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Do International Roaming Alliances Harm Consumers?

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Summary

We develop a model of international roaming in which mobile network operators (MNOs) compete both on the wholesale market to sell roaming services to foreign operators and on the retail market for subscribers. The operators own a network infrastructure only in their home country. To allow their subscribers to place or receive calls abroad, they have to buy roaming services provided by foreign MNOs. In the absence of international alliances, competition between foreign operators would drive wholesale unit prices down to marginal costs. However, international alliances are endogenously formed since they serve as a commitment device to soften competition on the retail market, leading to excessively high per call prices.

Keywords: International Roaming, Vertical Relations, Regulation

JEL Classification: D43, L13, L42, L96

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Do international roaming alliances harm consumers?*

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Abstract

We develop a model of international roaming in which mobile network operators (MNOs) compete both on the wholesale market to sell roaming services to foreign operators and on the retail market for subscribers. The operators own a network infrastructure only in their home country. To allow their subscribers to place or receive calls abroad, they have to buy roaming services provided by foreign MNOs. In the absence of international alliances, competition between foreign operators would drive wholesale unit prices down to marginal costs. However, international alliances are endogenously formed since they serve as a commitment device to soften competition on the retail market, leading to excessively high per call prices.

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1 Introduction

International roaming provides subscribers with the possibility to use their mobile phone outside the geographical coverage area of their home operator's network, by

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means of a visited network. A Mobile Network Operator (MNO) that allows subscribers of a foreign operator to access its network acts as host operator. For roaming services, a host operator charges wholesale prices to the roaming subscribers' home operator that in turn charges retail prices to its subscribers. Roaming services include the possibility to receive or to place calls as well as to use mobile data services such as SMS. MNOs are typically active on two related markets: They offer roaming services to foreign operators and buy roaming services for own traveling subscribers on the wholesale market. In addition, they compete in their home country on the retail market for subscribers.

The European market for international roaming accounted for approximately €8.5 billion or 5.7% of the estimated total mobile industry revenues in 2005 (European Commission, 2006). At the same time, roaming contributed almost 12% to the European mobile industry profits. In 2006, the European Commission assessed that both the average roaming retail and wholesale prices were unjustifiably high. For example, it estimated that the per-minute costs (including a margin for fixed costs) for originating, transmitting and terminating an outgoing roaming call were approximately 20 cents, while wholesale prices were on average about 75 cents and retail prices were roughly €1.10. This raises the question why competition has not been effective in the roaming market.

In this paper we argue that *international* alliances of MNOs with networks in different countries may result in inefficiently high wholesale prices that would not be sustainable otherwise.[1] Such alliances were allegedly formed to facilitate the provision of roaming services. Affiliated operators typically agree on special roaming wholesale conditions based on the promise to direct roaming subscribers preferably to other alliance members. In contrast, ordinary roaming agreements do usually not encompass the obligation to direct subscribers to each other. They just specify the roaming wholesale prices that an operator charges when hosting traveling subscribers of another foreign operator. We claim that because of strategic considerations MNOs prefer to form alliances in order to commit to trade roaming services at inefficiently high wholesale prices. As we show, this allows MNOs to soften competition on the retail market and thereby increases total profits.

In our model, in each of two equally sized countries two MNOs compete on the retail market à la Hotelling for subscribers. We focus on subscribers' demand for roaming calls abroad. To provide this service, each operator needs to access the foreign operators' infrastructure. Operators may form international alliances and mutually promise to procure roaming services exclusively from their partner network.

[1] One example is the *Freemove* alliance whose web page can be found under http://www.freemovealliance.com. See Sutherland (2010b) for further examples in Asia.

In this case they jointly negotiate on a mutual wholesale price. Operators may also post wholesale prices and buy roaming services without being affiliated to an alliance. MNOs first set the wholesale roaming prices and decide from which foreign operator to buy roaming services. Then they offer two-part retail tariffs to potential subscribers in their home country.

In the absence of alliances, competition among foreign operators to host traveling subscribers drives down wholesale prices for roaming services. In contrast to models of network-interconnection, there is no "competitive bottleneck" in the sense that no particular foreign operator has to provide the roaming services.[2] Operators will thus direct their subscribers to the foreign network that offers the lowest wholesale price.

Agreeing in an alliance on wholesale prices above the true marginal costs serves as commitment to compete less aggressively for subscribers. At the retail level, a higher wholesale price is perceived as an increase in the marginal cost and is passed through to customers. Since retail tariffs are strategic complements in our model, this induces the domestic competitor to raise its fixed fee which in turn has a positive feed-back effect on the first operator's profit. Within an alliance each operator exclusively hosts the foreign partner's traveling subscribers and a reciprocal wholesale price is charged. Therefore, additional expenses caused by a higher wholesale price are perfectly recouped from wholesale profits earned with the partner's traveling subscribers. Increasing the wholesale price within one alliance also increases the profits of competing operators. This might explain why domestic competitors rarely complained when international alliances were formed.

Our findings are interesting in light of recent technological developments that have increased the strategic importance of roaming alliances. The European Commission (2006) estimated that roughly 80% of the roaming traffic was already actively directed by use of these technologies in 2006. Before 2000, operators had only limited technical means to determine which foreign network their subscribers would use.[3] Customers that did not manually register in a particular foreign network were almost randomly assigned among foreign operators. Not being able to direct subscribers to networks that offer cheap roaming services induced MNOs to charge high wholesale prices even without the help of alliances. Hence, the strategic importance of alliances increased as network selection technologies improved.

Further practical issues can be addressed by help of our model. First, the Groupe

[2] In models of interconnected networks subscribers usually become member at one particular network which then becomes monopolist for the access to this subscriber. Ex ante competition for subscribers but a de-facto monopoly of access ex post is denoted as "competitive bottleneck". See e.g. Armstrong (2002); Armstrong and Wright (2009).

[3] For a detailed technical description, see e.g. Stumpf (2001), Salsas and Koboldt (2004) or European Commission (2005).

Speciale Mobile Association (GSMA), to which most of the MNOs are affiliated, created a common framework to simplify the negotiations on roaming agreements between operators.[4] It contains a non-discrimination clause that restricts MNOs to offer similar wholesale terms for roaming services to all foreign operators. In an extension, we account for this clause by restricting operators to apply the same wholesale price that has been fixed within an alliance also for unilateral roaming agreements. Surprisingly, this clause even amplifies the anti-competitive impact of alliances, since too high wholesale prices within alliances then also obstruct competition for unilateral roaming agreements. Second, the European Commission introduced a price cap both at the retail and at the wholesale level in 2007 and maintained it in 2012 and there is an intense debate about the effects of such an intervention (see e.g. BEREC (2010)). In our setup, introducing a binding price cap only at the retail level decreases the usage prices but typically also reduces the equilibrium consumer surplus. As operators compete in two part tariffs at the retail level, if the usage price is bounded above, operators may increase the unregulated monthly fee by even more. This so-called *waterbed effect* may turn seemingly helpful regulatory interventions on its head.

While our setup is tailored to the international roaming market, there are other important applications, such as the market for cash withdrawals. Banks often only own an automated teller machine (ATM) network in their home country and have to rely on the infrastructure of foreign banks in order to allow customers to withdraw money abroad.

Turning to the existing literature, our model exhibits what Carter and Wright (1994) call symbiotic production: Each operator offers roaming services as intermediate products to foreign operators, and resells roaming services from foreign operators to own subscribers. Carter and Wright (1994) assume that there is a monopolistic operator in each country and find that double marginalization leads to inefficiently high retail prices. They conclude that both operators and consumers would be better off if operators cooperated and bilaterally reduced their wholesale prices. In contrast, we show that the role of alliances is reversed when there is competition both on the retail and on the wholesale markets. This is because in our model price competition at the wholesale level eliminates a positive markup and thus the problem of double marginalization without alliances.

Laffont, Rey, and Tirole (1998) find that the collusive power of access prices vanishes if operators compete in two-part tariffs. In our model, higher wholesale prices

[4] These Standard Terms for International Roaming Agreement (STIRA) were created in 1996 and received conditional exemptions from the cartel prohibition under Article 81 (3) of the EC Treaty according to Sutherland (2010a).

allow to raise profits even though firms compete in two-part tariffs on their home market. In the roaming market, if an operator enters into an international alliance and agrees on a high wholesale roaming price, the domestic competitor's perceived costs for roaming services remain unchanged. Due to the different impact on competing operators compared to two-way network interconnection models such as Laffont, Rey, and Tirole (1998), roaming wholesale prices are not neutral in our model.

There are also conceptual similarities to the literature of vertical relationships.[5] In particular, Shaffer (1991) shows that downstream firms might prefer paying higher unit prices for intermediate goods and receiving a fixed compensation to low unit prices if this serves as a commitment device to soften downstream competition. For the same reason operators prefer to commit to a high wholesale price in our model. However, our reasoning does not require fixed payments to compensate higher unit prices since operators mutually provide roaming services in an alliance. In addition, the existing literature has analyzed competition in *linear* prices on the downstream market so far. To our knowledge, our paper is the first to show that operators may also exploit strategic complementarity even though competing in *nonlinear* prices in the downstream market.

Recently, a small literature that analyzes the international roaming market emerged. Salsas and Koboldt (2004) as well as Lupi and Manenti (2006, 2009) also consider a setup of two operators in each of two countries. However, Salsas and Koboldt (2004) do not explicitly take into account that each operator is active both on the wholesale market and on the retail market and therefore cannot consider the possibility of international alliances. Lupi and Manenti (2006, 2009) assume that operators act as local monopolists on the retail market. Therefore, they do not analyze operators' incentives to set high wholesale prices in order to soften retail competition. In their setup, alliances optimally set wholesale prices at marginal costs, which is not in line with the current evidence. In addition, Lupi and Manenti (2009) do not explain why alliances emerge endogenously.

The remainder of the paper is organized as follows: In the next section, we formally introduce our basic model. Section 3 characterizes the equilibrium retail tariffs for given wholesale prices. In Section 4 we first show that equilibrium wholesale prices equal marginal cost in the absence of international alliances and typically increase in the number of alliances. Section 5 adds a first stage in which alliances can be formed. As a result, two competing alliances endogenously emerge in the absence of regulatory constraints. In Section 6, we discuss further issues such as the role of network selection technologies, the impact of a non-discrimination clause, of introducing price caps and we generalize the set of wholesale instruments before we

[5] See e.g. Bonanno and Vickers (1988), Shaffer (1991) and Rey and Stiglitz (1995).

conclude in Section 7.

2 The Model

There are two countries A and B as well as two MNOs with index 0 and 1 in each country. Operator xi is active in *home* country $x \in \{A, B\}$ and has position $i \in \{0, 1\}$. Each operator's network covers only its home country. Thus, subscribers have to be hosted by another operator while traveling abroad. We assume that operators dispose of technological means to determine on which foreign network their traveling subscribers register. We focus on outgoing roaming calls that subscribers may place while traveling abroad and assume that it is the only service which MNOs offer to their subscribers. In particular, we abstract from nationwide calls.[6]

In order to allow own subscribers to place roaming calls abroad, operators have to buy these services on the *wholesale market* from a foreign MNO which then hosts these customers. Thus, each operator competes with its domestic competitor on the *wholesale market* to sell roaming services to foreign operators. They also compete on the *retail market* for subscribers which live in the operator's home country.

Cost structure: Each of the four operators incurs the same marginal cost $c \geq 0$ when a traveling subscriber places a roaming call.[7] In addition, operators have to incur monthly fixed costs $C_F \geq 0$ per subscriber, e.g. for billing.

Retail market: MNOs offer a two-part tariff: Operator xi charges a usage price $p_{xi} \in \mathbb{R}$ per roaming call and a (monthly) fixed fee $F_{xi} \in \mathbb{R}$. When a consumer places q roaming calls, she has to pay in total $p_{xi}q + F_{xi}$.

As in Laffont, Rey, and Tirole (1998), networks are differentiated à la Hotelling. In each country, there are consumers of mass 1 whose tastes l are uniformly distributed on the segment $[0, 1]$. The operators are located at the two extremities and the index $i \in \{0, 1\}$ also indicates their position. Each consumer may join at most one network which generates a fixed surplus v_0. Placing q roaming calls generates a *gross surplus* $u(q)$. Consumers have quasilinear preferences in wealth such that the (incremental) utility of a consumer with taste l who joins operator xi and places q roaming calls is

$$-\frac{1}{2\sigma}|i - l| + u(q) - p_{xi}q - F_{xi} + v_0 \,.$$

[6] Further services such as nationwide calls could be included in the model at the cost of tractability. Due to competition in two part tariffs, usage prices would be set equal to perceived marginal costs. The surplus generated by these services is then captured by the parameter v_0 introduced below.

[7] This marginal cost includes origination, transfer and termination. For simplicity, we assume that all roaming calls are terminated at some third party fixed network so that we can abstract from traffic generated by the termination of roaming calls.

The term $-\frac{1}{2\sigma}|i-l|$ expresses the loss of utility in case the joined network does not correspond exactly to the consumers taste where $\sigma > 0$ parametrizes the degree of taste differentiation. A consumer that does not join either network receives utility that is normalized to 0. For technical convenience, we assume that joining a network is sufficiently attractive (i.e. v_0 is high enough) so that all subscribers join a network on the relevant range of prices.[8] Preferences are the same in both countries. Note that consumers care only about their domestic operator, not about which foreign operator handles their roaming calls.[9]

The optimal individual demand and the resulting consumers' value from roaming calls are defined as

$$\begin{aligned} q(p) &\equiv \arg\max_q \{u(q) - pq\} , \\ v(p) &\equiv u(q(p)) - pq(p) . \end{aligned}$$

Since subscribers have quasilinear preferences concerning wealth, the value function v satisfies the envelope condition $v'(p) = -q(p)$. We maintain the following mild assumption throughout the paper:

Assumption 1 *Per customer demand $q(p)$ is non-negative, continuously differentiable and non-increasing on $\mathbb{R}$: $q(\cdot) \in \mathbb{R}_+$, $q'(\cdot) \leq 0$. Subscribers have a strictly positive demand for roaming services at the true marginal cost: $q(c) > 0$.*

For future reference we define the *net surplus* of a tariff as

$$w(p, F) \equiv v(p) - F . \tag{1}$$

Economically, the net surplus indicates how much of the value $v(p)$ created by placing roaming calls retains with the subscriber.

If the difference between the net surpluses offered by competing retail contracts in country x is not too large ($|w_{xi} - w_{xj}| < \frac{1}{2\sigma}$), both operators achieve a strictly positive market share. In this case, the market share of operator i in country x is

$$n_{xi} = n(w_{xi}, w_{xj}) \equiv \frac{1}{2} + \sigma\left(w_{xi} - w_{xj}\right) . \tag{2}$$

[8] This assumption is commonly made the literature on network interconnection. See e.g. Laffont, Rey, and Tirole (1998, p. 7) for further discussion.

[9] One justification for this assumption relies on a heterogeneous coverage. A subscriber usually prefers to join a network that offers good coverage at places where she lives and works. In contrast, when signing a mobile phone contract, a subscriber is usually less aware of the foreign places where she will use roaming services.

If instead operator i offers a contract that is far more attractive than its competitor's tariff ($w_{xi} \geq w_{xj} + \frac{1}{2\sigma}$), it corners the whole market.

The OECD (2009) points out that consumers may not take roaming prices fully into account when selecting an operator. Our model can be easily adapted to account for boundedly rational consumers. For example, we could assume that the fraction $\kappa \in (0,1)$ of consumers is not aware of the roaming prices and joins either operator with probability 1/2. Under this assumption, our analysis essentially remains unchanged after replacing σ with the adapted taste differentiation $\tilde{\sigma} = (1-\kappa)\,\sigma$.

Wholesale market: In order to allow subscribers to use foreign networks, operators may either conclude *roaming agreements* or form *international alliances*.

A *roaming agreement* specifies that operator xi hosts subscribers of operators yj but does not contain any obligation that operator xi also buys roaming services from operator yj. MNOs compete to become host operator for foreign subscribers by simultaneously posting a wholesale price per roaming call.[10] If operator yj accepts the offer of operator xi, then they conclude a roaming agreement which fixes the wholesale price $\tilde{a}_{xi}$.

Mobile operators with different home countries may also form *international alliances*.[11] Within an alliance, operators negotiate on a wholesale price at which they *mutually* provide roaming services. Alliance members commit to direct their subscribers to the partner network abroad. It will become clear that the appeal of alliances lies precisely in the commitment that subscribers are possibly not hosted by the cheapest operator abroad. After a wholesale price has been negotiated, it becomes public knowledge.[12] This assumption reflects that the wholesale prices, which are also called Inter-Operator-Tariffs, are published by the GSM Association. Note that members of an alliance may *sell* roaming services to foreign operators that are outside of an alliance.[13]

Figure 1 summarizes the structure of the model with an example. Operators $A0$ and $B0$ are affiliated to an alliance and host each other's subscribers at the wholesale price a_0. In addition, operator $A0$ also hosts subscribers of $B1$ while $A1$ buys roaming services from operator $B1$.

Timing: The base model consists of the following stages:

[10] Note that the restriction to linear wholesale prices prevents the use of two-part tariffs to soften competition as in Shaffer (1991).

[11] We suspect that domestic regulation agencies would prohibit alliances that would involve more than one MNO of a country. Members of these alliances could then collude on their domestic retail prices as well, thereby weakening competition.

[12] The results would be qualitatively similar when assuming privately negotiated wholesale prices and symmetric beliefs as discussed in Pagnozzi and Piccolo (2012).

[13] Regulation authorities might prohibit alliances that force members not to sell to outsiders as this behavior might be perceived illegal.

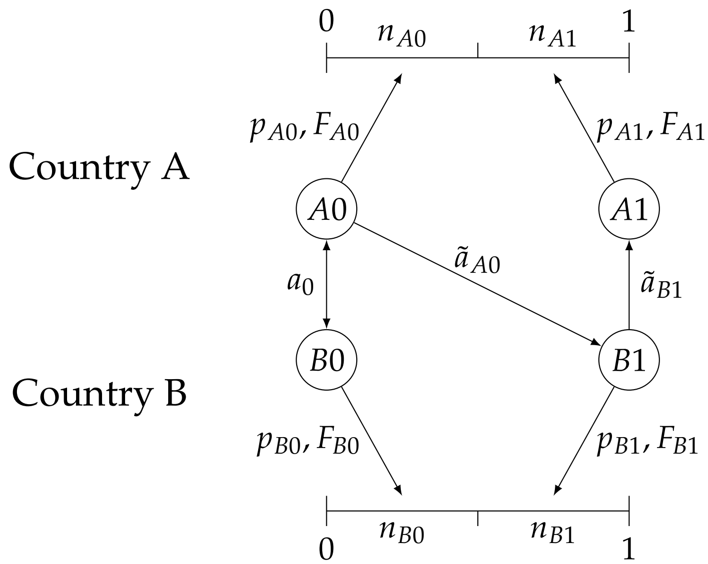

Figure 1: Model Setup - Overview

1. Members of an alliance negotiate on the wholesale price for roaming calls within their alliance.

2. MNOs simultaneously post wholesale roaming prices for operators that are not affiliated with an alliance.[14] MNOs that do not pertain to an alliance choose which foreign operator hosts their traveling subscribers.

3. Operators set retail tariffs. Consumers subscribe to their preferred network and place their roaming calls.

The sequential structure allows MNOs to set their wholesale prices strategically. It reflects that due to legal and practical reasons, wholesale prices can be changed less easily than retail tariffs.[15] We look for subgame perfect Nash equilibria and solve the model by backward induction.

3 Retail equilibrium

In this section, we take as given the choice of the foreign host operator and characterize the equilibrium retail tariffs, market shares and retail profits.

The perceived marginal cost of the reselling operator xi, which we denote as c_{xi}, equals the wholesale price of its host operator. For example, if roaming services for

[14]The results remain unchanged if wholesale prices that are set within alliances are not publicly known before MNOs post wholesale prices for unilateral roaming agreements.

[15]In Europe, the Standard Terms for International Roaming Agreement (STIRA) issued by the GSM Association provide guidelines how wholesale prices have to be set. They prescribe that wholesale prices have a validity of at least six months.

traveling subscribers of operator Ai are provided by operator Bj then the perceived marginal cost of operator Ai is $c_{Ai} = a_{Bj}$. Per subscriber, an operator earns $\pi^R_{xi} = q(p_{xi})\,(p_{xi} - c_{xi}) + F_{xi} - C_F$.

To derive the profit maximizing retail tariff, it is convenient to express the profit in terms of the retail per call price p_{xi} and the net surplus w_{xi} rather than in terms of p_{xi} and F_{xi}. The retail profit is thus $\Pi^R_{xi} = n(w_{xi}, w_{xj})\,(q(p_{xi})(p_{xi} - c_{xi}) + v(p_{xi}) - w_{xi} - C_F)$.

The availability of two-part tariffs yields pricing at perceived marginal cost, that is $p^*_{xi} = c_{xi}$.[16] Intuitively, setting the usage price equal to the perceived marginal cost avoids any dead-weight loss (from the viewpoint of the reselling operator).[17] The fixed fee is then used to extract $v(c_{xi}) - w_{xi}$ without causing any inefficiencies. Using the optimal per call price, the retail profit of operator xi simplifies to

$$\Pi^R_{xi} = \Pi^R(w_{xi}, w_{xj}, c_{xi}) \equiv n(w_{xi}, w_{xj})\,(v(p_{xi}) - w_{xi} - C_F)\ . \tag{3}$$

When both domestic operators serve the market, the corresponding first order condition determines the profit maximizing level of net surplus

$$w^*(c_{xi}, w_{xj}) \;=\; \frac{1}{2}[v(c_{xi}) + w_{xj} - C_F - \frac{1}{2\sigma}]\,. \tag{4}$$

Solving the system of best responses allows us to characterize the retail equilibrium as follows.

Lemma 1 *A retail equilibrium always exists. If the difference between perceived marginal costs is not too big, namely $|v(c_{x0}) - v(c_{x1})| \leq \frac{3}{2\sigma}$, the retail equilibrium is uniquely characterized by*

$$w^*(c_{xi}, c_{xj}) \;=\; \frac{2}{3}v(c_{xi}) + \frac{1}{3}v(c_{xj}) - \frac{1}{2\sigma} - C_F\,, \tag{5}$$

$$n^*(c_{xi}, c_{xj}) \;=\; \frac{1}{2} + \frac{\sigma}{3}[v(c_{xi}) - v(c_{xj})]\,, \tag{6}$$

$$\Pi^{R*}(c_{xi}, c_{xj}) \;=\; \frac{\left(n^*(c_{xi}, c_{xj})\right)^2}{\sigma}\,. \tag{7}$$

If instead $v(c_{xi}) - v(c_{xj}) > \frac{3}{2\sigma}$, then there exists a unique equilibrium in weakly undomi-

[16] This finding is by now well understood. See e.g. Laffont, Rey, and Tirole (1998); Armstrong (2002). This claim is formally proved in Lemma 1.

[17] If $q'(c_{xi}) = 0$, then $p^*_{xi} = c_{xi}$ is not a strict maximizer of $\pi^R(p_{xi}, a_{xi}, c_{xi})$, and its maximum is also attained by other per call prices. However, the usage prices do not affect the best response of the retail competitor. As all retail per call prices that attain the maximum retail profits are economically equivalent, we treat them as one equivalence class.

nated strategies[18] *where operator xi serves the whole market and offers $w^*_{xi} = \frac{1}{2\sigma} + v(c_{xj}) - C_F$, while its competitor sets $w^*_{xj} = v(c_{xj}) - C_F$.*

Proof. See Appendix A. ■

Increasing an operator's perceived marginal cost has two effects. First, it directly reduces operator xi's retail profit. Second, it softens retail competition.[19] Intuitively, the competitor anticipates that operator xi optimally reduces its subscribers' net surplus when its marginal cost increases. Since net surpluses are strategic complements by equation (4), competitor xj optimally also offers less attractive contracts to its own subscribers.[20] The total impact of an increase of operator xi's perceived marginal cost on its retail profit is

$$\frac{\mathrm{d}\Pi^{R*}_{xi}}{\mathrm{d}c_{xi}} = \frac{\partial \Pi^R_{xi}}{\partial w_{xj}} \frac{\mathrm{d}w^*_{xj}}{\mathrm{d}c_{xi}} + \frac{\partial \Pi^R_{xi}}{\partial c_{xi}} = -\frac{2n^*_{xi}}{3} q(c_{xi}) \,. \tag{8}$$

Since the negative direct effect of a cost increase dominates the positive strategic effect, an operator *unilaterally* prefers lower wholesale roaming prices. However, as we show in the next section, within an alliance the negative direct effect will be offset by gains at the wholesale level, while the strategic effect remains.

4 Wholesale Equilibrium

This section analyzes the equilibrium wholesale prices that obtain for a given number of alliances. We suppose that operators with the same index i form alliances, which is without loss of generality due to our symmetry assumptions.

Wholesale prices of unilateral roaming agreements

We first derive the equilibrium wholesale prices for roaming services that will be offered to MNOs which have not formed an alliance. Recall that joining an alliance does not preclude MNOs from *selling* roaming services to foreign operators that do *not* pertain to this alliance. So each operator xi may offer (simultaneously with its domestic competitor xj) to act as host operator for subscribers of country y at the wholesale price $\tilde{a}_{xi}$. For simplicity and without loss of generality, we suppose that

[18] See Palfrey and Srivastava (1991) for a definition of the undominated Nash Equilibrium concept. An undominated NE may not consist of strategies that are weakly dominated.

[19] By Lemma 1, if the difference in perceived per call costs is too big so that the competitor stays out of the market, a marginal increase in own per call costs triggers no strategic effect of softer competition.

[20] This conclusion relies on the stability of the retail equilibrium. For a comprehensive discussion of strategic complementarity, see e.g. Bulow, Geanakoplos, and Klemperer (1985).

operators cannot discriminate the wholesale price according to which foreign operator buys roaming services. By the results of the previous section, any operator that is not member of an alliance optimally buys roaming services from the foreign operator which offers the lowest wholesale price.

In the absence of alliances, operators thus compete in a standard Bertrand way to serve as host operator. It is profitable to undercut the wholesale price of the domestic competitor as long as the wholesale margin $\tilde{a}_{xi} - c$ is strictly positive. By the usual Bertrand reasoning, any operator offers roaming services at wholesale price $\tilde{a}^*_{xi} = c$ in equilibrium.

A similar reasoning holds if one alliance has been formed. Suppose operators xi and yi belong to an alliance while xj and yj remain without alliance. As before, by undercutting slightly any rival's price $\tilde{a}_{xj}$ above the true marginal cost, operator xi additionally earns strictly positive wholesale profits from selling to yj. Undercutting $\tilde{a}_{xj}$ also reduces the retail market share of the partner network, but this effect is negligible when undercutting slightly, since then the perceived marginal cost of operator yj and hence the retail market shares stay almost constant. As operator xj also undercuts any $\tilde{a}_{xi} > c$, the unique equilibrium prices are again $\tilde{a}^*_{xi} = \tilde{a}^*_{xj} = c$.

If two alliances have been created, then all operators are committed to buy roaming services from their partner network, so that unilateral roaming agreements play no role. We can thus summarize:

Proposition 1 *In unilateral roaming agreements, the equilibrium wholesale price for roaming services equals the cost of providing a roaming call c. In particular, this applies if international alliances are not feasible.*

Proof. In the text. ■

Wholesale prices within alliances

Both members of an alliance commit to buying roaming services exclusively from the foreign partner network, even in case another foreign operator offers cheaper wholesale prices for roaming services. There are indications that such a commitment is indeed sustainable.[21] For example, the European regulating agency BEREC recently reported that the choice of the visited network by an affiliated MNOs is "determined

[21] Taking into account that alliances operate over a longer period, such a commitment also appears to be theoretically sustainable. In a repeated game, after an MNO deviates from its commitment and directs a large part of its roaming traffic to non-affiliated MNOs (which is easily detectable), the alliance breaks up and the deviating MNO is temporarily "punished" by loosing the additional profit from being affiliated in an alliance.

by the presence of a partner and not so much by the discounts an alternative visited MNO could offer".[22]

Formally, suppose that the operators xi and yi have formed an alliance. For simplicity, we assume that each alliance negotiates on a single bilateral wholesale roaming price that maximizes the joint profit and applies for roaming calls in both directions: $a_{Ai} = a_{Bi} \equiv a_i$. As shown in Appendix C, when modeling the negotiation and assuming equal bargaining power, symmetric operators would deliberately choose $a_{Ai} = a_{Bi}$. We also consider wholesale agreements with two part tariffs in Section 6.4.

Since the negotiated wholesale prices become public knowledge, the ensuing retail equilibrium tariffs are as described in Section 3, treating the own wholesale price as a perceived marginal cost: $c_{xi} = a_i$. Indeed, after wholesale prices have been set in an alliance, an operator cannot affect the retail market share of its foreign partner any more. Hence the wholesale profit is treated as constant when deciding on the own retail tariff for domestic subscribers.

Operator xi's overall profit comes from reselling roaming calls to subscribers in its home country x and from selling roaming services to operator yi. When the competing operators xj and yj buy roaming services at perceived marginal costs $c_{xj} = c_{yj} \equiv c_j$, all members of alliance i achieve equal market shares $n^*_{Ai} = n^*_{Bi} \equiv n^*_i$ and equal retail profits $\Pi^{R*}_{Ai} = \Pi^{R*}_{Bi} \equiv \Pi^{R*}_i$ because of symmetric costs and demand across countries.[23] Therefore, each member of alliance i earns the total profit

$$\Pi_i = \Pi(a_i, c_j) \equiv n^*(a_i, c_j) \left[\pi^W(a_i) + \pi^{R*}(a_i, c_j)\right] \tag{9}$$

where

$$\pi^W(a_i) \equiv q(a_i)[a_i - c]$$

denotes the per customer wholesale profit. Suppose now that all operators obtain a positive market share. Then, using the results of Section 3, the marginal profit generated by an increase in the wholesale price of alliance i is

$$\frac{\partial \Pi}{\partial a_i}(a_i, c_j) = q(a_i) \left[\frac{1}{3}n^*_i - \epsilon(a_i)n^*_i - \frac{\sigma}{3}\pi^W(a_i)\right] \tag{10}$$

where $\epsilon(p) \equiv \frac{-(p-c)q'(p)}{q(p)}$ is the *markup* elasticity of per customer demand and $n^*_i = n^*(a_i, c_j)$.[24]

[22] BEREC (2010), p. 80. Sutherland (2010a) also points out that "some smaller operators claimed to be offering low wholesale prices but were unable to generate any business, it having been secured within the large groups and alliances" (p.24). Sutherland (2010b) notes similar findings in Asia.

[23] Both operators j have the same perceived marginal cost since they either form an alliance and negotiate on a reciprocal wholesale price a_j or remain without alliance and buy roaming services at the true marginal cost c.

[24] Note that the demand elasticity in markup terms is closely related to the price elasticity of de-

Three effects determine the marginal profit (10). These arise *indirectly* through a change of the ensuing equilibrium retail tariffs. The first term in (10) represents the positive *strategic* effect of softer competition discussed in Section 3. The last two terms refer to inefficiencies that arise when the wholesale price diverges from the true marginal cost. By Section 3, an increase of the wholesale price will be passed on to customers directly and causes undesired deadweight loss from the viewpoint of an alliance. In addition, increasing the wholesale price induces the operators to offer less attractive retail tariffs. This reduces the customer base and therefore the wholesale profit. Note that equation (10) does not contain any *direct* price effect. Since each member sells the same quantity of roaming calls to the foreign partner that it buys for own subscribers, any additional expenses for roaming services at the retail level are perfectly recouped at the wholesale level.

Setting marginal profits (10) to zero and rearranging, we obtain the Lerner condition

$$\frac{a_i^* - c}{a_i^*} = \frac{1}{3\left[\eta_q(a_i^*) + \eta_{n^*}(a_i^*, c_j)\right]} \tag{11}$$

where $\eta_q(a_i) \equiv -\frac{a_i q'(a_i)}{q(a_i)}$ is the *price* elasticity of per customer demand and $\eta_{n^*}(a_i, c_j) \equiv -\frac{\mathrm{d}n_i^*}{\mathrm{d}a_i}\frac{a_i}{n_i^*} = \frac{\sigma a_i q(a_i)}{3n_i^*}$ is the price elasticity of the equilibrium retail market share.[25]

We need the following technical assumption to guarantee existence and uniqueness of a wholesale equilibrium:

Assumption 2 *The markup elasticity of per customer demand $\epsilon(p)$ is non-decreasing for all prices above marginal costs whenever $\epsilon(p) \leq 1$.*

Assumption 2 assures that the marginal impact of deadweight loss is non-decreasing in the wholesale price. It is satisfied by many commonly used demand functions, including constant demand, linear demand or constant (price) elasticity demand.

Let $a^*(c_j)$ denote the wholesale price that maximizes alliance i's profits when the competing operators have the perceived marginal cost c_j. Based on the optimality condition (11), the following lemma establishes that wholesale prices are strategic complements on the relevant range.[26]

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mand which is defined as $\eta(p) \equiv \frac{-pq'(p)}{q(p)}$. The following relationship holds: $\epsilon(p) = \eta(p)\frac{(p-c)}{p} < \eta(p)$. In case of $c = 0$, the markup elasticity coincides with the price elasticity of per customer demand. See also Anderson, de Palma, and Nesterov (1995).

[25]In case of two alliances and a symmetric wholesale price, each alliance achieves a market share of $n_i^* = \frac{1}{2}$ and the price elasticity of the market share simplifies to $\eta_{n^*}(a_i) \equiv \frac{2}{3}\sigma a_i q(a_i)$.

[26]Formally, the relevant range is $\mathcal{E} = \left\{p \in \mathbb{R} | \epsilon(p) < \frac{1}{3} \wedge p \geq c \wedge q(p) > 0 \wedge v(p) > v(c) - \frac{3}{2\sigma}\right\}$ as shown in Appendix A.2.

Lemma 2 *If Assumption 2 holds, then a best response $a^*(c_j)$ uniquely exists and is strictly increasing in c_j on the relevant range.*

Proof. See Appendix A. ■

The own market share increases in the perceived marginal cost of the competing operators. A higher market share amplifies the strategic effect of softer competition, which results in a higher own profit maximizing wholesale price. We now turn to our main result:

Proposition 2 *Suppose that Assumption 2 holds.*

i) If a single alliance i is created, then the unique equilibrium wholesale price a^{1*} within this alliance is characterized by equation (11) *using $c_j = c$ and exceeds the true marginal cost: $a^{1*} > c$.*

ii) If two alliances are formed, a unique equilibrium in weakly undominated strategies exists in which both alliances set the symmetric wholesale price $a_0 = a_1 = a^*$.[27] *This equilibrium price is characterized by equation* (11) *using $c_j = a^*$ and exceeds the bilateral wholesale price in case only one alliance is formed: $a^* > a^{1*} > c$.*

Proof. See Appendix A. ■

Besides existence and uniqueness, Proposition 2 confirms that alliances set higher wholesale prices for roaming calls than would be socially optimal.[28] Assumption 2 assures existence and uniqueness but is not needed to derive that a strictly positive markup on the wholesale level necessarily occurs.

To understand the intuition for part i), let us compare the situation without alliances to that in which one alliance has emerged. Without alliances, Bertrand competition between foreign operators pushes the wholesale price down to marginal cost. Given this wholesale price each operator offers a two part tariff setting the price per call equal to the true marginal cost and extracting some of the consumer surplus via the fixed fee. When operators i form an alliance, competition still keeps the wholesale prices for the remaining two operators at the efficient level c. Within an alliance, members can jointly decide on the wholesale price. Raising the wholesale

[27]This refinement is only needed in case demand is constant below c to rule out implausible equilibria. In this case, there exist corner equilbria in which alliance i sets wholesale prices far below c and corners the whole market while the rival alliance j sets a wholesale price above c and is driven out of the market. The equilibrium price a_i^* is then weakly dominated by $a_i = c$. This class of equilibria is implausible since alliance j sets a_j^* far above c, knowing that lower prices would also guarantee non-negative profits and yield strictly higher profits if alliance i would adjust its price, too.

[28]In contrast to Laffont, Rey, and Tirole (1998), candidate equilibria are robust to big deviations. According to equation (10), the marginal profit becomes negative when the per customer wholesale profit π_i^W is large. Together with Assumption 2, this implies that equilibrium prices cannot exceed the marginal costs c by too much. Hence, a deviation as to corner the market would require wholesale prices below the true marginal costs and would not be profitable.

price of the alliance above marginal cost induces competing operators to offer less attractive retail contracts by the strategic complementarity discussed in Section 3. This strategic effect increases profits and is of first order. The additional expenses needed to procure roaming services for own subscribers are fully recouped since the foreign partner buys the same quantity of these services for its subscribers. A higher wholesale price also leads to a distorted retail tariff which is set so as to maximize the retail profit instead of the total profit. However, for wholesale prices close to the true marginal cost c the optimal retail tariff from the viewpoint of the alliance is almost attained, so that the impact from distortions on the total profit is of second order. Hence, starting out from a wholesale price equal to marginal cost, it is always optimal to raise the wholesale price at least somewhat once an alliance is formed.

According to part ii) of Proposition 2, the equilibrium wholesale prices further increase if a second alliance is formed. When the rivals j also form an alliance, they will negotiate on a wholesale price above c by the same reasoning as above. Since the optimal wholesale price is upward sloping in the competitor's price by Lemma 2, each alliance will set a higher wholesale price as would do a single alliance. Note however, that the equilibrium wholesale price remains below the level that maximizes the industry profits, characterized by $\frac{a^M - c}{a^M} = \frac{1}{\eta_q(a^M)}$.[29]

In Appendix C we allow for differing roaming demand across countries and find that the results presented above are continuously approached as the countries become more similar. If retail (wholesale) demand in country A is larger (smaller) than in country B and two alliances have formed, the equilibrium wholesale price for the country with higher retail roaming demand will be higher than the wholesale price of the smaller one: $a_A^* > a_B^*$. Intuitively, if the affiliated MNOs agreed on the wholesale price a^* derived in the fully symmetric setting, the benefit from an alliance would be smaller for operators in country A. By staying outside of an alliance, an operator in country A would forgo lower wholesale profits compared to its partner of country B in return for obtaining roaming calls for a wholesale price c. By adjusting the wholesale price a_{Ai} upwards and a_{Bi} downwards, the benefits from the alliance are distributed more evenly.

Relaxing the assumption of homogeneous customers does not qualitatively change our main result of harmful alliances as we show in Appendix B. There, we allow for light and heavy users, assuming that the mean demand for roaming calls of the pop-

[29] The role of wholesale prices differs from that of access-prices in Laffont, Rey, and Tirole (1998). In their model of network interconnection, even the industry monopoly profits can be attained provided the retail equilibrium exists since the access price equally applies to both domestic competitors. In our model, taking a_j as given and increasing the bilateral wholesale price of alliance i decreases its market share. The danger of losing too many subscribers keeps wholesale prices below the level that maximizes industry profits.

ulation is unchanged and that subscribers in both segments have the same degree of taste differentiation $1/\sigma$. We find that heavy users, which are particularly valuable for operators, are more inclined to switch to the competitor after an increase of the usage price. We show that even though the fear of losing heavy users reduces the equilibrium wholesale price somewhat, it remains strictly above the true marginal cost, where the marginal loss from distorted retail tariffs is still of second order.

Comparative Statics

We now present some comparative statics of the equilibrium wholesale price when two alliances are in place, which will be shown to be the configuration that obtains if alliances are endogenously formed. The same comparative statics obtain in case of only one alliance.

Proposition 3 *Suppose that Assumption 2 holds.*

i) The equilibrium wholesale price a^* decreases in the degree of competition on the retail market σ.

ii) The equilibrium wholesale price a^* decreases if the per customer demand is multiplied by some constant $\lambda > 1$.

iii) Suppose that the per customer demand function $\tilde{q}$ is more elastic than q: $\eta_{\tilde{q}}(p) > \eta_q(p)\ \forall p$. Denote the associated symmetric equilibrium wholesale prices by $\tilde{a}^*$ and a^*. If the per customer demand $\tilde{q}$ is weakly higher than q at the equilibrium price a^* (i.e. $\tilde{q}(a^*) \geq q(a^*)$), then the wholesale equilibrium price decreases in the elasticity of customer demand: $\tilde{a}^* < a^*$.

Proof. See Appendix A. ■

Part i) of Proposition 3 states that wholesale equilibrium prices are lower if taste differences of customers $1/\sigma$ are small. In this case the negative effect of losing market share when increasing the wholesale price is strong compared to the competition softening effect.

According to part ii), the equilibrium price decreases if the per customer demand rises uniformly. Intuitively, a higher demand implies that the usage price becomes more important relative to the differences in taste so that the market share becomes more elastic. Thus, increasing the wholesale price leads to a stronger reduction in market share and the forgone wholesale profit per customer increases due to a higher demand per customer. Due to the amplified negative effects from distorted retail tariffs, the equilibrium price decreases.

Part iii) compares differences in the elasticity of demand. When demand is more elastic, the dead-weight loss invoked by setting the wholesale price above marginal costs becomes more pronounced and thus disciplines alliances. The proposition also requires that the more elastic demand function $\tilde{q}$ exceeds the demand q at the equilibrium price a^*. This condition assures that operators have no countervailing incentive to raise the wholesale price due to a reduced elasticity of the market share.

Examples. The results of this section can be illustrated by some common demand functions that admit explicit solutions. First, we assume that the per customer demand q is constant: $q(p) = \bar{q}$. Clearly, in this case there is no concern of deadweight loss and an alliance trades off solely the benefits from softer competition with the loss of market share. The elasticity of the retail market share becomes $\eta_n(a_i) = \frac{\sigma a_i}{3n_i^*}\bar{q}$ and the equilibrium wholesale price can be explicitly determined by solving condition (11): $a^*_{\bar{q}} = c + \frac{1}{2\sigma\bar{q}}$. Clearly, it is decreasing in the degree of competition σ and in the demand $\bar{q}$.

Another example that admits an explicit solution is the commonly used constant elasticity demand $\tilde{q}(p) = \frac{A}{p}$. Using this specification, the equilibrium wholesale price is $a^*_{\tilde{q}} = c + \frac{c}{2+2\sigma A}$. If $A \geq \left(c\bar{q} + \frac{1}{2\sigma}\right)$ then $\tilde{q}(a^*_{\bar{q}}) \geq \bar{q}$ and the hypothesis of proposition 3, part iii) is satisfied. Indeed, for $A = \left(c\bar{q} + \frac{1}{2\sigma}\right)$, we have $a^*_{\tilde{q}} = c + \frac{c}{3+2\sigma\bar{q}c} < a^*_{\bar{q}}$.

5 Endogenous formation of alliances

We now endogenize the choice of MNOs to form alliances. Operators whose home network is in the same country may not collaborate within an alliance, for example due to legal constraints. Otherwise, all operators would agree on a wholesale price that maximizes joint *industry* profits. Therefore any alliance consists of exactly one MNO with home country A and another of country B.

Formally, we introduce a formation stage that takes place before wholesale prices are set. For simplicity, we assume that operator $A0$ may form an international alliance with $B0$ and $A1$ with $B1$. By the symmetry assumptions, this restriction is without loss of generality. Competing operators simultaneously decide on creating an alliance. We assume that operators form an alliance whenever this increases the total profit of its members in order to circumvent coordination issues.[30] Thus, to analyze how many alliances are created in equilibrium, we simply have to compare the equilibrium profits of each configuration.

Creating an alliance dominates staying alone. Suppose first that operators j do

[30]Putting aside coordination issues, this formulation generates the same results as a more complicated formation stage in which operators announce their choice and alliances are only formed if two operators agree to form an alliance.

not create an alliance and therefore buy roaming services at a wholesale price of c. Forming an alliance allows operators i to commit to a wholesale price that exceeds the true marginal cost. Since marginally increasing the wholesale price is profitable at c, this raises the total profit: $\Pi(a^{1*}, c) > \Pi(c, c)$. Suppose now that operators j form an alliance. Then, creating an additional alliance is even more profitable, since it additionally induces operators j to further increase their wholesale price to $a^* > a^{1*}$, which makes setting a high wholesale price within an alliance even more profitable: $\Pi(a^*, a^*) > \Pi(c, a^{1*})$.[31] This yields the following prediction:

Proposition 4 *Suppose that Assumption 2 holds. Then a unique subgame perfect equilibrium exists with two competing alliances being formed. In every country, the market is equally split between both alliances. Both alliances set the equilibrium wholesale price a^* characterized by Proposition 2, part ii).*

Proof. In the text. ■

Decomposing the total equilibrium profit shows that alliances increase the wholesale profit without lowering the equilibrium retail profit. Due to our simple Hotelling framework, the retail equilibrium profit $\Pi_i^{R*} = \frac{(n_i^*)^2}{\sigma}$ depends only on the market share but not on the absolute level of retail prices. Since the retail market is equally shared when either all operators stay alone or two alliances have been created, the retail equilibrium profit remains unchanged. However, with alliances, operators additionally earn a strictly positive wholesale margin which makes them better off in total. Subscribers are unambiguously worse off once alliances are introduced since the equilibrium retail usage price increases while the equilibrium fixed fee remains unchanged.

Note that the strategic effect is less likely to be achieved if operators Ai and Bi merge instead of forming an alliance. A merged operator i possesses a network in both countries. It therefore sets the retail prices in each country so as to maximize the sum of retail *and* wholesale profits of both countries. Hence, conducting a merger generates no strategic effects and leads to the same profits as staying alone.[32] As a policy implication, if creating an international alliance or an international merger generates additional positive effects beyond this model, then competition authorities should promote international mergers instead of alliances. Indeed, the OECD (2009)

[31] Formally, $\Pi(a^*, a^*) > \Pi(c, a^*) = \Pi(c, a^{1*}) + \int_{a^{1*}}^{a^*} \frac{\partial \Pi}{\partial a_j}(c, a_j) \mathrm{d}a_j > \Pi(c, a^{1*})$ where the first inequality is due to Lemma 2 and the second inequality follows from $\frac{\partial \Pi}{\partial a_j}(a_i, a_j) = \frac{1}{3} q(a_j) \left[2n_i^* + \sigma \pi^W(a_i)\right] > 0$.

[32] The merged firm may commit to delegate the retail pricing decision to local managers that maximize the retail profits for a given virtual wholesale price. Yet, to the extend that internal contracts may be overruled easily, they are inappropriate to credibly commit to inefficient behavior.

observes that the prices for roaming services drop, once operators with networks in different countries merge and therefore cannot credibly commit to excessive wholesale prices any longer.

6 Extensions

6.1 Non-discrimination clause

The framework which was introduced by the GSMA in 1996 contains a so called non-discrimination clause. According to this clause, an operator should apply the same terms and conditions on the wholesale market to all foreign operators when providing access to its network. In this section, we show that the non-discrimination clause impairs competition for unilateral roaming agreements and allows alliances to raise the rivals' marginal cost. Compared to the results of our base model, this leads to even higher usage prices and further increases equilibrium profits.

In the spirit of this clause, we now assume that operators have to charge the same wholesale price that has been negotiated within an alliance whenever they sell roaming services to non-affiliated operators. Note that a non-discrimination clause only affects the equilibrium wholesale prices if exactly one alliance has emerged, since in case of two alliances, all MNOs are committed to buy roaming services only within the same alliance. So, wholesale prices for non-affiliated operators are irrelevant.

The following proposition establishes that indeed all operators' profits are highest when only one alliance is formed and that this configuration obtains in equilibrium.

Proposition 5 *Suppose Assumption 2 holds and a non-discrimination clause is in place. Then a single alliance emerges in equilibrium that sets the unique profit-maximizing wholesale price a^{ND*}. The wholesale price a^{ND*} strictly exceeds the price a^* characterized by Proposition 2. Introducing a non-discrimination clause unambiguously increases all operators' profits and decreases both customer surplus and welfare.*

Proof. See Appendix A. ■

Suppose that only operators i have formed an alliance. Then operators $j \neq i$ generate positive wholesale revenues only if they offer a wholesale price not above the wholesale price a_i of alliance i. As a tie-breaking rule, we assume that whenever all operators of one country offer the same wholesale price, operators that do not pertain to an alliance buy all roaming services from a non-alliance operator. For a given a_i, the wholesale profit of operator xj that charges a wholesale price of $\tilde{a}_{xj}$ is

$$\tilde{\Pi}^W(\tilde{a}_{xj}, a_i) \equiv \begin{cases} 0 & \text{if} \quad \tilde{a}_{xj} > a_i \\ n^*(\tilde{a}_{xj}, a_i)\pi^W(\tilde{a}_{xj}) & \text{if} \quad \tilde{a}_{xj} \leq a_i \end{cases}$$

where $n^*(\tilde{a}_{xj}, a_i) \equiv \frac{1}{2} + \frac{\sigma}{3}\left(v(\tilde{a}_{xj}) - v(a_i)\right)$ and $\pi^W(a_i) \equiv q(a_i)[a_i - c]$ remain as already defined in Section 3 and 4, respectively. Denote by $\tilde{a}^*(a_i)$ the best response of the non-affiliated operators j as a function of the wholesale price a_i set by alliance i. Proposition 5 proves that $\tilde{a}^*(a_i)$ equals any wholesale price a_i up to some uniquely defined threshold $\bar{a}^\dagger$ which lies above the wholesale equilibrium price a^* defined by Proposition 2: $\tilde{a}_j{}^*(a_i) = a_i \quad \text{if } a_i \in \left[c, \bar{a}^\dagger\right]$. This is because operator xj sets $\tilde{a}_{xj}$ in order to maximize its *wholesale* profit and only internalizes that increasing the wholesale price reduces the retail market share but not that it also lowers the retail per customer profit of the reselling operator yj.

We now illustrate why the equilibrium price a^{ND*} that is charged by the members of the single alliance i unambiguously exceeds a^*. Alliance i cannot earn profits from selling roaming services to any operator j since non-affiliated operators weakly undercut the negotiated wholesale price whenever $a_i > c$. Any wholesale price a_i below $\bar{a}^\dagger$ yields a retail market share for alliance i of 1/2 since the non-affiliated operators j will exactly match this price. Raising the wholesale price from a^* to $\bar{a}^\dagger > a^*$ thus allows the alliance to increase its wholesale profit without losing market share.[33] Therefore, if only one alliance has emerged, the equilibrium wholesale prices of all operators are at least $\bar{a}^\dagger$.[34]

Intuitively, a non-discrimination clause allows operators in an alliance to commit not to undercut the wholesale prices of non-affiliated operators.[35] Similar to Ordover, Saloner, and Salop (1990), this commitment assures that rival operators will have to pay high wholesale prices for roaming services. The clause thus severely restricts competition to provide non-affiliated operators with roaming services and essentially allows an alliance to soften competition both at the retail *and* at the wholesale level. We suspect that in a symmetric setup of N operators, the non-discrimination

[33]The proof of Proposition 5 shows that $\epsilon(\bar{a}^\dagger) > 1$ so that lower per customer demand is more than offset by a higher margin.

[34]Note that higher wholesale prices partially obtain since the alliance sets its wholesale price before the non-affiliated operators. Since wholesale prices are strategic complements as shown by Lemma 2, if two alliances chose their wholesale prices sequentially, higher wholesale prices than a^* would obtain. But whenever $a^{ND*} = \bar{a}^\dagger$, then a^{ND*} even exceeds the wholesale price that would be set by the alliance i, if another alliance j observed a_i before negotiating on a_j. A sufficient condition for $a^{ND*} = \bar{a}^\dagger$ is $\sigma\pi^W(\bar{a}^\dagger) \leq 1$.

[35]In a different setup with secret contracts, Rey and Tirole (2007) recently reported that a non-discrimination clause may be harmful, since it confers commitment against opportunistic but socially desirable behavior. We have thus discovered another reason why commitment obtained by help of a non-discrimination clause may be advantageous for firms.

clause would induce the creation of $N-1$ alliances.

6.2 Policy Intervention

We now investigate the effects of imposing a retail price cap when two alliances have emerged. In practice, implementing a price cap at the retail level does not require collaboration with foreign regulators since it directly affects the country in which it is imposed. In contrast, a wholesale price cap clearly increases both welfare and consumer surplus in our model but usually requires international cooperation between regulators. Knowing the precise effects of a retail price cap appears thus necessary in order to select the optimal policy. The interest in this question is exemplified by the intense debate that took place before the European Commission introduced a price cap both at the retail and at the wholesale level in 2007.[36] Indeed, our results suggest that *solely* restricting the *retail usage* price is likely to have a detrimental effect on consumer surplus even in the absence of any informational asymmetries.

We first analyze the impact of a retail usage price cap $\overline{p}$ on the retail equilibrium tariffs for given wholesale prices. Remember that each operator xi optimally sets the retail usage price p_{xi} so as to maximize the retail surplus. If the wholesale price a_i exceeds the price cap, then the optimal choice is to set the usage price as high as possible, namely $p^*_{xi} = \overline{p}$. Abstracting from the fixed fee, the surplus per customer is thus $v(\overline{p})$ and the reselling operator bears a loss of $q(\overline{p})\,(a_i - \overline{p})$ for the roaming calls. The maximized surplus generated *at the retail level* is therefore:

$$\overline{v}(a_i) \equiv \begin{cases} v(\overline{p}) - q(\overline{p})\,(a_i - \overline{p}) & \text{if } a_i > \overline{p} \\ v(a_i) & \text{if } a_i \leq \overline{p} \end{cases} \tag{12}$$

Restricting the usage price not to exceed $\overline{p}$ reduces the surplus created at the retail level if $a_i > \overline{p}$ and if the demand is decreasing at $\overline{p}$.[37] The retail profit per customer is now $\overline{\pi_i}^R = \overline{v}(a_i) - \overline{w}_i - C_F$ where $\overline{w}_i$ is the subscriber's net surplus.

Since the retail equilibrium tariffs derived in Section 3 depend on a_i only through $v(a_i)$, they remain valid when a price cap is in place after replacing $v(a_i)$ by the function $\overline{v}(a_i)$. Whenever the wholesale prices of the competing alliances are close enough, namely $|\overline{v}(a_0) - \overline{v}(a_1)| < \frac{3}{2\sigma}$, both operators achieve a positive market share given by $\overline{n}^*_i = \frac{1}{2} + \frac{\sigma}{3}[\overline{v}(a_i) - \overline{v}(a_j)]$. In this case the equilibrium level of net surplus

[36] The European Commission (2006) discusses the impact of various policy interventions, including a pure retail price cap. The negative impact of the waterbed effect as set out in this section is not considered in the report.Ambjornsen, Foros, and Wasenden (2011) point out that a wholesale price cap may lead to inefficient investments to acquire more wholesale roaming traffic.

[37] We make the realistic assumption that operators cannot restrict the quantity of roaming calls per subscriber.

$\overline{w}_i^*$ conceded to consumers reads as follows:

$$\overline{w}_i^* = \frac{2}{3}\overline{v}(a_i) + \frac{1}{3}\overline{v}(a_j) - C_F - \frac{1}{2\sigma} \tag{13}$$

In particular, for symmetric wholesale prices the equilibrium per customer profit is $\overline{\pi}_i^{R*} = \frac{1}{2\sigma}$ as in Section 3.

We assume that the cap is imposed in both countries before operators negotiate on wholesale prices. For wholesale prices above $\overline{p}$ that give rise to a shared market, the total marginal profit of an operator is

$$\frac{\partial \overline{\Pi}^*}{\partial a_i}(a_i, a_j) = \frac{q(\overline{p})}{3}\left[\overline{n}_i^* - \sigma \overline{\pi}_i^W\right] \tag{14}$$

where $\overline{\pi}_i^W \equiv q(\overline{p})(a_i - c)$ denotes the per customer wholesale profit in case of a binding price cap. Marginally increasing the wholesale price above $\overline{p}$ leaves the retail usage price and therefore the deadweight loss unchanged. Setting the marginal profit equal to zero yields that the per customer wholesale profit is $\overline{\pi}^{W*} = \frac{1}{2\sigma}$ in any symmetric equilibrium. It exceeds the equilibrium per customer wholesale profit without price cap $\pi^{W*} = \frac{1-3\epsilon(a^*)}{2\sigma}$ derived from equation (10). Using $\overline{\pi}^{W*} = \frac{1}{2\sigma}$ with (12) and (13) yields the equilibrium net surplus per customer $\overline{w}^* = \overline{v}(\overline{a}^*) - \overline{\pi}^{W*} - \frac{1}{2\sigma} - C_F = v(\overline{p}) + q(\overline{p})\,(\overline{p} - c) - \frac{1}{\sigma} - C_F$ which is clearly maximal for $\overline{p} = c$. The next proposition establishes that even adopting the optimal retail price cap $\overline{p} = c$ typically decreases consumer surplus. Recall that a^* denotes the equilibrium wholesale price without price cap according to Proposition 2.

Proposition 6 *Suppose that Assumption 2 holds and that demand is decreasing at a^*: $q^{'}(a^*) < 0$. Then introducing a retail per call price cap $\overline{p} \leq a^*$ in both countries decreases consumer surplus and increases industry profits. If the price cap is not set below the true marginal cost and $\overline{p} < a^*$, total welfare increases. If the price cap is sufficiently close to the unrestricted equilibrium wholesale price (i.e. $q(\overline{p}) - q(a^*) < \frac{3\epsilon(a^*)}{2\sigma(a^*-c)}$), then the equilibrium wholesale price increases.*

Proof. See Appendix A. ■

If the mild conditions of Proposition 6 are satisfied, restricting the retail per call price decreases deadweight-loss and thus increases total welfare since the market remains covered.

Two countervailing effects determine how a price cap influences the wholesale equilibrium price. A retail price cap prevents operators from passing through high wholesale prices to subscribers. Therefore, increasing the wholesale price does not aggravate the deadweight-loss, which renders higher wholesale prices more attractive. On the other hand, a cap on the retail price guarantees that each subscriber places at least $q(\overline{p})$ calls. This increases the wholesale profit per customer and renders subscribers more valuable, thereby inducing alliances to set lower wholesale prices. Whenever the condition $q(\overline{p}) - q(a^*) < \frac{3\epsilon(a^*)}{2\sigma(a^*-c)}$ holds, the first effect dominates and higher wholesale prices obtain. If $\epsilon(a^*) > 0$, a price cap which is set close enough to a^* satisfies this condition and thus increases the wholesale price. By the same reasoning as in Section 5, two alliances emerge in equilibrium.

Our results suggest that in order to protect subscribers, price caps should preferably be imposed at the wholesale level. Sutherland (2010a) reports that the waterbed effect was mentioned in consultations on the roaming regulations. This might also explain why national regulation authorities have mostly chosen not to regulate retail roaming prices prior to the intervention of the European Commission.

6.3 The role of host network selection

This section analyzes the competitive impact of technological developments that have improved the home operators' control over the choice of foreign host networks for roaming. In contrast to our assumption of perfect network selection technologies, we now consider the other polar case of operators having no control which foreign network their subscribers use. In the past, traveling subscribers were assigned almost randomly to foreign networks for several reasons as discussed by Salsas and Koboldt (2004). Appendix D covers intermediate levels of control. As we show, the possibility of traffic direction increases the competitive pressure in the wholesale market. We find that alliances are without bite if the host network is randomly determined and conclude that the importance of international alliances has increased with those technological improvements.

We assume that operators cannot discriminate the retail usage price contingent on which foreign network is used. If price discrimination was feasible, subscribers would manually choose the cheapest network. Hence, operators could control the network selection by setting the price of the preferred foreign network lower than that of the non-desired network. The outcome would then be economically equivalent to our base model. However, according to European Commission (2005) there is empirical evidence that few subscribers are aware or engaged in manual network selection.

When buying roaming calls from foreign MNOs on the wholesale market, operator xi's perceived marginal cost is:

$$c_{xi} = \frac{1}{2}\left(a_{y0} + a_{y1}\right) \tag{15}$$

Again, the optimal per call price equals the perceived marginal cost: $p^*_{xi} = c_{xi}$. The retail equilibrium net surplus, market share and the equilibrium profits remain as established in Lemma 1. Since each operator has to procure half of the roaming services from each foreign operator, $c_{xi} = c_{xj}$. Thus the retail market is perfectly shared and the equilibrium profit is constant in a_{yi} by our results of Section 3: $\hat{\Pi}^{R*}_{xi} = \frac{1}{4\sigma}$.

No international alliances. In the absence of alliances, the wholesale demand does not depend on the actual market share of the reselling operators, since *both* purchase half of their traffic from operator xi. The total profit of operator xi is (the superscript NA refers to "no alliance"):

$$\hat{\Pi}^{NA}_{xi} = \hat{\Pi}^{R*}_{xi} + \frac{1}{2}\left(a_{xi} - c\right) q \left(\frac{1}{2}\left(a_{x0} + a_{x1}\right)\right) \tag{16}$$

Similar to Section 4, operator xi sets its wholesale price so as to maximize its wholesale profits $\frac{1}{2}\left(a_{xi} - c\right) Q_{xi}$. The following mild technical assumption assures that the per customer demand is elastic enough for an equilibrium to exist:

Assumption 3 *The markup elasticity of per customer demand $\epsilon(p)$ is increasing for all prices above marginal costs whenever $q(p) > 0$ and there exists some $\tilde{p} > c$ with $\epsilon(\tilde{p}) = 2$.*

Proposition 7 *Suppose that Assumption 3 holds and that operators cannot select the host network of their subscribers. If no alliances are feasible there exists a unique symmetric equilibrium wholesale price a^{NA*}, characterized by*

$$\frac{a^{NA*} - c}{a^{NA*}} = \frac{2}{\eta_q(a^{NA*})} \tag{17}$$

where $\eta_q(\cdot)$ is the price elasticity of per customer demand.

Proof. Rearranging the first order condition that is necessary for maximization of $\hat{\Pi}^{NA}_{xi}$ yields condition (17). Rewriting the marginal profit in terms of markup-elasticity and evaluating at $a_{xj} = a_{xi}$ yields $\frac{\partial \hat{\Pi}^{NA}}{\partial a_{xi}} = \frac{1}{2} q\left(a_{xi}\right)\left[1 - \frac{1}{2}\epsilon\left(a_{xi}\right)\right]$. Thus the first order condition is satisfied at $\tilde{p}$ which uniquely exists by Assumption 3. The profit is strictly quasiconcave since $\epsilon'(p) > 0$ whenever $q(p) > 0$ by assumption. ■

By Proposition 7, if operators cannot influence which foreign network their subscribers use to place roaming calls, the resulting equilibrium wholesale price is extremely high. Unilaterally increasing the wholesale price a_{xi} causes a negative externality on the rival, since the wholesale demand of operator xj is reduced while only the margin of operator xi increases. As operators do not take this externality into account, the resulting equilibrium price even exceeds the monopoly price.

Two international alliances. We now analyze the equilibrium outcome after operators with the same location have formed two competing alliances and omit the country index for brevity. Operators have to offer roaming services on the wholesale market to all foreign operators for the same price a_i that is negotiated within an alliance.[38] Thus, the only remaining virtue of alliances is to set the wholesale price cooperatively instead of competitively.

If both alliances have negotiated wholesale prices a_i and a_j, the profit of each operator in alliance i is

$$\hat{\Pi}_i \quad = \quad \hat{\Pi}_i^{R*} + \frac{1}{2}\left(a_i - c\right) q \left(\frac{1}{2}\left(a_0 + a_1\right)\right). \tag{18}$$

Since both the retail and the wholesale profit is the same as in the case of no alliances treated above, we conclude:

Proposition 8 *Suppose that Assumption 3 holds and that operators cannot select the host network of their subscribers. The formation of two alliances does not affect the wholesale equilibrium price, which remains characterized by* (17). *Ceterus paribus, with two alliances the equilibrium wholesale price under random network selection lies above that under perfect network selection given by Proposition 2, part ii).*

Proof. The proof of existence and uniqueness parallels that of Proposition (7), since the same objective function is maximized. Proposition C1 in Appendix D proves that the equilibrium price decreases with the quality of network selection. ■

Intuitively, there are two reasons why equilibrium prices are now higher than in the base model. Due to random network selection, the perceived marginal costs c_i of operators within alliance i *and* those of the rival alliance j equally depend on the wholesale price a_i. First, this makes an alliance's retail market share insensitive to increases of the own wholesale price. Second, raising the wholesale price a_i may increase the wholesale profit generated from sales to operators of the competing alliance.

The insight that without network control the presence of alliances does not affect the wholesale prices is at first glance surprising. One might conjecture that alliances

[38] This restriction facilitates the comparison with the results of the base model. When allowing MNOs to discriminate between members of the alliance and non-members, the wholesale price $\hat{a}_i$ that applies to non-members will be set extremely high and in many cases there is no equilibrium.

mitigate the problem of double marginalization as in Carter and Wright (1994).[39] Assuming linear retail and wholesale prices, Lupi and Manenti (2009) find that even without control of network selection, alliances negotiate reciprocal wholesale prices equal to marginal costs. However, as we analyze competition on the retail market with two part tariffs, no deadweight loss is caused at the retail level and double marginalization is not an issue. Hence, there is no externality that an alliance could internalize when coordinating on a wholesale price. Our model therefore provides an explanation why in Europe international roaming alliances were formed mainly after powerful network selection technologies have become available.

6.4 Wholesale fees per roaming subscriber

So far, we have assumed that operators can only charge linear prices at the wholesale level. This assumption reflects roughly the wholesale price structure that is used in practice at the moment. However, in this section we show that two-part tariffs at the wholesale level render alliances even more profitable. Now, operators may both charge a per call wholesale price and a fee that has to be paid for any foreign customer that visits the network.[40] We assume that operators with same position have formed alliances and omit the country index for brevity.

The per customer fee enters as perceived fixed cost and therefore renders customers less attractive at the retail level. The optimal retail per call price remains equal to the wholesale per call price of the alliance. Thus, the per customer profit is now $\tilde{\pi}_i^R = v(p_i) - w_i - \phi_i - C_F$. The retail profit of operator i conditional on alliance i having agreed on the wholesale price a_i and the per customer fee ϕ_i reads $\Pi_i^R = n(w_i, w_j)\tilde{\pi}_i^R$. Solving for the retail equilibrium as in Section 3 yields the retail equilibrium net surplus $w_i^* = \frac{2}{3}\left[v(c_i) - \phi_i\right] + \frac{1}{3}\left[v(c_j) - \phi_j\right] - \frac{1}{2\sigma} - C_F$.

Denote the per customer wholesale profit by $\tilde{\pi}_i^W = q(a_i)\left(\tilde{a}_i - c\right) + \phi_i$. The first order conditions which characterize the optimal per call wholesale price $\tilde{a}_i^*$ and the optimal per customer wholesale fee ϕ_i^* are

$$\frac{\sigma}{3}\tilde{\pi}_i^{R*} = \frac{\sigma}{3}\tilde{\pi}_i^{W*} + n_i^*\epsilon(\tilde{a}_i^*)\,, \tag{19}$$

$$\tilde{\pi}_i^{R*} = \tilde{\pi}_i^{W*} \tag{20}$$

[39]In contrast to our model, Carter and Wright (1994) assume that there is a monopolist in each country and that the monopolists set linear tariffs both at the wholesale and retail market. They find that if operators cooperatively set wholesale prices to maximize their profits, then both consumer surplus and profits exceed the uncooperative outcome since the double-marginalization problem is circumvented.

[40]Note that this pricing structure differs from two-part tariffs used for example as franchise fees. In our setup, the fixed fee is paid for any customer. In contrast, a franchise fee is paid only once.

where $\epsilon(\cdot)$ refers to the per customer demand elasticity in terms of markup as before. Inserting condition (20) into condition (19) yields $n_i^* \epsilon(\tilde{a}_i^*) = 0$ which for $n_i^* \neq 0$ is only satisfied for $\tilde{a}_i^* = c$. Hence, as long as operator i expects to achieve a strictly positive retail market share, it is optimal to set the wholesale per call price equal to the true marginal costs.

Proposition 9 *Suppose that Assumption 2 holds, that $q^{'}(c) < 0$ and that operators have formed two competing alliances. If each alliance can negotiate both on a wholesale per call price and on a per customer fee, there exists a unique symmetric equilibrium. The equilibrium wholesale per call price equals the true marginal cost c and the wholesale profit is $\tilde{\pi}_i^{W*} = \phi_i^* = \frac{1}{2\sigma}$. Compared to the symmetric equilibrium without per customer fees, characterized by Proposition 2, each operator's wholesale profit and welfare is higher.*

Proof. First note that in any symmetric equilibrium, each operator has market share $n_i^* = \frac{1}{2}$ and hence earns the retail profit $\tilde{\pi}_i^{R*} = \frac{1}{2\sigma}$. Inserting these values and $\tilde{a}_i^* = c$ into equation (20) yields $\phi_i^* = \frac{1}{2\sigma}$. Furthermore, this critical point is a maximum, since $\frac{\partial^2 \Pi}{\partial \phi_i^2}(\phi_i, \phi_j) = -\frac{1}{3} - \frac{\sigma}{9} < 0$ for (ϕ_i, ϕ_j) such that $n_i^* \in (0, 1)$. It can be easily verified that $\Pi(\phi_i, \phi_j) \leq \Pi(\phi_j - \frac{3}{2\sigma}, \phi_j)$ for all $\phi_i < \phi_j - \frac{3}{2\sigma}$, so that cornering the market is never optimal. If wholesale per customer fees are not feasible, by Proposition 2, $\pi^W(a_i^*) = \frac{1}{2\sigma} - \frac{3}{2}\sigma\epsilon(a_i^*) < \frac{1}{2\sigma} = \tilde{\pi}_i^{W*}$. The difference in welfare is $-\int_c^{a_i^*} (x - c)\, q'(x) \mathrm{d}x > 0$. ■

Intuitively, increasing the per customer fee reduces the per customer retail profit and thus softens retail competition. Starting from $\phi_i = 0$ and $a_i = c$, raising the per customer fee avoids deadweight loss and is thus more attractive than raising the wholesale price from the viewpoint of an alliance.

7 Conclusion

This paper presents a tractable model of international roaming in which operators compete at the same time both at the wholesale and at the retail level. We have shown that operators have incentives to form alliances and to commit to mutually providing roaming services at inefficiently high wholesale prices. As Section 6.3 points out, these alliances may serve to alleviate the competitive pressure that has lately increased due to recent improvements in network selection technologies.

Our analysis yields a number of policy implications. International alliances that are often claimed to improve efficiency, might reduce welfare and harm consumers. If operators mutually sell roaming services, it is difficult for regulatory agencies to discover whether wholesale prices are set for strategical reasons. As we have shown, in the roaming market, fixed fees as suggested by Shaffer (1991) are not needed in order to soften competition. From the perspective of a regulatory agency this means that the absence of two-part tariffs as often observed in the roaming wholesale market does not imply that wholesale prices are not set at a inefficiently high level for strategical reasons.

Another important insight is that the so-called *waterbed effect* might render seemingly helpful regulatory interventions useless or even detrimental. As is shown in Section 6.2, when regulators impose a binding retail price cap but leave the monthly fees unregulated, the waterbed effect might cause consumer surplus to decrease. Our analysis suggests that whenever regulators restrict one price instrument, then reactions of operators concerning their remaining instruments should be taken into account. If the regulation of all price instruments is not desired, then other measures might be more effective. For example, according to our model, a ban of international alliances might bring roaming prices down and increase welfare. Our suggestion might have constituted an alternative approach than the price cap on roaming prices which was introduced by the European Parliament in 2007.

Our model also illustrates that non-discrimination clauses that look innocent at first sight might have detrimental effects once the interaction with international alliances is taken into account. Therefore we advise to carefully review the rules of conduct that have been introduced by organizations as the GSM Association (to which almost all MNOs are affiliated) with respect to their competitive impact.

Notably, central predictions of Lupi and Manenti (2009) who also analyze the international roaming market are almost reversed in our model.[41] However, their model differs in important characteristics such as the retail price structure and the degree of retail competition. Therefore, regulators should carefully analyze which of the currently available models captures best the key characteristics of a given roaming market.

Our model delivers also some testable predictions for future empirical work: First, other things equal, roaming wholesale prices should increase in the share of MNOs that are affiliated with alliances. Second, as regards demand imbalances, affiliated MNOs of countries that are frequently visited should demand lower wholesale prices than those they pay for foreign roaming services for their own subscribers. Third, it might be particularly interesting to test whether the monthly fixed fees indeed went up in Europe after the roaming price caps were introduced in 2007 and further reduced in the following years.

[41] Assuming linear prices and monopolistic demand on the retail level, Lupi and Manenti, 2009 find that alliances improve efficiency since they serve to circumvent the double marginalization problem. However, they predict that alliances do not emerge in equilibrium.

A Appendix - Proofs of Lemmas & Propositions

A.1 Proof of Lemma 1

We omit the country index for brevity in what follows.

Suppose that $\left|v(c_i) - v(c_j)\right| < \frac{3}{2\sigma}$. We first show that (4) indeed maximizes retail profits given w_j^*. Since $\frac{\partial \Pi^R}{\partial p_i}(p_i, w_i, w_j, c_i) = n_i q'(p_i)(p_i - c_i)$, $\Pi^R(p_i, w_i, c_i) - \Pi^R(c_i, w_i, c_i) = n_i \int_{c_i}^{p_i} q'(p)(p - c_i)\mathrm{d}p \leq 0$ with strict inequality whenever $n_i > 0$ and $q(c_i) \neq q(p_i)$. Thus $p_i^* = c_i$ maximizes Π_i^R independently of w_i and w_j. Moreover, $\frac{\partial \Pi^R}{\partial w_i}(c_i, w_i, w_j^*, c_i) = 2\sigma\left(w_i^* - w_i\right)$ so that $\Pi^R\left(c_i, w_i^*, w_j^*, c_i\right) > \Pi^R\left(c_i, w_i, w_j^*, c_i\right)$.

Solving simultaneously the reaction functions (4) for both operators yields equation (5). Being a system of linearly independent equations, the solution is unique. The condition $\left|v(c_i) - v(c_j)\right| < \frac{3}{2\sigma}$ assures that the market share stays between zero and one.

We now show that whenever $v(c_i) - v(c_j) \geq \frac{3}{2\sigma}$ there exists a unique equilibrium in pure weakly undominated strategies, which entails $n_i^* = 1$ and $n_j^* = 0$.

We first establish that any such corner equilibrium necessarily involves $w_i^* = \frac{1}{2\sigma} + v(c_j) - C_F$ and $w_j^* = v(c_j) - C_F$. Define $\tilde{w}_i$ such that given w_j, operator i just serves the whole market: $\frac{1}{2} + \sigma\left(\tilde{w}_i - w_j\right) = 1$. Note that whenever $n_i^* = 1$ then necessarily $w_i^* = \tilde{w}_i$ as setting $w_i > \tilde{w}_i(w_j)$ would yield strictly lower profits.

We now show that whenever $n_j^* = 0$, then necessarily $w_j^* = v(c_j) - C_F$: Any strategy with $w_j > v(c_j) - C_F$ entails $\pi_i^R < 0$ and is weakly dominated by $p_j = c_j$ and $w_j = w_j^*$. Now suppose that $w_j < v(c_j) - C_F$ was an equilibrium. By the preceding discussion, necessarily $w_i = \tilde{w}_i(w_j)$. Then player j could achieve a strictly positive retail profit by deviating to $w_j + \frac{v(c_j) - C_F - w_j}{2}$ which contradicts equilibrium.

We now show that a unique corner equilibrium arises iff $v(c_i) - v(c_j) \geq \frac{3}{2\sigma}$. *If-Existence*: Given, $w_j^* = v(c_j) - C_F$ and $w_i^* = \frac{1}{2\sigma} - C_F + v(c_j)$, it can be directly verified that $\frac{\partial \Pi^R}{\partial w_i}(w_i, w_j^*, c_i) > 0$ for $w_i < w_i^*$ and $\frac{\partial \Pi^R}{\partial w_j}(w_j, w_i^*, c_i) < 0$ for $w_j > w_j^*$ which together with the preceding paragraphs confirms that w_i^* and w_j^* are mutually profit maximizing. *If-Uniqueness*: There exists no interior equilibrium since inserting $v(c_i) - v(c_j) \geq \frac{3}{2\sigma}$ into (6) yields $n_i^* \geq 1$ which is not interior. *Only-if*: Suppose that $0 \leq v(c_i) - v(c_j) < \frac{3}{2\sigma}$: For $w_j^* = v(c_j) - C_F$ as required in any corner equilibrium, the best response of player i is $w_i^* < \tilde{w}_i$ which implies $n_i^* < 1$ and therefore causes a contradiction.

A.2 Proof of Lemma 2

Define $\mathcal{E} = \left\{p \in \mathbb{R} | \epsilon(p) < \frac{1}{3} \wedge p \geq c \wedge q(p) > 0 \wedge v(p) > v(c) - \frac{3}{2\sigma}\right\}$. First we establish some auxiliary lemmas that will be also useful for other proofs.

Lemma A1 *Define $\psi(p) \equiv x(p)\left[z - \epsilon(p)\right] - y\,\pi^W(p)$ with $x(p) \geq 0$, $x(c) > 0$, $x'(p) \leq 0$, $z \in (0,1]$ and $y > 0$. If Assumptions 1 and 2 hold, then the equation $\psi(p) = 0$ has a unique solution $p^* > c$. This solution satisfies $\psi'(p^*) < 0$.*

Proof. There are three cases: a) There exists some $\hat{p}$ with $\epsilon(\hat{p}) = 1$; b) $\lim_{p\to\infty} \epsilon(p) = 1$ which implies that $\lim_{p\to\infty} \pi^W(p) > 0$; c) $\lim_{p\to\infty} \epsilon(p) = \bar{\epsilon} < 1$ which implies that $\lim_{p\to\infty} \pi^W(p) = \infty$.[42] In the first case, $\psi(\hat{p}) < 0$, while in the other two cases $\lim_{p\to\infty} \psi(p) < 0$. Since $\psi(c) = x(c)z > 0$, by continuity there exists a $p^* > c$ s.t. $\psi(p^*) = 0$. As $\psi'(p) = -x(p)\epsilon'(p) + x'(p)(z - \epsilon(p)) - yq(p)\left(1 - \epsilon(p)\right) < 0$ whenever $\psi(p) \geq 0$, p^* is unique. ■

Lemma A2 *If Assumption 2 holds, then:*

i) $\pi^W(a_i)$ is concave on $\mathcal{E}$ in a_i.

ii) Given $a_j \in \mathcal{E}$, any $a_i \in \mathcal{E}$ that satisfies the first order necessary conditions for being a local maximum of $\Pi(a_i, a_j)$ strictly maximizes $\Pi(a_i, a_j)$ in $\mathcal{E}$.

Proof. Part i) $\frac{\partial \pi^W}{\partial p}(p) = (p - c)q'(p) + q(p) = q(p)\left(1 - \epsilon(p)\right)$. Hence $\frac{\partial^2 \pi^W}{\partial p^2}(p) = q'(p)\left(1 - \epsilon(p)\right) - q(p)\,\epsilon'(p) < 0$ as $\epsilon'(p) \geq 0$ by Assumption 2 and $1 - \epsilon(p) > 0$ for $p \in \mathcal{E}$.

Part ii) By definition of $\mathcal{E}$, $\forall a_i, a_j \in \mathcal{E}$, since $|v(c) - v(a_i)| < \frac{3}{2\sigma}$ we have $n^*\left(a_i, a_j\right) \in (0,1)$. Define $\varphi(a_i, a_j) \equiv (1 - 3\epsilon(a_i))\, n^*\left(a_i, a_j\right) - \sigma\pi^W(a_i)$ and note that by (10), $\frac{\partial \Pi(a_i,a_j)}{\partial a_i} = \frac{1}{3}q(a_i)\varphi(a_i, a_j)$. The result follows from $\frac{\partial \varphi(a_i,a_j)}{\partial a_i} = -2\sigma q(a_i)\left[\frac{2}{3} - \epsilon(a_i)\right] - 3\epsilon'(a_i)n_i^* < 0$, which is true since $\sigma > 0$, $\epsilon(a_i) < \frac{1}{3}$ and $\epsilon'(a_i) \geq 0$ by Assumption 2. ■

Lemma A3 *For all (a_i, a_j) s.t. $n^*(a_i, a_j) \in (0,1)$ the following inequalities hold:*

i) If $a_i < c$ then $\frac{\partial \Pi(a_i,a_j)}{\partial a_i} > 0$.

ii) If $q(a_i) = 0$ then $\Pi(c, a_j) > \Pi(a_i, a_j)$.

iii) If $a_i > c$, $q(a_i) > 0$ and $\epsilon(a_i) \geq \frac{1}{3}$ then $\frac{\partial \Pi(a_i,a_j)}{\partial a_i} < 0$.

iv) If Assumption 2 holds and $a_i > c$, $q(a_i) > 0$, $v(a_i) < v(c) - \frac{3}{2\sigma}$ then $\frac{\partial \Pi(a_i,a_j)}{\partial a_i} < 0$.

[42] Integrating up $\frac{-(p-c)q'(p)}{q(p)} \leq 1 - \bar{\epsilon}\ \forall p \geq c$ yields $\int \frac{q'(p)}{q(p)}\mathrm{d}p \geq -\bar{\epsilon} \int \frac{1}{(p-c)}\mathrm{d}p$. Using $p > \underline{p} > c$, we get $\pi(p) \geq \pi(\underline{p})\left[\frac{p-c}{\underline{p}-c}\right]^{\bar{\epsilon}}$ which goes to infinity as $p \to \infty$.

Proof. Part i) By Assumption 1, $q(a_i) \geq q(c) > 0$ which implies that $\pi^W(a_i) < 0$ for $a_i < c$ and thus by equation (10), $\frac{\partial \Pi}{\partial a_i}(a_i, a_j) > 0$.

Part ii) Any a_i with $q(a_i) = 0$ implies that $a_i > c$ and $q^{'}(a_i) = 0$ by Assumption 1. As $q(a^{'}) = 0 \quad \forall a^{'} \geq a_i$, we have $v(a_j) \geq v(a_i)$ and hence $n^*(a_i, a_j) \leq \frac{1}{2}$. In addition, $q(a_i) = 0$ implies $q(a_i)(a_i - c) = 0$. Hence $\Pi(a_i, a_j) = \frac{1}{\sigma} n^*(a_i, a_j)^2 < \frac{1}{\sigma} n^*(c, a_j)^2 \leq \Pi(c, a_j)$ holds which contradicts a_i being optimal. To see that $\Pi(c, a_j) \geq \frac{1}{\sigma} n^*(c, a_j)^2$, distinguish two cases: if $v(c) - v(a_j) \leq \frac{3}{2\sigma}$, then $\Pi(c, a_j) = \frac{1}{\sigma} n^*(c, a_j)^2$ by Lemma 1. If $v(c) - v(a_j) > \frac{3}{2\sigma}$, then by the same Lemma $\pi_i^W > \frac{1}{\sigma}$ and hence $\Pi(c, a_j) > \frac{1}{\sigma} n^*(c, a_j)^2$.

Part iii) Since $\epsilon(a_i) \geq \frac{1}{3}$ and $q(a_i)(a_i - c) > 0$, $\frac{\partial \Pi}{\partial a_i}(a_i, a_j) = q(a_i) \left[\frac{-\sigma}{3} q(a_i)(a_i - c) + n^*(a_i, a_j) \left(\frac{1}{3} - \epsilon(a_i) \right) \right] < 0$.

Part iv) If $\epsilon(a_i) \geq \frac{1}{3}$ then by part iii) the claim follows. If $\epsilon(a_i) < \frac{1}{3}$ then by Assumption 2, for all $\tilde{a}_i \in [c, a_i]$, $\epsilon(\tilde{a}_i) \leq \epsilon(a_i)$. By definition $v^{'}(p) = -q(p)$ and the condition $v(c) - v(a_i) < \frac{3}{2\sigma}$ is equivalent to $\int_c^{a_i} q(a) \mathrm{d}a < \frac{3}{2\sigma}$. By Assumption 2, $\epsilon^{'}(\tilde{a}_i) \geq 0$ for $\tilde{a}_i \in [c, a_i]$ and thus $\pi^W(a_i) = \int_c^{a_i} (1 - \epsilon(a)) q(a) \mathrm{d}a \geq (1 - \epsilon(a_i)) \int_c^{a_i} q(a) \mathrm{d}a$. Therefore, $\int_c^{a_i} q(a) \mathrm{d}a \geq \frac{3}{2\sigma}$ implies $\pi^W(a_i) \geq (1 - \epsilon(a_i)) \frac{3}{2\sigma}$. From (10) we have $\frac{\partial \Pi}{\partial a_i}(a_i, a_j) \leq \left[\frac{1}{3} - \epsilon(a_i) - \frac{\sigma}{3} \pi^W(a_i) \right] q(a_i) \leq \left[\frac{1}{3} - \epsilon(a_i) - \frac{1}{2} (1 - \epsilon(a_i)) \right] q(a_i) = \frac{1}{2} \left[-\frac{1}{3} - \epsilon(a_i) \right] q(a_i) < 0$ where the first inequality is because $\left(\frac{1}{3} - \epsilon(a_i) \right) n_i^* \leq \frac{1}{3} - \epsilon(a_i)$. ■

Proof of Lemma 2.

Note that for all $a_i, a_j \in \mathcal{E}$, $n^*(a_i, a_j) \in (0, 1)$ by definition of $\mathcal{E}$.

Existence & Uniqueness: By Lemma A1, for any $a_j \in \mathcal{E}$ there exists a unique $\hat{a} \in \mathcal{E}$ such that $(1 - 3\epsilon(a_i)) n^*(\hat{a}, a_j) - \sigma \pi^W(a_i) = 0$. Since $\frac{\partial \Pi(a_i, a_j)}{\partial a_i} = \frac{1}{3} q(a_i) \varphi(a_i, a_j)$ and by Lemma A2, part ii), $a_i = \hat{a}$ strictly maximizes $\Pi(a_i, a_j)$ in $\mathcal{E}$. By Lemma A3, $\hat{a}$ remains a strict maximizer in $\mathbb{R}$.

Monotonicity in a_j: Any profit maximizing wholesale price $a^*(a_j)$ involves $\frac{\partial \Pi}{\partial a_i}(a^*(a_j), a_j) = 0$. By Lemma A2, part ii), any critical point is also a strict maximum with $\frac{\partial^2 \Pi}{\partial a_i^2}(a^*(a_j), a_j) < 0$. The claim thus follows from the implicit function theorem because differentiating (10) with respect to a_j yields $\frac{\partial^2 \Pi}{\partial a_i \partial a_j}(a^*(a_j), a_j) = \frac{\sigma}{3} q(a_i)^2 \left(\frac{1}{3} - \epsilon(a_i) \right) > 0$. ■

A.3 Proof of Proposition 2

We first prove the following auxiliary lemma:

Lemma A4 *Suppose two alliances are in place. In any equilibrium in weakly undominated strategies both alliances have a positive market share: $n^*(a_i^*, a_j^*) \in (0, 1)$.*

Proof. Suppose to the contrary that $n^*(a_i^*, a_j^*) = 1$ which implies $\Pi(a_j^*, a_i^*) = 0$. Define the highest wholesale price that allows to corner the market $\overline{a}_i$ implicitly by $v(\overline{a}_i) = v(a_j^*) + \frac{3}{2\sigma}$. We show that any $a_i < c$ is weakly dominated by $a_i^* = c$: Whenever a_j^* is such that $\overline{a}_i < c$, then for $a_i \in (\overline{a}_i, c)$, by equation (10), $\frac{\partial \Pi}{\partial a_i}(a_i, a_j) = q(a_i)\left[\left(\frac{1}{3} - \epsilon(a_i)\right) n_i^* - \frac{\sigma}{3}\pi^W(a_i)\right] > 0$ since $\pi^W(a_i) < 0$ and $\epsilon(a_i) \leq 0$. For $a_i < \overline{a}_i$, $\frac{\partial \Pi}{\partial a_i}(a_i, a_j) = -q(a_i)\epsilon(a_i) \geq 0$. Thus for $\overline{a}_i < c$ and for any $a_i < c$, $\Pi(c, a_j^*) > \Pi(a_i, a_j^*)$. If $\overline{a}_i \geq c$, then $\Pi(c, a_j^*) \geq \Pi(a_i, a_j^*)$.

Since $a_i^* \geq c$, the corner equilibrium involves $\Pi(a_i^*, a_j^*) \geq \Pi^R(a_i^*, a_j^*) \geq \frac{1}{\sigma}$. Then deviating to $\hat{a}_j = a_i^*$ yields $\Pi(\hat{a}_j, a_i^*) \geq \frac{1}{4\sigma}$ contradicting optimality of a_j^*. ■

Proof of Proposition 2.

Part i) By Proposition 1, $\tilde{a}_{xj}^* = c$ for all $x \in \{A, B\}$ and $j \in \{0, 1\}$. Therefore, the equilibrium wholesale price of the single alliance is characterized by the best response $a^{1*} = a^*(c)$. By Lemma 2, a^{1*} uniquely exists.

Part ii) Recall that $\mathcal{E} = \left\{p \in \mathbb{R} | \epsilon(p) < \frac{1}{3} \wedge p \geq c \wedge q(p) > 0 \wedge v(p) > v(c) - \frac{3}{2\sigma}\right\}$. We first show *existence* of a symmetric equilibrium $a_0 = a_1 = a^*$ and consequently $n_0^* = n_1^* = \frac{1}{2}$. By Lemma A3 of Section A.2 this equilibrium involves $a^* \in \mathcal{E}$. Define $\psi(p) \equiv (1 - 3\epsilon(p)) - 2\sigma\pi^W(p)$. By Lemma A1 of Section A.2, there is a unique $\hat{a} > c$ with $\psi(\hat{a}) = 0$.

It remains to show that the candidate $\hat{a}$ is indeed a symmetric equilibrium. By definition of ψ , $a_i = \hat{a}$ satisfies the necessary first order condition when $a_j = \hat{a}$. By Lemma A2 of Section A.2, the first order conditions are also sufficient for being a global maximum on $\mathcal{E}$. By Lemma A3, $a_i = \hat{a}$ remains a maximizer on the set of all $a_i \in \mathbb{R}$ such that $n(a_i, a_j) \in (0, 1)$. Setting a_i high enough so that $n_i = 0$ cannot be optimal either, as this gives zero profits.

It remains to show that $\Pi(\hat{a}, \hat{a}) \geq \Pi(a_i', \hat{a})$ for a_i' such that $n(a_i', \hat{a}) = 1$. Since $\hat{a} \in \mathcal{E}$, the inequality $v(c) < v(\hat{a}) + \frac{3}{2\sigma}$ holds. Cornering the market requires $v(a_i') \geq v(\hat{a}) + \frac{3}{2\sigma}$, and thus $a_i' < c$. For any $a_i < c$ such that $v(a_i) > v(a_j) + \frac{3}{2\sigma}$, marginal profits are $\frac{\partial \Pi}{\partial a_i}(a_i, a_j) = -q(a_i)\epsilon(a_i) \geq 0$ since $\epsilon(a_i) \leq 0$. Thus $\Pi(a_i', \hat{a}) \leq \Pi(c, \hat{a}) < \Pi(\hat{a}, \hat{a})$.

Uniqueness: There is no other symmetric equilibrium since any interior equilibrium must belong to $\mathcal{E}$ and since in $\mathcal{E}$ the necessary first order condition is uniquely satisfied at $\hat{a}$ by the previous discussion.

We now show that no asymmetric equilibrium exists. Suppose to the contrary that an asymmetric equilibrium with $a_i^* > a_j^*$ and hence $n_i^* < n_j^*$ exists. By Assumption 2, $a_i^* > a_j^*$ implies $\epsilon(a_i^*) \geq \epsilon(a_j^*)$. By Lemma A4, this equilibrium must involve a strictly positive market share for both alliances and a strictly positive per customer demand. The necessary first order conditions are:

$$\left(\frac{1}{3} - \epsilon(a_i^*)\right) n_i^* - \frac{\sigma}{3}\pi^W(a_i^*) \;\; = \;\; 0$$
$$\left(\frac{1}{3} - \epsilon(a_j^*)\right) n_j^* - \frac{\sigma}{3}\pi^W(a_j^*) \;\; = \;\; 0$$

But $\epsilon(a_i^*) \geq \epsilon(a_j^*)$ and $n_i^* < n_j^*$ implies $\left(\frac{1}{3} - \epsilon(a_i^*)\right) n_i^* < \left(\frac{1}{3} - \epsilon(a_j^*)\right) n_j^*$. Furthermore, by Lemma A3, $a_i^*, a_j^* \in \mathcal{E}$. Hence $\frac{1}{3} \geq \epsilon(a_i^*) \geq \epsilon(a_j^*)$ and thus $\pi^W(a_i^*) > \pi^W(a_j^*)$. Taken together this implies $\left(\frac{1}{3} - \epsilon(a_i^*)\right) n_i^* - \frac{\sigma}{3}\pi^W(a_i^*) < n_j^* \left(\frac{1}{3} - \epsilon(a_j^*)\right) - \frac{\sigma}{3}\pi^W(a_j^*) = 0$ which contradicts the first order necessary conditions.

Finally, we show that $a^* > c$: The necessary condition for $a_i^* = c$ is $n^*(c, a_j^*)\frac{q(c)}{3} = 0$ which is never true as $q(c) > 0$ by Assumption 1.

Rearranging the equilibrium condition $\psi(a^*) = 0$ yields the equilibrium per customer profits. ∎

A.4 Proof of Proposition 3

Rewriting condition (11) for a symmetric equilibrium yields

$$1 - 3\epsilon(a^*) - 2\sigma q(a^*)\,(a^* - c) = 0 \tag{21}$$

Part i) Applying the implicit function theorem on this condition, the claim is true if $\frac{\partial}{\partial a}\left(2\sigma q(a^*)\,(a^* - c) + 3\epsilon(a^*)\right) > 0$. By Assumption 2, $\epsilon^{'}(a^*) \geq 0$. In addition, $\frac{\partial}{\partial a} q(a^*)\,(a^* - c) > 0$ since $\epsilon(a^*) < \frac{1}{3}$ which completes the proof.

Part ii) By the same reasoning as in Part i), the claim holds because $1 - 3\epsilon(a^*) - 2\sigma\lambda q(a^*)\,(a^* - c)$ decreases in λ.

Part iii) Consider any pair of demand functions q and $\tilde{q}$ with $\eta_{\tilde{q}}(a) > \eta_q(a)\ \forall a \in \mathbb{R}$ and $\tilde{q}(a^*) \geq q(a^*)$. Since $\epsilon(a) = \eta_q(a)\frac{a-c}{a}$, $\eta_{\tilde{q}}(a) > \eta_q(a)$ implies $\epsilon_{\tilde{q}}(a) > \epsilon_q(a)$ for $a - c > 0$. We show that the equilibrium wholesale price $\tilde{a}^*$ that corresponds to per customer demand $\tilde{q}$ is higher than the equilibrium price a^* for demand q. By Lemma A1 of Appendix A.2, the function $\psi_q(a) \equiv 1 - 3\epsilon_q(a) - 2\sigma q(a)\,(a - c)$ is decreasing in a for $a \in \mathcal{E}$ and $\psi_q(c) = 1$. Define $\psi_{\tilde{q}}(a)$ likewise for demand $\tilde{q}$. To show that $\tilde{a}^* < a^*$, just note that $\psi_{\tilde{q}}(a^*) < \psi_q(a^*) = 0$ where the inequality comes from the hypothesis $\tilde{q}(a^*) \geq q(a^*)$ and $\epsilon_{\tilde{q}}(a) > \epsilon_q(a)$ and the last equality is the equilibrium condition of a^* being an equilibrium for demand q. Since $\psi_{\tilde{q}}(a^*) < 0$, by continuity there exists an $\tilde{a}^* < a^*$ such that $\psi_{\tilde{q}}(\tilde{a}^*) = 0$. This equilibrium candidate is indeed an equilibrium for demand $\tilde{q}$ by the proof of Proposition 2.

A.5 Proof of Proposition 5

For brevity we omit the country index whenever possible. Suppose w.l.o.g. that operators i have formed an alliance. The marginal wholesale profit of non-alliance operators j for $\tilde{a}_j < a_i$ is

$$\frac{\partial \tilde{\Pi}^W}{\partial \tilde{a}_j}(\tilde{a}_j, a_i) = q(\tilde{a}_j)\left[n^*(\tilde{a}_j, a_i)\left[1-\epsilon(\tilde{a}_j)\right] - \frac{\sigma}{3}\pi^W(\tilde{a}_j)\right]. \tag{22}$$

If Assumption 2 holds, then the wholesale profit is strictly quasiconcave since $-\frac{2\sigma q(\tilde{a}_j)}{3}\left(1-\epsilon(\tilde{a}_j)\right) - n^*(\tilde{a}_j, a_i)\epsilon'(\tilde{a}_j) < 0$. In addition, by Lemma A1 of Section A.2, there exists an unique $a^\dagger(a_i)$ such that $n^*(a^\dagger(a_i), a_i)\left[1-\epsilon(a^\dagger(a_i))\right] - \frac{\sigma}{3}\pi^W(a^\dagger(a_i)) = 0$. Quasiconcavity assures that the best response of operators j is

$$\tilde{a}_j^* = \tilde{a}^*(a_i) \equiv \begin{cases} a_i & \text{if} \quad a_i \leq \bar{a}^\dagger \\ a^\dagger(a_i) & \text{otherwise} \end{cases}$$

where $\bar{a}^\dagger$ is the highest value of a_i such that the operators j find it optimal to offer $\tilde{a}_j^* = a_i$. $\bar{a}^\dagger$ is uniquely defined by

$$\frac{1}{2}\left[1-\epsilon(\bar{a}^\dagger)\right] - \frac{\sigma}{3}\pi^W(\bar{a}^\dagger) = 0 \tag{23}$$

due to Lemma A1. Clearly for all $c < a_i < \bar{a}^\dagger$, $\frac{\mathrm{d}\tilde{a}_j^*}{\mathrm{d}a_i} = 1$. Denote the equilibrium wholesale price that obtains with two alliances according to Proposition 2 by a^*. Comparing equation (22) and (23), shows that whenever Assumption 2 holds, then $\bar{a}^\dagger > a^*$. For later use, we show that $\tilde{a}^*(a_i) > a^*$ whenever $a_i > a^*$. This property is clearly satisfied for $\bar{a}^\dagger \geq a_i > a^*$. For $a_i > \bar{a}^\dagger$, note that $a^\dagger(a_i) > a^*(a_i) > a^*$ where the first inequality is because $n^*(\tilde{a}_j, a_i)\left[1-\epsilon(\tilde{a}_j)\right] - \frac{\sigma}{3}\pi^W(\tilde{a}_j) > n^*(\tilde{a}_j, a_i)\left[\frac{1}{3}-\epsilon(\tilde{a}_j)\right] - \frac{\sigma}{3}\pi^W(\tilde{a}_j)$ and both sides are decreasing in $\tilde{a}_j$ whereas the second inequality comes from the monotonicity of $a^*(a_i)$ and the fact that $a^*(a^*) = a^*$.

We now analyze the equilibrium price a_i^{ND*} that obtains when only one alliance has been formed. Taking into account the best response of operators j, the marginal profit of a member of alliance i reads now as follows:

$$\begin{aligned} \frac{\partial \Pi^{ND}}{\partial a_i}(a_i) = q(a_i)\Bigg[\left(\frac{1}{3}-\epsilon(a_i)\right) n^*(a_i, \tilde{a}_j^*) \\ +\frac{\sigma}{3}\left(\frac{q(\tilde{a}_j^*)}{q(a_i)}\frac{\mathrm{d}\tilde{a}_j^*}{\mathrm{d}a_i}\left(\frac{2n^*(a_i, \tilde{a}_j^*)}{\sigma} + \pi^W(a_i)\right) - \pi^W(a_i)\right)\Bigg] \end{aligned} \tag{24}$$

For $c < a_i < \bar{a}^\dagger$, equation (24) simplifies to $\frac{\partial \Pi^{ND}}{\partial a_i}(a_i) = q(a_i)\frac{1}{2}\left(1-\epsilon(a_i)\right)$ because

$\tilde{a}^*(a_i) = a_i$ implies that the market share and thus the retail profits remain constant as a_i is slightly increased.

Now we show that a maximizer a^{ND*} exists. By equation (22), $\epsilon(\tilde{a}_j^*) < 1$ which implies $\epsilon'(\tilde{a}_j^*) \geq 0$ by Assumption 2. For $a_i > \bar{a}^\dagger$, applying the implicit function theorem yields

$$\frac{\mathrm{d}\tilde{a}_j^*}{\mathrm{d}a_i} = \frac{\sigma q(a_i)\left(1-\epsilon(\tilde{a}_j^*)\right)}{2\sigma q(\tilde{a}_j^*)\left(1-\epsilon(\tilde{a}_j^*)\right) + 3\epsilon'(\tilde{a}_j^*) n^*(\tilde{a}_j^*, a_i)}$$

and thus $0 \leq \frac{q(\tilde{a}_j^*)}{q(a_i)} \frac{\mathrm{d}\tilde{a}_j^*}{\mathrm{d}a_i} < \frac{1}{2}$. Inserting this into equation (24) yields

$$\begin{aligned}\frac{\partial \Pi^{ND}}{\partial a_i}(a_i) &\leq q(a_i)\left[\left(\frac{2}{3} - \epsilon(a_i)\right) n^*(a_i, \tilde{a}^*(a_i)) - \frac{\sigma}{6}\pi^W(a_i)\right] \\ &\leq q(a_i)\left[\left(\frac{2}{3} - \epsilon(a_i)\right)\frac{1}{2} - \frac{\sigma}{6}\pi^W(a_i)\right]\end{aligned}$$

for $a_i > \bar{a}^\dagger$.

If $\frac{\partial \Pi^{ND}}{\partial a_i}(\bar{a}^\dagger) \leq 0$, define $\hat{a} = \bar{a}^\dagger$. Otherwise, define $\hat{a}$ as the solution to $\left(\frac{2}{3} - \epsilon(a_i)\right)\frac{1}{2} - \frac{\sigma}{6}\pi^W(a_i) = 0$ which uniquely exists according to Lemma A1. By Assumption 2, $\forall a_i > \hat{a}$, $\frac{\partial \Pi^{ND}}{\partial a_i}(\hat{a}) \leq 0$. Since $[c, \hat{a}]$ is a compact interval, by the Weierstrass-Theorem, there exists some $a^{ND*} \in [c, \hat{a}]$ that maximizes $\Pi^{ND}(a_i)$ and which is also a global maximum by the preceding paragraph .

To see that $a^{ND*} > a^*$, note that for all $a_i < \bar{a}^\dagger$, $\tilde{a}^*(a_i) = a_i$ and therefore $\frac{\partial \Pi^{ND}}{\partial a_i}(a_i) = \frac{\partial \Pi}{\partial a_i}(a_i, a_i) + q(a_i)\left(\frac{1}{3} + \frac{\sigma}{3}\pi^W(a_i)\right)$. Since $a^* < \bar{a}^\dagger$, $\frac{\partial \Pi}{\partial a_i}(a^*, a^*) = 0$ and $\frac{\partial \Pi}{\partial a_i}(a_i, a_i) > 0 \quad \forall a_i \in [c, a^*]$ implies $\frac{\partial \Pi^{ND}}{\partial a_i}(a_i) > 0 \quad \forall a_i \in [c, a^*]$. Hence $a^{ND*} > a^*$.

Given the equilibrium prices, each operator sells roaming services to exactly one foreign operator, so that the total profits remain as defined in equation (9). To see that $\Pi(\tilde{a}_j{}^*(a^{ND*}), a^{ND*}) > \Pi(a^*, a^*)$, note that $\tilde{a}_j{}^*(a^{ND*}) > a^*$ as shown above. Since also $\tilde{a}_j{}^*(a^{ND*}) \leq a^{ND*}$, $\Pi(\tilde{a}_j{}^*(a^{ND*}), a^{ND*}) \geq \Pi(\tilde{a}_j{}^*(a^{ND*}), \tilde{a}_j{}^*(a^{ND*})) > \Pi(a^*, a^*)$ where the last inequality is due to $\epsilon(a^{ND*}) < 1$. Since a^{ND*} maximizes Π^{ND}, $\Pi(a^{ND*}, \tilde{a}^*(a^{ND*})) \geq \Pi(\bar{a}^\dagger, \tilde{a}^*(\bar{a}^\dagger)) = \Pi(\bar{a}^\dagger, \bar{a}^\dagger) > \Pi(a^*, a^*)$.

Following our approach laid out in Section 5, a single alliance is endogenously formed since $\Pi(a^{ND*}, \tilde{a}^*(a^{ND*})) > \Pi(a^*, a^*)$ and $\Pi(\tilde{a}^*(a^{ND*}), a^{ND*}) > \Pi(a^*, a^*)$.

A.6 Proof of Proposition 6

We first prove the following auxiliary Lemma:

Lemma A5 *If Assumption 2 holds and $q'(a^*) < 0$, then $v(c) - v(a^*) < \frac{1}{2\sigma}$, where a^* is the equilibrium wholesale price defined by Proposition 2.*

Proof. The equilibrium condition $\frac{\partial \Pi}{\partial a_i}(a^*, a^*) = 0$ yields $\pi^{W*} \equiv q(a^*)(a^* - c) = \frac{1-3\epsilon(a^*)}{2\sigma}$. Assumption 2 implies that $v(c) - v(p) \leq \frac{\pi^W(p)}{1-\epsilon(p)}$ for any $p \in \mathcal{E}$. Both results together yield $v(c) - v(a^*) \leq \frac{\pi^W(a^*)}{1-\epsilon(a^*)} = \frac{1-3\epsilon(a^*)}{2\sigma(1-\epsilon(a^*))} < \frac{1}{2\sigma}$ where the last inequality is due to $\frac{1}{3} \geq \epsilon(a^*) > 0$. ■

We now show *existence* of a unique symmetric equilibrium. Denote the wholesale price that obtains after the retail price cap has been introduced by $\overline{a}^*$ and the equilibrium net surplus as $\overline{w}^*$. Similar to the proof of Proposition 2, we define $\overline{\psi}(a) \equiv \frac{6}{q(\overline{p})} \frac{\partial \overline{\Pi}^*}{\partial a_i}(a, a) = 1 - 2\sigma q(\overline{p})(a - c)$. We claim that that wholesale prices $a_0 = a_1 = \overline{a}^*$ with $\overline{a}^*$ being uniquely characterized by $\overline{\psi}(\overline{a}^*) = 0$ support an equilibrium.

Next we show that $\overline{\Pi}(a_i, \overline{a}^*)$ is strictly quasiconcave in a_i if both alliances have a positive market share: Define $\overline{n}^*(a_i, a_j) \equiv \frac{1}{2} + \frac{\sigma}{3}\left[\overline{v}(a_i) - \overline{v}(a_j)\right]$ using the generalized value $\overline{v}(\cdot)$ of (12). For $a_i \geq \overline{p}$, $\frac{\partial \overline{\Pi}}{\partial a_i}(a_i, \overline{a}^*) = \frac{q(\overline{p})}{3}\left[\overline{n}^*(a_i, \overline{a}^*) - \sigma \overline{\pi}^W(a_i)\right]$ with $\overline{\pi}^W(a_i) \equiv q(\overline{p})(a_i - c)$. Since $\frac{\partial \overline{\Pi}}{\partial a_i}(\overline{a}^*, \overline{a}^*) = 0$ and $\overline{n}^*(a_i, \overline{a}^*)$ decreases in a_i while $\overline{\pi}^W(a_i)$ increases in a_i, we have $(\overline{a}^* - a_i)\frac{\partial \overline{\Pi}}{\partial a_i}(a_i, \overline{a}^*) > 0$ for $a_i > \overline{p}$ and $a_i \neq \overline{a}^*$. For $a_i < \overline{p}$, $\frac{\partial \overline{\Pi}}{\partial a_i}(a_i, \overline{a}^*) = \frac{q(a_i)}{3}\left[(1 - 3\epsilon(a_i))\,\overline{n}^*(a_i, a_j) - \sigma \pi^W(a_i)\right]$which differs from (10) only by the market share $\overline{n}^*(a_i, \overline{a}^*)$ instead of $n^*(a_i, a^*)$. We show below that $\overline{v}(\overline{a}^*) < v(a^*)$ which implies $\overline{n}^*(a_i, \overline{a}^*) > n^*(a_i, a^*)$ for $a_i < \overline{p}$. Since by hypothesis $\overline{p} \leq a^*$, we have $\frac{\partial \overline{\Pi}}{\partial a_i}(a_i, \overline{a}^*) > \frac{\partial \Pi}{\partial a_i}(a_i, a^*) > 0$ where the last inequality is due to Lemma A2. By definition of $\overline{\psi}$, the equilibrium price $\overline{a}^*$ locally strictly maximizes both alliances' profits.

It remains to prove that drastic deviations in order to corner the market are unprofitable. We first show that given $\overline{p} \leq a^*$, any deviation wholesale price $\tilde{a}_i$ to corner the market requires that $\tilde{a}_i < c$ or equivalently $v(\tilde{a}_i) > v(c)$. To derive a lower bound for $\overline{v}^* \equiv \overline{v}(\overline{a}^*)$, note that $\overline{v}^* = v(\overline{p}) - q(\overline{p})\,(\overline{a}^* - \overline{p}) = v(c) - \overline{\pi}^{W*} - \int_c^{\overline{p}} \epsilon(p) q(p) \mathrm{d}p$ with $\overline{\pi}^{W*} \equiv q(\overline{p})(\overline{a}^* - c)$. The equilibrium condition $\overline{\psi}(\overline{a}^*) = 0$ implies $\overline{\pi}^{W*} = \frac{1}{2\sigma}$. Besides, $\overline{p} \leq a^* \in \mathcal{E}$ guarantees that $\int_c^{\overline{p}} \epsilon(p) q(p) \mathrm{d}p \leq \epsilon(\overline{p})\,(v(c) - v(\overline{p})) \leq \frac{1}{3}\,(v(c) - v(a^*)) < \frac{1}{6\sigma}$, where the last inequality is due to Lemma A5. Taken together, $\overline{v}^* > v(c) - \frac{4}{6\sigma}$. Cornering the market requires $v(\tilde{a}_i) \geq \overline{v}^* + \frac{3}{2\sigma} > v(c) + \frac{5}{6\sigma} > v(c)$. For any $a_i < c$ such that $v(a_i) > \overline{v}^* + \frac{3}{2\sigma}$, marginal profits are $\frac{\partial \overline{\Pi}}{\partial a_i}(a_i, a_j) = -q(a_i)\epsilon(a_i) \geq 0$ since $\epsilon(a_i) \leq 0$. Thus $\overline{\Pi}(\tilde{a}_i, \overline{a}^*) \leq \overline{\Pi}(c, \overline{a}^*) < \overline{\Pi}(\overline{a}^*, \overline{a}^*)$.

The preceding two paragraphs establish that there is no profitable deviation, which completes the proof of existence.

We now show that $\overline{v}^* < v(a^*)$, which suffices to prove that any binding price cap reduces the consumer surplus since $\overline{w}^* - w^* = \overline{v}^* - v(a^*)$. The condition $\overline{v}^* = v(\overline{p}) - q(\overline{p})(\overline{a}^* - \overline{p}) < v(a^*)$ can be rewritten as $v(\overline{p}) + q(\overline{p})(\overline{p} - c) - \overline{\pi}^{W*} < v(a^*)$ and is satisfied if $v(c) - \overline{\pi}^{W*} < v(a^*)$ since $v(\overline{p}) + q(\overline{p})(\overline{p} - c) \leq v(c)$. Reordering this condition and using $\overline{\pi}^{W*} = \frac{1}{2\sigma}$ yields $v(c) - v(a^*) < \frac{1}{2\sigma}$ which is true by Lemma A5.

If $\overline{p} < a^*$, then clearly $v(\overline{p}) + q(\overline{p})(\overline{p} - c) > v(a^*) + q(a^*)(a^* - c)$ and total welfare increases.

Comparing $\overline{\psi}(a)$ to $\psi(a)$ defined in the proof of Proposition 2 yields $\overline{\psi}(a) - \psi(a) = 3\epsilon(a) + 2\sigma(q(a) - q(\overline{p})(a - c)$. Therefore, the condition $\overline{\psi}(a^*) > \psi(a^*) = 0$ holds by the hypothesis $q(\overline{p}) - q(a^*) < \frac{3\epsilon(a^*)}{2\sigma(a^*-c)}$. Since $\overline{\psi}'(a) = -\sigma q(\overline{p}) < 0$, $\overline{\psi}(a^*) > 0$ implies $\overline{\psi}(\overline{a}^*) = 0$ for $\overline{a}^* > a^*$.

B Heterogeneous consumers

Our main result of this section is that heterogeneous consumers lead to unambiguously lower profits in equilibrium. However, alliances still allow to raise equilibrium profits. We assume that operators of both countries with same position in their home market have formed alliances and omit the country index for brevity. We focus on candidate symmetric equilibria that satisfy the necessary first order conditions of profit maximization.

Retail demand structure. In contrast to our main setup, there are two types of consumers indicated by θ_k with $k \in \{L, H\}$ and $\theta_L < \theta_H$.[43] A consumer of type θ_k values roaming calls according to $v_k(p) \equiv \theta_k v(p)$ with $v(p)$ defined as in Section 2. Likewise, $u_k(q)$ denotes the utility that a subscriber of type θ_k obtains from consuming q roaming calls.[44] Subscribers still have quasilinear preferences so that the demand of an θ_k subscriber is given by $q_k(p) \equiv \theta_k q(p)$. The measure of subscribers remains normalized to 1 in every country. A proportion β of these are *light users* with type θ_L and relatively low demand. The remaining fraction of $1 - \beta$ are *heavy users* characterized by θ_H. Without loss of generality, we normalize $\theta_L < 1 < \theta_H$ such that $\beta\theta_L + (1 - \beta)\theta_H \equiv 1$.[45] For future reference, we define the heterogeneity of consumers as the variance of their type: $\rho \equiv \beta(\theta_L - 1)^2 + (1 - \beta)(\theta_H - 1)^2$. The base model with homogeneous consumers corresponds to $\rho = 0$. All consumers have the same degree of differentiation σ and the consumers' location is stochasti-

[43] In a model of network interconnection, Dessein (2003) uses a similar setup.

[44] Note that due to our specification, $u_k(q) \neq \theta_k u(q)$ in general.

[45] This normalization allows us to interpret $q(p)$ as the mean demand per consumer at the per call price p.

cally independent from their type. The consumers' type is observable to the MNOs. We discuss below the implications of relaxing this assumption.

Retail pricing structure. Operator i sets the retail per call price p_{ki} and the fixed fee F_{ki} for a type θ_k subscriber. We equivalently express the problem in terms of price per call p_{ki} and net surplus $w_{ki} \equiv v_k(p_{ki}) - F_{ki}$.

Wholesale pricing structure. MNOs cannot discriminate the wholesale prices according to which type of customer the roaming calls are sold finally. They still charge a linear wholesale price a_i to foreign operators.

Retail equilibrium. By the same reasoning as in Section 3, it is optimal to set the usage price equal to marginal cost. Given the perceived marginal cost c_i and the per customer cost C_F, the retail profits of operator i are then

$$\Pi_i^R = \beta n_{Li}\pi_{Li}^R + (1-\beta)\, n_{Hi}\pi_{Hi}^R \tag{25}$$

with $\pi_{ki}^R = \pi_k^R(w_{ki}, c_i) \equiv v_k(c_i) - w_{ki} - C_F$ being the per customer retail profit and $n_{ki} = n_k(w_{ki}, w_{kj}) \equiv \frac{1}{2} + \sigma(w_{ki} - w_{kj})$ being the market share in segment $k \in \{L, H\}$. Solving for the equilibrium net surplus and market share yields

$$\begin{aligned} w_{ki}^* &= \theta_k \left(\frac{2}{3} v(c_i) + \frac{1}{3} v(c_j) \right) - \frac{1}{2\sigma} - C_F & (26) \\ n_{ki}^* &= \frac{1}{2} + \frac{\theta_k \sigma}{3} \left(v(c_i) - v(c_j) \right) & (27) \end{aligned}$$

The further results of this section can be conveniently expressed in terms of the equilibrium *share of roaming calls* (as opposed to the market share of *subscribers*), defined as $\tilde{n}_i^* \equiv \beta n_{iL}^* \theta_L + (1-\beta)\, n_{iH}^* \theta_H$. Inserting the equilibrium retail market shares (27) yields $\tilde{n}_i^* = \frac{1}{2} + \frac{\sigma}{3} \left(v(c_i) - v(c_j) \right) (1+\rho)$. The factor $1+\rho$ indicates that the equilibrium share of roaming calls $\tilde{n}_i^*$ reacts more sensitively to differences in the perceived marginal costs compared to the equilibrium *share of subscribers* n_i^*. According to (26), an operator that faces higher unit costs offers a less attractive tariff especially to heavy users. Since the degree of differentiation $1/\sigma$ is independent of the type, the market shares in the heavy user segment are less balanced than in the light user segment. Inserting the optimal tariffs in (25) and rearranging yields the retail equilibrium profit

$$\Pi_i^{R*} = \Pi^{R*}(c_i, c_j) \equiv \frac{\sigma\rho}{9} \left(v_i - v_j \right)^2 + \frac{1}{\sigma} \left(\frac{1}{2} + \frac{\sigma}{3} \left(v_i - v_j \right) \right)^2 \tag{28}$$

with $v_i \equiv v(c_i)$. The marginal retail equilibrium profit with respect to the perceived unit cost is

$$\frac{\partial \Pi^{R*}}{\partial c_i}(c_i, c_j) \equiv -\frac{2q(c_i)}{3}\tilde{n}_i^* \, . \tag{29}$$

Wholesale equilibrium. When setting the retail tariffs, operators consider the negotiated wholesale prices as perceived marginal costs. Thus, the profit per member of alliance i is now $\Pi_i = \Pi(a_i, a_j) \equiv \tilde{n}_i^* q(a_i)\,(a_i - c) + \Pi^{R*}(a_i, a_j)$. Whenever the wholesale prices a_0 and a_1 do not differ too much, that is $|v(a_0) - v(a_1)| < \frac{3}{2\sigma\theta_H}$, the marginal profit is:

$$\frac{\partial \Pi}{\partial a_i}(a_i, a_j) = q(a_i)\left[\left(\frac{1}{3} - \epsilon(a_i)\right)\tilde{n}_i^* - \frac{\sigma}{3}\pi^W(a_i)\,(1+\rho)\right]$$

Rearranging the first order condition yields the Lerner formula

$$\frac{a^* - c}{a^*} = \frac{1}{3\left[\eta_q(a^*) + \eta_{\tilde{n}_i^*}(a^*)\right]} \tag{30}$$

where $\eta_q(a_i)$ is the price elasticity of the mean per customer demand and $\eta_{\tilde{n}_i^*}(a_i) \equiv -\frac{\mathrm{d}\tilde{n}_i^*}{\mathrm{d}a_i}\frac{a_i}{\tilde{n}_i^*}$ refers to the price elasticity of the equilibrium *share of calls*. In particular, a symmetric equilibrium entails $\tilde{n}_i^* = \frac{1}{2}$ and thus $\eta_{\tilde{n}_i}(a_i) = \frac{2\sigma}{3}\,(1+\rho)\,a_i q(a_i)$. Now we can identify the effect of consumer heterogeneity on the candidate equilibrium wholesale price:

Proposition B1 *Suppose that equation* (30) *uniquely characterizes the equilibrium wholesale price and that Assumption 2 holds. Then an increase in consumer heterogeneity ρ, holding everything else constant, reduces the symmetric wholesale equilibrium price.*

Proof. In any symmetric equilibrium, the condition $\left(\frac{1}{3} - \epsilon(a^*)\right)\frac{1}{2} - \frac{\sigma}{3}\pi^W(a^*)\,(1+\rho) = 0$ must be satisfied. The left hand side is clearly decreasing in ρ and if Assumption 2 holds, it is decreasing in a^*. Application of the implicit function theorem on this condition yields $\frac{da^*}{d\rho} < 0$. ■

Intuitively, consumer heterogeneity renders increasing the wholesale price less profitable relative to the gains from softer retail competition, since this leads to a loss of disproportionately many heavy users.

Non observable customer types: Even when customer types are unobservable for the MNOs, the results of this section are likely to carry over. In this case, MNOs have to elicit this information by offering incentive compatible contracts. However, it is easy to verify that for any symmetric wholesale price, the retail tariffs (26) indeed satisfy the incentive constraints for truth telling.[46] This somewhat surprising finding

[46]However, after a deviation from a symmetric equilibrium wholesale price, the incentive conditions may bind.

is in line with the observation of Armstrong and Vickers (2001) and Rochet and Stole (2002) that private information of consumers may not cause any quantity distortions in certain competitive environments.[47]

C Asymmetric country size

In this section, we relax the assumption that both countries are symmetric. Suppose that country A has mass $\theta > 1$ consumers, while the mass of consumers in country B remains 1. All consumers have the same demand q for roaming calls when traveling abroad and all further assumptions of the main model remain unchanged. For brevity, we derive the wholesale equilibrium assuming two alliances have been formed, but similar results emerge if there is only one alliance.

It is straight forward to derive that the equilibrium retail prices and the retail market shares $n^*(c_{xi}, c_{xj})$ remain unchanged. However, because there are mass θ consumers in country A, the retail equilibrium profit in country A is now $\Pi_A^{R*}(c_{Ai}, c_{Aj}) \equiv \theta\Pi^{R*}(c_{Ai}, c_{Aj})$ where $\Pi^{R*}(c_{xi}, c_{xj}) = \frac{\left(n^*(c_{xi}, c_{xj})\right)^2}{\sigma}$ remains as before. Likewise, the wholesale profit of operators in country B is now $\Pi_B^W(a_{Bi}, a_{Bj}) \equiv \theta\Pi^W(a_{Bi}, a_{Bj})$ where $\Pi^W(a_{xi}, a_{xj}) = n^*(a_{xi}, a_{xj})\pi^W(a_{xi})$. Thus, the total profit of operators i in country A and B is $\Pi_A(a_{Ai}, a_{Aj}, a_{Bi}, a_{Bj}) \equiv \theta\Pi^{R*}(a_{Bi}, a_{Bj}) + \Pi^W(a_{Ai}, a_{Aj})$ and $\Pi_B(a_{Ai}, a_{Aj}, a_{Bi}, a_{Bj}) \equiv \Pi^{R*}(a_{Ai}, a_{Aj}) + \theta\Pi^W(a_{Bi}, a_{Bj})$ if operators i set wholesale prices a_{Ai} and a_{Bi}, and operators j set wholesale prices a_{Aj} and a_{Bj}, respectively.

We assume that the members of alliance i will engage in Nash Bargaining (with equal bargaining strength, see e.g. Mas-Colell, Whinston, and Green (1995), p. 842) in order to determine the wholesale prices a_{Ai} and a_{Bi} simultaneously with members of alliance j. In case the negotiations break up, both MNOs will compete without being affiliated to an alliance and the total profits amount to $\Pi_A(c, a_{Aj}, c, a_{Bj})$ and $\Pi_B(c, a_{Aj}, c, a_{Bj})$. Therefore, the additional profits from forming alliance i for the participating MNOs is $\Delta\Pi_x(a_{Ai}, a_{Aj}, a_{Bi}, a_{Bj}) \equiv \Pi_x(a_{Ai}, a_{Aj}, a_{Bi}, a_{Bj}) - \Pi_x(c, a_{Aj}, c, a_{Bj})$ with $x \in \{A, B\}$. The Nash Bargaining wholesale prices will be set to maximize the product of each member's additional profits from being affiliated to the alliance. That is, the Nash Bargaining wholesale prices are

$$(a_{Ai}^*, a_{Bi}^*) = \arg\max_{a_{Ai}, a_{Bi}} \Delta\Pi_A(a_{Ai}, a_{Aj}, a_{Bi}, a_{Bj})\Delta\Pi_B(a_{Ai}, a_{Aj}, a_{Bi}, a_{Bj})$$

given the wholesale prices of the rival MNOs a_{Aj} and a_{Bj}. The necessary first order conditions for a_{Ai}^* and a_{Bi}^* are

[47] They also discuss the sensitivity of this result with respect to assumptions like symmetry.

$$\frac{\partial \Pi^{R*}}{\partial a_{Ai}}(a^*_{Ai}, a_{Aj})\Delta\Pi_A(a^*_{Ai}, a_{Aj}, a^*_{Bi}, a_{Bj}) + \frac{\partial \Pi^{W}}{\partial a_{Ai}}(a^*_{Ai}, a_{Aj})\Delta\Pi_B(a^*_{Ai}, a_{Aj}, a^*_{Bi}, a_{Bj}) = 0,$$
$$\frac{\partial \Pi^{R*}}{\partial a_{Bi}}(a^*_{Bi}, a_{Bj})\Delta\Pi_B(a^*_{Ai}, a_{Aj}, a^*_{Bi}, a_{Bj}) + \frac{\partial \Pi^{W}}{\partial a_{Bi}}(a^*_{Bi}, a_{Bj})\Delta\Pi_A(a^*_{Ai}, a_{Aj}, a^*_{Bi}, a_{Bj}) = 0.$$

Define $\psi_A(a_A, a_B) \equiv \frac{1}{q(a_A)}\left(\frac{\partial \Pi^{R*}}{\partial a_i}(a_A, a_A)\Delta\Pi_A(a_A, a_A, a_B, a_B) + \frac{\partial \Pi^{W}}{\partial a_i}(a_A, a_A)\Delta\Pi_B(a_A, a_A, a_B, a_B)\right)$ and $\psi_B(a_A, a_B) \equiv \frac{1}{q(a_B)}\left(\frac{\partial \Pi^{R*}}{\partial a_i}(a_B, a_B)\Delta\Pi_B(a_A, a_A, a_B, a_B) + \frac{\partial \Pi^{W}}{\partial a_i}(a_B, a_B)\Delta\Pi_A(a_A, a_A, a_B, a_B)\right)$.

If there are two competing alliances, both alliances set the same equilibrium prices since in each country operators are symmetric in terms of cost and position: $a^*_{x0} = a^*_{x1} = a^*_x$ for $x \in \{0, 1\}$.

Proposition B2 *If Assumption 2 (markup-elasticity increases in the price) holds, then the equilibrium wholesale price of the larger country A is higher than the wholesale price of the smaller one:* $a^*_A > a^*_B$.

Proof. Suppose to the contrary that $a^*_B > a^*_A$. In any interior equilibrium the first order conditions $\psi_A(a^*_A, a^*_B) = 0$ and $\psi_B(a^*_A, a^*_B) = 0$ must hold. As $\Delta\Pi_x(a^*_A, a^*_A, a^*_B, a^*_B) > 0$ for $x \in \{A, B\}$, the first order conditions necessarily imply $\frac{\partial \Pi^W}{\partial a_i}(a^*_A, a^*_A) > 0$ and $\frac{\partial \Pi^W}{\partial a_i}(a^*_B, a^*_B) > 0$ and hence $\epsilon(a^*_B) < 1$. By Assumption 1, also $\epsilon(a) < 1$ for $a \in [a, a^*_B]$. In addition, $a^*_B > a^*_A$ implies $\frac{\partial \Pi^W}{\partial a_i}(a^*_B, a^*_B)\frac{1}{q(a^*_B)} < \frac{\partial \Pi^W}{\partial a_i}(a^*_A, a^*_A)\frac{1}{q(a^*_A)}$ since $\frac{d\left(\frac{\partial \Pi^W}{\partial a_i}(a,a)\frac{1}{q(a)}\right)}{da} = \frac{-\sigma q(a)}{3}(1 - \epsilon(a)) - \frac{1}{2}\epsilon'(a) < 0$ for a such that $\epsilon(a) < 1$. As $\frac{\partial \Pi^{R*}}{\partial a_i}(a, a)\frac{1}{q(a)} = -\frac{1}{3}$, both first order conditions being satisfied requires $\Delta\Pi_A(a^*_A, a^*_A, a^*_B, a^*_B) > \Delta\Pi_B(a^*_A, a^*_A, a^*_B, a^*_B)$. But

$$\Delta\Pi_A(a^*_A, a^*_A, a^*_B, a^*_B) - \Delta\Pi_B(a^*_A, a^*_A, a^*_B, a^*_B)$$
$$= (\theta - 1)\left[\frac{1}{4\sigma} - \frac{1}{2}q(a^*_B)(a^*_B - c) - \frac{n^*(c, a^*_B)^2}{\sigma}\right] + \frac{1}{2}\left[q(a^*_A)(a^*_A - c) - q(a^*_B)(a^*_B - c)\right] + \frac{1}{\sigma}\left(n^*(c, a^*_A)^2 - n^*(\right.$$

is negative for $a^*_B > a^*_A$ since all three terms are negative: the first term is negative because $\frac{n^*(c, a^*_B)^2}{\sigma} > \frac{1}{4\sigma}$, the second term is negative because $n^*(c, a^*_B) > n^*(c, a^*_A)$ and the third term because $q(a^*_A)(a^*_A - c) - q(a^*_B)(a^*_B - c) < 0$ as $\epsilon(a) < 1$ for $a \in [a^*_A, a^*_B]$. This contradicts $\Delta\Pi_A(a^*_A, a^*_A, a^*_B, a^*_B) > \Delta\Pi_B(a^*_A, a^*_A, a^*_B, a^*_B)$. ■

There is a simple intuition behind this result: if negotiations of operators *i* break down, then both will sell and buy wholesale roaming calls for the true marginal cost *c*. Since retail (wholesale) demand in country *A* is larger (smaller) than in country *B*, it is more profitable for an operator in country *A* to forgo wholesale profits in return for obtaining roaming calls for a wholesale price c. Therefore, if all operators agreed on the same wholesale price a^* derived in the fully symmetric setting, the additional profit from an alliance would be larger for operators in country B: $\Delta\Pi_B(a^*,a^*,a^*,a^*) > \Delta\Pi_A(a^*,a^*,a^*,a^*)$. By adjusting the wholesale price a_{Bi} downwards and a_{Ai} upwards, the benefits from the alliance are distributed more evenly. Therefore, in equilibrium (in which competing alliances set the same wholesale prices) the wholesale price for roaming services of country A MNOs exceed those of country B MNOs.

If the size of the countries does not differ by too much, an equilibrium indeed exists.

Proposition B3 *Suppose that alliances' profits are single peaked in* (a_{Ai}, a_{Bi}), $i \in \{0,1\}$ *on the relevant range. Then, there is an equilibrium characterized by* $\psi_A(a_A^*, a_B^*) = 0$ *and* $\psi_B(a_A^*, a_B^*) = 0$ *for* θ *sufficiently close to* 1.

Proof. Clearly, for $\theta = 1$ the equilibrium conditions $\psi_A(a_A^*, a_B^*) = 0$ and $\psi_B(a_A^*, a_B^*) = 0$ are satisfied for $a_A^* = a_B^* = a^*$ since both conditions simplify to $\frac{\partial \Pi^{R*}}{\partial a_i}(a^*,a^*) + \frac{\partial \Pi^W}{\partial a_i}(a^*,a^*) = 0$ which holds by definition of a^*. It is straight-forward to confirm that for $\theta = 1$, $\frac{\partial \psi_A}{\partial a_A}(a^*,a^*) = \frac{\partial \psi_B}{\partial a_B}(a^*,a^*) < 0$, $\frac{\partial \psi_A}{\partial a_B}(a^*,a^*) = \frac{\partial \psi_B}{\partial a_A}(a^*,a^*) = 0$, which implies $\frac{\partial \psi_A}{\partial a_A}(a^*,a^*)\frac{\partial \psi_B}{\partial a_B}(a^*,a^*) - \frac{\partial \psi_A}{\partial a_B}(a^*,a^*)\frac{\partial \psi_B}{\partial a_A}(a^*,a^*) > 0$. Hence, by the Implicit Function Theorem, there exist a_A^* and a_B^* that satisfy the equilibrium conditions for θ close to 1. By the assumption that all alliances' profits are single peaked in (a_{Ai}, a_{Bi}), the equilibrium conditions are also sufficient for an equilibrium. ■

The conditions which characterize the equilibrium wholesale prices approach equilibrium condition (11) of the base model as both countries converge in terms of size. The Proposition establishes that because the equilibrium conditions are converging as θ approaches 1, there are also wholesale prices in the vicinity of a^* that satisfy the equilibrium conditions.[48]

D Appendix - Continuous model of network selection

We assume that at most the proportion $\bar{\gamma} \in [0.5, 1]$ of roaming calls can be directed to a particular foreign network.[49] This bound on the proportion reflects the fact that the

[48]It is straight forward that at (a_A^*, a_B^*), the local second order assumptions are satisfied. However, additionally assuming single-peakedness is necessary in order to assure in addition that (a_A^*, a_B^*) also globally maximize the additional profits of each alliance.

[49]This specification is equivalent to the following assumption: Operators can direct their subscribers to the desired foreign network only with probability $\tilde{\gamma} \in [0,1]$. The remaining subscribers are assigned randomly to the host networks. Then, $\overline{\gamma} = \tilde{\gamma} + \frac{1}{2}(1-\tilde{\gamma}) = \frac{1}{2}(1+\tilde{\gamma})$. See also Salsas and Koboldt (2004), Section 3.5 for a slightly different assumption.

restriction does not come from capacity constraints (which would render an absolute constraint more plausible) but rather from an unreliable technology which cannot guarantee that a subscriber registers in the preferred network. We have analyzed the polar cases of perfect network selection ($\bar{\gamma} = 1$) and of no control ($\bar{\gamma} = 0.5$) in the base model and in Section 6.3, respectively.

For clarity, we present the results from the viewpoint of operators with home network in country A. When buying roaming calls from foreign MNOs on the wholesale market, operator Ai may decide to buy proportion γ_{Ai} from operator $B0$ and proportion $1 - \gamma_{Ai}$ from operator $B1$. Operator Ai's perceived marginal cost is:

$$c_{Ai} = \gamma_{Ai} a_{B0} + (1 - \gamma_{Ai})\, a_{B1} \tag{31}$$

Assuming that operators cannot discriminate the retail prices according to which host network provides the roaming services, the optimal per call price equals the perceived marginal cost: $p^*_{Ai} = c_{Ai}$. The equilibrium net surplus, market shares and the retail equilibrium profits remain as established in Lemma 1.

We now turn to the wholesale market.

No international alliances. As discussed in Sections 3 and 4, operators prefer to buy roaming calls from the cheapest foreign operator.

$$\gamma^*_{Ai} = \begin{cases} \bar{\gamma} & \text{if } a_{B0} < a_{B1} \\ 1 - \bar{\gamma} & \text{if } a_{B0} > a_{B1} \end{cases}$$

We define the optimized perceived marginal cost of operator Ai as the cheapest possible mean cost for roaming calls, given the posted prices of foreign operators:

$$c^*_{Ai} = c^*(a_{B0}, a_{B1}) \equiv \bar{\gamma} \min\{a_{B0}, a_{B1}\} + (1 - \bar{\gamma}) \max\{a_{B0}, a_{B1}\}$$

The main implication of imperfect host network selection is that operators may generate positive demand even when not offering the cheapest wholesale price. We assume for simplicity that foreign operators divide the traffic evenly among both domestic networks if these offer equal wholesale prices. Using the results of the retail equilibrium, in the absence of alliances the total wholesale demand of operator Ai (where the superscript NA means "no alliance") is:

$$Q^{NA}_{Ai} = Q^{NA}(a_{Ai}, a_{Aj}) \equiv \begin{cases} \bar{\gamma} q\left((1 - \bar{\gamma})\, a_{Aj} + \bar{\gamma} a_{Ai}\right) & \text{if } a_{Ai} < a_{Aj} \\ \frac{1}{2} q(a_{Ai}) & \text{if } a_{Ai} = a_{Aj} \\ (1 - \bar{\gamma})\, q\left((1 - \bar{\gamma})\, a_{Ai} + \bar{\gamma} a_{Aj}\right) & \text{if } a_{Ai} > a_{Aj} \end{cases}$$

The demand is independent of the actual market share of the reselling operators, since for all price combinations, both foreign operators purchase the same part of their traffic at operator Ai. The overall profit of operator Ai is therefore:

$$\Pi^{NA}_{Ai} = \Pi^{NA}(a_{Ai}, a_{Aj}) \equiv \Pi^{R*}(c_{Ai}, c_{Aj}) + (a_{Ai} - c)\, Q^{NA}(a_{Ai}, a_{Aj})$$

Operator Ai sets its wholesale price in order to maximize its wholesale profit $(a_{Ai} - c)\, Q^{NA}(a_{Ai}, a_{Aj})$.

Lemma C1 *Suppose that Assumption 3 holds. For* $\bar{\gamma} \in (0.5, 1)$*, there is no pure strategy equilibrium.*

Proof. We first show that there is no symmetric equilibrium. Suppose to the contrary that $a^*_{A0} = a^*_{A1}$. If $a^*_{A0} = c$, then increasing the own price increases wholesale profits. If $a^*_{A0} > c$, then undercutting slightly increases the profit.

We now show that there is no asymmetric equilibrium. Let p^* denote the maximizer of $(p - c)\, q(p)$.[50] Suppose to the contrary w.l.o.g. that $a^*_{A0} \neq a^*_{A1}$. Then there exists an operator Ai such that $a^*_{Ai} \neq p^*$. But then there exists an $\hat{a}_{Ai}$ such that $\text{sign}(\hat{a}_{Ai} - a_{Aj}) = \text{sign}(a^*_{Ai} - a_{Aj})$ and $|\hat{a}_{Ai} - p^*| < |a^*_{Ai} - p^*|$. By assumption 3, this implies that $(\hat{a}_{Ai} - c)\, Q^{NA}(\hat{a}_{Ai}, a^*_{Aj}) > (a^*_{Ai} - c)\, Q^{NA}(a^*_{Ai}, a^*_{Aj})$ and therefore contradicts equilibrium. ■

Under imperfect network selection the fully competitive equilibrium of Section 4 vanishes and there is no other equilibrium in which both operators set higher wholesale prices. Intuitively, there is no equilibrium with $a^*_{A0} = a^*_{A1} = c$ because deviating upwards generates strictly positive wholesale profits.

Two international alliances. We now analyze the equilibrium outcome after operators with the same location have formed two competing alliances and omit the country index for brevity. We maintain all assumptions of Section 6.3, except that now, the proportion $\bar{\gamma} \in [0.5, 1]$of an operator's subscribers are directed to foreign partner network to place roaming calls.

If both alliances have negotiated the wholesale prices a_i and a_j, the equilibrium wholesale demand for roaming calls of operator i is

$$Q_i = Q(a_i, a_j) \equiv \bar{\gamma} n^*_i q\left(\bar{\gamma} a_i + (1 - \bar{\gamma})\, a_j\right) + (1 - \bar{\gamma})\,(1 - n^*_i)\, q\left(\bar{\gamma} a_j + (1 - \bar{\gamma})\, a_i\right)$$

where $n^*_i = \frac{1}{2} + \frac{\sigma}{3}\left[v\,(c_i) - v\,(c_j)\right]$ is the equilibrium retail market share and $c_i = \bar{\gamma} a_i + (1 - \bar{\gamma})\, a_j$. The profit of each operator in alliance i is:

[50] Which exists by Assumption 3.

$$\Pi_i = \Pi(a_i, a_j) \equiv \Pi^{R*}(c_i, c_j) + (a_i - c)\left[\bar{\gamma} n_i^* q(c_i) + (1-\bar{\gamma})(1-n_i^*) q(c_j)\right] \quad (32)$$

If both firms realize a strictly positive market share, the marginal profit with respect to the own wholesale price is:

$$\begin{aligned} \frac{\partial \Pi}{\partial a_i}(a_i, a_j) &= Q(a_i, a_j) + \frac{\mathrm{d}n_i^*}{\mathrm{d}a_i}\left[2\frac{n_i^*}{\sigma} + (a_i - c)\left(\bar{\gamma} q(c_i) + (1-\bar{\gamma}) q(c_j)\right)\right] \\ &\quad + (a_i - c)\left[\bar{\gamma}^2 n_i^* q'(c_i) + (1-\bar{\gamma})^2 (1-n_i^*) q'(c_j)\right] \end{aligned} \quad (33)$$

with $\frac{\mathrm{d}n_i^*}{\mathrm{d}a_i} = \frac{\sigma}{3}\left((1-\bar{\gamma}) q(c_j) - \bar{\gamma} q(c_i)\right)$. Considering a symmetric equilibrium with $a_i^* = a_j^* = a^*$ and therefore $c_i^* = c_j^* = a^*$ as well as $n_i^* = \frac{1}{2}$ yields

$$\frac{a^* - c}{a^*} = \frac{1 - \frac{2}{3}(2\bar{\gamma} - 1)}{\left[\left(\bar{\gamma}^2 + (1-\bar{\gamma})^2\right)\eta_q(a^*) + (2\bar{\gamma} - 1)^2 \eta_n(a^*)\right]} \quad (34)$$

where $\eta_q(\cdot)$ is the price elasticity of the per customer demand and $\eta_n(a^*) \equiv \frac{2}{3}\sigma a^* q(a^*)$ is the price elasticity of the retail market share for $a_j = a_i = a^*$ in case of perfect traffic direction.[51]

Comparing (34) with the equilibrium characterization (11) of the base model reveals that for the same wholesale price a_i, the right hand side of (34) is always larger than that of (11) since $1 - \frac{2}{3}(2\bar{\gamma} - 1) \geq \frac{1}{3}$, $\bar{\gamma}^2 + (1-\bar{\gamma})^2 \leq 1$ and $(2\bar{\gamma} - 1) \leq 1$ hold. These observations allow to establish that imperfect traffic steering leads to higher equilibrium wholesale prices:

Proposition C1 *Suppose that assumption 2 holds. Then the equilibrium wholesale price a^* in any symmetric equilibrium is decreasing in the quality of the traffic steering technology $\bar{\gamma}$.*

Proof. Using (33) with $a_i = a_j$ and $\frac{\mathrm{d}n_i^*}{\mathrm{d}a_i}|_{a_i = a_j} = \frac{\sigma}{3} q(a_i)(1 - 2\bar{\gamma})$ and reordering, yields the first order condition

$$1 - \frac{2}{3}(2\bar{\gamma} - 1)\left[1 + (2\bar{\gamma} - 1)\sigma(a^* - c) q(a^*)\right] - \epsilon(a^*)\left(\bar{\gamma}^2 + (1-\bar{\gamma})^2\right) = 0$$

As the the middle term is strictly negative for $\bar{\gamma} > 0.5$ and 0 for $\bar{\gamma} = 0.5$, it follows that $\epsilon(a^*)\left(\bar{\gamma}^2 + (1-\bar{\gamma})^2\right) < 1$. Applying the implicit function theorem yields

[51] Both $\eta_q(\cdot)$ and $\eta_n(a^*)$ are defined as in Section 4.

$$\frac{\mathrm{d}a^*}{\mathrm{d}\bar{\gamma}} = \frac{2\left[1 + 2\sigma q(a^*)\left(a^* - c\right)\right] + 2\epsilon(a^*)\left(2\bar{\gamma} - 1\right)}{-\left(2\bar{\gamma} - 1\right)^2 \sigma q(a^*)\left(1 - \left(\bar{\gamma}^2 + (1 - \bar{\gamma})^2\right)\epsilon(a^*)\right) - \frac{3}{2}\left(\bar{\gamma}^2 + (1 - \bar{\gamma})^2\right)\epsilon'(a^*)}$$

Clearly, the denominator of the right hand side is strictly negative since $1 - \left(\bar{\gamma}^2 + (1 - \bar{\gamma})^2\right)\epsilon(a^*) > 0$ and $\epsilon'(a^*) \geq 0$ by assumption 2. The numerator is strictly positive. Taken together $\frac{\mathrm{d}a^*}{\mathrm{d}\bar{\gamma}} < 0$. ■

Intuitively, there are two channels that cause a higher equilibrium price when network selection is imperfect ($\bar{\gamma} < 1$). First, compared to the base model ($\bar{\gamma} = 1$), the retail market share is less sensitive to increases of the wholesale price. This is because the perceived marginal costs c_i of operators within alliance i depend less on the own wholesale price a_i while the perceived marginal costs of operators of the rival alliance j depend partly on a_i. Second, under imperfect traffic direction, operators of alliance j have to procure a proportion $1 - \bar{\gamma}$ of their roaming calls from alliance i. When selling to non-alliance operators, the alliance does not take lower retail profits that are implied by a higher wholesale price into account, which renders a high wholesale price more attractive.

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