following model joins elements from LRT, Carter and Wright (1999) and JLT. Two telecommunications networks are situated at the extreme points of a Hotelling line, with firm 1 at point 0, and firm 2 at point 1. Each network supports a fixed cost per client of f_i and has constant marginal costs of origination and transport of c_{0i}, and of termination of c_{ti}, with resulting on-net cost $c_i = c_{0i} + c_{ti}$. Network i charges an access price of a_i for terminating calls from its competitor, resulting in off-net costs $c_{fi} = c_{0i} + a_j$. In order to concentrate on the setting of retail prices we assume that access charges are set by a sectoral regulator.[1] An example of the situation portrayed here is that of two competing mobile networks whose termination charges are regulated. The latter now is usual in the EU, following the 2002 set of directives on telecommunications. Denote the market share of network i by α_i, with $\alpha_1 + \alpha_2 = 1$ since we assume that the whole market is covered in equilibrium.

Firms set either linear prices or two-part tariffs, and price discriminate between on-net and off-net calls. Network i's prices for on-net and off-net

[1] The analysis of M2M and F2M access prices prices will be done in a follow-up paper.

calls, and the fixed fee, are p_{ii}, p_{ij} and F_i, respectively, with $i, j \in \{1, 2\}$, $j \neq i$. For a linear tariff we simply set $F_i = 0$ in the following expressions.

A mass 1 of consumers is distributed uniformly along the Hotelling line. The consumer at location x has a utility loss of $\frac{1}{2\sigma}|x - l|$ if he adheres to the network at location l. Furthermore, similar to Carter and Wright (1999), consumers receive an additional utility $\beta = A/\sigma$ if they adhere to network 1, where A is the "*ex ante*" increase in its market share (before equilibrium effects). This assumption models an incumbency or reputation advantage of network 1. Its purpose is to make the market equilibrium asymmetric, with $\alpha_1 > \alpha_2$.

As in JLT consumers receive utility by making and receiving calls. The direct utility of making calls is $u(q)$, where q is the length of the call in minutes, and if the price per minute is p, the indirect utility is $v(p) = \max_q \{u(q) - pq\}$. The associated demand function is $q_{ij} = q(p_{ij})$. In the following we will use a constant elasticity demand function $q(p) = p^{-\eta}$, where $\eta > 1$, thus $u(q) = \frac{\eta}{\eta-1} q^{\frac{\eta-1}{\eta}}$ and $v(p) = \frac{1}{\eta-1} p^{1-\eta}$. The utility of receiving a call of duration q is $\gamma u(q)$, where $\gamma \in [0, 1]$.

For simplicity we assume a balanced calling pattern, i.e. each consumer calls each other consumer with the same probability, independent of which network they belong to. This does *not* imply that the actual traffic will be balanced, because the lengths of calls depend on their respective prices per minute (which will differ in equilibrium).

The utilities of adhering to network 1 or 2 are

$$U_1(x) = w_1 + \beta - \frac{1}{2\sigma}x, \; U_2(x) = w_2 - \frac{1}{2\sigma}(1 - x) \tag{1}$$

where

$$\begin{aligned} w_i &= \alpha_i [v(p_{ii}) + \gamma u(q_{ii})] + \alpha_j [v(p_{ij}) + \gamma u(q_{ji})] - F_i && (2) \\ &= \alpha_i h_{ii} + \alpha_j h_{ij} - F_i && (3) \end{aligned}$$

where $h_{ij} = v(p_{ij}) + \gamma u(q_{ji})$. The indifferent consumer is located at $x = \alpha_1$, therefore

$$\alpha_1 = \frac{1}{2} + A + \sigma(w_1 - w_2). \tag{4}$$

This implicit equation for α_1 can be solved for

$$\alpha_1 = \frac{1/2 + A + \sigma(h_{12} - h_{22} - F_1 + F_2)}{1 + \sigma(h_{12} + h_{21} - h_{11} - h_{22})}. \tag{5}$$

Firms' profits are described by the standard expression

$$\pi_i = \alpha_i \left[\alpha_i \left(p_{ii} - c_i\right) q_{ii} + \alpha_j \left(p_{ij} - c_{fi}\right) q_{ij} + F_i - f_i + \alpha_j \left(a_i - c_{ti}\right) q_{ji}\right] \quad (6)$$

Consumer surplus is given by

$$CS = \int_0^{\alpha_1} U_1(x)\, dx + \int_{\alpha_1}^{1} U_2(x)\, dx = \alpha_1 \left(w_1 + \frac{A}{\sigma}\right) + \alpha_2 w_2 - \frac{\alpha_1^2 + \alpha_2^2}{4\sigma}, \quad (7)$$

while total welfare is $W = CS + \pi_1 + \pi_2$.

4 The Equilibrium On-/Off-Net Pricing Structure

The main aim of this section is to characterize how the equilibrium on-net / off-net pricing structure depends on the asymmetry in market shares. We do not consider possibly anti-competitive conduct here; this will be done in section 6.

First we consider linear prices , i.e. $F_i = 0$. Defining the Lerner indices $L_{ii} = (p_{ii} - c_i)/p_{ii}$ and $L_{ij} = (p_{ij} - c_{fi})/p_{ij}$, we obtain the following result:

Lemma 1 *The on-net / off-net pricing structure of network i is characterized by the following relation:*

$$L_{ij} = \frac{1}{\eta} + \frac{(1+\gamma\eta)^{-1} - \alpha_i}{1-\alpha_i} \left(L_{ii} - \frac{1}{\eta}\right). \quad (8)$$

The slope decreases in $\gamma\eta$ and α_i.

Proof. We keep market share α_1 and prices p_{22} and p_{21} fixed, and determine how prices p_{11} and p_{12} will be set (the calculations for firm 2 are analogous). Firm 1 solves $\max_{p_{11},p_{12}} \pi_1$ s.t. $\alpha_1 - \frac{1}{2} - A - \sigma(w_1 - w_2) = 0$, which leads to the pair of conditions

$$\begin{aligned} \alpha_1 \left(1 - \frac{p_{11} - c_1}{p_{11}} \eta\right) + \lambda\sigma(1+\gamma\eta) &= 0, \\ \alpha_1\alpha_2 \left(1 - \frac{p_{12} - c_{f1}}{p_{12}} \eta\right) + \lambda\sigma(\alpha_2 - \alpha_1\gamma\eta) &= 0, \end{aligned}$$

where λ is the associated Lagrange multiplier (positive in a stable equilibrium). Dividing both equations leads to the above result. ■

This relation between both Lerner indices is a straight line which passes through the monopoly point $L_{ii} = L_{ij} = \frac{1}{\eta}$. If there is no utility associated to receiving calls then both on-net and off-net Lerner indices are equal, as in LRT. On the other hand, if this utility is positive but small ($\gamma < \frac{\alpha_j}{\eta\alpha_i}$ or $\alpha_i < \frac{1}{1+\gamma\eta}$) then L_{ij} increases with L_{ii}, while it may even decrease (towards the monopoly value) if receivers' utility is large ($\gamma > \frac{\alpha_j}{\eta\alpha_i}$). In both these cases L_{ij} is higher than L_{ii}, which means that independently of each firm's off-net cost the relative margin charged over and above this cost is higher for off-net calls. If the access charge is above cost then this effect is reenforced.

The reason why the off-net Lerner indices are higher than the corresponding on-net ones is that the call externality confers additional utility to the clients of the rival network. By raising its off-net price a network will limit the number of call minutes that reach these clients, and therefore improve its competitive position. Note that naturally a higher off-net price of network i *as such* reduces its attractiveness, but this is no contradiction to the above argument since clients of *both* networks are made worse off. If we start out from the equilibrium off-net prices in the absence of a call externality, then taking this externality into consideration provides an incentive to raise the off-net price above their previous equilibrium value.

Two important observations follow:

1. Since the slope of the relationship in (8) decreases in α_i, the firm with the larger market share would have a higher off-net Lerner index if on-net Lerner indices were equal. That is, for similar cost levels (including access charges) and on-net prices the large network's off-net price will be significantly higher than the small network's. This effect would only be reversed if the small network chose significantly higher on-net prices (We will see below that this does not happen in equilibrium).

2. Since the off-net price is lower in the small network if on-net prices are similar, there will be an imbalance in interconnected traffic between both networks even under a balanced calling pattern, with an access deficit persistently lowering the profits of the small network. This deficit results from the internalization of the call externality of on-net receivers, which is stronger on the larger network. Therefore at this level of analysis it does not result from anti-competitive behavior.[2]

As concerns two-part pricing, Jeon, Laffont and Tirole (2004, p. 105) derive the profit-maximizing price structure. Keeping market share α_i constant,

[2]Later in Section 6 we will see whether there can be an anti-competitive role for off-net prices.

they substitute

$$F_i = \alpha_i h_{ii} + \alpha_j v\left(p_{ij}\right) - \alpha_i \gamma u\left(q_{ij}\right) + K_i \tag{9}$$

into π_i, where K_i does not depend on p_{ii} or p_{ij}. Maximizing π_i with respect to these variables then leads to

$$\tilde{p}_{ii} = \frac{c_i}{1+\gamma},\ \tilde{p}_{ij} = \frac{c_{fi}}{1+\gamma\alpha_i/\alpha_j} \text{ if } \alpha_i < \frac{1}{1+\gamma},\ \tilde{p}_{ij} = \infty \text{ otherwise.} \tag{10}$$

In terms of Lerner indices,

$$L_{ii} = -\gamma, L_{ij} = \frac{\alpha_i}{\alpha_j}\gamma \text{ if } \alpha_i < \frac{1}{1+\gamma},\ L_{ij} = 1 \text{ otherwise.} \tag{11}$$

On-net prices internalize receivers' utility of receiving calls, leading to an efficient price below marginal cost. On the other hand, off-net prices remain above marginal cost and increase in own market share (towards infinity as α_i approaches $1/\left(1+\gamma\right)$ while the Nash equilibrium still exists). Again, the higher off-net price reduces the rival network's attractiveness through limiting the number of call minutes its customers will receive.

Last but not least, the profit-maximizing fixed fee is

$$\tilde{F}_i = f_i + \alpha_i \frac{H}{\sigma} - 2\alpha_i\left(\tilde{p}_{ii} - c_i\right)\tilde{q}_{ii} + \left(\alpha_i - \alpha_j\right)\left[\left(\tilde{p}_{ij} - c_{fi}\right)\tilde{q}_{ij} + \left(a_i - c_{ti}\right)\tilde{q}_{ji}\right]. \tag{12}$$

It increases in α_i at $\alpha_i = \frac{1}{2}$, therefore at least for similar market shares the fixed fee is larger for the larger firm.

We conclude that, regardless of whether tariffs are linear or two-part, the larger firm has an incentive to set a higher on-net/off-net differential than the small firm. In the next section we will determine the actual equilibrium market shares, and the resulting equilibrium price differentials.

5 The Market Equilibrium

5.1 Linear tariffs

In this section we will determine the form of the Nash equilibrium in linear tariffs. Firm i solves $\max_{p_{ii},p_{ij}} \pi_i$ given the competitor's prices $\left(p_{jj}, p_{ji}\right)$. This Nash equilibrium has been characterized by Berger (2004) for symmetric networks using a graphical method, since the equilibrium cannot be found analytically even in the symmetric case. In the asymmetric case not even a graphical method is feasible since four prices (instead of only two) must be determined, therefore we take recourse to numerical solutions.[3] As shown in the previous literature, a Nash equilibrium in prices will exist if σ and γ are close enough to zero and a_i close enough to c_{0i}. In all numerical results presented here we have taken care to check that the second-order and boundary conditions are satisfied, and that the equilibria are stable.

Before showing how the equilibrium price differentials are determined, we offer a telling example of how differently on-net and off-net prices affect asymmetric firms' profits. In Figure 1 we portray a pricing equilibrium at the parameter constellation $c_1, c_2, c_{1f}, c_{2f} = 1$ (cost-based access), $f_1, f_2 = 0$, $\eta = 2$, $\gamma = 0.1$, $\sigma = 1$ and $A = 0.2$.[4,5] The resulting equilibrium prices are $p_{11} = 1.37$, $p_{12} = 1.59$, $p_{22} = 1.21$, $p_{21} = 1.35$, with market share $\alpha_1 = 0.63$ and profit share $\pi_1/(\pi_1 + \pi_2) = 0.67$. There are various important observations, which we have found to be generically true in asymmetric equilibria:

1. The larger firm sets higher prices. This implies that even with a balanced calling pattern the realized traffic is unbalanced in favor of the large firm, i.e. the small firm bears an access deficit if access is priced above cost.

2. Even though we have assumed cost-based access in this example, off-net prices are always higher than on-net prices, with the larger firm setting a higher differential. This is due to the call externality ($\gamma > 0$).[6]

3. The equilibrium market share of the large firm is smaller than the "ex ante market share" of $0.5 + A = 0.7$ since the small firm gains some market share due to its lower prices. For the same reason the large firm's share of the profits is higher than its market share but still lower than its "ex ante market share".

[3] The algorithms have been implemented in Matlab 6.5, and are available from the author on request.

[4] We will use this parameter constellation as the base case for the following numerical results. Naturally we have checked the validity of our results for a wide range of different parameter values.

[5] Our algorithm does not check specifically for multiple equilibria. It still can identify multiple equilibria if different starting values for the algorithm converge to different solutions, or if parameter changes lead to jumps in the changes of the equilibria. This has never occurred for the parameter values considered.

[6] For comparison, with $\gamma = 0$ the resulting Nash equilibrium would be $p_{11} = p_{12} = 1.48$, $p_{22} = p_{21} = 1.33$, with market share $\alpha_1 = 0.63$.

4. In Figure 1 we can see that the large firm's profits are much more sensitive to its on-net price than to its off-net price. For the small firm both prices are equally relevant.

In the following we will see how the pricing equilibria change in some important parameters such as the size of the ex ante asymmetry, the call externality, product differentiation, and the reciprocal access charge.

Size of the asymmetry: Figure 2 shows how the equilibrium changes if we let the "ex ante" asymmetry parameter A vary between 0 and 0.5. The values for the smaller (larger) firm correspond to market shares smaller (larger) than one half. Note that the last three graphs plot equilibrium prices and profits again equilibrium (not ex ante) market shares. We observe the following:

1. The "ex ante" asymmetry A is translated into equilibrium market shares by only about two thirds. This result is due to the lower prices set by the smaller firm.

2. Apart from setting lower prices, the smaller firm has a significantly smaller on-net / off-net differential. As its market share becomes large the larger firm's off-net price increases more than proportionally.

3. A 10% increase (decrease) in market share from the symmetric equilibrium leads to an increase (decrease) of 26% in profits, again due to the price difference.

Size of call externality: Figure 3 shows how increasing γ affects the equilibrium, where he have restricted γ to be sufficiently small for Nash equilibria to exist. We find the following:

1. As γ increases the market share of the larger firm increases, but only slightly.

2. Both on-net prices are decreasing in γ, and the large firm's off-net price increases. Maybe surprisingly, the small network's off-net price first increases, due to the usual attempt to limit the call externality, but then decreases as γ becomes large enough. This decrease is due to the small firm's fight for market share; with an on-net price approaching marginal cost it needs to use its off-net price to attract consumers. Alas, this comes at the price of creating an even larger traffic imbalance.

3. With a small call externality both prices of the large firm are higher, but for γ large enough the large network's on-net price falls below the small network's off-net price. If access were priced above cost this would happen for smaller values of γ.

4. The on-net / off-net differential is higher if the call externality is larger.

5. Profits decrease significantly, as is known from the study of symmetric equilibria, because the call externality makes firms compete harder for customers. The small firm loses relatively more than the large firm.

Extent of product differentiation: Figure 4 shows how different values of σ affect equilibrium prices, with the lower limit $\sigma = 0$ corresponding to a complete lack of competitive interaction, where market divides at $\alpha_1 = \frac{1}{2} + A$.

1. As σ increases the stronger competition drives down the market share of the larger firm, and all prices and profits decrease.

2. At some point the large firms on-net price falls below the small firm's off-net price.

3. The on-net / off-net differential is higher if competition is more intense.

Reciprocal termination charges: Figure 5 shows the effect of the regulator's choice of reciprocal access charges on the equilibrium. If the reciprocal access charge is increased, then

1. The large firm's market share increases slightly.

2. On-net prices decrease by about 50% of the increase in the access charge for the large firm, and 70% for the small firm, and on-net Lerner indices decrease. Off-net price go up, with the increase corresponding to 130% of the change in the access charge for the large firm, and 70% for the small firm, while both Lerner indices decrease.

3. The on-net / off-net differential is increases. This is true even for the Lerner indices, which take into account that off-net costs increase with the access charge.

4. The large firm's profits peak at a reciprocal access charge *above* termination cost, while the small firm's profits are highest at an access charge *below* termination cost.

To sum up the results concerning on-net / off-net differentials with linear tariffs:

Remark 2 *With linear tariffs, the following holds in the Nash equilibrium of the pricing game:*

1. *Firms' on-net / off-net differentials increase with their equilibrium market share.*

2. *Both firms' on-net / off-net differentials increase if:*

   - *the call externality is larger (higher γ);*
   - *competition is more intense (higher σ);*
   - *the reciprocal access charge is higher.*

5.2 Two-part tariffs

In this section we derive the equilibrium price differentials with two-part tariffs, which JLT only considered for symmetric networks (i.e. $\alpha_i = \frac{1}{2}$). We have shown above that the on-net price is independent of market share, while the off-net price is rather sensitive to it.

Holding the competitor's prices (p_{jj}, p_{ji}, F_j) fixed, firm i solves $\max_{p_{ii},p_{ij},F_i} \pi_i$. Just as with linear tariffs the equilibrium cannot be found analytically, so that we must use numerical solutions. Generically, we observe the following:

1. As shown in the previous section, on-net prices are below marginal cost and the same for both firms, and off-net price remain above but relatively close to marginal cost.

2. The larger firm charges higher off-net prices than the small firm, and therefore has a higher on-net / off-net price differential.

3. The larger firm charges higher fixed fees than the small firm, and earns higher profits.

4. The equilibrium market share of the larger firm is smaller than its "ex ante market share".

Observations 2 and 4 describe outcomes that are identical in competition with linear tariffs, while observations 1 (and 3) are characteristic of two-part tariffs. The on-net / off-net price differentials observed under two-part tariffs are not very different from the ones under linear pricing, for the same values of the underlying parameters.

We will now consider the equilibria resulting for variations in the parameters considered above.

Size of the asymmetry: Figure 6 shows how the equilibrium changes if we let the "ex ante" asymmetry parameter A vary between 0 and 0.5. As above, the values for the smaller (larger) firm correspond to market shares smaller (larger) than one half. We observe the following:

1. The "ex ante" asymmetry A is translated into equilibrium market shares by only about one third, half of what we found under linear pricing. Again this result is due to the lower prices set by the smaller firm.

2. The smaller firm sets a lower fixed fee and off-net price, and therefore has a significantly smaller on-net / off-net differential. As market share rises the larger firm's off-net price increases more than proportionally.

3. A 10% increase (decrease) in market share from the symmetric equilibrium leads to an increase (decrease) of about 40% in profits, this time mainly due to the difference in fixed fees.

Size of call externality: Figure 7 shows how increasing γ affects the equilibrium, where he have restricted γ to be sufficiently small for Nash equilibria to exist. We find the following:

1. As γ increases the market share of the larger firm increases, but almost unnoticeably. The effects on prices and profits are dramatic, though.

2. Both on-net prices are decreasing in γ, and both firms' off-net prices increase, with the large firm's increasing twice as fast. Both fixed fees fall in parallel.

3. The on-net / off-net differentials are higher if the call externality is larger, and again profits decrease significantly.

Extent of product differentiation: Figure 8 shows how different values of σ affect equilibrium prices.

1. As σ increases the stronger competition drives down profits and the fixed fees, but contrary to competition with linear tariffs market shares and off-net price change very little (the large firm's goes up, while the small firm's goes down).

2. The resulting on-net / off-net differential is almost independent of σ.

Reciprocal termination charges: Figure 9 shows the effect of the regulator's choice of reciprocal access charges on the equilibrium. If the reciprocal access charge is increased, then

1. The large firm's market share increases slightly.

2. On-net prices remain constant, but both off-net prices increase in line with cost, as it seems. In fact, the large firm's off-net price increases about 25% faster than the access charge, and therefore its Lerner index increases (not pictured here). At the same time, the small firm's off-net price simply transmits the cost increase 1-1, and its Lerner index decreases.

3. The on-net / off-net differentials of both firms increase, roughly in line with the access charge for the small firm, but faster for the large firm.

4. Fixed fees and profits fall significantly. Firms would be best off at a zero access charge (bill-and-keep).

When comparing these results with those under linear tariffs, we find:

Remark 3 *1. Firms with larger equilibrium market share charge higher prices or fixed fees. The only exception is the on-net price under two-part tariffs, which firms choose at the efficient level throughout.*

2. Firms' on-net / off-net differential increases with their equilibrium market share. This differential is driven by high off-net prices in both cases, even though it is countered by high on-net prices under linear tariffs.

3. Some exogenous factors such as ex ante *asymmetry and the size of the call externality have similar effects on prices.*

4. Less product differentiation decreases on-net and off-net prices strongly under linear tariffs, while it has (almost) no effect on both prices under two-part tariffs. In the latter case firms compete mainly through fixed fees.

5. Higher reciprocal access charges lead to a more than proportional increase in the large firm's off-net price, and to a less than proportional one for the small firm. The main difference concerning pricing is that higher access prices lead to lower on-net price with linear tariffs, and to lower fixed fees with two-part tariffs. As concerns profits, under linear pricing the large firm prefers a reciprocal access charge above cost, while in all other cases firms prefer access charges below cost.

6 Can Termination-based Price Discrimination Be Used Anti-competitively?

Until now we have assumed that both firms try to maximize their profits, which results in the standard Nash equilibrium of the game. A completely different question is that of anti-competitive or predatory pricing, in which firm 1 tries to make firm 2 leave the market by targeting its profits, more specifically by minimizing them. This can obviously be done by choosing arbitrarily low on-net prices p_{11}, driving the market share and profits of firm 2 to zero. At the same time, high off-net prices can reduce the utility that clients of the other network obtain by receiving calls. Therefore the *possibility* of predation is easily established if we are willing to let firm 1 inflict arbitrary losses on itself (in the short run).

A more interesting question is the following: What is the on-net / off-net pricing structure that emerges from "limited" predation? That is, for a given target profit level of firm 2, how does firm 1 trade off optimally between low on-net and high off-net prices, and how much does this cost in terms of lost profits in the short run? Finally, can this pricing structure be distinguished, especially under limited information about costs and demand, from Nash equilibrium pricing?

We therefore consider the following "predation game", whose Nash equilibrium we will call the "predation equilibrium": With linear tariffs firm 1 solves,[7] given (p_{22}, p_{21}), and some maximum profit level $\bar{\pi}_2$ of firm 2,

$$\max_{p_{11},p_{12}} \pi_1 \; s.t. \; \pi_2 \leq \bar{\pi}_2, \tag{13}$$

while firm 2 maximizes π_2 over (p_{22}, p_{21}), given (p_{11}, p_{12}). By lowering $\bar{\pi}_2$ towards $-\infty$ we can reproduce "unconstrained" predation.

As a first step we consider firm 1's optimal pricing structure for fixed market shares. We find the following:

Lemma 4 *In the predation equilibrium with linear tariffs, the on-net / off-net pricing structure of the predating firm* 1 *is characterized by the following relation:*

$$L_{12} = \frac{1}{\eta} + \frac{(1+\gamma\eta)^{-1} - \alpha_1}{1-\alpha_1}\left(L_{11} - \frac{1}{\eta}\right) + \mu\frac{a_2 - c_{t2}}{p_{12}} \tag{14}$$

where $\mu \geq 0$ *is the Lagrange multiplier of the condition* $\pi_2 \leq \bar{\pi}_2$*. The predated firm 2's pricing structure is given by (8).*

[7] In a previous version of this paper we considered the equivalent problem $\min_{p_{11},p_{12}} \pi_2 \; s.t. \; \pi_1 \geq \bar{\pi}_1$.

Proof. As in the derivation of Lemma 1 we fix market share α_1, and solve, given (p_{22}, p_{21}),

$$\max_{p_{11},p_{12}} \pi_1 \ s.t. \ \alpha_1 - \frac{1}{2} - A - \sigma(w_1 - w_2) = 0, \ \pi_2 \leq \bar{\pi}_2.$$

With Lagrange multipliers λ and μ, first-order conditions are

$$\begin{aligned} \alpha_1 \left(1 - \frac{p_{11} - c_1}{p_{11}} \eta\right) + \lambda\sigma(1 + \gamma\eta) &= 0 \quad (15) \\ \alpha_1\alpha_2 \left(1 - \frac{p_{12} - c_{1f}}{p_{12}} \eta\right) + \lambda\sigma(\alpha_2 - \alpha_1\gamma\eta) + \mu\alpha_1\alpha_2 \frac{a_2 - c_{20}}{p_{12}} \eta &= 0. \end{aligned}$$

Substituting out λ and solving for L_{12} we obtain the above result. As concerns firm 2 nothing changes since it solves the same problem as before. ■

This result means that under predation the relation describing firm 1's pricing structure shifts if access is not priced at cost: With an access price higher (lower) than cost, firm 1's off-net price will be higher (lower). This makes sense because of the positive (negative) effect of terminating calls from network 1 on firm 2' profits.

On the other hand, if access is priced at cost then the relation as such between the two prices does not change. Nevertheless, market shares and the overall price levels will differ, therefore in any case we now must consider the full equilibrium in Figure 10. As in the previous figures, for simplicity we only consider cost-based access, therefore the additional effect just identified is absent.

In these numerical solutions the most right-hand value of firm 2's profits corresponds to the Nash equilibrium profits (without predation, that is). At this profit level the predation equilibrium prices coincide with the prices in the Nash equilibrium. This is intuitive since, given firm 2's Nash equilibrium prices, firm 1 can only obtain its Nash equilibrium profits by choosing its Nash equilibrium prices. Any intensification of predation, to a lower profit level of firm 2, corresponds to a continuous change in prices, market shares and profits starting from the Nash equilibrium.

We find the following:

Remark 5 *If firms compete in linear tariffs, and if the larger firm practices "limited" predatory pricing, then*

1. *As the degree of predation increases:*

(a) *The large firm's on-net price falls rapidly below the small firm's prices, while its off-net price first decreases and then increases above the Nash equilibrium level. As a consequence, the large firm's on-net / off-net differential increases strongly.*

(b) *The small firm's on-net and off-net prices both decrease slowly, leading to a slight reduction in the on-net / off-net differential.*

2. *There are "decreasing returns to scale" in predation: A further reduction in the small firm's profit is bought at increasing profit reductions for the large firm.*

So how does predatory pricing differ from Nash equilibrium pricing with linear tariffs? The large firm's on-net price is substantially closer to cost, while its off-net price does not budge much initially. This means that the resulting large on-net / off-net differential is driven by the on-net price, not the off-net price.As predation intensifies the differential is increasingly driven by the increase in the off-net price.

With two-part pricing, firm 2 responds as above in (10), while firm 1 now solves the predation problem with a two-part tariff. The equilibrium pricing structure is described in the following Lemma:

Lemma 6 *In the predation equilibrium with two-part tariffs, the on-net / off-net pricing structure of the predating firm* 1 *is characterized by the following relation:*

$$L_{11} = -\gamma,\ L_{12} = \frac{\alpha_1}{\alpha_2}\gamma + \mu\frac{a_2 - c_{t2}}{p_{12}} \text{ if } \alpha_1 < \frac{1}{1+\gamma},\ p_{12} = \infty \text{ otherwise.} \quad (16)$$

where $\mu > 0$ *is the Lagrange multiplier of the condition* $\pi_2 \leq \bar{\pi}_2$. *The predated firm 2's pricing structure is given by (10).*

Proof. First we will substitute F_1 as in (9) into profits π_1. Again keeping market shares constant, firm 1's optimal pricing structure solves, given (F_2, p_{22}, p_{21}),

$$\max_{p_{11},p_{12}} \pi_1 \ s.t.\ \pi_2 \leq \bar{\pi}_2.$$

While the first-order condition for p_{11} does not change, for p_{12} it becomes

$$p_{12} : 0 = \left(1 - \frac{(p_{12} - c_{1f})}{p_{12}}\eta\right) - \left(1 - \frac{\alpha_1}{\alpha_2}\gamma\eta\right) + \mu\frac{a_2 - c_{t2}}{p_{12}}\eta = 0. \quad (17)$$

Solving these equations for p_{11} and p_{12} leads to the above results. As firm 2 solves the same problem as before its pricing structure does not change. ■

As compared to (10) the on-net price maintains its (efficient) value, but the off-net price increases if the access price exceeds cost. That is, we encounter the same effect as with linear tariffs. With cost-based access the value of the off-net price depends on the unknown equilibrium market shares. This implies that we again need to solve numerically for the equilibrium in order to determine the resulting pricing structure. The results are presented in Figure 11, again starting from the right at the Nash equilibrium profit level (with cost-based access).

Remark 7 *If firms compete in two-part tariffs, and if the larger firm practices "limited" predatory pricing, then*

1. *As the degree of predation increases (i.e. the large firm's profits decrease):*

    (a) *Both firms' on-net prices remain constant. The large firm's off-net price increases strongly (approaching the monopoly price), while the small firm's off-net price decreases weakly (approaching marginal cost).*

    (b) *The large firm's on-net / off-net differential increases strongly, while the small firm's decreases slightly.*

    (c) *Both fixed fees decrease, with the large firm's eventually being smaller.*

2. *There are "decreasing returns to scale" in predation: A further reduction in the small firm's profit is bought at increasing profit reductions for the large firm.*

Again even limited predation has some effects. With two-part tariffs what distinguishes predation from the Nash equilibrium is a high off-net price and a low fixed fee by the large firm. These are countered essentially only by a lower fixed fee charged by the small firm. Contrary to the case of linear tariffs, the on-net prices do not move, which is intuitive since they are already set at the efficient (and therefore in this context profit-maximizing) level.

The main feature that is shared by predation under linear and two-part tariffs is the fact that the on-net / off-net price differential of the large firm increases significantly, while that of the small firm decreases slightly. But here the similarities end: With linear tariffs it is a very low on-net price that is the main instrument of predation, while under two-part tariffs a low fixed fee and a high off-net price play this role. Again both are intuitive: The objective of the low fixed fee is the reduction in the small firm's market share, while the aim of the high off-net price is to reduce the call externality benefitting the small firm's clients.

One may ask whether the presence of the call externality makes any difference. In fact, it is decisive for the results. In the absence of a call externality, with linear pricing the on-net/off-net differential is driven mainly by the access price, even under predation. The presence of the call externality leads to significantly higher off-net prices by the predating firm, and therefore to a much larger differential. With two-part tariffs both on-net and off-net prices are equal to cost if there is no call externality, while with the externality they are below and far above cost, respectively. Without the call externality any differential stems from access charges different from cost. With the call externality the differential is driven by the market share difference and strategic considerations.

Summing up:

Remark 8 *Predation by the large firm, both with linear or two-part tariffs, is characterized by a large on-net / off-net differential by the large firm, and a differential similar to the "competitive" Nash equilibrium one for the small firm. These differentials would appear to be much smaller when the call externality is not taken into account. With linear tariffs the instrument of predation is a low on-net price, while with two-part tariffs the large firm employs a low fixed fee and a high off-net price.*

7 Conclusions

We have presented a model where asymmetric telecommunications networks compete in either linear or two-part tariffs in the presence of call externalities. Both asymmetry and call externalities are found to have strong effects on the equilibrium on-net and off-net prices, and the resulting on-net / off-net differential: Large firms charge significantly higher off-net prices, and allow for a higher on-net / off-net differential. This is true under both linear and two-part tariffs.

We have also considered the pricing structures that a large firm would employ if it engaged in (limited) predatory activity against a smaller rival. Both for linear and two-part tariffs we found that predation is characterized by a large on-net / off-net differential, but the reasons for this large differential are rather different. While with linear tariffs it is caused by a low on-net price, with two-part tariffs it is the off-net price that is very high (accompanied by a low fixed fee).

Further research will consider more closely the effects on prices, and welfare in general, of setting access prices reciprocally above or below costs, and, more importantly, setting them asymmetrically. The latter point is of significant interest since small mobile networks have repeatedly expressed the desire to set higher access charges than their larger rivals, supposedly in order to compensate for the asymmetry in market shares. Haucap and Dewenter (2003) allow for asymmetric regulation of access charges, but do not consider on-net prices at all. Peitz (2005) also deals with the question of asymmetric access charges under on-net / off-net price discrimination, but does not take into account the effect of call externalities.

An additional avenue of research will be the inclusion of at least one further network to be able to model existing markets more realistically, with large, medium-sized and small players.

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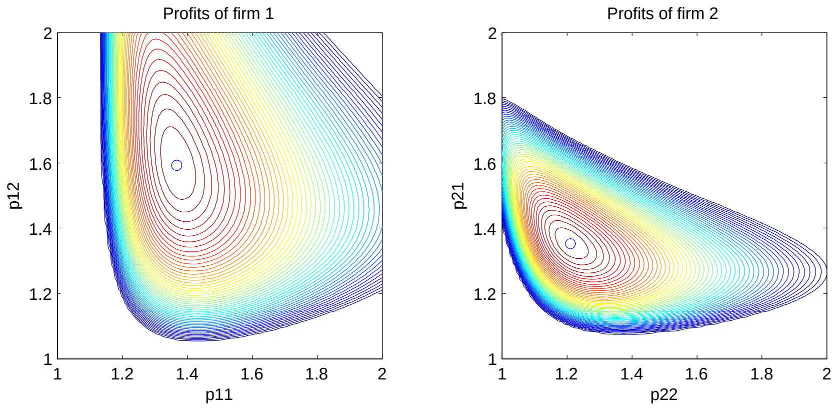

Figure 1: Deviation profits from Nash equilibrium in linear tariffs. Parameter values: $c_i = c_{if} = 1$, $f_i = 0$, $\eta = 2$, $\gamma = 0.1$, $\sigma = 1$, $A = 0.2$.

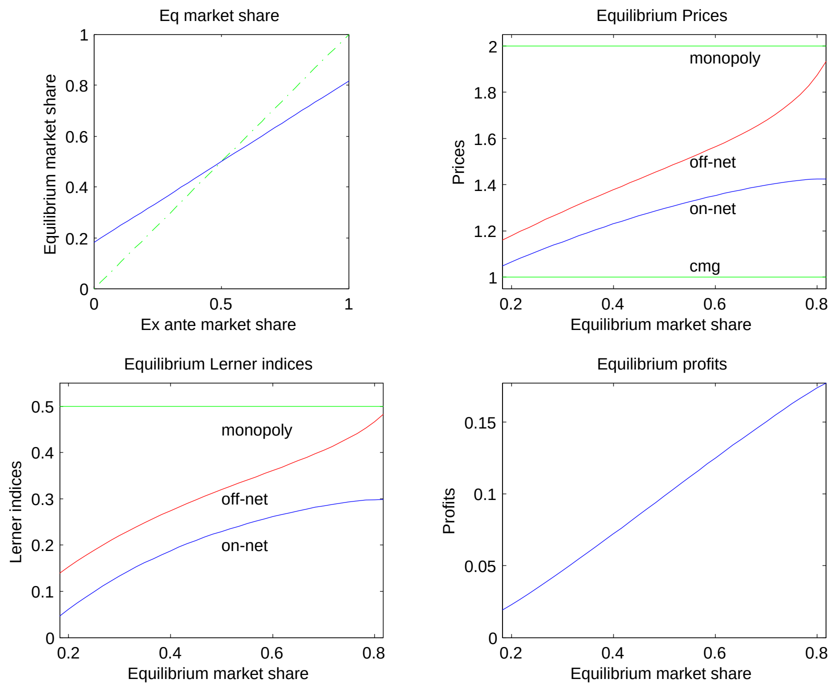

Figure 2: Nash equilibria in linear tariffs as A changes between -0.5 and 0.5. Parameter values: $c_i = c_{if} = 1$, $f_i = 0$, $\eta = 2$, $\gamma = 0.1$, $\sigma = 1$.

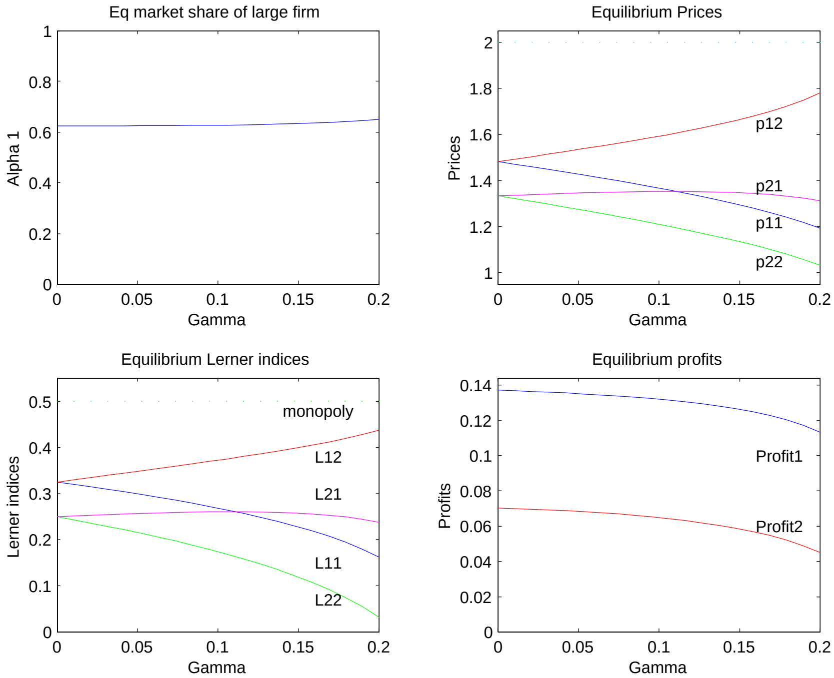

Figure 3: Nash equilibria in linear tariffs as γ changes between 0 and 0.2. Parameter values: $c_i = c_{if} = 1,\ f_i = 0,\ \eta = 2,\ \sigma = 1,\ A = 0.2$.

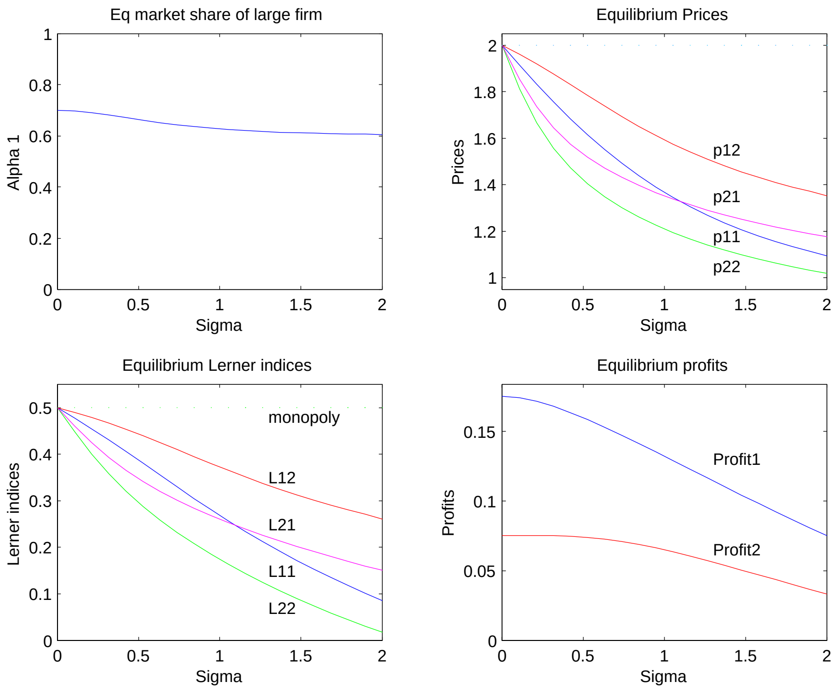

Figure 4: Nash equilibria in linear tariffs as σ changes between 0 and 2. Parameter values: $c_i = c_{if} = 1,\ f_i = 0,\ \eta = 2,\ \gamma = 0.1,\ A = 0.2$.

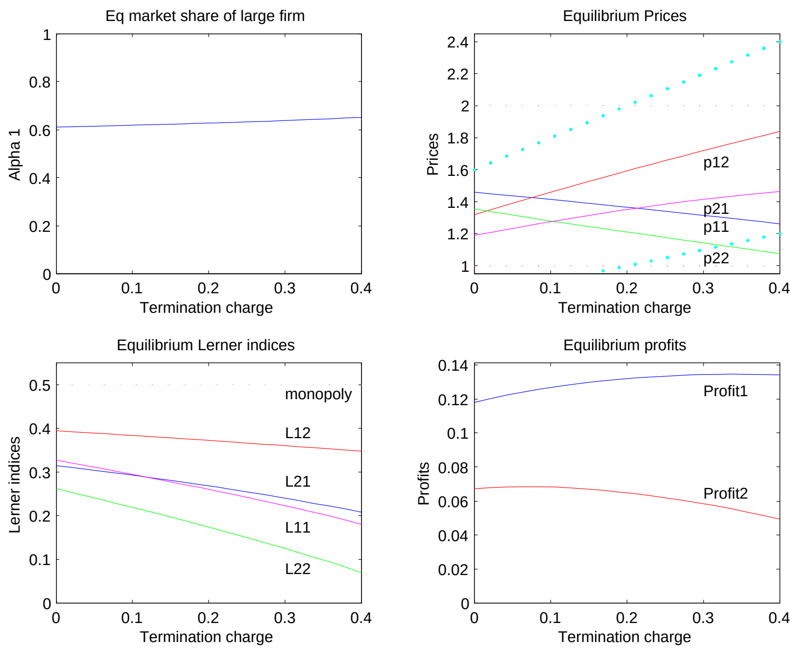

Figure 5: Nash equilibria in linear tariffs as reciprocal termination charge $a_1 = a_2$ changes between 0 and 0.4. Parameter values: $c_i = 1$, $c_{0i} = 0.2$, $f_i = 0$, $\eta = 2$, $\gamma = 0.1$, $\sigma = 1$, $A = 0.2$.

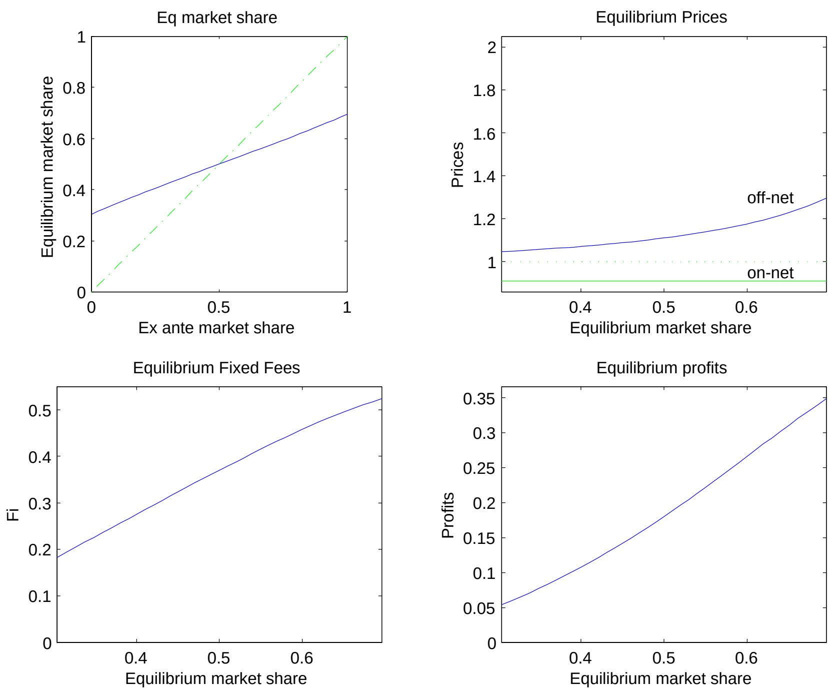

Figure 6: Nash equilibria in two-part tariffs as A changes between -0.5 and 0.5. Parameter values: $c_i = c_{if} = 1$, $f_i = 0$, $\eta = 2$, $\gamma = 0.1$, $\sigma = 1$.

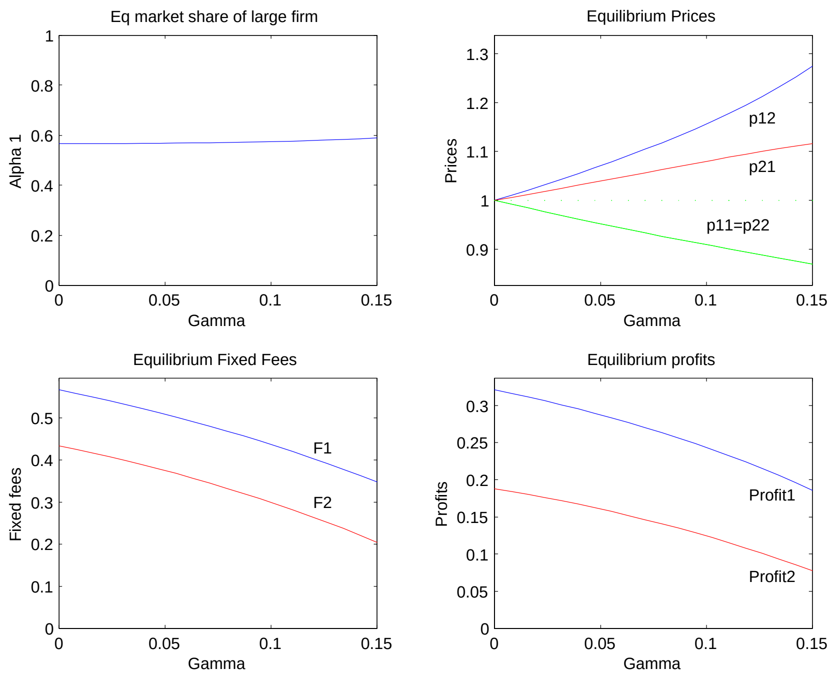

Figure 7: Nash equilibria in two-part tariffs as γ changes between 0 and 0.15. Parameter values: $c_i = c_{if} = 1$, $f_i = 0$, $\eta = 2$, $\sigma = 1$, $A = 0.2$.

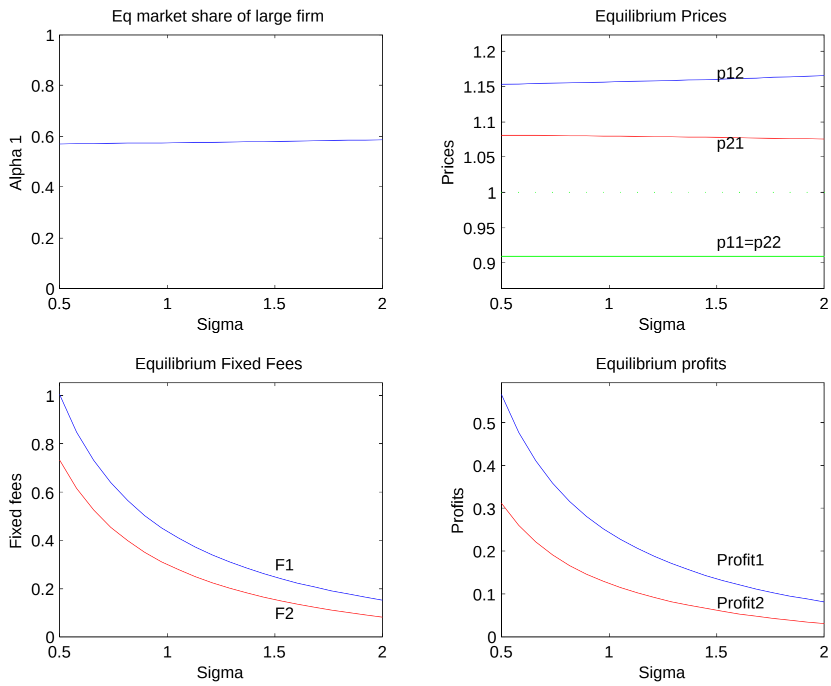

Figure 8: Nash equilibria in two-part tariffs as σ changes between 0.5 and 2. Parameter values: $c_i = c_{if} = 1$, $f_i = 0$, $\eta = 2$, $\gamma = 0.1$, $A = 0.2$.

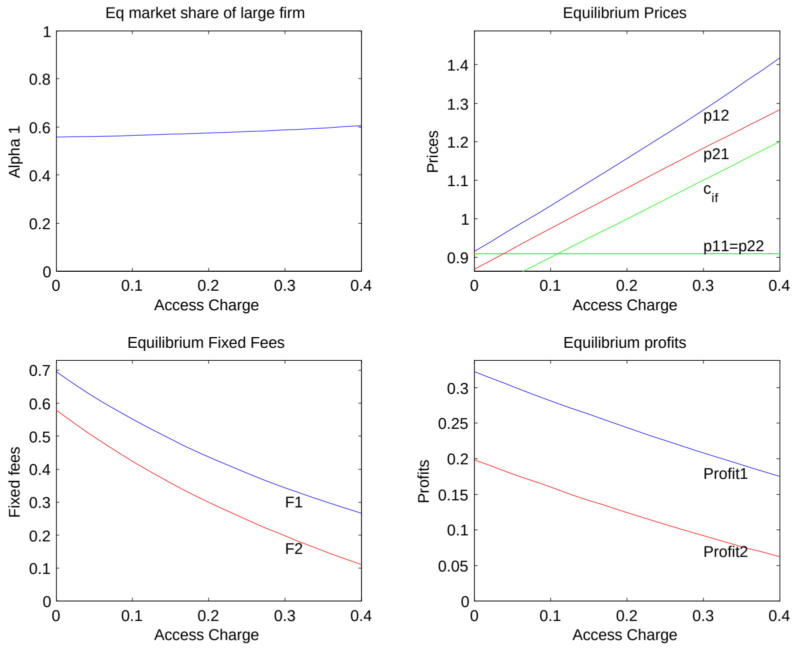

Figure 9: Nash equilibria in two-part tariffs as reciprocal termination charge $a_1 = a_2$ changes between 0 and 0.4. Parameter values: $c_i = 1$, $c_{0i} = 0.2$, $f_i = 0$, $\eta = 2$, $\gamma = 0.1$, $\sigma = 1$, $A = 0.2$.

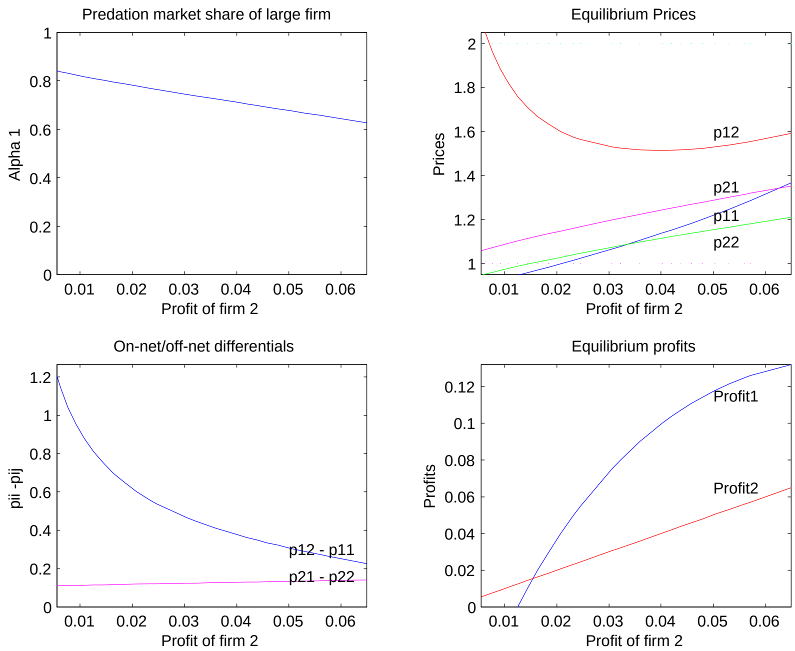

Figure 10: Predation Equilibria with linear tariffs as profits of firm 2 are decreased from the Nash equilibrium level. Parameter values: $c_i = c_{if} = 1$, $f_i = 0$, $\eta = 2$, $\gamma = 0.1$, $\sigma = 1$, $A = 0.2$.

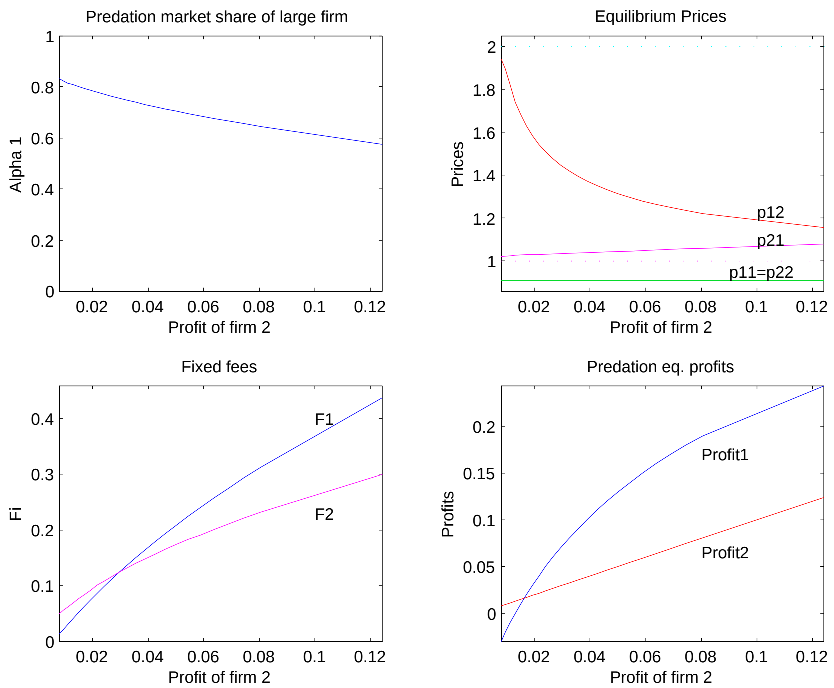

Figure 11: Predation Equilibria with two-part tariffs as profits of firm 2 are decreased from the Nash equilibrium level. Parameter values: $c_i = c_{if} = 1$, $f_i = 0$, $\eta = 2$, $\gamma = 0.1$, $\sigma = 1$, $A = 0.2$.