Mobile Virtual Network Operators: A Virtual Prisoners' Dilemma?*

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Abstract

In this article, we analyze the incentives of mobile network operators to concede access to their networks to mobile virtual network operators. We develop a two-stage model, where in the first stage an entrant mobile virtual network operator negotiates an access price with three incumbent mobile network operators, and in stage 2 firms compete on Salop's circle. The incumbents may be symmetrically or asymmetrically located on the circle, to reflect differences in consumer shares. For some levels of asymmetry, the incumbents face a prisoners' dilemma with respect to conceding access to their networks. Entry by a mobile virtual network operator may lead to lower retail prices. However, entry may also lead to higher retail prices for the host and for the entrant.

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1 Introduction

In this article, we analyze the incentives of mobile network operators to concede access to their networks to mobile virtual network operators. As a by-product of our analysis, we also describe the impact on prices and profits of the entry of mobile virtual network operators.

As Table 1 illustrates, mobile telephony markets are characterized by the presence of a small number of *Mobile Network Operators*, *MNOs*,[1] by a high degree of concentration and, in some cases, also by the presence of *Service Providers*, *SPs*.[2] The large investments required to deploy a mobile telephony network limit the number of *MNOs* that the market can accommodate. However, the scarcity of radioelectric spectrum is the main barrier to entry by additional *MNOs*. The entry of firms that offer only a limited range of services, such as the resale of minutes purchased from *MNO*s, can also promote competition, at least in some dimensions like price. However, to the extent that these firms cannot replicate the full range of services offered by *MNO*s, or develop new innovative services, their ability to compete with *MNO*s is limited. *Mobile Virtual Network Operators*, *MVNOs*,[3] can be an answer to this problem. They make possible the entry of firms that offer consumers a portfolio of services indistinguishable from those provided by *MNO*s, without requiring the allocation of additional radioelectric spectrum.

[*Table* 1]

In order to operate, a *MVNO* needs to obtain access to the radio access network of an *MNO*.[4] In principle both parties can negotiate freely a mutually beneficial agreement, whereby the *MNO* concedes access to its network to the *MVNO*. However, some wonder whether *MNO*s will voluntarily negotiate agreements with *MVNO*s, since the services the latter provide compete with the *MNO*s' own retail services.[5] As it is well known, the monopolist owner of a

[1] A *Mobile Network Operator* is a firm that owns a public mobile telephony network.

[2] Usually, the term *Service Provider* is used to designate a firm that resells minutes purchased from a *MNO*. Here we use the term in the broader sense of a firm that provides services in the mobile telephony industry, without being a mobile network operator.

[3] A *Mobile Virtual Network Operator* is a firm that offers mobile telephony services without holding a licence to use the radioelectric spectrum, and therefore without a mobile radio access network, but that issues its own branded *SIM*-cards, has its own unique mobile network code, and operates a physical network infrastructure comprising as a minimum: **(i)** a Mobile Switching Centre, **(ii)** a Home Location Register, and **(iii)** an Authentication Centre. A full *MVNO* has also: **(i)** an Equipment Identity Register and associated signalling capabilities, and **(ii)** an Intelligent Network platform to provide its customers with its own value-added services.

[4] The radio access network consists of: the masts, the base stations and the frequencies. Access to the radio access network requires at least roaming privileges. *Roaming* is the ability of a customer of a mobile telephony firm to use its handset to automatically access service from another *MNO*.

[5] See, e.g., Commission for Communications Regulation (2004), Office of the Director of Telecommunications

bottleneck production factor, which is also present in the downstream retail market, may have the incentive and the ability to restrict access to the bottleneck production factor, in order to restrict competition in the downstream retail market.[6] An example of this is a monopolist owner of a public switched telephone network, which may want to restrict access to its local loop, in order to restrict competition on the markets of fixed telephony or broadband access to the Internet.

In mobile telephony, there are at least three reasons to suspect that *MNOs* have different incentives than fixed telephony incumbents, with respect to giving access to their networks. First, typically *MNOs* are not monopolist providers of a network. Therefore, even if a *MNO* denies access to its network to an entrant, there is no guarantee that the entrant will not obtain access elsewhere. Second, also because *MNOs* are not monopolists, an *MNO* that hosts a *MVNO* will share with other *MNOs* the revenue loss caused by an entrant. This mitigates the negative impact that entry may have on the revenues of the host *MNO*. Third, if entry cannot be blocked, then it is probably better for each *MNO* to be the one that gives access to the entrant. This allows the host *MNO* to earn additional wholesale revenues, that at least partially compensate the loss in retail revenues caused by the entrant. Altogether, this suggests that *MNOs* may face a prisoners' dilemma. They would be better off if entry did not occur. However, individually they have incentives to rush to be the one who gives access to the entrant.

We develop a two-stage model to analyze these issues. We model the industry as a differentiated product oligopoly on Salop's circle (Salop (1979)). In the first stage, an entrant negotiates the access price with three incumbent *MNOs*. In the second stage, firms compete on prices. A distinguishing characteristic of our approach is that the *MNOs* may be symmetrically or asymmetrically located on the circle, with the degree of asymmetry captured by a parameter. The varying relative location of firms on the loop is intended to capture differences in consumer shares.

The model confirms our intuition. For some values of the assymetry parameter, it is a dominant strategy for *MNOs* to concede access to the entrant, although they would be better off without entry. However, this intuition requires two qualifications. First, for some values of

Regulation (2000) and Oftel (1999). It is unclear whether access to the services required by *MVNO*s could be mandated by National Regulatory Agencies under the Framework Directive 2002/21/EC and in particular the Access Directive 2002/19/EC. It is also unclear whether, if mandated, access to these services should be provided at cost plus or retail minus, i.e., according to the efficient component pricing rule (e.g., Baumol (1983), Baumol and Sidak (1994), and Willig (1979)).

[6]See, e.g., Baumol and Sidak (1994), Biglaiser and DeGarba (2001), Economides (1998), Krattenmaker and Salop (1986), or Sibley and Weisman (1998). For a dissenting view see Bork (1954).

the asymmetry parameter, although entry is the unique equilibrium of the first stage bargaining game, the incumbents do not face a prisoners' dilemma. For the incumbents, conceding access is not a dominant strategy. Second, for other values of the asymmetry parameter, aside from the equilibrium where entry occurs without being a dominant strategy to concede access, there is also an equilibrium where the incumbents deny access to their network. These results highlight the importance of product differentiation and firm asymmetry in the outcome of the bargaining game over the access price.

As expected, entry by a *MVNO* may lead to lower retail prices. Interestingly, however, entry may also lead the retail prices of the host *MNO* and of the *MVNO* to rise above the pre-entry levels. When the host is a contiguous rival of the entrant, by hiking its price it increases the sales of the entrant, and thereby its own wholesale revenues. When access is sold above marginal cost, if the entrant is otherwise equally efficient than the incumbents, overall it will have higher costs than the incumbents. As a consequence, the entrant may charge a price higher than the prices the incumbents charged prior to entry.

Despite the fact that mobile virtual network operators were launched five years ago, in the *UK*, Sweden and Finland, to our knowledge there is no economic literature on this issue, or in the related issue of roaming. Our article relates to: **(i)** the literature on vertical foreclosure, and **(ii)** the literature on raising rivals' costs. The first literature strand, in the case in which the upstream market is monopolized, was reviewed by Tirole (1988), pp. 193-4. That literature addresses the question of whether a vertically integrated firm can increase its profitability by foreclosing the rivals on the downstream market. Ordover et al. (1990) analyzed the case of oligopolistic vertical integration with an oligopolistic upstream market. The second literature strand on raising rivals' costs, e.g., Salop and Scheffman (1987), addresses the issue of whether an upstream monopolist that participates in the downstream market will try to raise rivals' costs. By doing so it induces the downstream rivals to contract their market share, leaving a larger share of downstream oligopoly profits for its downstream subsidiary. Economides (1998) showed that an upstream monopolist that is also present in the downstream market has the incentive to raise costs of its downstream rivals through discriminatory quality degradation, until they are driven out of the market. Vickers (1995) showed that an upstream monopolist also present in a downstream oligopolistic market, and regulated under asymmetric information, also has incentives to raise rivals' costs.

The remainder of the article is organized as follows. In section 2 we present the model, whose equilibria we characterize in section 3. In sections 4 and 5 we conduct the analysis of the model. Section 6 concludes.

2 Model

2.1 Environment

Consider a mobile telephony industry where firms sell horizontally differentiated products.[7] Initially there are three mobile network operators, the *Incumbents*.[8] A fourth firm, the *Entrant*, is a mobile virtual network operator that wants to join the industry. Each incumbent owns a mobile network. To operate, the entrant has to buy access to the radio access network of one of the incumbents.[9] The game has two stages. In *stage* 1, the entrant negotiates an access price with the incumbents.[10] In *stage* 2, the firms present in the market choose prices simultaneously.

2.2 Consumers

There is a large number of consumers, formally a continuum, whose measure we normalize to 1. Consumers are uniformly distributed along a loop of unit length and have quadratic transportation costs, where y^2 measures the cost of traveling distance y. Each consumer has a unit demand, and a finite reservation price of V. The value of V is sufficiently high so that the market is covered, i.e., all consumers purchase the service.[11]

2.3 Firms

We index firms with subscript $i = 1, 2, 3, 4$. The production process involves two types of activities. One type of activities relates to the operation of a radio access network and has a cost of c per consumer. The other type of activities includes the operation of the remaining part

[7] Horizontal product differentiation is a natural assumption for two reasons. First, because although it is unclear if the portfolios of products of the *MNO*s differ much, it is clear that brands play a fundamental role in the competition between *MNO*s. Second, because one of the distinctive characteristics of an *MVNO*, compared with say an *SP*, is that it can offer a product differentiated from those of its rivals, including its host *MNO*.

[8] Three is the minimum number of incumbents required to make the discussion of asymmetry interesting. Besides, three is the average number of *MNO*s in the *EU*.

[9] Typically, each *MVNO* buys access from only one *MNO*, although an *MNO* may sell access to several *MVNO*s.

[10] This is obviously a simplification. The host and the entrant negotiate over several dimensions, such as the prices of origination and termination traffic, the elements of the host's network that the entrant will hire and the capacity that the entrant expects to use. Typically a contract between a host and an entrant involves non-linear price schedules, with payments flowing in both directions. The entrant might be compensated by the host: **(i)** if it brings new customers to the network, **(ii)** if it increases the total network traffic, or, **(iii)** if it makes the use of the network more evenly divided throughout the day.

[11] It can be shown that $V - c > \frac{1}{4}$ is a sufficient condition for this to happen.

of the mobile telephony network and retailing.[12] Since the second type of activities requires inputs that are transacted in competitive markets, we assume that their cost per consumer is identical across firms, and normalize its value to be zero. Denote by α_i the access price of the bottleneck input of firm i, and denote by $z_i := \alpha_i - c$, the access price of the bottleneck input net of the marginal cost, the *Net Access Price* for short, with which it is more convenient to work. Denote by P_i, the retail price of firm $i = 1, 2, 3, 4$.

The bargaining game unfolds as follows. First, the incumbents simultaneously make access price offers to the entrant. Afterwards, the entrant decides which offer to accept, if any. If the entrant rejects all offers, he exits the industry and receives a payoff of 0; if he accepts one of the offers, he proceeds with the incumbents to stage 2 of the game.[13] Denote by Z_i, a subset of $\Re_0^+$, the strategy space in stage 1 of firms $i = 1, 2, 3$. The strategy space of firm 4 in stage 1 is the set $\{none, one, two, three\}$ where "*none*" means that firm 4 rejects all offers, "*one*" means that firm 4 accepts the offer of firm 1, etc. Since this is a very particular, although natural, bargaining game, in section 5.2 we discuss other bargaining games.

$[Figure\ 1]$

The incumbents are located clockwise according to their number, as illustrated in Figure 1. The distance between firms 3 and 1, moving clockwise, is δ on $(0, 1)$. Parameter δ measures the degree of asymmetry between the incumbents. Firm 2 is located equidistantly between these two firms. The entrant locates in the midpoint of the largest available gap. This implies that if δ belongs to $\left(\frac{1}{3}, 1\right)$, the entrant locates between firms 1 and 3; and if δ belongs to $\left(0, \frac{1}{3}\right]$, the entrant locates either between firms 1 and 2, or between firms 2 and 3. This way of modeling asymmetry imposes that two of the incumbents are identical. If δ belongs to $\left(\frac{1}{3}, 1\right)$, without entry there are two large firms and one small firm. If δ belongs to $\left(0, \frac{1}{3}\right]$, without entry there is one large firm and two small firms. Nevertheless, this specification encompasses several cases of interest with a single parameter: **(i)** if $\delta = \frac{1}{3}$ there is pre-entry symmetry; **(ii)** if $\delta = \frac{1}{2}$ there is post-entry symmetry; and **(iii)** if $\delta = 1$ there is pre-entry product homogeneity.[14] We analyze

[12] I.e., distribution, billing, bad debt collection and customer support.

[13] In a one stage bargaining game with two players, i.e., in the ultimatum game, the bargaining power lies with the party that makes the offer. Our case is different because: **(i)** more than one player makes offers, **(ii)** the players that make offers are not all identical. Our type of bargaining game has been widely used in the literature, e.g., by Barros and Cabral (2000). Considering games similar to those of Binmore and Herrero (1988), Corominas-Bosch (2003), or Rubinstein and Wolinsly (1990) would lead to qualitatively similar results.

[14] If $\delta = 1$, all incumbents are located on the same point. If $\delta = 0$, firms 1 and 3 are located on the same point.

first the case where δ belongs to $\left(\frac{1}{3}, 1\right)$. In section 5.3, we discuss the case where δ belongs to $\left(0, \frac{1}{3}\right]$.

A stage 1 *strategy* for firms 1, 2, and 3 is a net access price z_i on Z_i, defined ahead. A stage 1 *strategy* for firm 4 is an acceptance rule, that says which offer the entrant should accept, if any, given the incumbents' offers of access prices, $AC : Z_1 \times Z_2 \times Z_3 \longrightarrow \{none, one, two, three\}$. A stage 2 *strategy* for the firms present in the market is a pricing rule P_i, that says which price firms should charge, given the access price offers of the incumbents and the acceptance decision of the entrant.

Denote by D_i, the demand of firm i, which will be described ahead. The profit of the incumbents that do not sell access are: $\pi_i = (P_i - c)\, D_i$. The profit of the entrant is: $\pi_4 = (P_4 - \alpha_i) D_4$. And the profit of the incumbent that hosts the entrant is:

$$\pi_i = \underbrace{(P_i - c)\, D_i}_{\text{retail profits}} + \underbrace{(\alpha_i - c)\, D_4}_{\text{wholesale profits}}.$$

2.4 Equilibrium

A *Subgame Perfect Nash Equilibrium in Pure Strategies* is: **(i)** a profile of net access price offers, **(ii)** an acceptance rule and **(iii)** a profile of pricing rules for the firms present in the market, such that:

(E1) firms choose their pricing rules to maximize profit, given the rivals' pricing rules, and given the entrant's acceptance decision and the incumbents' net access price offers;

(E2) the entrant chooses an acceptance rule to maximize profit, given the stage 2 pricing rules;

(E3) the incumbents choose net access prices to maximize profit, given the other incumbents' net access prices, and given the entrant's acceptance rule and the stage 2 pricing rules.

3 Equilibrium

In this section we construct the model's equilibria by backward induction. Hence, we characterize first the equilibrium prices and afterwards the equilibrium bargaining.

3.1 Pricing Game

Next we characterize the equilibrium prices and profits: **(i)** for the case where firm 4 rejects the access price offers of all of the incumbents and therefore there is no entry, **(ii)** for the case where the entrant accepts the offer of the non-contiguous rival firm 2, and **(iii)** for the case where the entrant accepts the offer of a contiguous rival, either firm 1 or firm 3. When entry is hosted by a contiguous competitor of the entrant, since firms 1 and 3 are identical, we analyze only the case where access is provided by firm 1.

3.1.1 No Entry

We use superscript "n" to denote variables or functions associated with this case.

Denote by $l_{i,i'}$, the location of the consumer indifferent between purchasing from firm i or firm i', and denote by l_i, the location on the loop of firm i. For the consumer indifferent between firms i and i':

$$P_i + (l_{i,i'} - l_i)^2 = P_{i'} + (l_{i,i'} - l_{i'})^2,$$

or equivalently,

$$l_{i,i'} = \frac{1}{2}\left[\frac{P_{i'} - P_i}{l_{i'} - l_i} + (l_i + l_{i'})\right].$$

We assume that all firms have a positive demand for their products, i.e. $l_{i,i+1} < l_{i+1,i+2}$, for all i. For firm i, located between firms i' and i'', demand is given by:

$$D_i(P_i, P_{i'}, P_{i''}) = l_{i,i''} - l_{i',i} = \frac{1}{2}\left[\frac{P_{i''} - P_i}{l_{i''} - l_i} + \frac{P_{i'} - P_i}{l_i - l_{i'}} + (l_{i''} - l_{i'})\right].$$

With this expression one can obtain the demand for each firm in the cases where there is no entry and where there is entry.[15] One merely has to replace l_i, $l_{i'}$, and $l_{i''}$ by the location of the relevant firms. In the case where there is no entry, the demand of firm 1 is given by:

$$D_1(P_1, P_2, P_3) = \frac{1}{2}\left[\frac{P_3 - P_1}{\delta} + \frac{P_2 - P_1}{(1-\delta)/2} + \frac{1+\delta}{2}\right].$$

The first-order condition for price of firm i is:

$$(P_i - c)\frac{\partial D_i}{\partial P_i} + D_i = 0.$$

The next Lemma presents the equilibrium prices.

Lemma 1: *Let δ belong to $\left(\frac{1}{3}, 1\right)$. Without entry, in equilibrium the incumbents charge prices:*

$$P_i^n(\delta) = \begin{cases} c + \frac{(1-\delta)(\delta+3)\delta}{4(2\delta+1)} & i = 1,3 \\ c + \frac{(1-\delta)\left(1+4\delta-\delta^2\right)}{8(2\delta+1)} & i = 2. \end{cases}$$

■

[15] Only the prices of the contiguous rivals enter a firm's demand function.

As expected, firms 1 and 3 charge the same price, which is no smaller than the price of firm 2: $P_1^n(\delta) = P_3^n(\delta) \geq P_2^n(\delta)$. All consumer shares are positive without the need to place additional restrictions on δ. As expected, firms 1 and 3 have the same profit, which is no smaller than the profit of firm 2.

3.1.2 Entry Hosted by a Non-Contiguous Competitor

We use superscript "2" to denote variables or functions associated with this case.

The first-order condition for price for firms 1, 2, and 3 is:[16]

$$(P_i - c)\frac{\partial D_i}{\partial P_i} + D_i = 0 \tag{1}$$

In addition, the first-order condition for price for firm 4 is:

$$(P_4 - \alpha_2)\frac{\partial D_4}{\partial P_4} + D_4 = 0 \tag{2}$$

Let $z_2^a := \frac{3\delta}{8+4\delta}$, whose role will be explained ahead. The next Lemma gives the equilibrium prices.

Lemma 2: *Let δ belong to $\left(\frac{1}{3}, 1\right)$. Suppose there is entry hosted by firm 2 with net access price z_2 on $[0, z_2^a]$. In equilibrium, the incumbents and the entrant charge prices:*

$$P_i^2(z_2;\delta) = \begin{cases} c + \frac{(1-\delta)(3\delta+4z_2)}{12} & i = 1,3 \\ c + \frac{(1-\delta)(3+4z_2)}{24} & i = 2 \\ c + \frac{4(4-\delta)z_2+3\delta}{24} & i = 4. \end{cases}$$

■

The condition that z_2 is no larger than z_2^a ensures that the consumer shares are positive.

In order to compare these prices, consider first the case where δ belongs to $\left[\frac{1}{2}, 1\right)$. Equilibrium prices can be ranked as follows: $P_4^2(z_2;\delta) \geq P_1^2(z_2;\delta) = P_3^2(z_2;\delta) \geq P_2^2(z_2;\delta)$. The entrant, firm 4, sets the highest price for two reasons. First, because he has the highest marginal cost, $z_2 \geq 0$. And second, because he faces a larger demand than the other firms: any of the incumbents has closer rivals. The host, firm 2, sets the lowest price also for two reasons. First, because he faces stronger, or closer, competition. And second, because he is located the furthest away from the firm with the highest marginal cost and price.

[16]From footnote 15, $\frac{\partial D_4}{\partial P_2} = 0$, for δ on $\left(\frac{1}{3}, 1\right)$.

Consider now the case where δ belongs to $\left(\frac{1}{3}, \frac{1}{2}\right)$. Firm 4 has a smaller demand and larger costs than its rivals. Firms 1 and 3 have an intermediate demand, but are located close to a high cost firm. Firm 2 has a large demand and both its contiguous rivals have low costs. The level of demand, the level of costs and the level of costs of the contiguous rivals push prices in opposite directions. Consequently, any ranking can occur depending on z_2 and δ, as illustrated in Figure 2.

[*Figure* 2]

The next Remark collects some auxiliary results that will be useful later.

Remark 1: *Let* δ *belong to* $\left(\frac{1}{3}, 1\right)$ *and* z_2 *belong to* $[0, z_2^a]$.

(i) *The profit functions of firms* 1 *and* 3, $\pi_1^2(\cdot;\delta)$ *and* $\pi_3^2(\cdot;\delta)$, *are increasing in the net access price,* z_2.

(ii) *The profit function of the entrant,* $\pi_4^2(\cdot;\delta)$, *is decreasing in the net access price,* z_2, *and has a root for* $z_2^a(\delta)$.

(iii) *The profit function of the host,* $\pi_2^2(\cdot;\delta)$, *is concave in the net access price,* z_2, *and has a point of maximum with respect to the net access price at* $z_2^*(\delta)$, *where* $z_2^*(\delta) < z_2^a(\delta)$. ■

3.1.3 Entry Hosted by a Contiguous Competitor

We use superscript "1" to denote variables or functions associated with this case.

The demands are similar to those presented in section 3.1.2 with the obvious differences.

The first-order conditions are also similar with the exception of that of the host, firm 1, which becomes:

$$(P_1 - c)\frac{\partial D_1}{\partial P_1} + D_1 + (\alpha_1 - c)\frac{\partial D_4}{\partial P_1} = 0 \tag{3}$$

Let $z_1^a := \frac{3\delta}{4+8\delta}$. The next Lemma gives the equilibrium prices.

Lemma 3: *Let* δ *belong to* $\left(\frac{1}{3}, 1\right)$. *Suppose there is entry hosted by firm* 1 *with net access price* z_1 *on* $[0, z_1^a]$. *In equilibrium, the incumbents and the entrant charge prices:*

$$P_i^1(z_1;\delta) = \begin{cases} c + \frac{(1-\delta)(3\delta+11z_1)}{12} & i = 1 \\ c + \frac{(1-\delta)(3+8z_1)}{24} & i = 2 \\ c + \frac{(1-\delta)(3\delta+5z_1)}{12} & i = 3 \\ c + \frac{3\delta+4(5-2\delta)z_1}{24} & i = 4. \end{cases}$$

■

As in section 3.1.2, the condition that z_1 is no larger than z_1^a ensures that the consumer shares are positive.

Firms 2, 3, and 4 face the same incentives with respect to pricing as in the case where firm 2 is the host. The host, firm 1, has an additional incentive. Inspection of (3) shows that by hiking its price, firm 1 increases the entrant's sales, $\frac{\partial D_4}{\partial p_1} > 0$, and hence, its own wholesale revenues. Comparison between (3) and (1) shows that this incentive is not present when firm 2 is the host. Firms 1 and 3 are symmetrical with respect to location and costs. However, the additional incentive firm 1 has to increase its price implies that it charges a higher price than firm 3: $P_1^1(z_1;\delta) \geq P_3^1(z_1;\delta)$.

For the case where δ belongs to $\left[\frac{1}{2},1\right)$, equilibrium prices can be ranked as follows: $P_4^1(z_1;\delta) > P_1^1(z_1;\delta) > P_3^1(z_1;\delta) > P_2^1(z_1;\delta)$. Firm 2 sets the lowest retail price for three reasons. First, because it is not a contiguous competitor of the high cost, and high price, entrant. Second, because it faces stronger, or closer, competition. And third, because unlike firm 1 it has no wholesale activity. Firm 4, on the contrary sets a high price because it has higher costs and more distant competitors.

Again, for δ on $\left(\frac{1}{3},\frac{1}{2}\right)$ any price ranking may occur, depending on z_1 and δ. If $z_1 = 0$, for instance, we have $P_2^1(z_1;\delta) > P_1^1(z_1;\delta) = P_3^1(z_1;\delta) > P_4^1(z_1;\delta)$. Firms are symmetric with respect to cost, and only location matters when setting prices. An increase in z_1 implies a higher marginal cost for firm 4. This gives firm 4, as well as its direct competitors, firms 1 and 3, an incentive to set a higher prices. The incentive is smaller for the latter two firms than for firm 4.

The next Remark collects some auxiliary results that will be useful later.

Remark 2: *Let δ belong to $\left(\frac{1}{3},1\right)$ and z_1 belong to $[0,z_1^a]$.*

(i) *The profit functions of firms 2 and 3, $\pi_2^1(\cdot;\delta)$ and $\pi_3^1(\cdot;\delta)$, are increasing in the net access price, z_1.*

(ii) *The profit function of the entrant, $\pi_4^1(\cdot;\delta)$, is decreasing in the net access price, z_1, and has a root for $z_1^a(\delta)$.*

(iii) *The profit function of the host, $\pi_1^1(\cdot;\delta)$, is concave in the net access price, z_1, and has a point of maximum with respect to the net access price at $z_1^*(\delta)$, where $z_1^*(\delta) < z_1^a(\delta)$.* ■

3.1.4 The Impact of Entry on Prices

Next we compare the price levels for the case where firm 1 is the host and the case where firm 2 is the host, with the case where there is no entry.

By definition of $z_i^*(\delta)$, if firm i could impose freely a net access price to the entrant, it would choose $z_i^*(\delta)$. For this motive, we will refer to $z_i^*(\delta)$ as the *Monopoly Net Access Price* of firm $i = 1, 2, 3$. We restrict the net access prices to be no higher than the monopoly net access price of the host, because further increases in the net access price reduce the profit of both the host and the entrant.

The next Proposition describes the impact of entry on prices.

Proposition 1: *Let* δ *belong to* $\left(\frac{1}{3}, 1\right)$*, and* z_i *on* $[0, z_i^*(\delta)]$ *be given.*

(i) *Let firm* 1 *be the host. The retail prices of firms* 2 *and* 3 *are lower than when there is no entry. The retail price of firm* 1 *may be lower or higher than when there is no entry. The retail price of firm* 4 *may be lower or higher than the retail prices of the incumbents when there is no entry.*

(ii) *Let firm* 2 *be the host. The retail prices of all incumbents are lower than when there is no entry. The price of firm* 4 *may be lower or higher than the retail prices of the incumbents when there is no entry.*

(iii) *If all incumbents charge the same net access price, the retail prices are higher for all firms when firm* 1 *is the host than when firm* 2 *is the host.* ■

[*Figure* 3]

When firm 1 is the host, the retail prices of firms 2 and 3 decrease compared with the case where there is no entry, due to the increase in competition. As illustrated by Figure 3, the price of firm 1, however, may increase or decrease when compared with the case where there is no entry. Inspection of (3) shows that by hiking its price, firm 1 increases the sales of the entrant, $\frac{\partial D_4}{\partial p_1} > 0$, and thereby, its own wholesale revenues. Figure 3 also illustrates that the price of the entrant may be higher or lower than the prices of the incumbents in the case where there is no entry, depending on the values of the net access price, z_1, and the asymmetry parameter, δ. An increase in z_1 means an increase in the marginal cost of the entrant. As a consequence, firm 4 raises its price, which allows the incumbents to set higher prices too. A larger δ means that firm 4 will be at a larger distance from both of its contiguous competitors, firms 1 and 3, and will therefore have a larger demand. Thus, the price of the entrant is increasing in z_1 and in δ. Note that if the net access price is equal to zero, $z_i = 0$, or sufficiently low, entry decreases the retail prices of the incumbents, but not necessarily the price of the entrant. As Figure 3 illustrates, if δ is large, i.e., if $\delta > 0.679$, the price of the entrant may be larger than the prices of the incumbents in the case where there is no entry, even when $z_i = 0$. The reason is that for such a large δ, the contiguous competitors of the entrant are located at a large distance, which gives the entrant some local market power.[17] If the net access price is above above zero, price increases after entry by the host and the entrant are more likely, for the same value of δ. In addition, the set of parameters values for which the price of firms 1 and 4 may increase after entry is larger. This suggests that the possibility that the prices of the host and the entrant after entry may exceed the pre-entry price levels is potentially relevant.

When firm 2 is the host, the retail prices of all incumbents decrease compared with the case where there is no entry, due to the increase in competition.[18] The price of firm 2 decreases by a smaller amount than those of the contiguous competitors of the entrant, firms 1 and 3, because firm 2 is only affected by a second order effect. As a consequence, the retail consumer share of firm 2 decreases. The price of the entrant, firm 4, may again be higher or lower than the prices of the incumbents in the case where there is no entry, depending on the values of the net access price, z_2, and the asymmetry parameter, δ. For the same reasons as when firm 1 is the host, the price of the entrant is increasing in δ and z_2.

3.2 Bargaining Game

Next we characterize the equilibria of the bargaining game. First, we discuss the case where one of the contiguous competitors of the entrant, firm 3, does not negotiate access to its network, perhaps because it is capacity constrained. We will adjust the notation accordingly. Afterwards, we discuss the case where all incumbents negotiate access to their networks with the entrant. As it will become clear later, it is more instructive to present the analysis in this order.

3.2.1 Acceptance Rule of Firm 4 when only Firms 1 and 2 Negotiate

From Remarks 1 and 2, the profit function of the host, $\pi_i^i(\cdot;\delta)$, is concave with respect to the net access price. Denote by $\overline{\overline{z}}_i(\delta)$, the strictly positive level of the net access price of firm i that generates the same profit for the host as a 0 net access price , i.e., $\pi_i^i(\overline{\overline{z}}_i(\delta);\delta) \equiv \pi_i^i(0;\delta)$.

[17] Nevertheless, consumers are better off with entry due to the reduction in transportation costs. They could always switch to firm 1 and firm 3 which, for low values of z_1 are both setting lower prices than before entry took place.

[18] The relevant figure for this case is qualitatively similar to Figure 3 and is therefore omitted. The main difference is that the host's price always decreases.

We restrict, without loss of generality, the stage 1 strategy space of firm i to be $Z_i = \left[0, \overline{\overline{z}}_i(\delta)\right]$. Also, from Remarks 1 and 2, the profit function of the entrant, $\pi_4^i(\cdot;\delta)$, is strictly decreasing in z_i. Thus, net access prices larger than $z_i^a(\delta)$ imply a null consumer share and no profits for the entrant. Consequently, we will say that net access price offers larger than $z_i^a(\delta)$ are *Unacceptable*, and that net access price offers no larger than $z_i^a(\delta)$ are *Acceptable*. We assume that when the entrant is indifferent between being hosted by firm 1 or firm 2, he chooses firm 1, and that when indifferent between entering the market or not, he chooses the latter.

When faced with a pair of offers, the entrant prefers purchasing access from firm 1 rather than from firm 2, if and only if, $\pi_4^1(z_1;\delta) \geq \pi_4^2(z_2;\delta)$, or equivalently, $z_2 \geq \beta(\delta) z_1$ with $\beta(\delta) := \frac{2\delta+1}{\delta+2}$. This function is strictly increasing, with $\beta(1) = 1$. Since $\beta(\delta) < 1$, under equal circumstances, i.e., if $z_1 = z_2$, the entrant prefers to buy access from firm 1 rather than from firm 2. This happens because when firm 1 is the host it sets a higher retail price than when firm 2 is the host, as stated in Proposition 1. The entrant benefits from this since firm 1 is one of its contiguous competitors. An increase in δ increases the set of values of (z_1, z_2) for which firm 4 prefers to buy access from firm 1 rather than from firm 2. Note also that $z_2^a(\delta) = \beta(\delta) z_1^a(\delta)$.

Given the previous discussion, the optimal acceptance rule of the entrant when only firms 1 and 2 negotiate is:

$$AC(z_1, z_2; \delta) = \begin{cases} \textit{none} & \text{if } \; z_i^a(\delta) \leq z_i \leq \overline{\overline{z}}_i(\delta),\ i = 1, 2 \\ \textit{one} & \text{if } \; 0 \leq z_1 < z_1^a(\delta),\ \beta(\delta) z_1 \leq z_2 \leq \overline{\overline{z}}_2(\delta) \\ \textit{two} & \text{if } \; 0 \leq z_2 < \min\left\{z_2^a(\delta), \beta(\delta) z_1\right\}. \end{cases}$$

3.2.2 Best Response Correspondence of Firm 1 when only Firms 1 and 2 Negotiate

Recall that if firm i could impose freely an access price to the entrant, it would choose the monopoly access price, $z_i^*(\delta)$. Let $z_i^{**}(\delta)$ be the value of the net access price of firm i, that the rival, firm i', can undercut by setting its monopoly net access price. Then $z_2^{**}(\delta) := \beta(\delta) z_1^*(\delta)$ and $z_1^{**}(\delta) := \frac{z_2^*(\delta)}{\beta(\delta)}$.

Assume first that firm 2 made an unacceptable offer to the entrant, i.e., made an offer $z_2 \geq z_2^a(\delta)$. Firm 1 has two options: **(i)** set its monopoly net access price, $z_1^*(\delta)$, or **(ii)** make an unacceptable offer, $z_1 \geq z_1^a(\delta)$. The proximity to the entrant, i.e., the value of δ, determines which of the two options is the best response. If δ is small, i.e., if $\delta < 0.426$, then firm 1 is better off without entry, and the best response is to make an unacceptable offer. On the contrary, if δ is large, i.e., $\delta \geq 0.426$, the best response is to offer the monopoly net access price. This happens because when δ is relatively small, the products of the entrant and of firm

1 are close substitutes. Hence, the retail profits of firm 1 decrease significantly with entry. As a consequence, despite being able to set the monopoly net access price, and have significant wholesale profits, firm 1 prefers not to concede access to its network.

Consider now the case in which firm 2 makes an acceptable offer to the entrant, i.e., an offer $z_2 < z_2^a(\delta)$. Firm 1 has two options: **(i)** undercut firm 2, or **(ii)** make an unacceptable offer. If the offer of firm 2 is high, i.e., if $z_2 \geq z_2^{**}(\delta)$, firm 1 can undercut firm 2 with its monopoly net access price, whereas if the offer of firm 2 is low, i.e., if $z_2 < z_2^{**}(\delta)$, firm 1 has to offer a net access price lower than its monopoly net access price, $z_1 = \frac{z_2}{\beta(\delta)} < z_1^*(\delta)$, to be chosen by the entrant as the host. In either case, firm 1 best responds by undercutting its rival. This happens because entry will take place, regardless of the offer of firm 1, which only determines which firm will be the host. If nearby entry is inevitable because firm 2 made an acceptable offer, firm 1 clearly prefers to be the host. The wholesale revenue compensates some of its unavoidable retail losses, and, in addition, its retail price will also be higher.

The resulting best response correspondence is represented in Figure 4.

$[Figure\ 4]$

The next Lemma formalizes the previous discussion.

Lemma 4: *The net access price best response correspondence of firm* 1 *when only firms* 1 *and* 2 *negotiate is:*

$$\zeta_1(z_2;\delta) = \begin{cases} \left(z_1^a(\delta), \overline{\overline{z}}_1(\delta)\right) & \text{if } \ z_2^a(\delta) \leq z_2 \leq \overline{\overline{z}}_2,\ \delta \leq 0.426 \\ z_1^*(\delta) & \text{if } \ z_2^{**}(\delta) \leq z_2 < z_2^a(\delta)\ ;\text{ or, } z_2^a(\delta) \leq z_2 \leq \overline{\overline{z}}_2(\delta),\ \delta > 0.426 \\ \frac{z_2}{\beta(\delta)} & \text{if } \ 0 \leq z_2 < z_2^{**}(\delta) \end{cases}$$

■

3.2.3 Best Response Correspondence of Firm 2 when only Firms 1 and 2 Negotiate

As in the previous case, assume first that firm 1 made an unacceptable offer to the entrant, $z_1 \geq z_1^a(\delta)$. Again, firm 2 has two options: **(i)** set its monopoly net access price, $z_2^*(\delta)$, or **(ii)** make an unacceptable offer, $z_2 > z_2^a(\delta)$. As before, the best response depends on the value of δ. If δ is small, i.e., $\delta < 0.526$, the best response is to make an unacceptable offer. On the contrary, if δ is large, i.e., $\delta \geq 0.526$, the best response is to offer the monopoly net access price. As stated in Proposition 1, entry hosted by firm 2 leads to lower retail prices, compared with the case where there is no entry. Thus, firm 2 is only willing to be the host if its wholesale revenues more than compensate these retail losses. For this to happen, firm 4 must have large consumer shares. This happens for large values of δ, i.e., happens when the entrant is selling a product that is sufficiently differentiated from the product of the incumbents.

Consider now the case in which firm 1 makes an acceptable offer to the entrant, $z_1 < z_1^a(\delta)$. Again, firm 2 has two options: **(i)** undercut firm 1, or **(ii)** make an unacceptable offer. If the offer of firm 1 is very high, i.e., if $z_1 > \max\{z_1^{**}(\delta), \check{z}_1^c(\delta)\}$, where the values $\check{z}_1^c(\delta)$ and $z_1^c(\delta)$, below, are defined in the appendix, then although firm 2 can undercut firm 1 with its monopoly net access price, the best response is to make an unacceptable offer. The reason is that if firm 1's offer is high enough, i.e., $z_1 > \check{z}_1^c(\delta)$, it is better for firm 2 to let the entrant accept it, and take advantage of the higher equilibrium retail prices, than to undercut firm 1 and become the host. If the offer of firm 1 is not as high, but can still be undercut when firm 2 sets its monopoly net access price, i.e., if $z_1^{**}(\delta) < z_1 < \check{z}_1^c(\delta)$, then firm 2 best responds by undercutting firm 1 and setting its monopoly net access price. This happens because letting firm 1 be the host leads to a smaller increase in retail prices than in the previous case, given that the net access price is smaller. As a result, letting firm 1 be the host is less appealing than being the host with the monopoly net access price $z_2^*(\delta)$. If the offer of firm 1 is lower than $z_1^{**}(\delta)$, firm 2 cannot undercut it with $z_2^*(\delta)$, but only with the lower $z_2 = \beta(\delta)z_1 - \varepsilon$, with $\varepsilon > 0$ arbitrarily small. A situation similar to the one just described occurs if $z_1^c(\delta) < z_1 < z_1^{**}(\delta)$. The best response is to make an unacceptable offer because entry hosted by firm 1 will result in high retail prices due to the net access price being high. However, if the offer of firm 1 is low, i.e. $z_1 < \min\{z_1^{**}(\delta), z_1^c(\delta)\}$, post-entry retail prices would be relatively low and firm 2 would not benefit from entry hosted by firm 1 as much as it would when undercutting it, by setting $z_2 = \beta(\delta)z_1 - \varepsilon$.

The next Lemma formalizes the previous discussion.

Lemma 5: *The net access price best response correspondence of firm* 2 *when only firms* 1 *and* 2 *negotiate is:*

$$\zeta_2(z_1;\delta) = \begin{cases} \left(z_2^a(\delta), \overline{\overline{z}}_2(\delta)\right) & \text{if } z_1^c(\delta) < z_1 < z_1^{**}(\delta);\text{ or, } \max\{z_1^{**}(\delta), \check{z}_1^c(\delta)\} < z_1 < z_1^a(\delta); \\ & \quad \text{or, } z_1^a(\delta) \le z_1 \le \overline{\overline{z}}_1(\delta),\ \delta \le 0.526 \\ z_2^*(\delta) & \text{if } z_1^{**}(\delta) < z_1 < \check{z}_1^c(\delta);\text{ or, } z_1^a(\delta) \le z_1 \le \overline{\overline{z}}_1(\delta),\ \delta > 0.526 \\ \beta(\delta)z_1 - \varepsilon & \text{if } 0 \le z_1 < \min\{z_1^{**}(\delta), z_1^c(\delta)\} \end{cases}$$

■

3.2.4 Equilibria when only Firms 1 and 2 Negotiate

The next Lemma characterizes the equilibria of the bargaining game.

Lemma 6: *Suppose that only firms* 1 *and* 2 *negotiate.*

(i) *If δ belongs to $\left(\frac{1}{3}, 0.426\right)$ there are two equilibria. In one of the equilibria, firms* 1 *and* 2 *offer a net access price equal to zero, $z_i = 0$, and the entrant accepts the offer of firm* 1*. In the other equilibrium, firms* 1 *and* 2 *offer any net access price on $\left(z_i^a(\delta), \overline{\overline{z}}_i(\delta)\right)$, and the entrant rejects both offers.*

(ii) *If δ belongs to $(0.426, 0.474)$ there are two equilibria. In one of the equilibria, firms* 1 *and* 2 *offer a net access price equal to zero, $z_i = 0$, and the entrant accepts the offer of firm* 1*. In the other equilibrium, firm* 1 *offers the monopoly net access price, $z_1^*(\delta)$, firm* 2 *offers any net access price on $\left(z_2^a(\delta), \overline{\overline{z}}_2(\delta)\right)$, and the entrant accepts the offer of firm* 1*.*

(iii) *If δ belongs to $(0.474, 1)$ there is one equilibrium. Firms* 1 *and* 2 *offer a net access price equal to zero, $z_i = 0$, and the entrant accepts the offer of firm* 1*.* ■

[*Figure* 5]

Figure 5 represents case (ii) in Lemma 6.

It is not surprising that selling access at marginal cost is an equilibrium for any δ. In a market with two or more sellers and one buyer, the bargaining power lies with the shorter side of the market, even though the incumbents do not sell identical wholesale services. Competition between sellers should push the access price to marginal cost. When both incumbents set $z_i = 0$, the host makes zero profits in the wholesale market. In addition, the retail profits are independent of which firm actually hosts the entrant. Hence, if one incumbent sells access at marginal cost, $z_i = 0$, the other is indifferent between selling access at the same price or not selling access at all, given that the retail profits will be the same and wholesale profits will be null in either case.

What is less obvious is why there are other equilibria besides the incumbents selling access at marginal cost for δ on $\left(\frac{1}{3}, 0.474\right)$, but not for δ on $(0.474, 1)$. We discuss these equilibria next. If δ is small, i.e., if δ belongs to $\left(\frac{1}{3}, 0.426\right)$, the market share of the entrant is relatively small. If firm 2 is the host, increased retail competition drives down retail prices, as stated in Proposition 1. Firm 2 loses retail consumer share, even when selling at lower prices. As wholesale revenues are also small, because the entrant has a small market share, it is not profitable for firm 2 to sell access to its network. If the host is firm 1, its equilibrium price may increase with entry. However, there is also a business stealing effect, because the entrant is one of its contiguous competitors. Again, since the wholesale revenues are small, it is not profitable for firm 1 to sell access to its network. This explains why it is an equilibrium for both incumbents not to sell access to their networks. If δ takes intermediate values, i.e., if δ belongs to $(0.426, 0.474)$, it is profitable for firm 1 to sell access at the monopoly price because its wholesale activity is sufficiently large, and its retail price will also increase. However, the demand of firm 4 is relatively small. Thus, it is more profitable for firm 2 to benefit from the increase in the price of firm 1, than to undercut firm 1 and become the host to a small entrant. Finally, if δ is large, i.e., if δ belongs to $(0.474, 1)$, the entrant, firm 4, has a large market share. This implies that whoever is the host has large wholesale revenues. Competition to be the host is intense and, therefore, the equilibrium access price falls to marginal cost.

3.2.5 Equilibria when all Incumbents Negotiate

Next we discuss the case where all incumbents negotiate access to their networks. Firms 1 and 3 sell an identical wholesale service. We assume that when indifferent between firm 1, firm 2, and 3, the entrant chooses the firm 1. The optimal acceptance rule of the entrant is:

$$AC(z_1, z_2, z_3; \delta) = \begin{cases} \textit{none} & \text{if } \; z_i^a(\delta) \leq z_i \leq \overline{\overline{z}}_i(\delta),\; i = 1,2,3 \\ \textit{one} & \text{if } \; 0 \leq z_1 < z_1^a(\delta),\; \beta(\delta) z_1 \leq z_2 \leq \overline{\overline{z}}_2(\delta),\; z_1 \leq z_3 \leq \overline{\overline{z}}_3(\delta) \\ \textit{two} & \text{if } \; z_2 < \min\{z_2^a(\delta), \beta(\delta) z_1, \beta(\delta) z_3\} \\ \textit{three} & \text{if } \; z_3 < z_1^a(\delta),\; z_3 \leq \frac{1}{\beta(\delta)} z_2,\; z_3 < z_1 \end{cases}.$$

As in the case where only firms 1 and 2 negotiate, all incumbents offering access at marginal cost, and all incumbents making unacceptable offers are still equilibria. This happens due to symmetry between firms 1 and 3. However, it is no longer an equilibrium for firm 1 to offer its monopoly net access price. If this happens, the best response of firm 3 is to undercut this net access price. By symmetry, the best response of firm 1 is also to undercut firm 3. Hence, both firms will undercut each others' wholesale prices down to marginal cost.[19]

The next Lemma summarizes the previous discussion.

Lemma 7: *Let δ belong to $\left(\frac{1}{3}, 1\right)$. Suppose that all three incumbents negotiate.*

(i) *If δ belongs to $\left(\frac{1}{3}, 0.426\right)$ there are two equilibria. In one of the equilibria, the incumbents offer a net access price equal to zero, $z_i = 0$, and the entrant accepts the offer of firm 1. In the*

[19] Note that $\lim_{\varepsilon \to 0^+} \pi_3^3(z_1 - \varepsilon; \delta) > \pi_3^1(z_1; \delta)$, if and only if, $z_1 < \frac{3\delta}{5\delta+7}$ which is always true given that $z_1^*(\delta) < \frac{3\delta}{5\delta+7}$, for δ on $\left(\frac{1}{3}, 1\right)$.

other equilibrium, the incumbents offer any net access price on $\left(z_i^a(\delta), \overline{\overline{z}}_i(\delta)\right)$*, and the entrant rejects all offers.*

(ii) *If* δ *belongs to* $(0.426, 1)$ *there is one equilibrium. The incumbents offer a net access price equal to zero,* $z_i = 0$*, and the entrant accepts the offer of firm* 1*.* ■

4 Analysis: The Impact of Entry on Profits

In this section, we analyze the impact of entry on profits, both when the host is a contiguous and a non-contiguous rival of the entrant. We also discuss the incentives to enter the industry and to concede access.

The next Proposition describes the impact of entry on profits.

Proposition 2: *Let* δ *belong to* $\left(\frac{1}{3}, 1\right)$*, and* z_i on $[0, z_i^*(\delta)]$ *be given.*

(i) *Let firm* 1 be the host. *The profits of firms* 2 *and* 3 *are lower than when there is no entry. The profit of firm* 1 *may be lower or higher than when there is no entry.*

(ii) *Let firm* 2 *be the host. The profits of firms* 1 *and* 3 *are lower than when there is no entry. The profit of firm* 2 *may be lower or higher than when there is no entry.*

(iii) *If all incumbents charge the same net access price, firms* 1, 3 *and* 4 *have higher profits when firm* 1 *is the host, than when firm* 2 *is the host; industry profits are also higher.* ■

[*Figure* 6]

The profits of any non-host incumbent decrease with entry. This means that the decrease in their prices, stated in Proposition 1, more than compensates any eventual increase in consumer shares that may result from one of its competitors, namely firm 1 when it is the host, setting a higher price. Regarding the host, the larger the net access price, z_i, and the asymmetry parameter, δ, are, the more likely it is profitable to concede access to its network, as illustrated in Figure 6. A high z_i represents both a higher wholesale mark-up, and larger equilibrium retail prices. Either of these two effects is likely to compensate for any business stealing effect caused by nearby entry. A high δ also means that the entrant sells a product that has no close substitute. This implies both that the entrant faces a large demand, and that the post-entry price competition will be less intense. Either of these two factors benefits the host. Finally, under equal circumstances, i.e., if $z_1 = z_2 = z_3$, firms 1, 3 and 4, and also the industry as a whole, have higher profits when entry is hosted by a contiguous competitor than when entry is hosted by a non-contiguous competitor. This occurs because retail prices are higher in the former case, as stated in Proposition 1, and also because by assumption, the market is always fully covered.

The set of values of the assymetry parameter for which it is profitable to sell access to the bottleneck input is larger for the contiguous rivals of the entrant, firms 1 and 3, than for the non-contiguous rival of the entrant, firm 2. In fact, for δ on $(0.426, 0.526)$ it is only profitable for firms 1 or 3 to sell access to its bottleneck input. For smaller values for δ, entry by firm 4 is not profitable for any of the incumbents, regardless of the access price. Finally, for larger values of δ, entry is profitable for any host for some values of the access price, not necessarily the equilibrium ones.

The case in which δ is large, i.e., in which δ belongs to $(0.526, 1)$, configures the prisoners' dilemma. To see this consider the following simplification of the stage 1 bargaining game. Suppose that each of the incumbents has only two possible strategies: **(i)** deny selling access, or **(ii)** sell access to the entrant at the optimal price, undercutting a rival, if necessary. The first strategy corresponds to making an unacceptable offer, $z_i \geq z_i^a(\delta)$. The second strategy is a simplification of our game because it does not specify the access price. It turns out that the second strategy is dominant for any of the three incumbents. Suppose that firms 2 and 3 deny selling access. Firm 1 best responds by selling access at the monopoly net access price, $z_1^*(\delta)$. Suppose now that at least one of firms 2 and 3 sells access. Firm 1 best responds by undercutting the lowest of the two net access prices, independently of its value, as discussed in subsections 3.2.2 and 3.2.5. Now reverse the roles, and suppose firm 1 and firm 3 deny selling access. Firm 2 best responds by selling access. Suppose that at least one of firms 1 and 3 sells access below the monopoly net access price, $z_i < z_i^*(\delta)$. Firm 2 best responds by undercutting the lowest of the two net access prices, independently of its value. Summing up, if two of the incumbents deny selling access, the third incumbent best responds by providing access. If at least one of the incumbents sells access, the third incumbent best responds by undercutting the best offer of its rivals. Hence, it is optimal for each incumbent to sell access, regardless of the strategies of its rivals. However, the incumbents have higher profits if there is no entry than if entry occurs. In other words, although selling access to firm 4 is a dominant strategy for the incumbents, they would like to credibly commit not to do so. Note that this does not depend on the net access prices falling to zero. As illustrated in Figure 6, the profits of the host are higher when there is no entry than when entry occurs, provided that the net access price is not too high.

Interestingly, for δ on $(0.426, 0.526)$, the unique equilibrium is also for firms to sell access at a zero net access price. However, the situation is different from the prisoner's dilemma. If firms 1 and 3 deny selling access, firm 2 best responds by also denying to sell access. Hence, providing access is not a dominant strategy for all firms.

5 Extensions

In this section, we consider three extensions of the model of section 2. First, we describe the case where the incumbents collude. Second, we discuss other bargaining games. Third, we analyze the case where without entry there is large firm and two small firms, i.e., the case where δ belongs to $\left(0, \frac{1}{3}\right]$.

5.1 The Cartel

Next we discuss the impact of the incumbents operating as a cartel on the incentives to concede access to their networks.

Consider the following modifications of the model of section 2. The incumbents, instead of behaving independently, set the access price and the retail prices in order to maximize their joint profits, i.e., behave as a *Cartel*. The entrant competes with the cartel on the retail market. Given that incumbents maximize joint profits, it is irrelevant whether the host is contiguous to the entrant or not. The consumer valuation, V, is sufficiently high to ensure that the market is still fully covered. We focus on the case where δ belongs to $\left(\frac{1}{3}, 1\right)$.

We use superscript "c" to denote variables or functions associated the case of the cartel without entry, and use superscript "ce" similarly for the case of the cartel with entry. Denote the highest access price for which the market is fully covered when the incumbents behave as a cartel by:

$$\overline{z}^{ce} := \begin{cases} V - c - \frac{1}{12}\delta\left(4-\delta\right) - \left(\frac{5}{12}\delta - \frac{1}{6}\right)^2 & \text{if } \delta \geq \frac{13}{19} \\ V - c - \frac{1}{12}\delta\left(4-\delta\right) - \left(\frac{3}{8} - \frac{3}{8}\delta\right)^2 & \text{if } \delta < \frac{13}{19}. \end{cases}$$

The next lemma presents the equilibrium prices.

Lemma 8: *Let δ belong to $\left(\frac{1}{3}, 1\right)$.*

(i) *Without entry, in equilibrium the cartel charges prices:*

$$P_i^c(\delta) = \begin{cases} V - \left(\frac{\delta}{2}\right)^2 & & i = 1,3 \\ V - \left(\frac{\delta}{2}\right)^2 + \frac{(1-\delta)^2}{8} & \delta > \frac{3}{7} & i = 2 \\ V - \left(\frac{1-2\delta}{2}\right)^2 & \delta < \frac{3}{7} & i = 2 \end{cases}$$

(ii) *Suppose there is entry with net access price* z^{ce} *on* $[0, \overline{z}^{ce}]$*. In equilibrium, the cartel and the entrant charge prices:*

$$P_i^{ce}(z^{ce};\delta) = \begin{cases} c + z^{ce} + \frac{\delta(4-\delta)}{12} & i = 1,3 \\ c + z^{ce} + \frac{2\delta+\delta^2+3}{24} & i = 2 \\ c + z^{ce} + \frac{\delta(\delta+2)}{12} & i = 4 \end{cases}$$

■

As expected, for the same levels of the net access price, $z_1 = z^{ce}$, cartel prices following entry are higher than when firm 1 is the host and the incumbents behave independently. Besides, the prices of all of the incumbents increase with entry if δ is sufficiently large, i.e. δ belongs to $\left(\frac{3}{7}, 1\right)$.

All prices increase by the same amount with z^{ce}, so that the price differences across firms, and therefore consumer shares, do not change. As a consequence, cartel profits increase in z^{ce}. Under the assumption that the market is fully covered, $\overline{z}^{ce}$ is the profit maximizing net access price.

The next Remark compares the cartel profits with and without entry.

Remark 3: *Let* δ *belong to* $\left(\frac{1}{3}, 1\right)$*. The cartel profits are higher with entry than without entry if and only if* δ *belongs to* $[0.622, 1)$*.* ■

From Lemma 7, if the incumbents behave independently, conceding access to their networks is the unique equilibrium only if δ belongs to $[0.426, 1)$. We can thus conclude that, although under more restrictive conditions than those of an industry where the incumbents behave independently, even a cartelized industry may allow entry. In particular, a cartel allows entry if δ is large, i.e., if δ belongs to $(0.622, 1)$. The intuition is simple. If δ is large, then some consumers are located at a large distance from the firms 1 and 3. This means that the cartel prices have to be relatively low to induce these consumers to purchase the service. An entrant located half way between firms 1 and 3 reduces the transportation costs of these consumers drastically, and can therefore charge a larger price. Hence, despite the increase in competition, conceding access to its network generates two positive effects for the cartel. First, the cartel can charge higher prices to the consumers that it keeps after entry. Second, the cartel obtains a large wholesale profit from the consumers lost to the entrant. The net access price is lower than the pre-entry prices net of production costs. However, the increase in retail prices more than compensates these losses. If δ is small, the reduction in transportation costs is not as significant, and the entrant is closer competitor of the cartel.

5.2 Other Bargaining Games

Next we explore two ways of generalizing the bargaining game of section 2. First, we let the number of entrants increase, but maintain the assumption that the industry can support at most four firms. Second, we let both the number of entrants and the number of firms that the industry can support increase, but maintain the assumption that each incumbent can host at most one entrant.[20] The purpose of this exercise is twofold. First, clarify the role of the assumption that only one additional firm can enter the industry. Second, show how the relative number of players on the two sides of the market affects the bargaining power.

Consider the following modifications of the bargaining game of section 2. There are n entrants. First, the incumbents simultaneously make public access price offers to the entrants. Afterwards, the entrants decide simultaneously which offer to accept, if any. If the offer of an incumbent is chosen by more than one entrant, the incumbent chooses at random which entrant to host. If the number of pairs formed exceeds the number of additional firms that the market can support, the pairs that enter the market are chosen at random.

The Industry can support at most Four Firms Let δ belong to $\left(\frac{1}{3}, 1\right)$ and suppose first that as in section 3.2.4, only two of the incumbents, firms 1 and 2, negotiate access to their networks. For any number of entrants, $(z_1, z_2) = (0, 0)$, are equilibrium net access prices. The entrants choose firm 1 as the host. Now suppose that as in section 3.2.5, all three incumbents negotiate access to their networks. For any number of entrants, $(z_1, z_2, z_3) = (0, 0, 0)$, are equilibrium net access prices. The entrants choose firm 1 as the host. In addition, in both cases the other types discuused in section 3.2 continue to occur. To sum up, as long as the industry can support only one additional firm, the increase in the number of entrants does not concede any additional bargaining power to the incumbents. In fact it does not change the equilibria of section 3.2.

Each Incumbent can host at most One Entrant Let $\delta = \frac{1}{3}$, and suppose that all incumbents negotiate access to their networks, and the industry can accommodate 6 firms.[21]

[20] There is also a third possibility: increase simultaneously the number of entrants, the number of firms that the industry can support, and the number of entrants that each incumbent can host.

[21] The analysis of the more general cases where δ belongs to $\left[\frac{1}{3}, 1\right)$, or the industry can accommodate more than six firms, require discussing more seriously where the entrants ought to locate, which is beyond the scope

Each entrant locates at the midpoint of two incumbents. Now the monopoly net access price is identical for all incumbents: $z_1^*(n) = z_2^*(n) = z_3^*(n) = z^*(n)$. There are two types of equilibria. FirsThere is also an equilibrium in which none of the incumbents provides access to an entrant. Regarding the equilibria where entry occurs, the equilibrium net access prices are:

$$(z_1, z_2, z_3) = \begin{cases} (0,0,0) & \text{if } n \leq 2 \\ (z^*(n), z^*(n), z^*(n)) & \text{if } n \geq 3 \end{cases}$$

The entrants are indifferent between the incumbents they choose as the host. If there are one or two entrants, since there are more firms offering access than firms demanding access, the entrants have all the bargaining power and access to the incumbents' networks is sold at marginal cost. If there are three entrants, since there is the same number of players on each side of the market, the bargaining power lies with the side that makes the offers, the incumbents, and access to their networks is sold at the monopoly net access price. If there are four or more entrants, since the incumbents are the shorter side of the market, again they enjoy full market power.

5.3 The Case of One Large Firm

Next we consider the case where δ belongs to $\left(0, \frac{1}{3}\right]$. Recall that in this case entry will either take place between firms 1 and 2 or between firms 2 and 3. Since these two cases are identical we analyze only the former. Now, contrary to the case where δ belongs to $\left(\frac{1}{3}, 1\right)$, there will not be any type of post-entry symmetry between any of the incumbents.

The way in which entry affects the retail prices of the host and the other incumbents is qualitatively similar to that of the previous case, and therefore will not be discussed.

Under equal circumstances, i.e., if $z_1 = z_2 = z_3$, the entrant prefers to buy access from firm 2 rather than from firm 1, and from firm 1 rather than from firm 3. Since the access prices are equal, the choice of the entrant is based on the retail prices the rivals charge after entry. Firm 3, the incumbent non-contiguous to the entrant, is the less appealing host because it will set the lower retail prices after entry. Firm 1 and 2 are contiguous to the entrant. Hence, as hosts, they have an incentive to increase their retail prices after entry. Firm 3 is also contiguous to firms 1 and 2, and is closer to firm 1 than to firm 2. The proximity of firm 3 hampers the incentives of firm 1 to hike its price. As a consequence, if firm 2 is the host, retail prices are larger than when firm 1 is the host. Given that the entrant will have a larger demand because its competitors set higher prices, the entrant prefers to be hosted by firm 2.

of this article.

Regarding the incumbents, it can be shown that, for all δ on $\left(0, \frac{1}{3}\right]$, both firms 1 and 2 have incentives to undercut any offer by any rival, provided that the offers are below the monopoly levels. Therefore, if one acceptable offer is made, the equilibrium for the net access price is zero, $z_i = 0$. Note however, that firm 3 does not have incentives to undercut any offer by any rival. Hence we do not have the prisoners' dilemma. If δ belongs to $\left(0.191, \frac{1}{3}\right]$, there is also an equilibrium in which all incumbents make unacceptable offers.[22] For δ on $\left(\frac{1}{3}, 1\right]$, this type of equilibrium exists if δ is sufficiently small, while for δ on $\left(0, \frac{1}{3}\right]$, it exists if δ is sufficiently large. This occurs because the location of the entrant changes from between firms 1 and 3, to between firms 1 and 2. In the first case a smaller δ means the entrant is closer to its direct competitors whereas in the second case this is true when δ is larger.

6 Conclusion

This article sheds light into the question of whether mobile network operators have incentives to concede access to their networks to mobile virtual network operators. We showed that for mobile network operators the incentives to provide access to their networks may differ from those of a monopolist provider of a fixed public switched telephone network. In particular, for some levels of asymmetry, mobile network operators may face a prisoners' dilemma with respect to conceding access to their networks. However, the model has other types of equilibria. We also showed that the entry of mobile network operators does not lead to an unqualified decrease in prices.

In Brito and Pereira (2005) we analyze the incumbents incentives to preempt mobile virtual network operators. We do not address in this article and leave for further research the important question of evaluating the impact of the entry of additional firms on the incentives of mobile network operators to invest in their networks.

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A Appendix

In the appendix we prove the results in the main text. The proofs of Lemmas 1, 2, 4, 5 and 7, and Remarks 1 and 2 are obvious, and therefore are omitted.

Proposition 1: ***(i)*** Note that:

$$\begin{cases} P_1^1(z_1,\delta) - P_1^n(\delta) > 0 \\ P_2^1(z_1,\delta) - P_2^n(\delta) > 0 \\ P_3^1(z_1,\delta) - P_3^n(\delta) > 0 \\ P_4^1(z_1,\delta) - P_1^n(\delta) > 0 \end{cases} \Leftrightarrow \begin{cases} z_1 > z_1^1(\delta) := \frac{6\delta-3\delta^2}{11(2\delta+1)} \\ z_1 > \frac{6\delta-3\delta^2}{8(2\delta+1)} > z_1^*(\delta) \\ z_1 > \frac{6\delta-3\delta^2}{5(2\delta+1)} > z_1^*(\delta) \\ z_1 > z_1^4(\delta) := \frac{3\left(6\delta+2\delta^2-5\right)\delta}{4(2\delta+1)(2\delta-5)} \end{cases}.$$

It is straightforward to check that $z_1^*(\delta) > z_1^1(\delta)$ for $\delta \in \left(\frac{1}{3},1\right)$. Hence, it is possible that after entry the host will raise its retail price provided that the access price exceeds $z_1^1(\delta)$. The same holds for $z_1^4(\delta)$. The curves represented in Figure 3 are $z_1^1(\delta)$, $z_1^4(\delta)$ and $z_1^*(\delta)$.

(ii) One can easily check that $P_i^2(z_2;\delta) - P_i^n(\delta) > 0 \Leftrightarrow z_2 > \frac{6\delta-3\delta^2}{4(2\delta+1)}$, for $i = 1,2,3$. Note that this is impossible given that $\frac{6\delta-3\delta^2}{4(2\delta+1)} > z_2^*(\delta)$, for $\delta \in \left(\frac{1}{3},1\right)$. Finally, $P_4^2(z_2;\delta) - P_1^n(\delta) > 0 \Leftrightarrow z_2 > z_2^4(\delta) := \frac{\left(15\delta-18\delta^2-6\delta^3\right)}{4(2\delta+1)(4-\delta)}$. It is straightforward to check that $z_2^*(\delta) > z_2^4(\delta)$ for $\delta \in \left(\frac{1}{3},1\right)$.

(iii) If $z_1 = z_2 = z_3 = z > 0$, then for $\delta \in \left(\frac{1}{3},1\right)$:

$$\begin{cases} P_1^1(z,\delta) - P_1^2(z,\delta) = \frac{7}{12}(1-\delta)z > 0 \\ P_2^1(z,\delta) - P_2^2(z,\delta) = \frac{1}{6}(1-\delta)z > 0 \\ P_3^1(z,\delta) - P_3^2(z,\delta) = \frac{1}{12}(1-\delta)z > 0 \\ P_4^1(z,\delta) - P_4^2(z,\delta) = \frac{1}{6}(1-\delta)z > 0 \end{cases}.$$

■

Lemma 4: If firm 2 offers $z_2 > z_2^{**}(\delta)$, given $AC(\cdot)$, the entrant chooses firms 1's offer even if $z_1 = z_1^*(\delta)$.

If firm 2 offers $z_2 \geq z_2^a(\delta)$, since $\pi_1^*(\delta) > \pi_1^n(\delta)$ if and only if $\delta \in (0.426, 1)$, it follows that firm 1 best responds by offering $z_1 = z_1^*(\delta)$ if $\delta \in (0.426, 1)$, and by offering $z_1 \in \left(z_1^a(\delta), \overline{\overline{z}}_1(\delta)\right)$ if $\delta \in \left(\frac{1}{3}, 0.426\right]$.

If firm 2 offers $z_2 \in (z_2^{**}(\delta), z_2^a(\delta))$, since $\pi_1^*(\delta) > \pi_1^2(z_2,\delta)$ for $(z_2,\delta) \in Z_2 \times \left(\frac{1}{3},1\right)$, it follows that firm 1 best responds by offering $z_1^*(\delta)$. If firm 2 offers $z_2 \in (0, z_2^{**})$, then firm 1 best responds by undercutting firm 2, i.e., by offering $z_1 = \frac{z_2}{\beta(\delta)} - \varepsilon$ with $\varepsilon \to 0^+$ if and only if $\lim_{\varepsilon\to 0^+} \pi_1^1(\frac{z_2}{\beta(\delta)} - \varepsilon, \delta) \geq \pi_1^2(z_2,\delta)$ which is equivalent to $z_2 > z_2^c(\delta)$ with $z_2^c(\delta) :=$

$\frac{6(\delta^2-\delta+6)(2\delta+1)\delta}{(208\delta+133\delta^2+7\delta^3+84)}$ Note that $z_2^*(\delta) < z_2^{**}(\delta) < z_2^c(\delta)$ for $\delta \in \left(\frac{1}{3}, 1\right)$, so that it is always better for firm 1 to undercut firm 2's offer. ■

Lemma 5: If firm 1 offers $z_1 < z_1^{**}(\delta)$, denote by $z_1^c(\delta) := \frac{9(\delta+2)\delta^2}{2(19\delta+4\delta^2+4)(\delta+1)}$, the level of the net access of firm 1 for which firm 2 is indifferent between undercutting and not undercutting firm 1, i.e., $\lim_{\varepsilon\to 0^+} \pi_2^2(\beta(\delta)z_1^c(\delta)-\varepsilon,\delta) =: \pi_2^1(z_1^c(\delta),\delta)$. For firm 2 undercutting firm 1 is better if $z_1 < z_1^c(\delta)$. Note that $z_1^{**}(\delta) < z_1^c(\delta)$ if and only if $\delta > 0.405$. If firm 1 offers $z_1 > z_1^{**}(\delta)$, denote by $\breve{z}_1^c(\delta) := \frac{3}{8}\left(\sqrt{1-\frac{\delta(\delta-4)^2}{(5\delta+\delta^2+12)(\delta-1)}}-1\right)$, the net access price for firm 1 for which the maximum equilibrium profit of firm 2 when it is the host equals its equilibrium profit when firm 1 is the host, $\pi_2^*(\delta) \equiv \pi_2^1(\breve{z}_1^c(\delta),\delta)$. For firm 2, being the host and charging $z_2^*(\delta)$ is better if $z_1 < \breve{z}_1^c(\delta)$.

If firm 1 offers $z_1 > z_1^a(\delta)$, since $\pi_2^*(\delta) > \pi_2^n(\delta)$ if and only if $\delta > 0.526$, then firm 2 best responds by offering $z_2^*(\delta)$ if $\delta > 0.526$, and by offering $z_2 > z_2^a(\delta)$ otherwise.

Assume now $z_1^{**}(\delta) < z_1 < z_1^a(\delta)$. If $z_1 \in (\max\{z_1^{**}(\delta), \breve{z}_1^c(\delta)\}, z_1^a(\delta))$, then firm 2 best responds by offering $z_2 > z_2^a(\delta)$. This occurs because, although setting $z_2 = z_2^*(\delta)$ would make the entrant choose firm 2's offer, firm 1's offer is so high that it is better to let the entrant accept it and free ride on the higher equilibrium prices. If $z_1 \in (z_1^{**}(\delta), \breve{z}_1^c(\delta))$, firm 2 prefers to undercut firm 1 by setting $z_2 = z_2^*(\delta)$.

Finally, assume that $z_1 < z_1^{**}(\delta)$. If $z_1 \in (0, \min\{z_1^{**}(\delta), z_1^c(\delta)\})$, then firm 2 best responds by offering $z_2 = \beta(\delta)z_1 - \varepsilon$, with $\varepsilon \to 0^+$. Otherwise it will set $z_2 > z_2^a(\delta)$ ■

Lemma 6: ***(i)*** Let $\delta \in \left(\frac{1}{3}, 0.426\right)$. For $\delta \in \left(\frac{1}{3}, 0.405\right)$, $\max\{z_1^c(\delta), \breve{z}_1^c(\delta)\} < z_1^{**}(\delta)$.

For $z_2 \geq z_2^a(\delta)$, firm 1's best response is to offer $z_1 \in \left(z_1^a(\delta), \overline{\overline{z}}_1(\delta)\right)$. But if $z_1 > z_1^a(\delta)$, and as $z_1^a(\delta) > z_1^c(\delta)$ for any $\delta \in \left(\frac{1}{3}, 1\right)$, firm 2's best response is to offer $z_2 \in \left(z_2^a(\delta), \overline{\overline{z}}_2\right)$. Hence, inadmissible offers by both firms is an equilibrium. For $z_2 \in (z_2^{**}(\delta), z_2^a(\delta))$, firm 1 should set $z_1^*(\delta)$. For $z_1 = z_1^*(\delta)$ and as $z_1^*(\delta) > z_1^c(\delta)$ when $\delta \in \left(\frac{1}{3}, 0.405\right)$, firm 2 should offer $z_2 \in \left(z_2^a(\delta), \overline{\overline{z}}_2\right)$. Hence, for $z_2 \in (z_2^{**}(\delta), z_2^a(\delta))$ there is no equilibrium. For $z_2 < z_2^{**}(\delta)$, firm 1's best-response is $z_1 = \frac{1}{\beta(\delta)}z_2 - \varepsilon < \frac{1}{\beta(\delta)}z_2^{**}(\delta) - \varepsilon < z_1^*(\delta)$. Two things may happen: either $z_1 < z_1^c(\delta)$, in which case firm 2's best response is $\beta z_1 - \varepsilon$, or $z_1 > z_1^c(\delta)$, in which case firm 2 ought to make an inadmissible offer. In the former case, both firms will undercut each other's offer until an equilibrium with both access prices equal to marginal cost is reached. In the latter case there is no equilibrium.

For $\delta \in (0.405, 0.426)$, we have $z_1^{**}(\delta) < \min\{\breve{z}_1^c(\delta), z_1^c(\delta)\}$.

For $z_2 \geq z_2^a(\delta)$, firm 1's best response is to offer $z_1 \in \left(z_1^a(\delta), \overline{\overline{z}}_1(\delta)\right)$. But if $z_1 > z_1^a(\delta)$ and as $z_1^a(\delta) > \breve{z}_1^c$ for any $\delta \in \left(\frac{1}{3}, 1\right)$, firm 2's best response is to offer $z_1 \in \left(z_2^a(\delta), \overline{\overline{z}}_2\right)$. Hence, no admissible offers by both firms is still an equilibrium. For $z_2 \in (z_2^{**}(\delta), z_2^a(\delta))$ firm 1 should offer $z_1 = z_1^*(\delta)$. But for $z_1 = z_1^*(\delta)$ and as $z_1^* > \breve{z}_1^c(\delta)$ for $\delta < 0.474$, firm 2 should offer, i.e. $z_2 \geq z_2^a(\delta)$. Hence, for $z_2 \in (z_2^{**}(\delta), z_2^a(\delta))$ there is no equilibrium. For $z_2 < z_2^{**}(\delta)$, firm 1's best-response is $z_1 = \frac{1}{\beta}z_2 - \varepsilon < \frac{1}{\beta}z_2^{**}(\delta) - \varepsilon < z_1^*(\delta)$. Three cases may happen: either $z_1 < z_1^{**}(\delta)$ in which case firm 2's best response is $z_2 = \beta z_1 - \varepsilon$, or $z_1 \in (z_1^{**}(\delta), \breve{z}_1^c(\delta))$, in which case firm 2's best response is $z_2 = z_2^*(\delta)$, (however, note that $\zeta_1(z_2^*; \delta) = z_1^{**} - \varepsilon < z_1^{**}$), or $z_1 > \breve{z}_1^c(\delta)$ in which case, firm 2 ought to offer $z_2 \in \left(z_2^a(\delta), \overline{\overline{z}}_2(\delta)\right)$. In the first case, both firms will undercut each other's offer until an equilibrium with both access prices equal to marginal cost is reached. In the other cases there is no equilibrium.

(ii) Consider now that $\delta \in (0.426, 0.474)$. For $z_2 \geq z_2^a(\delta) > z_2^{**}(\delta)$, firm 1's best response is $z_1 = z_1^*(\delta) > \breve{z}_1^c(\delta)$. In this case, firm 2's best response is to offer $z_2 \in \left(z_2^a(\delta), \overline{\overline{z}}_2(\delta)\right)$. Hence, $\left(z_1^*(\delta), \left(z_2^a(\delta), \overline{\overline{z}}_2\right), one\right)$ is an equilibrium . For $z_2 \in (z_2^{**}(\delta), z_2^a(\delta))$, firm 1's best response function is still $z_1 = z_1^*(\delta) > \breve{z}_1^c(\delta)$ to which firm 2 should offer $\in \left(z_2^a(\delta), \overline{\overline{z}}_2(\delta)\right)$. There is no equilibrium in this case. For $z_2 \in (z_2^*(\delta), z_2^{**}(\delta))$, firm 1's best response is $z_1 = \frac{1}{\beta}z_2 - \varepsilon > z_1^{**}$ and two things may happen: either $z_1 > \breve{z}_1^c(\delta)$ in which case firm 2 should respond with $z_2 \in \left(z_2^a(\delta), \overline{\overline{z}}_2(\delta)\right)$, or $z_1 < \breve{z}_1^c(\delta)$ and firm 2 should respond with $z_2 = z_2^*(\delta)$. Finally, for $z_2 < z_2^*(\delta)$, $\zeta_1(z_2; \delta) = \frac{1}{\beta}z_2 - \varepsilon < z_1^{**}(\delta)$ and $\zeta_2(z_1; \delta) = \beta z_1 - \varepsilon$ and both access prices equal to marginal cost is an equilibrium.

(iii) Finally if $\delta \in (0.474, 1)$ we have three relevant intervals: For $\delta \in (0.474, 0.526)$ we have $z_1^{**}(\delta) < \min\{\breve{z}_1^c(\delta), z_1^c(\delta)\}$. For $z_2 > z_2^a(\delta)$, firm 1's best response is $z_1 = z_1^* < \breve{z}_1^c(\delta)$. In this case, firm 2's best response is $z_2 = z_2^*(\delta) < z_2^a(\delta)$. Therefore, $\left(z_1^*(\delta), \left(z_2^a(\delta), \overline{\overline{z}}_2(\delta)\right), one\right)$ is no longer an equilibrium. For the other values that z_2 may take the previous case holds.

For $\delta \in (0.526, 0.682)$ we have the following ordering for the relevant values that z_1 can take: $z_1^{**}(\delta) < z_1^*(\delta) < z_1^c(\delta) < \breve{z}_1^c(\delta) < z_1^a(\delta) < \overline{\overline{z}}_1(\delta)$. The analysis is the same as in the previous case.

Finally, for $\delta > 0.682$ we have $z_1^{**}(\delta) < z_1^*(\delta) < z_1^c(\delta) < z_1^a(\delta) < \breve{z}_1^c(\delta) < \overline{\overline{z}}_1(\delta)$. The analysis is the same as in the previous case. ■

Proposition 2: Let $\varphi_j^i(z_i, \delta) := \pi_j^i(z_i, \delta) - \pi_i^n(\delta)$.

(i) It is easy to check that: $\frac{\partial \varphi_i^1(z_1,\delta)}{\partial z_1} > 0$, $i = 2, 3$. Additionally, if $z_1 = z_1^*(\delta)$ we have: $\frac{\partial \varphi_i^1(z_1^*(\delta),\delta)}{\partial z_1} < 0$, $i = 2, 3$. As for firm 1, we already showed that $\pi_1^1(z_1, \delta)$ is concave in z_1 and has a maximum at $z_1^*(\delta)$. Besides, we have that $\varphi_1^1(z_1, \delta) > 0$ if and only if $z_1 \in (\underline{z}_1(\delta), \overline{z}_1(\delta))$.

Note that the interval $[\underline{z}_1(\delta), \overline{z}_1(\delta)]$ is empty for $\delta \in \left(\frac{1}{3}, 0.426\right)$, and that $z_1^*(\delta) < \overline{z}_1(\delta)$ for $\delta \in [0.426, 1)$. Note also that: $\varphi_1^1(0,\delta) < 0$, and $\varphi_1^1(z_1^*(\delta),\delta) > 0$ if and only if $\delta \in [0.426, 1)$.

(ii) It is straightforward to show that $\varphi_1^2(z_2^*(\delta),\delta) = \varphi_3^2(z_2^*(\delta),\delta) < 0 < \frac{\partial \varphi_1^2(z_2,\delta)}{\partial z_2}$. As for firm 2, we have that $\varphi_2^2(z_2,\delta) > 0$ if and only if $z_2 \in (\underline{z}_2(\delta), \overline{z}_2(\delta))$. Note that the interval $[\underline{z}_2(\delta), \overline{z}_2(\delta)]$ is empty for $\delta \in \left(\frac{1}{3}, 0.526\right)$ and that $z_1^*(\delta) < \overline{z}_1(\delta)$ for $\delta \in [0.526, 1)$. Note also that.$\varphi_2^2(0,\delta) < 0$, and $\varphi_2^2(z_2^*(\delta),\delta) > 0$, if and only if, $\delta \in [0.526, 1)$. Thus, firm 2's profits may either increase or decrease with entry.

(iii) Let $z_1 = z_2 = z_3 = z < \frac{3\delta}{8+4\delta}$. Then: $\pi_i^1(z,\delta) - \pi_1^2(z,\delta) > 0$, $i = 1, 3, 4$, $\sum_{j=1}^4 \left(\pi_j^1(z,\delta) - \pi_j^2(z,\delta)\right) > 0$, and

$$\pi_2^1(z,\delta) - \pi_2^2(z,\delta) = -\frac{1}{12}\delta^{-1}\left(2\delta - 8z - 6\delta z + \delta^2 + 2\delta^2 z\right) z$$

■

Lemma 8: ***(i)*** The highest price that firms 1 and 3 can set that will ensure that all consumers located between them still purchase the service is $P_1 = P_3 = V - (\frac{\delta}{2})^2$. If the consumer equidistant from firms 1 and 3 purchased from firm 2, then all consumers would do the same. But all consumers purchasing at firm 2 is clearly not optimal for the cartel. If $P_1 = P_3 = V - (\frac{\delta}{2})^2$ the cartel profit function is:

$$\pi_{1+2+3} = (P_1^c - c)\left(2\frac{P_2 - P_1^c}{1-\delta} + \frac{1+\delta}{2}\right) + (P_2 - c)\left[\frac{1}{2}\left(2\frac{P_1^c - P_2}{(1-\delta)/2} + 1 - \delta\right)\right]$$

which is a concave, and maximized at

$$P_2^c = P_1^c + \frac{(1-\delta)^2}{8} = V - (\frac{\delta}{2})^2 + \frac{(1-\delta)^2}{8}$$

However, we must impose that the consumers purchasing at firm 2 have a positive surplus. Consumers purchasing at firm 2 are at a distance x from firm 2 given by

$$P_2^c + x^2 = P_1^c + (\frac{1-\delta}{2} - x)^2 \Leftrightarrow x = \frac{1-\delta}{8}$$

which must be larger than $\frac{1-2\delta}{2}$ to ensure that every consumer has a positive surplus. However, as $\frac{1-2\delta}{2} > \frac{1-\delta}{8} \Leftrightarrow \delta < \frac{3}{7}$, the optimal price that ensures full market coverage for $\delta < \frac{3}{7}$ must be lower and such that the indifferent consumer has zero surplus:

$$P_2^c = V - \left(\frac{1-2\delta}{2}\right)^2$$

(ii) The derivation of the equilibrium prices is straightforward. Next we show that the expression of $\overline{z}^{ce}$ conforms with the definition. Consumers with the lowest surplus are either the one indifferent between firms 1 and 4 or the one indifferent between firms 1 and 2. The total surplus, i.e., valuation minus price minus transportation cost, is, respectively,

$$V-\left[c+z+\frac{\delta\left(4-\delta\right)}{12}\right]-\left[\frac{1}{12}\left(5\delta-2\right)\right]^{2}$$
$$V-\left[c+z+\frac{\delta\left(4-\delta\right)}{12}\right]-\left[\left(\frac{3}{8}\right)\left(1-\delta\right)\right]^{2}$$

Both must be positive so that the market is covered. Hence, as the cartel's profit is increasing in z^{ce} this will be set at:

$$\overline{z}^{ce}=\min\left\{V-c-\frac{1}{12}\delta\left(4-\delta\right)-\left(\frac{5}{12}\delta-\frac{1}{6}\right)^{2},V-c-\frac{1}{12}\delta\left(4-\delta\right)-\left(\frac{3}{8}-\frac{3}{8}\delta\right)^{2}\right\}$$

That is,

$$\overline{z}^{ce}=\begin{cases} V-c-\frac{1}{12}\delta\left(4-\delta\right)-\left(\frac{5}{12}\delta-\frac{1}{6}\right)^{2} & \delta>\frac{13}{19}\\ V-c-\frac{1}{12}\delta\left(4-\delta\right)-\left(\frac{3}{8}-\frac{3}{8}\delta\right)^{2} & \delta<\frac{13}{19}\end{cases}$$

■

Remark 3: From Lemma 8, without entry, cartel profits are:

$$\pi^{c}_{1+2+3}=\begin{cases} V-c-\frac{1}{32}\left(\delta+1\right)\left(4\delta+\delta^{2}-1\right) & \text{if } \delta\geq\frac{3}{7}\\ V-c+\frac{1}{4}\left(6\delta-12\delta^{2}+6\delta^{3}-1\right) & \text{if } \delta<\frac{3}{7}\end{cases}$$

and with entry, cartel profits are:

$$\pi^{ce}_{1+2+3}=\begin{cases} V-c-\frac{1}{288}\left(19\delta+31\delta^{2}+5\delta^{3}-1\right) & \delta\geq\frac{13}{19}\\ V-c-\frac{1}{576}\left(43\delta^{2}-44\delta+10\delta^{3}+63\right) & \delta<\frac{13}{19}\end{cases}$$

If $\delta<\frac{3}{7}<\frac{13}{19}$, then $\pi^{c}_{1+2+3}>\pi^{ce}_{1+2+3}$. If $\frac{3}{7}<\delta<\frac{13}{19}$, then $\pi^{c}_{1+2+3}>\pi^{ce}_{1+2+3}$ if and only if $\delta<0.622$. Finally, if $\delta>\frac{13}{19}$, then $\pi^{c}_{1+2+3}<\pi^{ce}_{1+2+3}$. ■

Countries	MNO	SP	Pen. Rate	Pre-Paid Cards	C1	C2
Austria	*4*	*3*	*93%*	*45%*	*43%*	*69%*
Belgium	*3*	*0*	*79%*	*64%*	*52%*	*85%*
Denmark	*4*	*16*	*90%*	*21%*	*33%*	*54%*
Finland	*3*	*10*	*94%*	*4%*	*46%*	*73%*
France	*3*	*0*	*71%*	*40%*	*48%*	*84%*
Germany	*4*	*8*	*82%*	*51%*	*40%*	*78%*
Greece	*4*	*0*	*82%*	*60%*	*38%*	*73%*
Holland	*5*	*1*	*86%*	*58%*	*37%*	*60%*
Italy	*3*	*0*	*98%*	*91%*	*46%*	*81%*
Ireland	*3*	*0*	*88%*	*74%*	*54%*	*94%*
Luxemburg	*2*	*3*	*122%*	*60%*	*36%*	*63%*
Portugal	*3*	*0*	*90%*	*78%*	*52%*	*83%*
Spain	*3*	*2*	*90%*	*57%*	*50%*	*96%*
Sweden	*4*	*21*	*103%*	*59%*	*45%*	*85%*
U.K.	*4*	*59*	*91%*	*68%*	*26%*	*51%*

Souce: 10th Report

Table 1: Mobile Telephony Sector in the EU-15

B Tables

C Figures

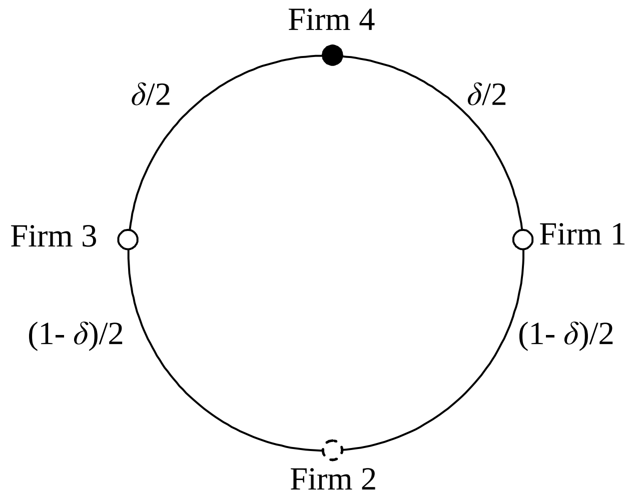

Figure 1: Firms' locations on the loop for δ on $\left(\frac{1}{3}, 1\right)$.

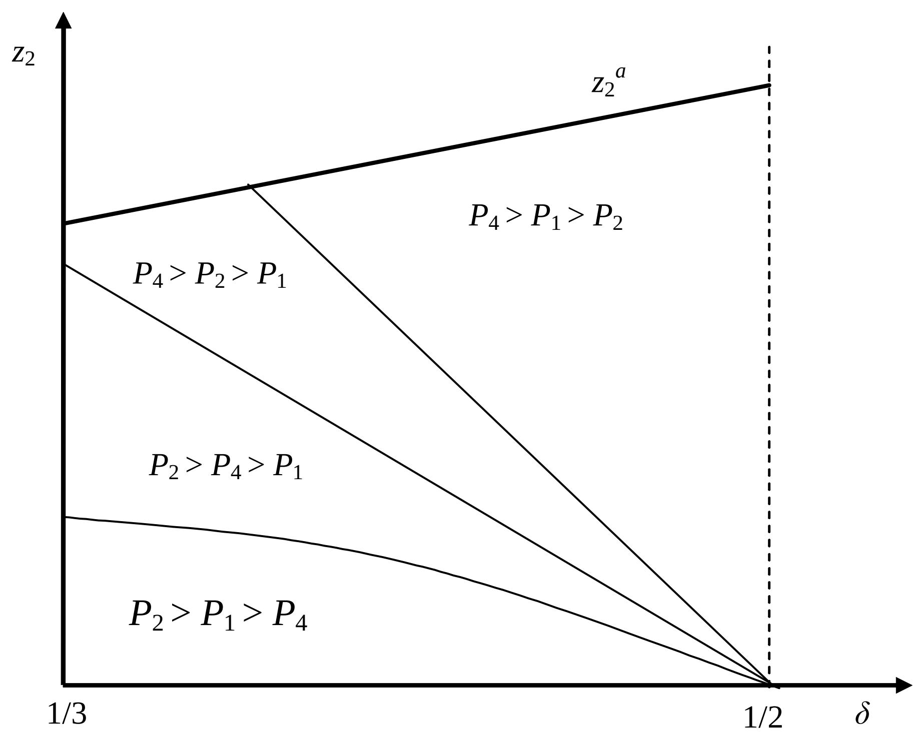

Figure 2: Price rankings when firm 2 is the host and δ belongs to $\left(\frac{1}{3}, \frac{1}{2}\right)$. Note that $P_1 = P_3$.

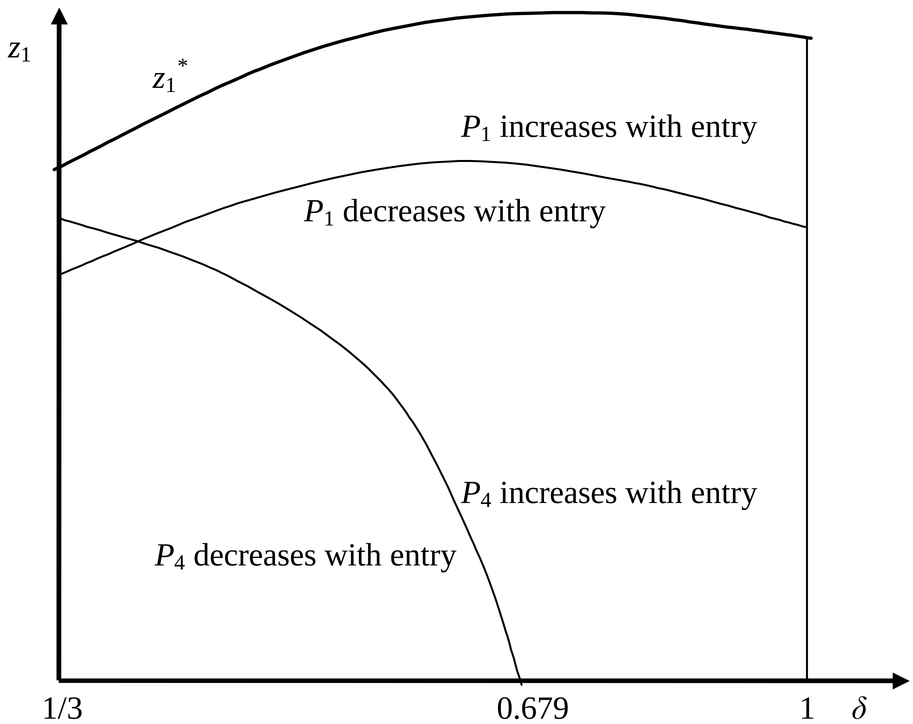

Figure 3: Change in prices of the host and the entrant following entry hosted by firm 1.

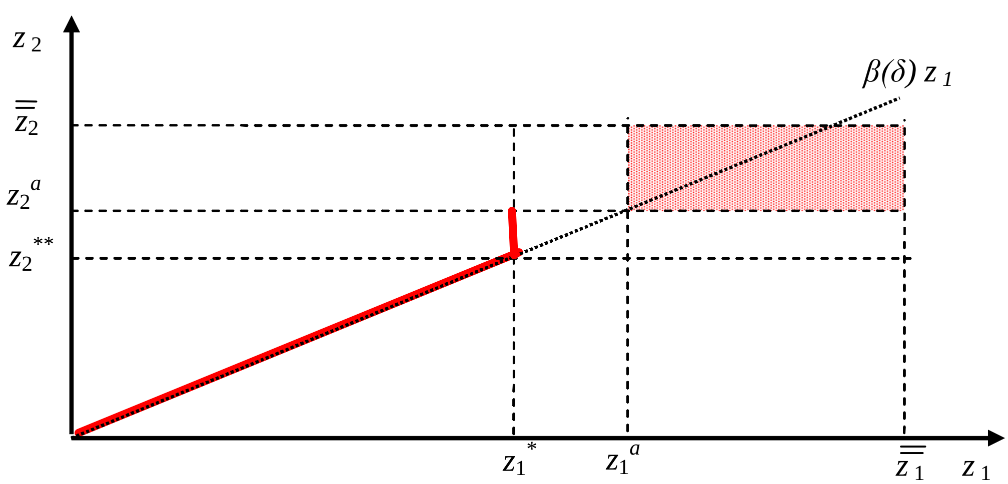

Figure 4: Firm 1's best response correspondence for δ on $\left(\frac{1}{3}, 0.426\right)$.

The shaded rectangle represents the case in which firm 1 prefers that no entry occurs, rather than being the monopolist access seller. The vertical segment at z_1^* corresponds to the case in which firm 1's offer is accepted even though the price is set at the monopoly level. Finally, the upward sloping straight line refers to the case in which z_2 is so low that it forces firm 1 to price below the monopoly level to be the chosen host. If $\delta > 0.426$ firm 1's best response is to set z_1^* even for $z_2 > z_2^a$.

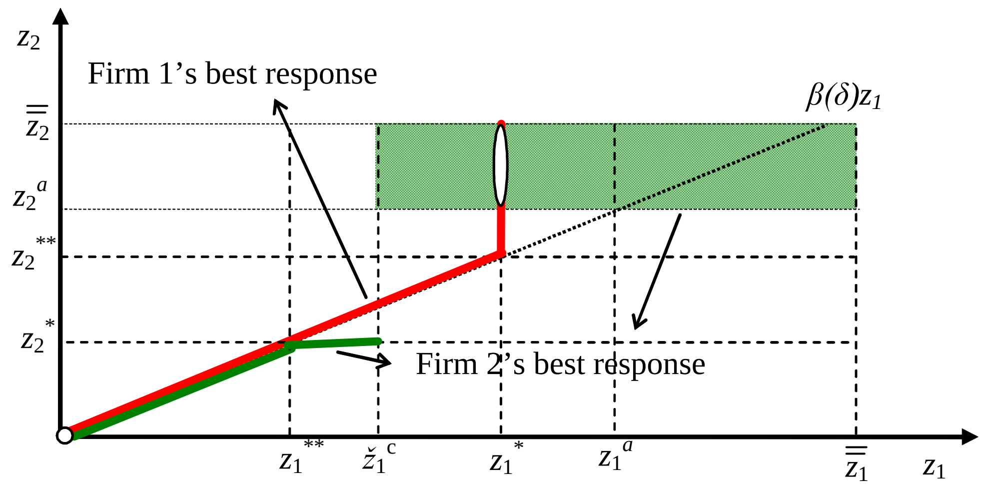

Figure 5: Equilibria for δ on $(0.426, 0.474)$.

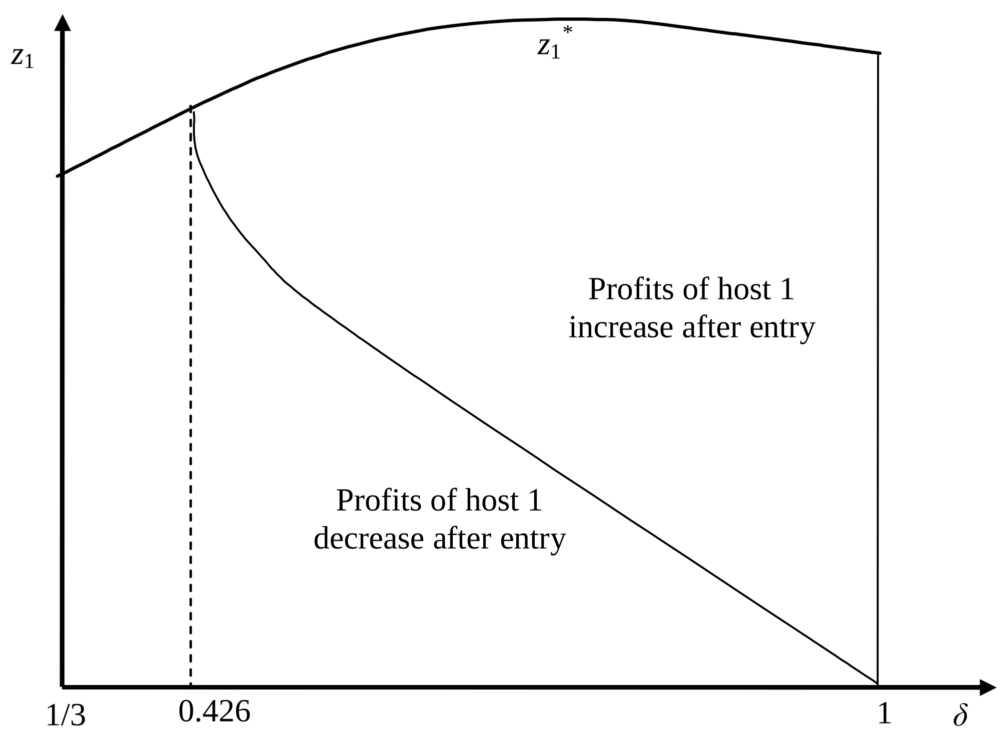

Figure 6: Changes in profits when firm 1 is the host.

The figure for the case in which the host is firm 2 is qualitatively similar, with 0.426 replaced by 0.526.