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ROAMING THE WOODS OF REGULATION: PUBLIC INTERVENTION *VS* FIRMS COOPERATION IN THE WHOLESALE INTERNATIONAL ROAMING MARKET

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Roaming the woods of regulation: public intervention *vs* firms cooperation in the wholesale international roaming market

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Abstract

Despite a general trend of lower charges for mobile calls, prices for international roaming calls have remained at levels surprisingly high. The apparent reluctance of European mobile network operators to lower roaming tariffs is generating many antitrust concerns. This paper discusses in a two country - two firm framework, the distortions associated with the functioning of the current system governing wholesale international roaming agreements based on Inter Operator Tariffs (IOTs) and the role played by cross border roaming alliances between foreign operators. We describe how competition between roaming operators at the wholesale level is influenced by the adoption of traffic redirection techniques. The paper shows that when mobile operators act un-cooperatively and traffic redirection techniques allow only partial control on traffic flows, competition between roaming operators may not guarantee a reduction in IOTs and, consequently, on retail tariffs. We propose a simple and effective regulatory price cap mechanism to restore efficiency in the wholesale market. When mobile operators cooperate within a cross border alliance, internal IOTs are set at cost and retail prices are lower.

Keywords:	Mobile telecommunications, international roaming, interconnection, traffic direction techniques, Inter-Operator Tariffs, alliances.
JEL classification:	L13; L51; L42; L96.

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1 Introduction

In a speech to the European Regulators Group in February 2006, Viviane Reding, the European Commissioner for information society and media, expressed her frustration that "in spite of many warnings and policy initiatives, (international) roaming prices remain unjustifiably high at the retail level".[1] This quotation is the best evidence of the difficulties encountered by European regulatory bodies in establishing effective competition in the international roaming market using the provisions of the European regulatory framework for electronic communications.

According to the recommendation on relevant markets within the electronic communications sector susceptible to *ex ante* regulation, retail international roaming services "include the ability to make and to receive calls whilst in a country other than the one where the end user has established his or her network subscription".[2] Retail international mobile roaming services rely on wholesale international roaming services that are the services offered by a domestic mobile network operator (MNO, hereafter) providing access and capacity to a foreign MNO for the purpose of enabling the subscribers of the latter to make and receive calls while on another operator's network abroad; therefore, wholesale international roaming services are provided "by a domestic MNO (visited network) to a MNO in another country (home network)".[3]

For international roaming to work effectively, the operators of the visited and the home network have to sign a roaming agreement, usually bilateral in nature, based on a common framework developed by the GSM Association that specifies the terms and conditions on which the roaming service takes place. The charging principle for international roaming is the Inter Operator Tariff (IOT, hereafter); the IOT is a wholesale payment formally defined as a tariff scheme between mobile network operators, charged by the visited network operator to the home network operator for the use of the visited network. Retail tariffs to end users are commonly derived by adding a mark-up to foreign IOTs.[4]

[1]See SPEECH/06/09, Viviane Reding, "Towards a true internal market for electronic communications," European Regulators Group, Paris, 8 February 2006, available at `http://europa.eu.int/`.

[2]Commission recommendation 2003/311/EC of 11 February 2003 on relevant product and service markets within the electronic communications sector susceptible to *ex ante* regulation in accordance with Directive 2002/21/EC of the European Parliament and of the Council on a common regulatory framework for electronic communication networks and services.

[3]Ibidem, page 30.

[4]Recently, operators are introducing simplified retail tariffs such as averaged retail roaming prices or single retail

Until not many years ago, customers roaming away from their home country were almost randomly distributed over all visited country's mobile networks, a technical condition which is hardly conductive to competition; but since 2003, European MNOs have increasingly adopted traffic direction techniques enabling them to direct the traffic generated by their customers abroad to a mobile network of their choice in the visited country.[5] During the same period the market has experienced the emergence of a number of alliances of mobile operators and pan-european groups, within which roaming terms and conditions are set cooperatively by its members.[6] Traffic direction techniques have therefore been used to direct traffic on the networks requiring the lowest IOT or, simply and more commonly, on the networks of the members of the same alliance or group.

The developments briefly described in the previous paragraph seemed able to extend to the international roaming segment the same level of growth, both in terms of penetration and usage (ITU, 2003), and the same dramatic fall in prices experienced in other segments of the mobile communications market. Unfortunately international roaming charges have remained at their 2000 levels which, according to a study of the International Telecommunications Users Association (INTUG), reported in Sutherland (2001), were so high that the difference in retail prices between roamed and non-roamed international mobile calls to the same destination within the EU was up to 500%.

As vividly represented by Commissioner Reding's frustration, the apparent reluctance of mobile operators to lower roaming tariffs has caused concerns amongst mobile customers, consumers' associations, national regulatory agencies and competition authorities. During the last few years, a number of complaints concerning high roaming charges, collusion on roaming rates, as well as refusal to deal at national and international level have been sent to the European Commission which in 2001, started an official investigation. The market for wholesale international roaming has been also included in the list of relevant markets of the electronic communications sector susceptible of *ex-ante* regulation. This implies that National Regulatory Authorities (NRAs) have to define the

roaming prices for roaming services in a particular country or group of countries; others have introduced so-called "flat rate" or "one rate" charges for home calls, that is, uniform rates for home calls placed when roaming in the Euro zone.

[5] It is estimated that nowadays MNOs are able to direct up to 80% of their users' traffic.

[6] Currently, in Europe there are two alliances between network operators: Freemove, Starmap and three groups: the Orange, the T-mobile and the Vodafone group.

relevant product market of wholesale international roaming and to assess the presence of operators with Significant Market Power.[7] In case dominance is found within the relevant market, NRAs have to identify adequate remedies to restore competition.

All these reasons make wholesale international roaming a market of particular interest; although, recently, some light on the inner workings of the IR market has been shed by European Regulators Group (2005), a document that provides guidance to national regulatory agencies in the assessment of the competitiveness of international roaming services, the underlying dynamics of the market are still by large obscure and not clearly understood. We move from a recent contribution by Salsas and Koboldt (2004) where the authors provide a theoretical description of the market for wholesale international roaming. We extend their contributions in various ways; our aim is to provide a more comprehensive framework able to describe the main determinants of IOTs by European mobile operators that include the more recent commercial and regulatory developments of the market.

In this paper we use a two country - two firm framework to discuss the distortions associated with the workings of the system based on IOTs currently governing roaming agreements and to analyze the role that cross border alliances may play towards a reduction of these distortions. A crucial element of our analysis is the operators' adoption of traffic redirection techniques; we show that when MNOs act uncooperatively, they tend to set IOTs above cost thus increasing retail prices; this is due to standard double marginalization arguments. Unlike what is often claimed at regulatory level, we show that traffic redirection may be effective in inducing mobile operators to cut wholesale charges only if it allows perfect redirection; in the presence of less then perfect control on traffic redirection, as it is currently the case, we show that the competition game between wholesale operators does not converge towards an efficient equilibrium. Efficiency can be restored through regulation of IOTs in the form of a simple and not very intrusive price cap mechanism. When MNOs cooperate on equal footing within a cross border alliance, internal IOTs are set at cost and retail prices are lower.

The structure of the paper is the following: in Section 2 we describe the typical wholesale international roaming scenario; in Section 3 we present the model and the solutions for the uncooperative and the cooperative setting; finally, in section 4 we draw some concluding remarks.

[7] See Stumpf (2004) for a discussion of the main issues related to the definition of the relevant product market of wholesale international roaming and to the assessment of operators with significant market power.

2 Definition and data on roaming charges

In a typical international roaming scenario, a roaming user from country $\tilde{C}$ visiting a given country C places a call either to a subscriber of an operator of the visited country or to a subscriber of an operator of the home country $\tilde{C}$; this latter case is depicted in Figure 1.[8]

FIGURE 1 ABOUT HERE

Independently of the destination of the call, the roamer pays a retail price for the originated call to its own operator which, in turns, pays an IOT to the foreign/visited operator for originating, conveying and terminating the call to its destination.[9]

IOTs are defined within the framework of the Standard Terms for International Roaming Agreement (STIRA) issued by the GSM Association; according to this framework, MNOs have the obligation to apply non-discriminatory IOTs to all mobile network operators in each individual country. However, MNOs can offer discounts or other benefits to foreign operators (i.e. members of the same alliance).[10]

In July 2005, in a tentative to stimulate pro-competitive forces and to induce mobile network operators to lower roaming tariffs, the European Commission launched a web-site aimed at increasing consumers' awareness of roaming charges and at helping them to get a better deal when using their mobile phones abroad.[11] Table 1 provides a sample of the figures published on this dedicated web-site:[12] for each pair of home and visited network in the first two columns, it is shown the price charged by the home MNO for making a call to the home country (column 3) and the price for receiving a call from the home country (column 4).[13] Note that, as in the example of Figure 1, IOTs

[8] We say "typical" because roaming users may also place calls to subscribers of third countries' networks.

[9] International roaming is an end-to-end service.

[10] See Valletti (2003) for a comprehensive and detailed discussion of the STIRA and of its consequences on operators' market power.

[11] See `http://europa.eu.int/information_society/activities/roaming/why/index_en.htm`.

[12] All prices are inclusive of VAT and refer to a four-minute call placed on a week-day at peak time.

[13] International roaming services are the only services within Europe for which it applies, even if partially, the receiving party pays principle. In fact, the calling party – who may be not aware that the called party has roamed away – pays the standard rate for calling a mobile subscriber in his home country, and the called party pays the call re-routing from his home country to the visited country.

apply only to the former type of calls, while they do not apply to the latter.[14] Therefore, we use the tariff charged by MNOs for terminated roamed calls as "benchmark" tariffs for international mobile phone calls absent the payment of the IOT. In the last column, we have computed the percentage difference between the two tariffs; since this price differential can be largely imputed to the presence of the IOT paid by the home MNO, it represents a good proxy of the impact of the current wholesale international roaming regime on retail prices.

Home country (home operator)	Visited country (roaming partner)	Placing a call EUR 4 min call	Receiving a call EUR 4 min call	Δ %
Austria (A1)	Estonia (Elisa)	6.4	2	+ **220.0** %
Belgium (Mobistar)	Italy (TIM)	4.4	2	+ **120.0** %
Denmark (Sonofon)	France (Orange)	4.97	1.88	+ **164.4** %
Finland (Mobistar)	Italy (TIM)	4.4	2	+ **120.0** %
France (Bouygues)	Spain (Amena)	6	1.88	+ **219.1** %
Germany (Vodafone)	France (Orange)	5.1	2.36	+ **116.1** %
Italy (Wind)	UK (O2)	4	1.4	+ **185.7** %
The Netherlands (KPN)	Finland (Finnet)	5.52	2.76	+ **100.0** %
Spain (Movistar)	Ireland (Meteor)	3.32	2	+ **66.0** %
UK (Orange)	Portugal (Optimus)	4.7	1.76	+ **167.0** %

Table 1: A sample of roaming tariffs[15]

As it is immediately evident from this table, the price for an originated roaming call, for which the home MNO pays the IOT to the roaming network, is often twice that of a terminated roamed call; in many cases the difference is even larger. This very simple evidence confirms the various empirical analyzes that have been recently conducted suggesting that the current regime governing roaming agreements between foreign operators may be the source of strong inefficiencies, calling for regulatory intervention.

[14]In this case the home network pays to the visited network the standard mobile termination charge.

[15]Data collected in December 2005.

3 A model of international roaming with traffic redirection techniques

In this section, we extend Salsas and Koboldt (2004) (SK, hereafter) in various ways. Firstly, we present a model of international roaming agreements with two countries and two MNOs in each country. Each MNO acts both as visiting and as visited network; this puts us in a position to evaluate the impact of traffic asymmetries between countries on inter-operators tariffs, prices and profits. Taking into account the technical developments described in section 1, we then study how traffic direction technologies alter the strategic interaction between operators at the wholesale level. Finally, we model alliances between MNOs where operators co-operate in setting bilateral IOTs aimed at maximizing joint profits.

3.1 The framework

We focus on the simplest scenario where there are only two active firms in each of the two countries. We assume that each mobile network operator in each country makes roaming agreements with both operators in the foreign country.[16] Let us denote by $C \in \{1, 2\}$ and $\tilde{C} \in \{a, b\}$ the two MNOs active in country C and $\tilde{C}$ respectively. Each MNO both originates and receives roaming traffic.

Let $t_{C,\tilde{C}}$ be the share of roaming traffic generated by subscribers of network C (the home network) when they roam onto a given visited network $\tilde{C}$. Usually, $t_{C,\tilde{C}}$ depends on two factors: $i)$ the coverage of network $\tilde{C}$ and $ii)$ the efficiency of traffic control techniques that enable operators and/or subscribers to select the roaming operator.

We assume for simplicity that in each country all mobile networks guarantee full coverage; this assumption is taken on practical grounds since it often satisfied by most European mobile operators.

Traffic direction technologies play a pivotal role in our analysis; although European operators are increasingly adopting these technologies, they are still far from perfect, therefore we assume that each MNO is only partially able to divert the traffic generated by its customers when roaming abroad to a particular network.[17] Formally, we assume that each MNO is able to direct a portion

[16]This is a regular feature of the international roaming market: MNOs sign roaming agreements with all operators in each country in order to ensure their subscribers the widest coverage.

[17]The amount of roaming traffic that is currently directed by European MNOs, varies between almost zero to up to 80%. For instance, FICORA, the Finnish regulatory authority, estimated that more than half of the international

$\alpha \in [0, 1)$ of its subscribers' traffic on to a certain foreign network, that can either be the one that charges the lower IOT, or the one with which the domestic MNO co-operates within an alliance. The portion of traffic that is not redirected, is randomly shared out between the two foreign networks.

One of the key consequences of traffic direction is that foreign MNOs should compete on IOTs in order to attract roaming traffic; this is the main reason why traffic direction techniques are often considered by many European regulatory authorities an important factor able to increase competition at the wholesale level.[18]

3.1.1 Demand for roaming services

As in SK, the demand for roaming services depends on the weighted average price charged at the retail level by home operators, where the weights are given by the distribution of roaming traffic across visited networks. Let $p_{C,\tilde{C}}$ be the retail price charged to subscribers of the home operator C when roaming on the visited network $\tilde{C}$; given that $t_{C,\tilde{C}} \in [0, 1]$ represents the share of traffic generated by C's customers that goes on $\tilde{C}$'s network, the expected (or perceived) retail prices P_C and $P_{\tilde{C}}$ paid for roaming services by subscribers of the networks of the two countries are therefore:

$$P_C = t_{C,a}\, p_{C,a} + t_{C,b}\, p_{C,b} \qquad C = 1, 2 \tag{1}$$
$$P_{\tilde{C}} = t_{\tilde{C},1}\, p_{\tilde{C},1} + t_{\tilde{C},2}\, p_{\tilde{C},2} \qquad \tilde{C} = a, b$$

We also assume that the retail demand for roaming services faced by each operator is not affected by the prices charged by their rival for the same services. In fact, retail roaming prices are often only partially known by customers whose subscription decision is rarely affected by the prices of this class of services.[19] The main consequence of this assumption is that in the provision of international roaming services, each operator acts as a monopolist; assuming linear demand

roaming mobile calls made from Finland has been directed by foreign MNOs to the Finnish network of their choice. (FICORA, 2005a).

[18] Many documents by National Regulatory Authorities support this view. See NPTA (2004) or FICORA (2005a) *inter alios*.

[19] According to some consumers' surveys such as those run by the Finnish (FICORA, 2005b), the Irish and the British (Oftel-ODTR, 2002) regulatory agencies, there is a very low consumer awareness of international roaming charges. In particular, the survey run by FICORA in 2005 reveals that 90% of the users does not take into account international roaming prices in their decision to choose their mobile connection and that only 3% of the users takes them into account when subscribing to a network.

functions, we model the retail demand for roaming calls faced by the operators in the two countries as follows:

$$d_C = \phi\,(A - \epsilon\, P_C) \qquad \text{and} \qquad d_{\tilde{C}} = (A - \epsilon\, P_{\tilde{C}}) \qquad \epsilon,\, \phi > 0 \tag{2}$$

with $C \in \{1, 2\}$ and $\tilde{C} \in \{a, b\}$. The multiplicative parameter $\phi \geq 1$ captures any difference in the size of the market for international roaming between the two countries: if we assume, for the sake of simplicity, that individuals have identical characteristics (i.e. same preferences, same price elasticities) and we normalize to 1 the dimension of country $\tilde{C}$, then $\phi > 1$ implies that countries have different populations or, in a different but quantitatively neutral interpretation, are characterized by different individuals' propensities to travel abroad:[20] in both cases, for given prices, C and $\tilde{C}$ generate different demand for roaming calls. By allowing for different populations and/or travel propensities, we are able to look at the complex and often unclear relationships between the level of IOTs selected by the operators and the degree of imbalances in traffic flows.

Each network gives "access" to its infrastructures; the amount of access provided by, let's say, network 1 of country C depends on the total demand of retail services in country $\tilde{C}$. We denote by d^w_C and $d^w_{\tilde{C}}$ the aggregate wholesale demands for access faced by the visited operators $C \in \{1, 2\}$ and $\tilde{C} \in \{a, b\}$; formally:

$$d^W_C = t_{a,C}\, d_a + t_{b,C}\, d_b \qquad \text{and} \qquad d^W_{\tilde{C}} = t_{1,\tilde{C}}\, d_1 + t_{2,\tilde{C}}\, d_2. \tag{3}$$

3.1.2 Firms' Profits

Each MNO sets the retail prices charged to its customers when they roam abroad and the wholesale prices (the IOTs) charged to foreign operators when their (visiting) customers roam onto its network; therefore each MNO receives a wholesale tariff for each call placed by foreign customers when roaming on its network and it actually pays an IOT to the visited networks for every call placed by its customers when travelling abroad.

According to the STIRA that governs all international roaming relationships of the affiliates of the GSM association, IOTs must be non-discriminatory, i.e. each MNO cannot charge different IOTs to different MNOs of the same country. Therefore, in this 2×2 framework, each MNO sets only one inter-operator tariff. Let us indicate with w_i the per-call IOT set by MNO i; the profits

[20] One may think, for instance, at the case of countries that attract many tourists.

of operator $C \in \{1,2\}$ are therefore:

$$\pi_C = d_C\, t_{C,a}\,(p_{C,a} - w_a) + d_C\, t_{C,b}\,(p_{C,b} - w_b) + d_C^W\ (w_C - m)\,, \tag{4}$$

similarly, the profits of operator $\tilde{C} \in \{a,b\}$ are:

$$\pi_{\tilde{C}} = d_{\tilde{C}}\, t_{\tilde{C},1}(p_{\tilde{C},1} - w_1) + d_{\tilde{C}}\, t_{\tilde{C},2}(p_{\tilde{C},2} - w_2) + d_{\tilde{C}}^W\ (w_{\tilde{C}} - m)\,, \tag{5}$$

where m is the common marginal cost of providing roaming services,[21] and d_C, $d_{\tilde{C}}$, and d_C^W, $d_{\tilde{C}}^W$ are as defined in (2) and (3). The first two terms of these functions are the retail profits, while the last term is the wholesale profit obtained by granting roaming services to foreign MNOs.

3.2 Uncooperative IOTs

We start by considering the case where operators do not take part in any form of partnership and set their IOTs uncooperatively; retail prices are then derived from IOTs charged by foreign operators by adding an uniform mark-up to them. As in SK, we model this process as a two stage game: *i*) in the first stage, each operator independently set its non discriminatory wholesale tariff w_i, and *ii*) in the second stage, operators charge a mark-up to the IOT set by the visited network. This way of modelling the sequence of actions reflects the relative rigidity of IOTs; according to the STIRA, IOTs are valid for at least six months (OPTA, 2005). This implies that while operators are free to change prices almost instantaneously in reaction to market changes, IOTs cannot be changed so easily and once set, they remain in place for a while. Let μ_i be the operator i's mark-up on foreign IOTs; retail prices when the user is roaming on foreign networks are therefore:

$$p_{C,a} = (1 + \mu_C)\, w_a, \qquad p_{C,b} = (1 + \mu_C)\, w_b, \tag{6}$$

$$p_{\tilde{C},1} = (1 + \mu_{\tilde{C}})\, w_1, \qquad p_{\tilde{C},2} = (1 + \mu_{\tilde{C}})\, w_2, \tag{7}$$

where, as usual, $C \in \{1,2\}$ and $\tilde{C} \in \{a,b\}$. Therefore, operator C's and operator $\tilde{C}$'s maximization problems reduce to:

$$\begin{aligned} \max_{\mu_C} \quad \pi_C \quad = \quad & \phi\,(A - \epsilon\,(1 + \mu_C)\,(t_{C,a}w_a + t_{C,b}w_b))\,(t_{C,a}w_a + t_{C,b}w_b)\,\mu_C \\ & + (A - \epsilon\,(1 + \mu_a)\,(t_{a,1}w_1 + t_{a,2}w_2))\, t_{a,C}\,(w_C - m) \\ & + (A - \epsilon\,(1 + \mu_b)\,(t_{b,1}w_1 + t_{b,2}w_2))\, t_{b,C}\,(w_C - m) \end{aligned} \tag{8}$$

[21] To ensure the existence of the market, throughout the paper we assume $A - \epsilon\, m > 0$.

and

$$\begin{aligned}\max_{\mu_{\tilde{C}}} \quad \pi_{\tilde{C}} &= (A-\epsilon(1+\mu_{\tilde{C}})(t_{\tilde{C},1}w_1+t_{\tilde{C},2}w_2))(t_{\tilde{C},1}w_1+t_{\tilde{C},2}w_2)\mu_{\tilde{C}} \\ &+ (A-\epsilon\,(1+\mu_1)\,(t_{1,a}w_a+t_{1,b}w_b))\,t_{1,\tilde{C}}\,(w_{\tilde{C}}-m) \\ &+ (A-\epsilon\,(1+\mu_2)\,(t_{2,a}w_a+t_{2,b}w_b))\,t_{2,\tilde{C}}\,(w_{\tilde{C}}-m)\,. \end{aligned} \tag{9}$$

Taking the derivatives with respect to μ_i and solving the first order conditions, the second stage profit maximizing mark-ups are given by:

$$\mu_C = \frac{A-\epsilon\,(t_{1,a}w_a+t_{1,b}w_b)}{2\epsilon\;(t_{1,a}w_a+t_{1,b}w_b)} \qquad \text{and} \qquad \mu_{\tilde{C}} = \frac{A-\epsilon(t_{2,a}w_a+t_{2,b}w_b)}{2\epsilon\;(t_{2,a}w_a+t_{2,b}w_b)}. \tag{10}$$

3.3 First stage wholesale competition

We are now ready to derive the first stage equilibrium IOTs. The availability and the efficiency of traffic direction technologies plays a critical role in our analysis; as it will become clear in this section, the strategic behavior of operators and, consequently, the nature of wholesale competition, may radically change according to the effectiveness of traffic direction technologies in enabling MNOs to select the network where to roam on.

We start by presenting the benchmark case, the model where traffic is randomly shared out between foreign operators. We will then analyse the model's predictions when traffic redirection technologies are enabled.

3.3.1 Wholesale competition with random traffic distribution

With random traffic distribution, $\alpha = 0$ and $t_{C,\tilde{C}} = 1/2$: independently of the IOT charged, each operator expects to obtain half of the traffic generated by the customers of foreign operators; this implies is that there is no competition at the wholesale level. Therefore, replacing mark-ups (10) in (8) and (9), the first stage maximization problems faced by the operators in the two countries reduce to:

$$\max_{w_C} \qquad \pi_C = \phi\frac{(2A-\epsilon\;(w_a+w_b))^2}{16\epsilon} + \frac{1}{4}\,(2A-\epsilon\;(w_1+w_2))\,(w_C-m) \qquad C=1,2 \tag{11}$$

and

$$\max_{w_{\tilde{C}}} \qquad \pi_{\tilde{C}} = \frac{(2A-\epsilon\;(w_1+w_2))^2}{16\epsilon} + \frac{\phi}{4}\,(2A-\epsilon\;(w_a+w_b))\,\big(w_{\tilde{C}}-m\big) \qquad \tilde{C}=a,b. \tag{12}$$

Solving for the profit maximizing roaming charges, it is easy obtain the following:[22]

Remark 1 (the solution in SK)**.** *When MNOs act uncooperatively, they set IOTs above the marginal cost of providing roaming services:* $w_u^* = \frac{2A+\epsilon m}{3\epsilon} > m$. *Uncooperative IOTs do not depend on the size of the wholesale market for international roaming services.*

Plugging w_u^* in (10), (6) and (7), equilibrium retail prices and firms' profits reduce to:

$$p_u^* = \frac{5A + \epsilon m}{6\epsilon},$$

$$\pi_{C,u}^* = \frac{(\phi + 4)(A - \epsilon m)^2}{36\epsilon} \quad \text{and} \quad \pi_{\tilde{C},u}^* = \frac{(1 + 4\phi)(A - \epsilon m)^2}{36\epsilon}, \tag{13}$$

where the index u refers to the uncooperative scenario.

This result can be easily explained by invoking standard double marginalization arguments: each MNO provides an essential input to foreign networks (access to roaming infrastructures) and therefore charges the standard, above cost, monopoly price (IOT). At the retail level, each MNO takes as given the IOT set by the visited network and it adds a retail mark-up to the wholesale tariff. As in a standard model of vertically separated markets, the double markup distorts retail prices up, inducing both profit and welfare losses. Visual inspection of the equilibrium profits in (13) reveals a further consequence of the distortions related to double marginalization that deserves to be mentioned:

Corollary 1. *Operators of the larger country obtain lower profit than those of the smaller country; formally, if* $\phi > 1$, *then* $\pi_C < \pi_{\tilde{C}}$.

Operators in large countries send more roaming traffic abroad than the amount of traffic that they receive; this implies that they suffer of a traffic imbalance that translates into a wholesale loss. At the equilibrium, these losses more than outweigh the larger profits enjoyed by bigger firms at the retail level.[23]

The model used so far describes a scenario where there are only two active firms in each country, but across Europe mobile telecommunications have experienced an increase in the competitive

[22] Note that this solution replicates the one in SK.

[23] To have a better understanding of this rather counterintuitive result, compare the equilibrium wholesale margin, $w_u^* - m$, with the retail margin $p_u^* - w^*$: it is easy to verify that the wholesale margin exceeds the retail margin; this implies that operators of the smaller countries, that are those that receive more traffic and that supply larger amounts of wholesale roaming services, get an higher level of profits with respect to operators of larger countries.

conditions, therefore it may be interesting to evaluate the predictions of the model when in the two countries there are more than two active firms. The model can be easily generalized to represent a more competitive framework in order to prove the following:[24]

Remark 2. *Competition pushes wholesale IOTs and retail prices up.*

This is a quite surprising result: as the number of firms that operate in each country increases, the equilibrium IOTs and the final prices are larger than those in Remark 1. This is a consequence of random sharing of traffic among the networks of the visited country; in this context, the more competitive the market, the less elastic the wholesale demand faced by each operator: an increase in the IOT charged by a single operator implies a reduction in the amount of wholesale traffic it receives. Nevertheless, with random traffic, all the competing MNOs suffer from this reduction, which is equally shared across rivals: in other words, the more competitive the roaming market in a given country, the smaller the reduction in wholesale demand suffered by the individual MNO when it increases its IOT. Since the IOT is set according to the standard "inverse elasticity rule", a less elastic demand translates into a higher equilibrium IOT set by each operator. As a consequence, promoting competition by increasing the number of operators may have the undesired effect of increasing retail prices.

3.3.2 Wholesale competition with traffic redirection

As discussed in section 1, new technologies allow MNOs to direct the traffic of their users on the foreign network of their choice. The main consequence of these technologies is that MNOs can compete to attract roaming traffic; it is on this enhanced competitive pressure induced by traffic direction that European regulatory authorities place their hopes of a reduction in wholesale and, in turn, in retail charges that would make regulatory interventions unnecessary.

According to recent surveys run by the European national regulatory authorities, current technologies are still not perfect, therefore we assume that each mobile network is able to direct a share $\alpha \in (0, 1)$ of the traffic originated by their customers when abroad. Competition between visited networks is aimed only at attracting that portion α of traffic that domestic MNOs are able to direct towards the desired foreign operator. The remaining traffic is out of control of operators and it is randomly shared out among foreign networks.

[24] Formal details are in the Appendix.

Note that in the extreme, and unrealistic, scenario characterized by perfect traffic redirection techniques, MNOs would be able to direct the whole traffic generated by their customers onto the network of the visited operator charging the lowest IOT;[25] in this situation visited MNOs would fiercely compete to attract roaming traffic and, as in a standard Bertrand framework, competition over IOTs would drive them down to marginal cost, $w = m$. We can therefore derive the following corollary:

Corollary 2. *With perfect traffic control technologies,* $\alpha = 1$*, competition to attract traffic originated by customers roaming out drives IOTs down to cost.*

Nevertheless, the result of corollary 2 does no longer hold when traffic direction technologies are less than perfect: with even a small share of traffic randomly addressed, an operator may profitably deviate from the walrasian equilibrium by charging an IOT above cost and still face a strictly positive wholesale demand for roaming services.

To find the equilibrium IOTs we need to derive the demand function for roaming services faced by each domestic operator and the wholesale profits associated to any level of the IOT, given the IOT charged by the other domestic operator.

Consider MNO 1 in country C, but identical arguments apply to country $\tilde{C}$'s operators; if MNO 1's IOT is lower than the IOT charged by its rival, $w_1 < w_2$, then foreign MNOs a and b will direct the traffic generated by their customers, i.e the portion α of the traffic that they control, on the network of MNO 1, the cheapest. The remaining share of traffic is randomly addressed on the networks of MNO 1 and MNO 2. Formally, the share of MNO a's and MNO b's traffic that roams on MNO 1's infrastructures when $w_1 < w_2$ is $t_{\tilde{C},1} = \alpha + (1 - \alpha)/2$, $\tilde{C} \in \{a, b\}$. Clearly, MNO 2, that we assume to be the operator charging the higher IOT, receives only the random/uncontrolled share of traffic generated by MNO a's and MNO b's customers: $t_{\tilde{C},2} = (1 - \alpha)/2$.

When MNO 1 and MNO 2 charge the same IOT, MNO a and MNO b are indifferent between the two roaming partners; in this case, as a "splitting rule", we assume that the traffic generated by roaming customers of a given MNO is equally shared between visited networks; formally, if $w_1 = w_2$, then $t_{\tilde{C},1} = t_{\tilde{C},2} = 1/2$.

Applying these arguments to the above mark-ups and plugging them into the expressions for

[25] Note that we also need to assume 100% network coverage for α to be equal to 1.

wholesale demand (3), it is possible to obtain the wholesale profit[26] enjoyed by operator $i, j = 1, 2$, for any IOT charged by its domestic rival:

$$\pi_i^w(w_1, w_2) = \begin{cases} \frac{1}{4}\,(w_i - m)\,(1+\alpha)\,(2\,A - \epsilon\, w_i(1+\alpha) - \epsilon\, w_j(1-\alpha)) & \text{if} \quad w_i < w_j, \\ \frac{1}{2}(w_i - m)(A - \epsilon\, w_i) & \text{if} \quad w_i = w_j, \\ \frac{1}{4}\,(w_i - m)\,(1-\alpha)\,(2\,A - \epsilon\, w_i(1-\alpha) - \epsilon\, w_j(1+\alpha)) & \quad \text{otherwise.} \end{cases} \tag{14}$$

We are now in a position to prove the following:

Remark 3. *With imperfect traffic redirection techniques, $\alpha \in (0, 1)$, there is no Nash equilibrium in pure strategies in the determination of the IOT.*

A formal proof can be found in the Appendix, but the intuition can be easily explained. We have already discussed that when $\alpha > 0$, $w_1 = w_2 = m$ cannot be an equilibrium since each firm has an incentive to increase its IOT in order to get positive wholesale profits. It is easy to check that any pair of IOTs such that $w_1 = w_2 > m$ cannot be an equilibrium either; two possible cases emerge: *i*) the common IOT is sufficiently above cost, *ii*) the common IOT is not too large.

In the first case, firms have incentives either to undercut the rival according to a standard Bertrand-like competition game or to deviate by charging an IOT well below the one set by its rival; in both instances, the deviating operator gets the entire redirected traffic. Case *ii*) is more interesting: suppose, for example, that both firms charge the same IOT slightly above cost. In this case, the two firms share the market and obtain positive wholesale margins. Incentives to undercut the rival still exist also at a low level of the IOTs, provided that the per-unit loss in revenues is more than compensated by the increase in demand for roaming traffic. But operators may get even larger profits by raising their IOT instead of undercutting the rival, thus serving only the random portion of the wholesale market; we name this deviation as "overcharging", to differentiate it from the standard "undercutting" deviation typical of price competition. For the "overcharging" strategy to yield larger profits than the "undercutting" strategy, the operator must charge a very large IOT to compensate the loss in roaming traffic with a large mark-up. If both firms deviate and charge large and symmetric IOTs, then we are back to *i*) which, again, cannot be an equilibrium.[27]

[26]Formally, $\pi_i^w(w_1, w_2) = (w_i - m)\, d_i^w$, where d_i^w is defined in (3), i=1, 2.

[27]It is possible to show that an asymmetric equilibrium where one firm charges a low IOT and the rival serves only the random share of the market setting a high IOT does not exist. See the Appendix for details.

Note that these arguments hold true if and only if traffic direction techniques are not perfect, i.e for any $0 < \alpha < 1$; obviously, incentives to overcharge the rival are stronger the less effective the traffic direction technology (i.e. the smaller α).

A first consequence of this result is that contrary to what it is commonly perceived at regulatory level,[28] competition on IOTs to attract addressable traffic does not induce wholesale charges to converge at their cost level; this reveals that the increasing adoption of traffic control techniques does not guarantee "per-se" downward pressure on wholesale tariffs. Our result also provides an explanation to the empirical evidence that the increasing adoption of ever more efficient traffic control techniques has not been accompanied by a decrease in international roaming tariffs.

In order to have a complete understanding of the strategic interactions between operators in the determination of the wholesale charges, it is useful to present MNOs' reaction functions, i.e. the best IOT that MNO i can charge for any IOT set by the rival operator:[29]

$$w_i(w_j) = \begin{cases} \frac{1}{2}\frac{2\,A+\epsilon m(1-\alpha)-\epsilon\, w_j(1+\alpha)}{\epsilon(1-\alpha)} & \text{if} \quad w_j < \underline{w}(\alpha), \\ w_j - \sigma & \text{if} \quad \underline{w}(\alpha) < w_j < \overline{w}(\alpha), \\ \frac{1}{2}\frac{2\,A+\epsilon m(1+\alpha)-\epsilon\, w_j(1-\alpha)}{\epsilon(1+\alpha)} & \text{otherwise,} \end{cases} \tag{15}$$

where

$$\underline{w}(\alpha) = \frac{(\alpha+1)\,(6\,A + m\epsilon\,(\alpha+3)) - 4\,(A - \epsilon\, m)\,\sqrt{2\alpha\,(\alpha+1)}}{(\alpha+9)\,(\alpha+1)\,\epsilon},$$

and

$$\overline{w}(\alpha) = \frac{2A + m\epsilon\,(1+\alpha)}{(3+\alpha)\,\epsilon},$$

and σ is a small number. Figure 2 provides a graphical representation of expression (15): for IOTs levels above $\underline{w}(\alpha)$, wholesale competition drives them down, while for sufficiently low levels of the wholesale charges firms prefer to deviate by overcharging. This suggests that an IOT below $\underline{w}(\alpha)$, with $\underline{w}(\alpha) > m$, will never be observed, even with traffic direction.

Although traffic direction techniques do not ensure downward pressure on wholesale charges unless they do allow for perfect control, marginal cost pricing can still be induced through the implementation of a simple regulatory mechanism; indeed, visual inspection of operators' reaction

[28]See Valletti (2003).

[29]See the Appendix for details.

functions suggests that overcharging is the best deviating strategy when $w < \hat{w}$, where

$$\hat{w}(\alpha) = \frac{9\,A - (A - \epsilon\, m)\left(2\,\alpha + 3 - 2\,\sqrt{2}\sqrt{\alpha\,(\alpha+1)}\right) - m\epsilon\,\alpha\,(8+\alpha)}{\epsilon\,(1-\alpha)\,(\alpha+9)}.$$

From the above expression, corollary 3 follows immediately:

Corollary 3. *Regulating IOTs through a price cap mechanism such that each operator is free to charge its IOT w_i as long as $w_i < \hat{w}(\alpha)$, induces domestic operators to charge IOT at the cost and restores the efficiency guaranteed by perfect traffic redirection technologies.*

In order to prove this corollary, look at the reaction functions in Figure 2. Suppose that we are in a low IOT scenario (case *ii*) above) where both firms charge the same relatively low, although above cost, IOT; the cap $w_i < \hat{w}_i(\alpha)$ on firms' IOTs prevents operators to "overcharge" the rival: the only deviating strategy that remains available to both firms is to undercut their rival, i.e. to charge a slightly lower IOT in order to get the entire redirected traffic. In other words, once firms are prevented from overcharging, undercutting remains the unique profitable deviating strategy; therefore the equilibrium necessarily converges towards marginal cost pricing even without perfect control on traffic flows: $w_i = m$.

Note that the imposition of a cap on wholesale charges is one of the proposed measures actually under scrutiny by European regulators.[30] Our model confirms that this simple measure may effectively increase market efficiency. Note also that $d\hat{w}(\alpha)/d\alpha > 0$: the cap increases with the efficiency of traffic redirection technologies. In other words, the regulatory mechanism has to be set at tighter level the less efficient traffic direction techniques are.

3.4 Cooperative IOTs: cross border alliances and pan-European groups

As discussed in the introduction, European MNOs are increasingly cooperating through partnerships and alliances and, at the same time, pan-European groups are emerging as the result of acquisition strategies put in place by some operators. Foreign MNOs may cooperate in order to

[30]See the second phase consultation on a Proposal for a Regulation of the European Parliament and of the Council on mobile roaming services in the Single Market; available at `http://europa.eu.int/information_society/activities/roaming/docs/comments/public_consultation_2nd_phase.pdf`.

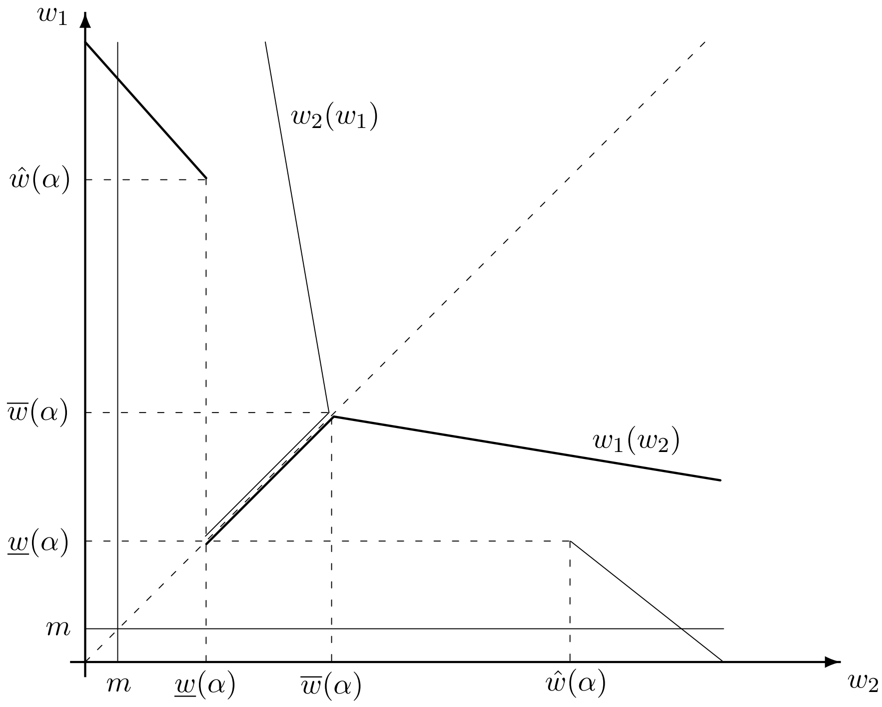

Figure 2: Reaction functions

offer better services to their customers when they travel abroad and to lower roaming retail prices; in fact, within alliances, IOTs are set at reciprocal attractive terms that allow operators to cut their retail prices. Let us assume that each operator in country C allies with an operator in $\tilde{\text{C}}$; for simplicity, we assume the following alliances: MNO 1 with MNO a, and MNO 2 with MNO b.

The formation of these agreements is encouraged by the adoption of ever efficient traffic control techniques that allow collaborating MNOs to keep on their networks the traffic generated by their customers. In our model, traffic direction techniques allow operators to have control on a share α of the traffic generated by their customers, while for the remaining traffic the roaming operator is randomly selected between the two foreign MNOs; this implies that the amount of traffic that is handled within and outside the alliance set by 1 and a are respectively: $t_{1,a} = t_{a,1} = \alpha + (1-\alpha)/2$ and $t_{1,b} = t_{b,1} = (1-\alpha)/2$.[31]

We model the alliance as a cartel at the wholesale level: the aim of the partnership is to set the internal IOT in order to maximize the sum of firms' profits. We also assume that allied parties set reciprocal IOTs, i.e. the same in both directions of the call. Formally, the reciprocal IOT set by

[31]Symmetrically, the the amount of traffic that is handled within and outside the alliance between 2 and b are respectively: $t_{2,b} = t_{b,2} = \alpha + (1-\alpha)/2$ and $t_{2,a} = t_{a,2} = (1-\alpha)/2$.

the alliance between operators 1 and a, $w_{1,a}$, is given by:[32]

$$w_{1,a} = argmax\{\pi_1 + \pi_a\}. \tag{16}$$

Note that in addition to the internal IOT, each MNO has also to set uncooperatively an IOT for the traffic generated by the customers of the un-affiliated operator: for example, MNO 1 charges its partner the cooperative IOT $w_{1,a}$, while it applies an uncooperative IOT w_1 to the traffic generated by MNO b's customers that randomly roam on its network.[33] Therefore, MNO 1's profits are given by:

$$\pi_1 = d_1\, t_{1,a}\,(p_{1,a} - w_{1,a}) + d_a\, t_{a,1}\,(w_{1,a} - m) + d_1\, t_{1,b}\,(p_{1,b} - w_b) + d_b\, t_{b,1}\,(w_1 - m)\,. \tag{17}$$

In the Appendix we prove the following remark:

Remark 4. *Members of an alliance set the internal IOT $w^*_{i,al}$ at the cost of providing roaming services: $w^*_{i,al} = m$. The IOT charged to foreign MNOs outside the alliance $w^*_{o,al}$ is set above cost at $w^*_{o,al} = \frac{A - \epsilon\,\alpha\, m}{\epsilon\,(1-\alpha)}$.*

Replacing the bargained IOT into second period mark-ups given in expression (10), we get equilibrium retail perceived prices and profits of the MNOs in the two countries:

$$P^*_{al} = \frac{3A + \epsilon\, m}{4\epsilon},$$

$$\pi^*_{C,al} = \frac{(2+\phi)\,(A - \epsilon\, m)^2}{16\epsilon} \qquad \text{and} \qquad \pi^*_{\tilde{C},al} = \frac{(1+2\,\phi)\,(A - \epsilon\, m)^2}{16\epsilon}.$$

If we compare equilibrium retail prices and MNO's profits stemming from cross-border alliances with those stemming from the uncooperative scenario with random sharing of traffic we are led to the following:

Corollary 4. *When MNOs set reciprocal IOTs cooperatively, average retail prices are lower and firms' profits are larger than in the uncooperative case with random network selection.*

[32]Similar arguments apply to the alliance between MNO 2 and MNO b.

[33]Note that, contrary to the scenario described in the previous section, the uncooperative IOTs apply only to random traffic, being the redirected traffic maintained on allied operators' infrastructure; since operators cannot compete to attract random traffic, they simply act as monopolists when setting the uncooperative IOT.

According to this corollary, alliances are Pareto superior to the uncooperative determination of IOTs: both firms and consumers are better off and social welfare is larger. Clearly, this result holds without traffic direction technologies since in this case the uncooperative equilibrium is undetermined.

Corollary 4 is interesting but, again, it is not surprising if one views the problem from a double marginalization perspective; by setting IOTs at the cost of providing roaming services, MNOs are able to eliminate wholesale margins: this, in turn, reduces retail tariffs and stimulates roaming traffic. Therefore, the effects of alliances are twofold: on the one hand they increase firms' profits, letting operators to make more money from retail customers, on the other hand they positively impact on consumers' surplus through lower retail prices. This situation goes under the name of "symbiotic production" and it is well known since the paper by Carter and Wright (1994) where the authors study the case of monopoly suppliers trading essential inputs with one another. Carter and Wright show that in this context *i*)producers can use per-unit tariffs to achieve cooperative outcomes without colluding directly over consumer prices and *ii*)that such form of collusion lowers consumer prices.

At the same time MNOs charge foreign un-affiliated operators an IOT that is larger than the marginal cost; noteworthy, this uncooperative IOT increases with α, the efficiency of traffic redirection techniques: $dw^*_{o,al}/d\alpha > 0$.[34] Nevertheless, it should also be noted that the larger α, the more efficient traffic direction techniques and the smaller the share of traffic to which $w^*_{o,al}$ applies. On average these two effects cancel each other out, explaining why equilibrium retail prices do not vary with α.

4 Conclusions

International roaming services allow subscribers of mobile network operators to make and receive calls abroad while maintaining their commercial relationship with their home mobile operator or service provider. Since mid 1990s, the functioning of the market for international roaming services has been the subject of an antitrust debate. The reason is that despite the overall downward trend

[34]This result seems to confirm what has been observed in many European countries, where the increase in the adoption of traffic redirection techniques by home networks has often been accompanied by an increase in the average level of IOTs. See FICORA (2005a) for details.

of mobile call tariffs, prices for international roaming calls have remained surprisingly high.

The main reason for the observed market inefficiency is to be found in the system that currently governs wholesale roaming agreements: the Standard International Roaming Agreement and the Inter Operator Tariff (IOT), the wholesale roaming charge, formally defined as a tariff between mobile network operators, charged by the visited network operator to the home network operator for the use of the visited network.

By moving from a recent contribution proposed by Salsas and Koboldt (2004), we develop a simple model aimed at describing the functioning and the effects on prices and consumers' welfare of the regime based on the IOT. Traffic direction techniques play a central role in our analysis; these techniques allow mobile operators to direct their end-customers, when abroad, on the network of their choice. Widespread adoption of this techniques by part of mobile operators is considered by many an important step toward a more competitive and efficient market.

We show that when mobile operators act uncooperatively and traffic redirection techniques are less than perfect, as it is currently the case, competition between roaming operators may not guarantee reductions in IOTs and, consequently, in retail tariffs. Nonetheless, efficiency can still be attained through the imposition of a simple and effective regulatory price cap mechanism in the wholesale market. Finally, we have shown that when mobile operators cooperate within a cross border alliance, internal IOTs are set at cost and retail prices are lower. Alliances between network operators may fall within the framework of symbiotic production proposed by Carter and Wright (1994) characterized by firms trading essential inputs with one another. In such framework, producers can trade the essential input by using per-unit tariffs to achieve cooperative outcomes without colluding directly over consumer prices and such collusion lowers consumer prices and increases social welfare.

We do not address the issue of national regulatory agencies' incentives to regulate their national markets. In fact, since NRA can only regulate the operators active in their country, any form of regulation on IOTs would ultimately benefit foreign consumers to the detriment of national operators' profits. This is the main reason why Commissioner Reding has proposed to the European Parliament and the Council a new regulation of roaming services in the single European market.

Appendix

Proof of Remark 2. Consider the more general $n \times l$ case, with $n > 2$ active operators in country C and $l > 2$ operators in country C̃. The analysis is formally identical to the 2×2 case presented in section 3.3.1; for the sake of simplicity, let us assume that the dimension of the two countries is the same: $\phi = 1$. Let $p_{C,\tilde{C}}$ be the retail price charged to subscribers of a representative operator of country C, $C = 1, \ldots, n$, when roaming onto a representative network of country C̃, $\tilde{C} = 1, \ldots, l$. According to the assumption of random selection, the probability of visiting each network in country C̃ is $1/l$; the average retail price P_C paid for roaming services by subscribers of the representative network is therefore: $P_C = \frac{1}{l} \sum_{v=1}^{l} p_{C,v}$.
Similarly, the average retail price $P_{\tilde{C}}$ paid for roaming services by subscribers of a representative network in country C̃ is: $P_{\tilde{C}} = \frac{1}{n} \sum_{j=1}^{n} p_{\tilde{C},j}$. The retail demand functions for roaming services faced by operators in country C and C̃ are therefore:

$$d_C = A - \frac{\epsilon}{l} \sum_{v=1}^{l} p_{C,v} \qquad \text{and} \qquad d_{\tilde{C}} = A - \epsilon \, \frac{\epsilon}{n} \sum_{j=1}^{n} p_{\tilde{C},j}.$$

Provided that operator C (resp. C̃) has a probability of $1/n$ (resp. $1/l$) of being visited, wholesale demand d_C^w and $d_{\tilde{C}}^w$ for access faced by the representative operators in the two countries are simply given by $d_C^W = \frac{1}{n} \, d_{\tilde{C}}$ and $d_{\tilde{C}}^W = \frac{1}{l} \, d_{\tilde{C}}$. Note that the elasticity of wholesale demand to changes in the IOT decreases the more competitive the market: *ceteris paribus*, an increase in the IOT charged by an individual operator in country C implies a reduction in the amount of traffic generated by customers of country C̃'s operators since it induces an increase in retail prices; on the other hand, with random traffic this reduction is equally shared among all n competing operators in C: as n gets larger, the reduction in wholesale demand suffered by an individual MNO after an increase in its IOT is smaller.
Operators' profits are the sum of retail and wholesale profits:

$$\pi_C = \frac{1}{l} \, d_C \left(\sum_{j=1}^{l} p_{C,j} - \tilde{w}_j \right) + (w_C - m) \, d_C^W \,,$$

$$\pi_{\tilde{C}} = \frac{1}{n} \, d_{\tilde{C}} \left(\sum_{i=1}^{n} p_{\tilde{C},i} - w_i \right) + (\tilde{w}_C - m) \, d_{\tilde{C}}^W \,,$$

where w_i and $\tilde{w}_j$ are the uncooperative IOTs set by the representative operator in country C and C̃ respectively. The solution of the two stage game (as in section 3.3.1) yields the symmetric equilibrium IOTs set by the representative operators in country C and in country C̃:

$$w_C^* = \frac{An + \epsilon \, m}{\epsilon \, (n+1)} \qquad \text{and} \qquad \tilde{w}_{\tilde{C}}^* = \frac{Al + \epsilon \, m}{\epsilon \, (l+1)}. \tag{18}$$

By substituting these expressions in MNOs' retail price and profit functions, we get the equilibrium retail price and firms' profits:

$$p_C^* = \frac{2\,Al + \epsilon\, m + A}{2\epsilon\,(l+1)}, \qquad p_{\tilde{C}}^* = \frac{2\,An + \epsilon\, m + A}{2\epsilon\,(n+1)},$$

$$\pi_C^* = \frac{(A - \epsilon\, m)^2\left(1 + 4\, n + n^2 + 2\, nl^2 + 4\, ln\right)}{4\epsilon\,(n+1)^2\,(l+1)^2}, \quad \pi_{\tilde{C}}* = \frac{(A - \epsilon\, m)^2\left(1 + 4\, l + l^2 + 2\, ln^2 + 4\, ln\right)}{4\epsilon\,(n+1)^2\,(l+1)^2}.$$

Remark 2 follows immediately. □

Proof of Remark 3. Wholesale competition with traffic redirection. MNO i wholesale profits are defined in expression (14). We want to define MNO i's reaction function: $w_i(w_j)$; when faced with a given IOT charged by MNO j, MNO i has three options: i) it may undercut the rival by charging $w_i = w_j - \varepsilon$, where ε is a small number; ii) it may "overcharge" MNO j by setting $w_i = \hat{w} > w_j$ or, iii) it may "undercharge" MNO j by charging a fairly lower IOT, $w_i = \ddot{w}_j < w_j$. Note that undercutting and undercharging are different strategies: although both imply that the operator gets the whole directed traffic, in the first case, MNO i charges an IOT which is just below w_j, while in the latter case MNO i charges a tariff well below that of its rival. This latter strategy occurs to be profitable when firm j charges a very high IOT: since $\pi_i^w(w_i < w_j)$ is a well shaped concave function, when w_j is excessively high and irrespectively on how large is w_j, MNO i may find it optimal to charge its "best" IOT rather than to undercut its rival.

Formally: undercutting represents the best strategy if the following conditions are verified:

$$\pi_i^w(w_i = w_j - \varepsilon) \; > \; \pi_i^w(\hat{w}_i, w_j),$$

$$\pi_i^w(w_i = w_j - \varepsilon) \; > \; \pi_i^w(\ddot{w}_i, w_j),$$

where $\hat{w}$ and $\ddot{w}$ are the best IOTs that operator i can charge when undercharging or overcharging MNO j: $\hat{w}_i = argmax_{w_i}\, \pi_i^w(w_i > w_j)$ and $\ddot{w}_i = argmax_{w_i}\, \pi_i^w(w_i < w_j)$. By differentiating (14) we get:

$$\frac{d\pi_i^w(w_i > w_j)}{dw_i} = \frac{1-\alpha}{4}\,\left(2\,A - \epsilon\, w_j(1+\alpha) + m\epsilon\,(1-\alpha) - 2\,\epsilon\, w_i(1-\alpha)\right) = 0,$$

and

$$\frac{d\pi_i^w(w_i < w_j)}{dw_i} = \frac{1+\alpha}{4}\,\left(2\,A - \epsilon\, w_j(1-\alpha) + m\epsilon\,(1+\alpha) - 2\,\epsilon\, w_i(1+\alpha)\right) = 0.$$

Rearranging these expressions, we obtain the optimal overcharging and undercharging IOTs, given the IOT charged by firm j:[35]

$$\hat{w}_i(w_j) = \frac{1}{2}\frac{2\,A + \epsilon\, m(1-\alpha) - \epsilon\, w_j(1+\alpha)}{\epsilon(1-\alpha)},$$

[35] Second order conditions are the same for both maximization problems and they are clearly satisfied: $\frac{d^2\pi_i^w(w_i > w_j)}{dw_i^2} = \frac{d^2\pi_i^w(w_i < w_j)}{dw_i^2} = -\frac{\epsilon}{2}(\alpha - 1)^2$.

$$\ddot{w}_i(w_j) = \frac{1}{2}\frac{2\,A + \epsilon\, m(1+\alpha) - \epsilon\, w_j(1-\alpha)}{\epsilon(1+\alpha)}.$$

Note that the above functions apply for $w_i > w_j$ and $w_i < w_j$ respectively. return MNO i's best overcharging and undercharging strategies for any IOT set by j. These two expressions, are the negatively sloped parts of the reaction function depicted in Figure 2. It is possible to show that:

a) that when MNO j charges an intermediate IOT, formally when $\underline{w} < w_j < \overline{w}$, where:

$$\underline{w} = \frac{(\alpha+1)\,(6\,A + m\,\epsilon\,(\alpha+3)) - 4\,(A - \epsilon\, m)\,\sqrt{2\alpha\,(\alpha+1)}}{(\alpha+9)\,(\alpha+1)\,\epsilon}, \quad \text{and} \quad \overline{w} = \frac{m\epsilon\,\alpha + \epsilon\, m + 2\,A}{(\alpha+3)\,\epsilon},$$

undercutting is the best strategy for MNO i;

b) overcharging, $w_i = \hat{w}_i(w_j)$ is the best strategy when $w_j < \underline{w}$, while undercharging $w_i = \ddot{w}_i(w_j)$, is the best strategy when $w_j > \overline{w}$.

This explains the shape of the reaction functions in Figure 2 (formally, expression (15)) and proves Remark 3. □

Proof of Remark 4. MNO 1's profit are those of (17). Second stage retail prices are still set as mark-ups over IOTs; we assume that each MNO sets a unique mark-up, i.e. operators do not set different mark-ups for roaming calls within or outside the alliance. Maximizing (17), it is easy to verify that second stage mark-up charged by MNO 1 and MNO a when MNO 1 allies with MNO a and MNO 2 allies with MNO b are:

$$\mu_1 = \frac{2A - \epsilon\, w_{1,a}(1+\alpha) - w_b(1-\alpha)}{2\epsilon\,\left(w_{1,a}(1+\alpha) + w_b(1-\alpha)\right)},$$

$$\mu_a = \frac{2A - \epsilon\, w_{1,a}(1+\alpha) - w_2(1-\alpha)}{2\epsilon\,\left(w_{1,a}(1+\alpha) + w_2(1-\alpha)\right)}.$$

Equilibrium IOTs are obtained by plugging second stage mark-ups into firms' profit functions; more precisely, the IOT set by the alliance between MNO 1 and MNO a is the solution to the following maximization problem:

$$w_{1,a} = argmax\left\{\frac{1}{2}\,(\pi_1 + \pi_a)\right\} \tag{19}$$

where

$$\begin{aligned}
\frac{1}{2}\,(\pi_1 + \pi_a) \quad = \quad & \left\{\frac{1}{16}\,\epsilon\,(1+\alpha)^2\,(\phi+1)\,(w_{1,\,a}\,m - \frac{1}{2}\,w_{1,\,a}{}^2) + \frac{(\phi+1)\,A^2}{8\,\epsilon}\right. \\
& + \frac{1}{8}\,((1-\alpha)\,(w_1 - w_2 + \phi\,(w_a - w_b)) - 2\,(\phi+1)\,m)\,A \\
& + \frac{1}{32}\epsilon\,(1-\alpha)((2\,(1+\alpha)\,(w_2 + \phi\, w_b) + 2\,(1-\alpha)\,(w_1 + \phi\, w_a) \\
& + 2\,w_{2,\,b}\,(\phi+1)\,(\alpha+1))m \\
& + (1-\alpha)\,(w_2{}^2 + \phi\, w_b{}^2 - 2\,w_1{}^2 - 2\,\phi\, w_a{}^2) \\
& \left. - 2\,(1+\alpha)\,w_{2,\,b}\,(w_1 + \phi\, w_a))\right\}.
\end{aligned}$$

Independent IOTs w_C and $w_{\tilde{C}}$ are derived from individual MNOs first order conditions. Therefore, equilibrium IOTs comes from the following system of cooperative and uncooperative first order conditions:[36]

$$\frac{d(\pi_1 + \pi_a)}{dw_{1,a}} = -\frac{1}{8}\,\epsilon\,(\alpha+1)^2\,(\phi+1)\,(w_{1,a}-c) = 0$$

$$\frac{d\pi_1}{dw_1} = \frac{1}{8}\,(2\,\epsilon\,w_1\alpha - 2\,\epsilon\,w_1 - \epsilon\,\alpha\,c - \epsilon\,w_{2,b}\alpha + 2\,A + \epsilon\,c - \epsilon\,w_{2,b})\,(1-\alpha) = 0$$

$$\frac{d\pi_a}{dw_a} = \frac{1}{8}\,(\epsilon\,w_{2,b}\alpha + \epsilon\,\alpha\,c - 2\,\epsilon\,w_a\alpha + \epsilon\,w_{2,b} - 2\,A + 2\,\epsilon\,w_a - \epsilon\,c)\,\phi\,(1-\alpha) = 0$$

Solving these first order conditions, Remark 4 follows immediately. □

[36]It is easy to verify that second order conditions are satisfied.

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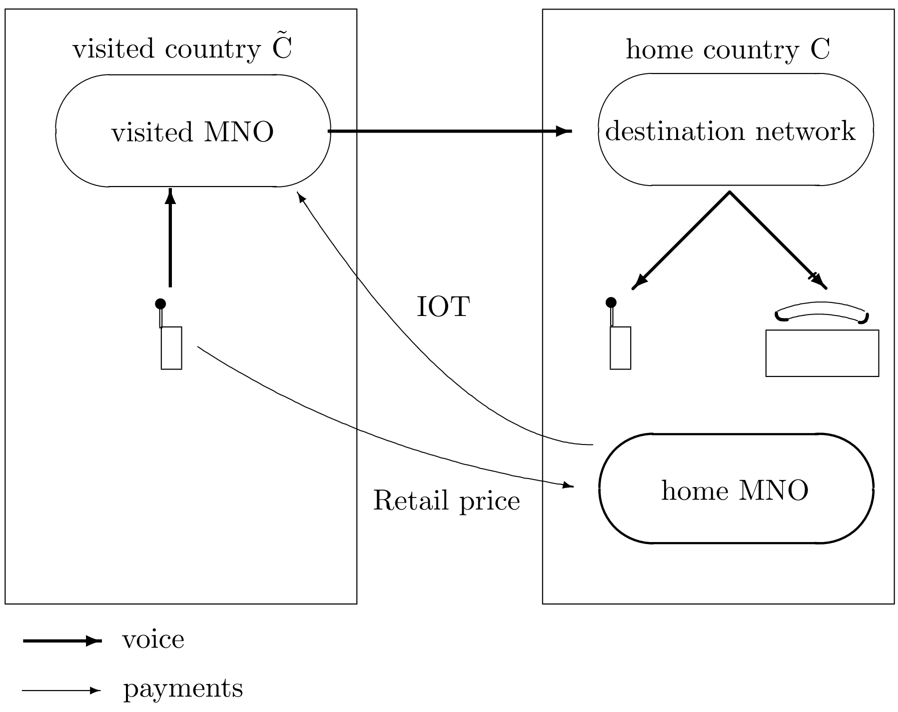

Figure 1: Mobile originated roamed call to the home country