International network competition under national regulation*

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Abstract

We extend the workhorse model of network competition to international calls. This model enables us to show that national regulatory authorities (NRAs) maximizing domestic welfare have incentives to increase termination rates above the social optimum to extract rent from international call termination. Excessive termination rates distort prices but transfer surplus from foreign to domestic consumers via intensified network competition. The model can explain the regulation of termination rates through rate floors. International network ownership and deregulation are alternatives to combat the incentives of NRAs to distort termination rates. We identify conditions under which each of these policies increases aggregate welfare.

Keywords: Conglomerate merger, international markets, national regulation, network competition, telecommunications, termination rates.

JEL classification: L51, L96.

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1 Introduction

Mobile telecommunication markets have gone global in terms of both traffic and ownership structure. Annual international non-VoIP call volumes have increased continuously over the last 20 years, from 55 billion minutes in 1994 to 340 billion minutes in 2014.[1] Former national telecommunication champions have expanded abroad and merged to create international network operators. Four international network operator groups, Vodafone, Telefonica/O2, T-mobile and Orange, share approximately 80% of the mobile subscriptions in the EU (Benzoni et al., 2011). In this paper, we analyze the consequences of the globalization of mobile telecommunication markets by allowing consumers to initiate and receive international calls in the workhorse model of network competition (Armstrong, 1998; Laffont et al., 1998a,b).

A key component of network competition is the termination rates that operators charge for connecting calls from networks at home and abroad. Termination rates are usually regulated because operators could otherwise use them to soften competition at the retail level. Our main finding is that a regulatory failure drives termination rates above the social optimum in international telecommunication markets. National regulatory authorities (NRAs) concerned with maximizing domestic welfare have an incentive to set excessive termination rates to extract termination rent from international calls. Termination rates are higher when the share of incoming international calls is larger because rent extraction is then more valuable. By the same token, the model predicts termination rates to be higher in countries with a large share of incoming international calls than in countries with mostly national calls.

Recent investigations opened against Germany (BEREC, 2014) and Finland (European Commission, 2015) point to the relevance of regulatory failure in telecommunication markets. Specifically, the NRAs in the two countries apply cost models that yield higher termination rates than the forward-looking, long-run incremental cost model recommended by the European Commission (2009). A key objective of introducing that model was precisely to (European Commission, 2015, p.9):

> "*ensure that regulators do not favour their national operators at the expense of operators in other Member States by not introducing fully cost-oriented mobile termination rates [...] This difference would be incurred at the expense of the operators, and eventually consumers, in the Member States from where the calls originate*."

Furthermore, in recent years, a growing number of non-OECD countries have introduced government-mandated termination rates for incoming international traffic. In effect, network operators (OECD,

[1] According to the market research firm TeleGeography, see http://www.telegeography.com/research-services/telegeography-report-database, accessed January 2016. VoIP refers to Voice over Internet Protocol, a phone service that works over the Internet instead of over the traditional telephone network. We exclude VoIP calls because they typically generate neither termination costs nor revenues.

2014, p.14) *"act as a government-sanctioned cartel, precluding competition and raising prices for consumers in the countries involved."*

The European Commission (2015) emphasizes favoritism of the domestic industry, but this is not a prerequisite for trade policy in a setting with international network competition. A higher termination rate intensifies domestic retail competition, which lowers equilibrium subscription fees. This "waterbed" effect is so strong that international termination rent is fully passed on to consumers in this model. Thus, the exercise of market power in international termination effectively transfers surplus from consumers abroad (through higher international call prices) to domestic consumers (through lower subscription fees).

The profit-maximizing termination rate is independent of international calls because of full pass-through. Hence, the regulated termination rates exceed the profit-maximizing level if the share of international calls is sufficiently large. In this case, NRAs can implement the desired regulation by means of a rate floor. Incidentally, the Swedish Ministry of Enterprise suggested in a recent proposal that domestic termination rates should be subject to a rate floor and not only a ceiling. OECD (2014) emphasizes rate floors more generally as an instrument for upholding excessive termination rates.

What can be done about the regulatory failure associated with national regulation? The examples of Germany and Finland suggest that even supra-national regulation would be problematic because NRAs have incentives to exaggerate network costs to justify high termination rates. Moreover, supra-national regulation may not be feasible, either because it violates principles of national policy making (e.g., the subsidiarity principle in the EU) or because there is no such regulatory authority in place (e.g., EU-U.S. termination). We therefore maintain the assumption of national regulation and consider remedies that are independent of information about network costs.

The first remedy is international consolidation (conglomerate mergers) of network operations, which is one of the policies under consideration in the EU.[2] Consolidation implies that a share of international calls is now terminated within the own network. Such on-net calls are not subject to any termination markup and are therefore priced more efficiently. Hence, the first and direct welfare effect of consolidation is increased call price efficiency. The increased share of on-net calls further implies a decline in international termination profit, which triggers a regulatory response that tends to bring the regulated termination rate closer to the social optimum. It follows that international consolidation can be welfare improving even without associated cost synergies.

Consolidation can possibly be welfare decreasing if the share of international calls is large because the regulated termination rates become more distorted as a consequence. One solution to this problem is deregulation–one of the long-term policy objectives of the EU. Recall that the NRAs'

[2] The aim is to increase market integration and allow greater economies of scale in the industry; see "EU steps up Single Telecoms Market Plan" by Daniel Thomas and James Fontanella-Khan in *Financial Times*, April 17 2013.

incentives to increase termination rates are stronger when international calls are more important, whereas profit-maximizing termination is independent of international call termination. Hence, termination rates are less distorted under deregulation than under regulation when the share of incoming calls is sufficiently large.

Our paper relates to three bodies of literature. First, all calls are initiated and terminated domestically in the workhorse model of *network competition* and in subsequent research; see Hoernig and Valletti (2012) for a survey. A single authority conducts regulatory oversight and determines termination rates, unless rates are unregulated and negotiated to maximize industry profit. Regulatory failure is not an issue in this literature because no foreign effects are associated with termination rates.

Second, the literature on *international termination* neglects the domestic market by assuming that there is only international call traffic; see Jakopin (2008) for a survey. There is an argument in favor of regulation in these models (see, e.g. Hakim and Lu, 1993; Wright, 1999) because unregulated network operators set excessive termination rates. We show that the regulated termination rate can be larger than the profit-maximizing termination rate, depending on the share of international calls, such that deregulation can actually dominate regulation in terms of aggregate welfare across the two countries. The fact that international call volumes are relevant to termination rates distinguishes our model from those for network competition as well as those for international termination.

A third related strand of literature is the research on *mobile roaming*. Salsas and Koboldt (2004) and Lupi and Manenti (2009) show how unregulated firms set excessive inter-operator tariffs (similar to termination rates) relative to the social optimum. Bühler (2015) demonstrates that roaming alliances can soften price competition when there is competition in both the wholesale and retail markets. The profit-maximizing termination rate is independent of international calls in our model. Instead, NRAs have incentives to increase international termination rent, an aspect that is not considered in the roaming literature.

The rest of the paper is organized as follows: Section 2 develops the baseline framework for analyzing national regulation in the presence of international calls and national network operators. Section 3 considers the case of international network ownership. In Section 4, we investigate the profitability and welfare consequences of international consolidation and deregulation. Section 5 concludes the paper with final remarks. The appendix contains a table of notations and detailed proofs.

2 National network operators

2.1 The model

We consider a three-stage game. Termination rates are set in the first stage. Unregulated network operators negotiate termination rates to maximize industry profit. Under regulation, NRAs set termination rates simultaneously and independently to maximize national welfare. In the second stage, network operators observe all termination rates and compete in non-linear prices to maximize unilateral profit. In the third stage, consumers decide which network to subscribe to and how many calls to make based upon tariffs and their beliefs about network size. We solve for the subgame perfect equilibrium by means of backward induction.

Demand There are two countries, "Home" and "Foreign", indexed by $k \neq l \in \{H,F\}$. A continuum of consumers with unit measure are uniformly distributed on the unit interval in each country. Each consumer subscribes to one of two national networks, indexed by $i \neq j \in \{1,2\}$, located at each end of the interval. A consumer subscribing to network ki pays the subscription fee t_{ki}, places $q_{ki} \geq 0$ calls at price $p_{ki} \geq 0$ per call to a fraction λ of the $\bar{s}_{ki}$ consumers she expects will subscribe to her network, makes $\widehat{q}_{ki} \geq 0$ calls at price $\widehat{p}_{ki} \geq 0$ per call to $\lambda \bar{s}_{kj}$ consumers she expects will be subscribing to the other national network, places $x_{ki} \geq 0$ ($\widehat{x}_{ki} \geq 0$) international calls at price $r_{ki} \geq 0$ ($\widehat{r}_{ki} \geq 0$) per call to $\lambda \theta_k \bar{s}_{li}$ ($\lambda \theta_k \bar{s}_{lj}$) consumers she expects will be subscribing to network li (lj) abroad and consumes a numeraire good in amount $y \geq 0$. The parameter $\lambda \in (0,1]$ captures the possibility that consumers may have a personal network that is (much) smaller than the total network. The size of the national network is normalized to one, whereas $\theta_k \in (0,1]$ captures the size of the international network in country k.

The representative consumer places her calls to maximize

$$\lambda \bar{s}_{ki} u(q_{ki}) + \lambda \bar{s}_{kj} u(\widehat{q}_{ki}) + \lambda \theta_k \bar{s}_{li} u(x_{ki}) + \lambda \theta_k \bar{s}_{lj} u(\widehat{x}_{ki}) + y$$

subject to the budget constraint

$$\lambda \bar{s}_{ki} p_{ki} q_{ki} + \lambda \bar{s}_{kj} \widehat{p}_{ki} \widehat{q}_{ki} + \lambda \theta_k \bar{s}_{li} r_{ki} x_{ki} + \lambda \theta_k \bar{s}_{lj} \widehat{r}_{ki} \widehat{x}_{ki} + y + t_{ki} \leq I.$$

Assume that call utility u is twice continuously differentiable, increasing and strictly concave ($u' > 0$, $u'' < 0$ and $u''' \geq 0$) in the relevant domain and that income I is sufficiently high that call demand depends entirely on the own-call price: $q(p) = u'^{-1}(p)$, with $q(0) < \infty$, $q(P) = 0$ for some $P > 0$. Let $v(p) = \max_{q \geq 0}(u(q) - pq)$ be the corresponding indirect call utility.

A consumer located at $b \in [0,1]$ derives utility

$$v_0 + \lambda \bar{s}_{ki} v(p_{ki}) + \lambda \bar{s}_{kj} v(\widehat{p}_{ki}) + \lambda \theta_k \bar{s}_{li} v(r_{ki}) + \lambda \theta_k \bar{s}_{lj} v(\widehat{r}_{ki}) - t_{ki} + I - \frac{1}{2\sigma} |b_{ki} - b| \tag{1}$$

from subscribing to network ki. In this equation, $|b_{ki} - b|$ is the virtual distance from network ki, and $1/2\sigma$ is the virtual transportation cost and a measure of horizontal differentiation. The lower σ is, the more differentiated the networks are. To ensure that all consumers subscribe to one of the two networks, we assume that the utility v_0 of holding a subscription is sufficiently high that $s_{k1} + s_{k2} = 1$, where s_{ki} is the size of network ki.

As is standard in these models, on-net/off-net price discrimination creates network externalities in the sense that the value of belonging to a network depends on the expected sizes $\bar{s}_{k1}$ and $\bar{s}_{k2}$ of the two national networks. Hence, a change in the subscription fee t_{ki} affects the value of subscribing to network ki both directly and indirectly through its effect on network size. What is not standard are the *international* network externalities arising from price discrimination in the international segment: with international calls, consumer net surplus in a country also depends on the expected distribution $\bar{s}_{l1}$ and $\bar{s}_{l2}$ of market shares abroad.

Let $\bar{\mathbf{s}} = (\bar{s}_{H1}, \bar{s}_{H2}, \bar{s}_{F1}, \bar{s}_{F2})$ be the expected distribution of market shares at home and abroad. Expectations must be fulfilled in equilibrium: $\bar{\mathbf{s}} = \mathbf{s}$, where $\mathbf{s} = (s_{H1}, s_{H2}, s_{F1}, s_{F2})$ is the realized distribution of market shares. A share $\delta \in [0,1)$ of consumers have responsive expectations (Hoernig, 2012; Hurkens and López, 2014) in the sense that they correctly anticipate and take network effects into account when they choose which network to subscribe to: $\bar{\mathbf{s}} = \mathbf{s}$. The other $1-\delta$ share of consumers have passive expectations. Using (1), we explicitly solve for subscription demand in Appendix A (eq. 23) as a function of the expected distribution of market shares, subscription fees, call prices and subscription utility parameters.

Network profit There are four national network operators (NNOs). NNO_{ki} derives its profit

$$\begin{aligned}
\pi_{NNOki} = \quad & \underbrace{s_{ki}\lambda[s_{ki}(p_{ki}-c)q_{ki} + s_{kj}(\widehat{p}_{ki}-c-m_k)\widehat{q}_{ki}]}_{\text{Domestic call profit}} \\
+ \quad & \underbrace{s_{ki}\lambda\theta_k[s_{li}(r_{ki}-c-m_l)x_{ki} + s_{lj}(\widehat{r}_{ki}-c-m_l)\widehat{x}_{ki}]}_{\text{Foreign call profit}} \\
+ \quad & \underbrace{s_{ki}(t_{ki}-f)}_{\text{Subscription profit}} + \underbrace{s_{ki}\lambda m_k(s_{kj}\widehat{q}_{kj} + \theta_l(s_{li}x_{li} + s_{lj}\hat{x}_{lj}))}_{\text{Termination profit}}
\end{aligned} \tag{2}$$

from three sources: initiated calls (call profit), subscription fees (subscription profit) and termination of received calls (termination profit). The marginal cost of an on-net call equals $c = c_O + c_T < P$, where c_O (c_T) is the marginal cost of call origination (termination). No additional costs are associated with international calls. The marginal cost of call origination plus the domestic termination rate a_k yields the perceived marginal cost of an off-net call $c_O + a_k = c + m_k$, where $m_k = a_k - c_T$ is the markup on termination in country k. Under the assumption of reciprocal domestic termination rates, all international calls have the same perceived marginal cost $c_O + a_l = c + m_l$. The marginal subscription cost is f. To ensure equilibrium existence and uniqueness, we assume throughout that $(p-c)q'(p)$ is weakly decreasing in p.[3]

Termination rates are the same for domestic off-net calls and incoming international calls for arbitrage reasons. If network capacity is sufficiently high, then each NNO can bypass the domestic termination rate by rerouting national off-net calls through the international network. For a marginal cost of rerouting equal to ε, it is strictly profitable to transit national calls through the international network if the termination $\widehat{a}_k$ of international calls is substantially cheaper than domestic termination: $\widehat{a}_k < a_k - \varepsilon$. If $\widehat{a}_k > a_k + \varepsilon$, then foreign networks can bypass the international termination rate by transiting calls destined for NNO_{ki} through NNO_{kj}.[4] Hence, termination arbitrage implies $\widehat{a}_k \in [a_k - \varepsilon, a_k + \varepsilon]$. Marginal rerouting costs are tiny in modern telecommunication networks; thus, we set $\varepsilon = 0$, and therefore, $\widehat{a}_k = a_k$. The key point is that arbitrage renders the termination rates for national and foreign calls interdependent. Setting $\widehat{a}_k = a_k$ is a simplification, albeit a realistic one.[5] Note also that $m_k \geq -c$ because network ki could make infinite profits by initiating an unbounded amount of off-net calls to network kj if $m_k < -c$. Finally, operator profit depends on the termination rate in both countries, thereby rendering each network operator a *common agency*.

2.2 Retail equilibrium

NNO_{ki} chooses the menu of call prices $\mathbf{p}_{ki} = (p_{ki}, \widehat{p}_{ki}, r_{ki}, \widehat{r}_{ki})$ and the subscription fee t_{ki} to maximize network profit π_{NNOki}. As was first shown by Laffont et al. (1998b), call prices are set equal to their perceived marginal cost at the optimum. We show in Appendix A that this result continues to hold in the current setting. To see the intuition, note that a marginal reduction in, for example, the domestic off-net price $\hat{p}_{ki}$ has benefit $\lambda s_{kj}\hat{q}_{ki}$ for every consumer in network ki under consistent beliefs, $\bar{\mathbf{s}} = \mathbf{s}$. This allows the operator to increase the subscription fee by $\lambda s_{kj}\hat{q}_{ki}$ while keeping all consumers equally well off as before. Hence, the market shares in all networks remain unchanged by this manipulation. To the operator, the direct loss in call revenue is exactly offset by a corresponding increase in the subscription revenue; see (2). However, as off-net call demand increases, the price cut is profitable if the markup is positive ($\hat{p}_{ki} > c + m_k$). In the opposite case

[3] Examples of utility functions with the desired properties are $u(q) = -\gamma \exp\{(Q-q)/\gamma\} - q$, with $Q > 0$, $\gamma > 0$, alternatively, $u(q) = -b^{-1}(1+1/\gamma)^{-1}(Q-q)^{1+1/\gamma}$, with $Q > 0$, $b > 0$ and $\gamma \in (0,1]$.

[4] OECD (2014) discusses popular methods for bypassing termination rates by rerouting calls.

[5] Around the turn of the millennium, local service providers in Sweden started to take advantage of the fact that the termination rates for incoming foreign calls were much smaller than the domestic termination rates, by rerouting national calls abroad or outright refusing to pay the national termination rates. Rerouting of calls became gradually unprofitable as the mobile network operators renegotiated international termination rates to close this arbitrage possibility (Stennek and Tangerås, 2002).

of a negative markup, the network operator profits from increasing $\hat{p}_{ki}$, resulting in contracting call demand. At the optimum, therefore, the network operator sets the domestic off-net price (and all other call prices) equal to the perceived marginal cost. As a consequence of the marginal cost pricing of calls, both domestic and foreign call profit in (2) are zero. Network *ki* therefore trades off a higher subscription markup against the loss in subscribers in its choice of subscription fee, considering also the effect on termination profit:

$$\begin{aligned}\frac{\partial \pi_{NNOki}}{\partial t_{ki}} = & \underbrace{s_{ki} + \tfrac{\partial s_{ki}}{\partial t_{ki}}(t_{ki} - f)}_{\text{Marginal subscription profit}} \\ + & \underbrace{\lambda m_k [\tfrac{\partial s_{ki}}{\partial t_{ki}}(s_{kj} - s_{ki})\widehat{q}_{kj} + \theta_l (\tfrac{\partial s_{ki}}{\partial t_{ki}}(s_{li}x_{li} + s_{lj}\widehat{x}_{lj}) + \tfrac{\partial s_{li}}{\partial t_{ki}} s_{ki}(x_{li} - \widehat{x}_{lj}))]}_{\text{Marginal termination profit}} = 0.\end{aligned} \tag{3}$$

Marginal termination profit captures the effect of charging a higher subscription fee on termination profit. The domestic effect is ambiguous. On the one hand, termination demand tends to fall because there are fewer subscribers to reach in network *ki*. On the other hand, termination demand tends to increase because there are more subscribers calling from the other network. With full market coverage and a balanced call pattern, the two effects cancel out at symmetric market shares: $s_{ki} = s_{kj}$. The foreign effect tends to be negative if incoming calls do not vary too much across foreign networks ($x_{li} \approx \widehat{x}_{lj}$) because, then, a loss in its own subscribers is not offset by any increase in the share of incoming international calls.

Lemma 1. *There exists a unique retail equilibrium* $(\mathbf{p}^*_{NNOk}, t^*_{NNOk})$ *in country* $k \neq l = H, F$ *characterized by* $\mathbf{p}^*_{NNOk} = (c, c + m_k, c + m_l, c + m_l)$ *and*

$$t^*_{NNOk} - f + \lambda \theta_l m_k \hat{x}(c + m_k) = \tfrac{1}{2\sigma}[1 - 2\sigma\lambda\delta(v(c) - v(c + m_k))] \tag{4}$$

under national network ownership if networks are sufficiently differentiated or if each subscriber calls a small fraction of the total network ($\sigma\lambda$ is small).

Proof. See Appendix A. □

The equilibrium subscription fee $t^*_{NNOk} = t^*_{NNO}(m_k, \theta_l)$ is set according to an inverse elasticity rule. The left-hand side of (4) is the markup of the subscription fee over the perceived marginal subscription cost. Subscribers are valuable in part because they receive off-net calls that generate termination profit. Any factor that increases the profit on termination (say an increase in θ_l) simultaneously intensifies competition for subscribers and lowers the subscription fee. The right-hand side of (4) is the inverse of the semi-elasticity of subscription demand

$$-\frac{\partial s_{ki}}{\partial t_{ki}}\frac{1}{s_{ki}}\bigg|_{\mathbf{p}_{k1}=\mathbf{p}_{k2}=\mathbf{p}^*_{NNOk},t_{k1}=t_{k2}=t^*_{NNOk}} = \frac{2\sigma}{1-2\sigma\lambda\delta(v(c)-v(c+m_k))}. \tag{5}$$

Recall from eq. (1) that the value of subscribing to network ki increases in size if on-net calls are cheaper than off-net calls. The network externality makes it easier for a network to attract customers by reducing the subscription fee because a higher market share further accentuates the benefit of belonging to that network. This network multiplier increases the elasticity of subscription demand and is larger when there is a greater utility difference $v(c)-v(c+m_k)$ between on-net and off-net calls.

One might suspect that an increase in the termination rate must hurt mobile customers because off-net calls are more expensive. However, subscriptions also become cheaper as a consequence of intensified network competition, except for very high termination rates:

$$\frac{\partial t^*_{NNOk}}{\partial m_k} = -\lambda\theta_l(\hat{x}(c+m_k)+m_k\hat{x}'(c+m_k)) - \lambda\delta\hat{q}(c+m_k). \tag{6}$$

The first term in (6) is the marginal impact of the change in international termination profit, which is stronger when the share θ_l of incoming international calls is larger. The second term identifies the increase in subscription elasticity. This effect is stronger when the share δ of consumers who respond to price differences in their choice of network is larger. The counteracting effect of the subscription fee is commonly known as the "waterbed" effect (e.g., Jullien and Rey, 2008; Armstrong and Wright, 2009). Historically, the waterbed effect was so strong that consumers paid less on average for mobile services in countries with higher termination rates (Genakos and Valletti, 2011 and 2015). In the current model, consumer expenditures are decreasing for all termination rates in the range between termination cost and the monopoly level if $\theta_l+\delta > \frac{1}{2}$.[6]

2.3 The profit-maximizing termination rate

Assume that the two *NNO*s in country k negotiate the reciprocal markup m_k to maximize domestic industry profit:

$$\begin{aligned}\pi_{NNO}(m_k) = {} & t^*_{NNO}(m_k,\theta_l) - f + \tfrac{\lambda}{2}m_k(\widehat{q}(c+m_k)+2\theta_l\hat{x}(c+m_k)) \\ = {} & \underbrace{\tfrac{1}{2\sigma}[1-2\sigma\lambda\delta(v(c)-v(c+m_k))]}_{\text{Subscription markup}} + \underbrace{\tfrac{\lambda}{2}m_k\widehat{q}(c+m_k)}_{\text{Domestic termination profit}}.\end{aligned} \tag{7}$$

[6] The monopoly termination rate induces monopoly retail prices on off-net calls: $\frac{m}{c+m} = -\frac{q(c+m)}{(c+m)q'(c+m)}$.

Industry profit is the sum of subscription and termination profit because calls are priced at the perceived marginal cost. Substituting in the subscription fee from Lemma 1 yields the expression on the second line above. Industry profit is independent of the termination profit on international calls because this part of the profit is fully passed on to consumers through the waterbed effect; see eq. (6). The remaining industry profit consists of the subscription markup plus the domestic termination profit.

The trade-off facing the two *NNO*s in the choice of a termination rate is between intensified retail competition through the waterbed effect and a higher profit on domestic termination:

$$\pi'_{NNO}(m_k) = \underbrace{-\lambda\delta\widehat{q}(c+m_k)}_{\text{Waterbed effect}} \quad + \underbrace{\tfrac{\lambda}{2}(\widehat{q}(c+m_k)+m_k\widehat{q}'(c+m_k)).}_{\text{Marginal domestic termination profit}} \tag{8}$$

Lemma 2. *The profit-maximizing termination markup under national network ownership is independent of international calls. It is characterized by*

$$\frac{m^*}{c+m^*} = \frac{1-2\delta}{\eta(c+m^*)} \tag{9}$$

in the interior optimum, where $\eta(p) = -q'(p)p/q$ is the price elasticity of call demand.

Proof. An optimum exists through maximization of the continuous function π_{NNO} over the closed interval $[-c, P-c]$. The optimum is unique because industry profit is strictly quasi-concave in m_k by the assumptions on $q(p)$ and $\delta < 1$. A solution represents an interior optimum if and only if $\pi'_{NNO}(m_k) = 0$, which is equivalent to (9). □

The waterbed effect is stronger when the share δ of responsive consumers is larger because the network externality is stronger; see eq. (6). In fact, it is optimal for firms to set a termination rate below cost when the share of responsive consumers is sufficiently large ($\delta > 1/2$). Henceforth, we refer to this situation as the case of an *excessive* waterbed effect. The marginal termination profit dominates the trade-off in the opposite case of a (*weakly*) *incomplete* waterbed effect ($\delta(\leq) < 1/2$), which renders the profit-maximizing termination markup (non-negative) positive. These results were established by Hoernig (2012) and Hurkens and López (2014) for the case of national network competition. Lemma 2 shows that the results extend to international calls. Off-net calls are typically more expensive than on-net calls under price discrimination. This price differential is equivalent to positive termination markups in the current model. Based upon actual price patterns, the most relevant case therefore appears to be that of an incomplete waterbed effect.

2.4 Regulation

This section derives the social optimum and analyzes the national regulation of termination rates in the presence of national network operators. We show how international calls cause NRAs to set termination rates above the level that maximizes aggregate welfare across the two countries.

Welfare in country k is a weighted sum of consumer surplus and industry profit, $CS_{NNOk}+(1-\alpha)\pi_{NNO}(m_k)$, where consumer surplus is the value of national on-net calls, national off-net calls and international calls, less the subscription fee:

$$CS_{NNOk}=\frac{\lambda}{2}v(c)+\frac{\lambda}{2}v(c+m_k)+\lambda\theta_k v(c+m_l)-t^*_{NNO}(m_k,\theta_l). \tag{10}$$

We have normalized consumer surplus by eliminating the utility v_0 of holding a subscription, income I and the average cost $1/8\sigma$ of differentiation, all of which are constant throughout based on the assumption of constant market size. $1-\alpha\leq 1$ is the weight attached to industry profit relative to consumer surplus. To ensure that the objective functions are well-behavied for termination rates below cost, we assume that $\alpha\leq min\{1;\frac{1}{2(1-\delta)}\}$. With expressions (7) and (10), national welfare becomes

$$\begin{aligned} w_{NNOk}(\mathbf{m},\theta,\alpha)= &\underbrace{\frac{\lambda}{2}(v(c)+v(c+m_k)+2\theta_k v(c+m_l))}_{\text{Consumer net surplus (gross of subscription fees)}} \\ +&\underbrace{\frac{\lambda}{2}m_k(\widehat{q}(c+m_k)+2\theta_l\hat{x}(c+m_k))}_{\text{Termination profit}}-\underbrace{\alpha\pi_{NNO}(m_k)}_{\text{Redistribution}}, \end{aligned} \tag{11}$$

where $\mathbf{m}=(m_H,m_F)$ and $\theta=(\theta_H,\theta_F)$. For simplicity, we have normalized industry profit by eliminating the constant subscription cost f. All else being equal, the policy maker would like to minimize industry profit because she attaches a larger weight to consumer surplus than to industry profit.

Social optimum Under the assumption of unregulated retail competition, the benevolent social planner chooses termination markups $\mathbf{m}$ to maximize the weighted sum of aggregate consumer surplus and industry profit:

$$w_{NNO}(\mathbf{m},\theta,\alpha)=\sum_{k=H,F}\frac{\lambda}{2}[v(c)+(1+2\theta_l)v(c+m_k)+m_k(\widehat{q}(c+m_k)+2\theta_l\hat{x}(c+m_k))-\frac{2}{\lambda}\alpha\pi_{NNO}(m_k)].$$

The marginal aggregate welfare effect of increasing the termination rate in country k is

$$\frac{\partial w_{NNO}}{\partial m_k}=\underbrace{\frac{\lambda}{2}m_k(\widehat{q}'(c+m_k)+2\theta_l\hat{x}'(c+m_k))}_{\text{Retail price distortion}}-\underbrace{\alpha\frac{\lambda}{2}((1-2\delta)\widehat{q}(c+m_k)+m_k\widehat{q}'(c+m_k))}_{\text{Domestic rent extraction}}. \tag{12}$$

The efficient solution is to set termination rates at marginal termination cost in both countries

($m_H = m_F = 0$) because this strategy minimizes price distortions in the retail market. However, the social planner may also care about redistributing income from industry to consumers ($\alpha > 0$). In this case, termination rates will generally be distorted away from the efficient level to extract rent:

Lemma 3. *The termination markup in country k that maximizes aggregate welfare under national network ownership is characterized by*

$$\frac{m^{soc}_{NNOk}}{c + m^{soc}_{NNOk}} = \frac{\alpha(2\delta - 1)}{1 - \alpha + 2\theta_l} \frac{1}{\eta(c + m^{soc}_{NNOk})} \tag{13}$$

in the interior optimum. The socially optimal termination rate is closer to the marginal termination cost when the share θ_l of incoming international calls is larger and when redistribution is less important (α is smaller).

Proof. The additive separability of the aggregate welfare function in m_H and m_F implies that the social planner can optimize separately over the two. The proof of existence and uniqueness as well as the characterization of the optimum are analogous to the proof of Lemma 2 and are therefore omitted. The comparative statics results in an interior optimum (assuming also that $\alpha(2\delta - 1) \neq 0$) follow from strict quasi-concavity of w_{NNO}, $\frac{\partial^2 w_{NNO}}{\partial m_k \partial \theta_l}|_{m_k = m^{soc}_{NNO_k}} = \lambda m^{soc}_{NNO_k} \hat{x}'(c + m^{soc}_{NNO_k})$ and $\frac{\partial^2 w_{NNO}}{\partial m_k \partial \alpha}|_{m_k = m^{soc}_{NNO_k}} = -\lambda \frac{1+2\theta_l}{2\alpha} m^{soc}_{NNO_k} \widehat{q}'(c + m^{soc}_{NNO_k})$. The first cross-partial derivative is positive (negative) if $m^{soc}_{NNO_k} < 0$ ($m^{soc}_{NNO_k} > 0$), which implies $dm^{soc}_{NNOk}/d\theta_l$ positive (negative). The second cross-partial derivative has the opposite properties. □

The termination markup that maximizes aggregate welfare across the two countries can be either positive or negative (for $\alpha > 0$) and larger or smaller than the profit-maximizing rate, depending on the strength of the waterbed effect (as measured by δ). However, the social optimum and the profit-maximizing rate are generally located on opposite sides of the efficient rate. The socially optimal termination rate is closer to the efficient level when the share of incoming international calls is larger because the price distortion on international calls is more important for welfare in that case. Intuitively, it deviates more from the efficient level when redistribution is more important. Under a *complete* waterbed effect ($\delta = 1/2$), the loss in subscription profit exactly matches the direct increase in termination profit of a higher termination rate in (8), causing network operators to prefer an efficient termination rate ($m^* = 0$). Furthermore, rent extraction from domestic firms is exactly proportional to the domestic retail price distortion in (12), in which case the aggregate welfare optimum corresponds to the efficient termination rate, independent of redistribution preferences. Hence, the social optimum and the profit-maximizing termination rate are identical in the special case of a complete waterbed effect.

National regulation Let us now contrast the socially optimal termination rate and the rate preferred by the network operators with the termination rate set by an NRA in country k (NRA_k). By assumption, NRA_k chooses the termination markup m_k to maximize the weighted sum of domestic consumer surplus and domestic industry profit, w_{NNOk}. The marginal domestic welfare effect of increasing the termination markup in country k is

$$\frac{\partial w_{NNOk}}{\partial m_k} = \underbrace{\tfrac{\lambda}{2} m_k(\widehat{q}'(c+m_k) + 2\theta_l \hat{x}'(c+m_k))}_{\text{Retail price distortion}} \underbrace{-\alpha\tfrac{\lambda}{2}((1-2\delta)\widehat{q}(c+m_k) + m_k\widehat{q}'(c+m_k))}_{\text{Domestic rent extraction}} + \underbrace{\lambda\theta_l\hat{x}(c+m_k).}_{\text{Foreign rent extraction}} \quad (14)$$

The retail price distortion and domestic rent extraction of an increase in the termination rate are the same as in the marginal aggregate welfare function (12). Hence, NRA_k would set the termination markup at the socially optimal level if there was no international dimension to network competition, i.e., $\theta_l = 0$. The final term above identifies a *rent extraction effect on international termination*, which tends to increase the termination rate.

Changes to the foreign termination rate have consequences for welfare at home ($\frac{\partial w_{NNOk}}{\partial m_l} = -\lambda\theta_k\hat{x}(c+m_l)$), but there is no associated effect on the marginal benefit of changing the domestic termination rate ($\frac{\partial^2 w_{NNOk}}{\partial m_k \partial m_l} = 0$). This additive separability of the domestic welfare function implies a lack of strategic interaction among regulatory authorities here. Furthermore, the fact that network operators are common agencies does not affect regulation in the present context. Each NRA behaves as a regulatory monopoly and sets the termination rate to balance the retail price distortion against the marginal rent extraction from domestic operators and international calls:

Proposition 1. *An NRA in country k maximizing domestic welfare sets the termination markup*

$$\frac{m^R_{NNOk}}{c+m^R_{NNOk}} = \frac{2\theta_l + \alpha(2\delta-1)}{1-\alpha+2\theta_l}\frac{1}{\eta(c+m^R_{NNOk})} \quad (15)$$

in interior equilibrium under national network ownership. The (interior) regulated termination rate is excessive compared to the social optimum and is larger when the share of incoming international calls is greater ($m^R_{NNOk} > m^{soc}_{NNOk}$ and $\partial m^R_{NNOk}/\partial\theta_l > 0$). This rate is smaller than the profit-maximizing termination rate and smaller when redistribution is more important if and only if the waterbed effect is incomplete and the share of incoming international calls is sufficiently small ($m^R_{NNOk} < m^*$ and $\partial m^R_{NNOk}/\partial\alpha < 0$ if and only if $\delta < 1/2$ and $\theta_l < \frac{1-2\delta}{4\delta}$).

Proof. The proof of existence and uniqueness as well as the characterization of the equilibrium are analogous to the proof of Lemma 2 and are therefore omitted. Strict quasi-concavity of w_{NNO} and w_{NNOk} plus $\frac{\partial w_{NNO}}{\partial m_k}|_{m_k=m^R_{NNOk}} = -\lambda\theta_l\hat{x}(c+m^R_{NNOk})$ and $\frac{\partial^2 w_{NNO_k}}{\partial m_k\partial\theta_l}|_{m_k=m^R_{NNOk}} = \frac{\lambda}{1+2\theta_l}\hat{x}(c+m^R_{NNOk})$ yield the first pair of comparative statics results. Strict quasi-concavity of π_{NNO} and w_{NNOk}

plus $\pi'_{NNO}(m^R_{NNOk}) = -\frac{\partial^2 w_{NNOk}}{\partial m_k \partial \alpha}|_{m_k = m^R_{NNOk}} = \frac{\lambda}{2}\frac{1-2\delta-4\delta\theta_l}{1-\alpha+2\theta_l}\widehat{q}(c+m^R_{NNOk})$ yield the second pair of results. □

Proposition 1 shows that the incentive to exploit market power in international termination prevents NRAs from reducing termination rates to the social optimum. If domestic and international termination rates were independent of one another, then the domestic termination rate would be set at the socially optimal level, whereas the international termination rate would be set at the monopoly level for any positive θ_l. As termination rates are linked through the arbitrage condition on bypass, the single regulated termination rate is a trade-off between domestic and international effects.

International rent extraction is relatively more important than retail price distortions when the share θ_l of incoming international calls increases, which raises the regulated termination rate. By the same token, the model predicts termination rates to be higher in countries with a larger share of incoming international calls compared to countries with mainly national calls.[7] In comparison, the profit-maximizing termination rate is independent of international calls. Hence, the regulated termination rate exceeds the profit-maximizing rate if the share of incoming international calls is sufficiently large. Finally, a stronger focus on redistribution (the NRA attaches a relatively larger weight α to consumer surplus relative to network profit) has an ambiguous effect on the regulated termination rate because rent extraction is positively or negatively related to increases in the termination rate depending on the strength of the waterbed effect and the share of incoming international calls.

Standard arguments would attribute the above exercise of trade policy to an incentive to favor the domestic industry. This is not the case here. Network competition yields a full pass-through of the rent on international termination to consumers, leaving domestic network operators independent of international calls; see eq. (7). Network operators abroad are not affected by any changes to the domestic termination rate; therefore, the exercise of market power in international termination effectively transfers surplus from consumers abroad (through higher international call prices) to domestic consumers (through lower subscription fees).

3 International network operators

The previous section established that NRAs have incentives to set excessive termination rates from an aggregate welfare perspective. This section discusses the consequences of conglomerate mergers between national network operators.

[7] Domestic welfare also depends on the share θ_k of outgoing international calls. However, the volume of outgoing international calls is determined by the termination rate m_l abroad and is therefore outside the control of NRA_k.

3.1 The model

The game is essentially the same as in Section 2. The only difference is that we now assume that the two national networks Hi and Fi are owned by international network operator INO_i, $i \in \{1,2\}$. We can think of each country as having one INO as a result of previous national monopolies expanding abroad. To maintain symmetry, assume that the degree of internationalization is the same in the two countries: $\theta_H = \theta_F = \theta$. The profit of INO_i equals $\pi_i = \pi_{Hi} + \pi_{Fi}$, where the national profit in country k now equals

$$\begin{aligned} \pi_{ki} = & \underbrace{s_{ki}\lambda[s_{ki}(p_{ki}-c)q_{ki}+s_{kj}(\widehat{p}_{ki}-c-m_k)\widehat{q}_{ki}]}_{\text{Domestic call profit}} \\ + & \underbrace{s_{ki}\lambda\theta[s_{li}(r_{ki}-c)x_{ki}+s_{lj}(\widehat{r}_{ki}-c-m_l)\widehat{x}_{ki}]}_{\text{Foreign call profit}} \\ + & \underbrace{s_{ki}(t_{ki}-f)}_{\text{Subscription profit}} + \underbrace{s_{ki}\lambda m_k(s_{kj}\widehat{q}_{kj}+\theta s_{lj}\widehat{x}_{lj})}_{\text{Termination profit}}. \end{aligned}$$

Compared to the profit of network ki under national ownership, eq. (2), the perceived marginal cost of an international call now depends on whether the call is terminated inside the own network abroad (with cost equal to c) or in the foreign network abroad (with cost equal to $c+m_l$). Previously, all international costs had the same perceived marginal cost $c+m_l$. This difference in the perceived marginal call cost implies that the INO engages in termination-based price discrimination even on international calls. Furthermore, the foreign termination profit is smaller than before (if $m_k > 0$) because INO_i is now paid to terminate calls from only one of the two foreign networks.

3.2 Retail equilibrium

INO_i chooses a menu of call prices $\mathbf{p}_i = (\mathbf{p}_{Hi}, \mathbf{p}_{Fi})$ and subscription fees $\mathbf{t}_i = (t_{Hi}, t_{Fi})$ to maximize π_i. Call prices are set at the perceived marginal cost even in this case, such that the optimal choice of subscription fee in country Hi is a trade-off between marginal subscription profit and marginal termination profit summarized for both countries:

$$\begin{aligned} \frac{\partial \pi_i}{\partial t_{Hi}} = & \underbrace{s_{Hi} + \sum_{k=H,F} \frac{\partial s_{ki}}{\partial t_{Hi}}(t_{ki}-f)}_{\text{Marginal subscription profit}} \\ + & \underbrace{\sum_{k=H,F} \lambda m_k[\frac{\partial s_{ki}}{\partial t_{Hi}}(s_{kj}-s_{ki})\widehat{q}_{kj} + \theta(\frac{\partial s_{ki}}{\partial t_{Hi}}s_{lj} - s_{ki}\frac{\partial s_{li}}{\partial t_{Hi}})\widehat{x}_{lj}]}_{\text{Marginal termination profit}} = 0, \end{aligned} \quad (16)$$

with a similar effect of increasing t_{Fi}.

Lemma 4. *There exists a unique retail equilibrium* $\mathbf{p}^*_{INO} = (\mathbf{p}^*_{INOH}, \mathbf{p}^*_{INOF})$ *and* $\mathbf{t}^*_{INO} = (t^*_{INOH}, t^*_{INOF})$ *characterized by* $\mathbf{p}^*_{INOk} = (c, c+m_k, c, c+m_l)$ *and*

$$t^*_{INOk} - f + \frac{\lambda}{2}\theta(m_k\widehat{x}(c+m_k) - m_l\widehat{x}(c+m_l)) = \frac{1}{2\sigma}[1 - 2(1+\theta)\sigma\lambda\delta(v(c) - v(c+m_k))] \quad (17)$$

under international network ownership if networks are sufficiently differentiated or if each subscriber calls a small fraction of the total network ($\sigma\lambda$ is small).

Proof. See Appendix A. □

The shift from national to international network operations implies a decline in the call prices of all international calls originating and terminating within the multinational network (if termination markups are positive) because the perceived marginal costs of those calls decrease from $c + m_H$ and $c + m_F$ to c. Competition for subscribers is affected in two ways. Termination-based price discrimination in the international segment gives rise to international call externalities (in addition to domestic call externalities). If on-net calls are cheaper than off-net calls, then positive international network externalities provide an additional benefit for network operators in reducing subscription fees, namely, the possibility of attracting additional subscribers abroad through a larger international network. Because the total size of the market is constant, these additional network externalities only serve to intensify competition and lower the equilibrium subscription fee $t^*_{INOk} = t^*_{INOk}(\mathbf{m}, \theta)$ in each country. This competition effect materializes as an international semi-elasticity that is higher than the national semi-elasticity (5):

$$-\frac{\left[s_{ki}\frac{\partial s_{li}}{\partial t_{li}} - s_{li}\frac{\partial s_{li}}{\partial t_{ki}}\right]}{\left[\frac{\partial s_{ki}}{\partial t_{ki}}\frac{\partial s_{li}}{\partial t_{li}} - \frac{\partial s_{li}}{\partial t_{ki}}\frac{\partial s_{ki}}{\partial t_{li}}\right]}\Big|_{\mathbf{p}_1=\mathbf{p}_2=\mathbf{p}^*_{INO}, \mathbf{t}_1=\mathbf{t}_2=\mathbf{t}^*_{INO}} = \frac{2\sigma}{1 - 2(1+\theta)\sigma\lambda\delta(v(c) - v(c+m_k))}.$$

Recall that a higher profitability of international call termination intensifies retail competition at home and lowers subscription fees under national network ownership. This incentive is comparatively weaker under international ownership because there is less termination of international off-net calls from the start and because a loss of subscribers at home then generates termination profit abroad. Because of the ambiguous effects of consolidation, equilibrium subscription fees can be higher or lower under international than national network ownership. This ambiguity also implies that the (domestic) waterbed effect

$$\frac{\partial t^*_{INOk}}{\partial m_k} = -\frac{\lambda}{2}\theta(\widehat{x}(c+m_k) + m_k\widehat{x}'(c+m_k)) - (1+\theta)\lambda\delta\hat{q}(c+m_k) \quad (18)$$

can be stronger or weaker than that under national network ownership.

3.3 The profit-maximizing termination rate

Assume that the two *INO*s jointly negotiate termination markups $\mathbf{m} = (m_H, m_F)$ to maximize total industry profit. All calls are priced at the perceived marginal cost; hence, industry profit in country k consists entirely of the subscription profit and termination profit

$$\begin{aligned} \pi_{INOk}(\mathbf{m}, \theta) = & \; t^*_{INOk}(\mathbf{m}, \theta) - f + \tfrac{\lambda}{2} m_k(\hat{q}(c+m_k) + \theta \hat{x}(c+m_k)) \\ = & \; \tfrac{1}{2\sigma}[1 - 2(1+\theta)\sigma\lambda\delta(v(c) - v(c+m_k))] + \tfrac{\lambda}{2}(m_k \hat{q}(c+m_k) + m_l \theta \widehat{x}(c+m_l)), \end{aligned} \quad (19)$$

where we have substituted in the subscription fee from Lemma 4 in the second line above and simplified. Industry profit now depends on the share of international calls because of the greater elasticity of subscription demand under international network ownership and because of price discrimination on international calls. Summing over both countries yields the total industry profit

$$\pi_{INO}(\mathbf{m}, \theta) = \sum_{k=H,F} \{\tfrac{1}{2\sigma}[1 - 2(1+\theta)\sigma\lambda\delta(v(c) - v(c+m_k))] + \tfrac{\lambda}{2} m_k(\hat{q}(c+m_k) + \theta \widehat{x}(c+m_k))\}.$$

The marginal effect

$$\frac{\partial \pi_{INO}}{\partial m_k} = \tfrac{\lambda}{2}(1+\theta)[(1-2\delta)\widehat{q}(c+m_k) + m_k \widehat{q}'(c+m_k)],$$

of increasing the termination markup rate in country k on profit is proportional to the trade-off facing the *NNO*s. Although the presence of an international network externality intensifies network competition and tends to lower the profit-maximizing termination rate, the countervailing effect of increased marginal termination profit goes in the opposite direction. Those two effects are proportional because of the balanced call pattern and symmetry. The following result is obvious:

Lemma 5. *The profit-maximizing termination rate is the same in both countries under international network ownership and identical to the rate under national network ownership. In particular, the profit-maximizing termination rate is independent of international calls.*

3.4 Regulation

In a departure from the previous section, we henceforth assume that $\alpha = 0$. We let one international network operator be located in each country. Domestic welfare is then the sum of the consumer surplus

$$CS_{INOk} = \tfrac{\lambda}{2}(v(c) + v(c+m_k) + \theta v(c) + \theta v(c+m_l)) - t^*_{INOk}(\mathbf{m}, \theta) \quad (20)$$

and profit $\frac{1}{2}\pi_{INO}(\mathbf{m},\theta)$ of the home INO. Using (19) and (20), we can express domestic welfare under international ownership as

$$\begin{aligned} w_{INOk}(\mathbf{m},\theta) = \; & \underbrace{\tfrac{\lambda}{2}(v(c)+v(c+m_k)+\theta v(c)+\theta v(c+m_l))}_{\text{Consumer net surplus (gross of subscription fees)}} \\ + \; & \underbrace{\tfrac{\lambda}{2}m_k(\widehat{q}(c+m_k)+\theta\hat{x}(c+m_k))}_{\text{Termination profit}} \\ + \; & \underbrace{\tfrac{1}{2}\pi_{INOl}(\mathbf{m},\theta)}_{\text{Ownerhip abroad}} - \underbrace{\tfrac{1}{2}\pi_{INOk}(\mathbf{m},\theta)}_{\text{Redistribution}} \end{aligned} \tag{21}$$

while neglecting unimportant constants. This expression differs from domestic welfare $w_{NNOk}(\mathbf{m},\theta,\theta,0)$ under national ownership in a number of important aspects; see eq. (11). Price discrimination in the international segment implies higher consumer net surplus because of the lower international call prices when termination markups are positive, but a loss in termination profit also occurs because there is less international termination. The two terms on the third line are new. The first represents the profit on operations abroad, and the second accounts for the part of domestic profit that floats out of the country owing to foreign ownership of one of the domestic networks.

Social optimum Redistribution of income between consumers and network operators vanishes based on the assumption of $\alpha=0$ such that retail prices are the only relevant factors for aggregate welfare:

$$w_{INO}(\mathbf{m},\theta) = \sum_{k=H,F} \tfrac{\lambda}{2}[(1+\theta)(v(c)+v(c+m_k))+m_k(\widehat{q}(c+m_k)+\theta\hat{x}(c+m_k))].$$

Efficiency is achieved by setting the termination rate equal to the marginal termination cost in both markets, $m^{soc}_{INOH}=m^{soc}_{INOF}=0$, which is the same as that under national ownership: $m^{soc}_{NNOH}=m^{soc}_{NNOF}=0$ (for $\alpha=0$). Such cost-based regulation is a realistic benchmark. Recall the discussion in the Introduction indicating that the European Commission (2009) recommends that NRAs use long-run incremental cost as a basis for regulating termination rates.

National regulation The NRA in country k, NRA_k, chooses the markup m_k to maximize domestic welfare, w_{INOk}. The marginal effect of a higher termination markup is

$$\begin{aligned} \frac{\partial w_{INOk}}{\partial m_k} = \; & \underbrace{\tfrac{\lambda}{2}m_k(\widehat{q}'(c+m_k)+\theta\widehat{x}'(c+m_k))}_{\text{Retail price distortion}} + \underbrace{\tfrac{\lambda}{2}\theta\hat{x}(c+m_k)}_{\text{Foreign rent extraction}} \\ & + \underbrace{\tfrac{\lambda}{4}\theta(m_k\widehat{x}'(c+m_k)+\widehat{x}(c+m_k))}_{\text{Marginal international profit}} - \underbrace{\tfrac{\lambda}{4}[(1-2\delta(1+\theta))\hat{q}(c+m_k)+m_k\hat{q}'(c+m_k)]}_{\text{Domestic rent extraction from foreign INO}}. \end{aligned}$$

The retail price distortion and rent extraction from foreign consumers are smaller in magnitude than they are under national network ownership (see 14) because a larger share of calls are terminated within the own international network. The first term on the second line is the marginal effect of increasing the domestic termination rate on INO profit abroad. Changes in the domestic termination rate are important because the magnitude of international termination profit affects competition abroad. Nevertheless, indirect rent extraction running through foreign profits is not sufficient to offset the effect of more calls being terminated on-net: if the first three effects were the only relevant ones, then regulated termination rates would be unambiguously lower under international ownership than under national ownership. The final effect determining the regulated termination rate is the desire to extract rent from the foreign *INO* active in the home market. The domestic waterbed effect is strong if the share θ of international calls is large or if the share δ of responsive consumers is large; see eq. (18). NRA_k then extracts *INO* profit by setting a termination rate above the level that would prevail under national ownership. In the opposite case with an incomplete waterbed effect and a small share of international calls, international ownership lowers the regulated termination rate.

Proposition 2. *An NRA in country k maximizing domestic welfare sets the termination markup*

$$\frac{m^R_{INO}}{c+m^R_{INO}} = \frac{3+2\delta}{1+3\theta}(\theta - \frac{1-2\delta}{3+2\delta})\frac{1}{\eta(c+m^R_{INO})} \tag{22}$$

in interior equilibrium under international network ownership. The (interior) regulated termination rate is excessive compared to the social optimum unless the waterbed effect is incomplete, and the share of international calls is very small ($m^R_{INO} \leq 0$ if and only if $\delta < 1/2$ and $\theta \leq \frac{1-2\delta}{3+2\delta}$). This rate is smaller than both the profit-maximizing termination rate and the regulated termination rate under national network ownership if and only if the waterbed effect is incomplete, and the share of international calls is sufficiently small ($m^R_{INO} < m^*$ and $m^R_{INO} < m^R_{NNOk}$ (for $\theta_H = \theta_L = \theta$ and $\alpha = 0$) if and only if $\delta < 1/2$ and *$\theta < \frac{1-2\delta}{4\delta}$).*

Proof. The proof of existence and uniqueness and the characterization of the equilibrium are analogous to the proof of Lemma 2 and are therefore omitted. The comparison with the social optimum follows directly from an inspection of (22). Strict quasi-concavity of π_{NNO} and w_{NNOk} plus $\pi'_{NNO}(m^R_{INO}) = \frac{2}{1+\theta}\frac{\partial w_{NNOk}}{\partial m_k}|_{m_k=m^R_{INO}} = \lambda\frac{1-2\delta-4\delta\theta}{1+3\theta}\hat{q}(c+m^R_{INO})$ yield the second result, where we (for the sake of comparison) have assumed that $\alpha = 0$ and $\theta_H = \theta_L = \theta$ also under national network ownership. □

Rent extraction from the foreign INO has a downward effect on the regulated termination rate if the waterbed effect is incomplete and if the share of international calls is sufficiently small. This downward pressure may even be sufficiently strong to push the regulated termination rate below the social optimum, in contrast to the case of national network ownership.

4 Welfare analysis

There is scope for regulation because unregulated network operators would distort termination rates in a collusive effort to increase industry profit. However, NRAs also have incentives to distort termination rates to extract rent from international termination and from foreign-owned network operators. In this section, we first analyze the welfare consequences of conglomerate mergers (international network consolidation) and then consider the effects of deregulation. Facilitating cross-border consolidation of network operations is one of the policies currently under consideration in the EU. Deregulation is a long-term policy objective of the EU. We identify the conditions under which each of these increases aggregate welfare.

4.1 The welfare effects of international network consolidation

Let $\tilde{w}_{NNO}(m) = w_{NNO}(m, m, \theta, \theta, 0)$ be the aggregate welfare under national network ownership when the termination markup m and the share θ of international calls are the same in both countries, and consumer surplus and industry profit carry equal weights in the welfare function ($\alpha = 0$). We define $\tilde{w}_{INO}(m) = w_{INO}(m, m, \theta)$ correspondingly. Then, $w^R_{INO} = \tilde{w}_{INO}(m^R_{INO})$ defines aggregate equilibrium welfare under international network ownership, and $w^R_{NNO} = \tilde{w}_{NNO}(m^R_{NNO})$ is the aggregate equilibrium welfare under national network ownership, where m^R_{NNO} is characterized in eq. (15) by setting $\theta_l = \theta$ and $\alpha = 0$. International network ownership has two welfare effects:

$$\begin{aligned} w^R_{INO} - w^R_{NNO} = \; & \underbrace{\lambda \theta [v(c) - v(c + m^R_{NNO}) - m^R_{NNO} \hat{x}(c + m^R_{NNO})]}_{\text{Reduced call price distortion}} \\ + \; & \underbrace{w^R_{INO} - \tilde{w}_{INO}(m^R_{NNO}).}_{\text{Regulatory response}} \end{aligned}$$

Holding the termination rate fixed at m^R_{NNO}, we find a direct welfare benefit stemming from the fact that international call prices are less distorted under international ownership. Second, national termination rates will change in response to the change in ownership structure. This regulatory response unambiguously increases welfare if the waterbed effect is incomplete ($\delta < 1/2$), and markets are characterized by an intermediate share of international calls ($\frac{1-2\delta}{3+2\delta} \leq \theta \leq \frac{1-2\delta}{4\delta}$) because the regulated termination rate is then less distorted under international than under national ownership, $0 \leq m^R_{INO} \leq m^R_{NNO}$ (see Proposition 2). For all other parameter configurations, the welfare effect of the regulatory response is either ambiguous ($m^R_{INO} < 0 < m^R_{NNO}$) or there is a trade-off between the benefit of the reduced call-price distortion and the welfare cost of the regulatory response ($0 < m^R_{NNO} < m^R_{INO}$). We arrange these observations in the following proposition:

Proposition 3. *Aggregate welfare is unambiguously higher under international network owner-*

ship than under national network ownership if the waterbed effect is incomplete, and the share of international calls is intermediate ($w^R_{INO} > w^R_{NNO}$ if $\delta < 1/2$ and $\theta \in [\frac{1-2\delta}{3+2\delta}, \frac{1-2\delta}{4\delta}]$). Otherwise, the welfare effect is ambiguous.

Proposition 3 treats changes in ownership structure as a policy variable. Certainly, regulators and competition authorities can sometimes block undesirable consolidation, but they cannot force private companies to merge. Furthermore, the anticipation that ownership change may subsequently influence regulation could affect the benefits of consolidation. Let symmetric consolidation refer to the case in which the four national network operators have merged into two international network operators. We let $\tilde{\pi}_{INO}(m) = \pi_{INO}(m,m,\theta)$ define total industry profit under international network ownership when the termination rate is the same in both countries. Then, $\pi^R_{INO} = \tilde{\pi}_{INO}(m^R_{INO})$ characterizes the equilibrium industry profit under symmetric consolidation and regulation, whereas $2\pi^R_{NNO} = 2\pi_{NNO}(m^R_{NNO})$ is the corresponding equilibrium industry profit under national network ownership. The net effect of symmetric consolidation on network profit is

$$\begin{aligned}\pi^R_{INO} - 2\pi^R_{NNO} = \lambda\theta[m^R_{NNO}\hat{x}(c+m^R_{NNO}) - 2\delta(v(c) - v(c+m^R_{NNO}))]\\ + \pi^R_{INO} - \tilde{\pi}_{INO}(m^R_{NNO}).\end{aligned}$$

The term on the first line above is the ambiguous effect of consolidation on network competition and termination profit when we hold the termination markup fixed at m^R_{NNO}. The term on the second line above is the negative regulatory response.

Lemma 6. *Symmetric consolidation increases total industry profit relative to national network ownership under regulation only if the waterbed effect is incomplete, and the share of international calls is sufficiently large ($\pi^R_{INO} \geq 2\pi^R_{NNO}$ only if $\delta < 1/2$ and $\theta > \frac{1-2\delta}{3+2\delta}$).*

Proof. The function $H(m) = m\hat{x}(c+m) - 2\delta(v(c) - v(c+m))$ is strictly quasi-concave with an interior maximum at m^*. If $\delta \geq 1/2$, then $m^* \leq 0 < m^R_{NNO} \leq m^R_{INO}$. Strict quasi-concavity of H and $\tilde{\pi}_{INO}$ then imply $0 = \lambda\theta H(0) > \lambda\theta H(m^R_{NNO}) = \tilde{\pi}_{INO}(m^R_{NNO}) - 2\pi^R_{NNO}$ and $\tilde{\pi}_{INO}(m^R_{NNO}) \geq \pi^R_{INO}$, respectively. Collecting inequalities yields $\pi^R_{INO} \leq \tilde{\pi}_{INO}(m^R_{NNO}) < 2\pi^R_{NNO}$. If $\delta < 1/2$ and $\theta \leq \frac{1-2\delta}{3+2\delta}$, then $m^R_{INO} \leq 0 < m^R_{NNO} < m^*$. Strict quasi-concavity of H and π_{NNO} then imply $\pi^R_{INO} - 2\pi_{NNO}(m^R_{INO}) = \lambda\theta H(m^R_{INO}) \leq \lambda\theta H(0) = 0$ and $\pi_{NNO}(m^R_{INO}) < \pi^R_{NNO}$, respectively. Collecting inequalities yields $\pi^R_{INO} \leq 2\pi_{NNO}(m^R_{INO}) < 2\pi^R_{NNO}$. □

Assume that all consolidation is symmetric and occurs under national regulation if and only if it increases aggregate industry profit ($\pi^R_{INO} > 2\pi^R_{NNO}$). The first implication of voluntary consolidation is that observed regulated termination rates will always be above the termination cost (assuming $\theta_H = \theta_L = \theta > 0$ and $\alpha = 0$). The markup is positive under national network ownership ($m^R_{NNO} > 0$); see Proposition 1. Consolidation will occur only in the parameter range that yields a positive markup under international network ownership ($m^R_{INO} > 0$); see Proposition 2.

The second implication of voluntary consolidation is that a policy that allows consolidation will improve welfare relative to a policy in which conglomerate mergers are prohibited, under a broad set of circumstances. Recall from Proposition 3 that consolidation is potentially harmful to welfare if the waterbed effect is strong ($\delta \geq 1/2$) or if the waterbed effect is incomplete and the share of international calls is small ($\delta < 1/2$ and $\theta < \frac{1-2\delta}{3+2\delta}$). However, consolidation is also privately unprofitable in those circumstances. Through a combination of Proposition 3 and Lemma 6:

Corollary 1. *Assume that all consolidation is symmetric and occurs under national regulation if and only if it increases aggregate industry profit ($\pi^R_{INO} > 2\pi^R_{NNO}$). A policy that allows consolidation is (weakly) welfare improving relative to a policy under which conglomerate mergers are prohibited, unless the waterbed effect is incomplete ($\delta < 1/2$) and the share of international calls is large ($\theta > \frac{1-2\delta}{4\delta}$). In this case, the welfare effect is ambiguous.*

This corollary shows that a first step toward increasing aggregate welfare under national regulation is to facilitate cross-border consolidation. This result is driven by increased efficiency in international call prices and improved regulatory performance. This finding arises independently of any additional cost synergies associated with cross-border consolidation. However, consolidation is not necessarily sufficient when international calls are very important ($\theta > \frac{1-2\delta}{4\delta}$) because, in that case, the regulated termination rates become so distorted after consolidation that aggregate welfare may decline. A second step to increasing aggregate welfare would be deregulation.

4.2 The welfare effects of deregulation

The welfare-maximizing regime is one that yields an equilibrium termination rate closest to the marginal cost because the aggregate welfare functions $\tilde{w}_{INO}$ and $\tilde{w}_{NNO}$ are single peaked in m. In light of lemmas 2 and 5 and propositions 1 and 2:

Proposition 4. *We hold the ownership structure fixed. Deregulation welfare dominates national regulation if the waterbed effect is (weakly) incomplete, and the share of incoming calls is sufficiently large ($\tilde{w}_{INO}(m^*) > w^R_{INO}$ and $\tilde{w}_{NNO}(m^*) > w^R_{NNO}$ if $\delta \leq 1/2$ and $\theta > \frac{1-2\delta}{4\delta}$).*

Proposition 4 underscores that deregulation may be preferable to decentralized regulation even if unregulated network operators have an incentive to agree on excessive termination rates. This occurs when markets are very international because, in such cases, the NRA would set even more distorted rates to extract rent from international termination.

Proposition 4 relies on the assumption that NRAs can force network operators to charge termination rates above what is privately profitable ($m^R_{NNO} > m^*$ and $m^R_{INO} > m^*$). One way to achieve this objective involves using a termination rate floor.[8] Notably, the Swedish Ministry of Enterprise has recently proposed that termination rates in Sweden should be subject precisely to a regulated floor rather than only to a ceiling, as is currently the case. This proposal has emerged in light of an increase in the share of international calls. The fraction of outgoing non-VoIP international calls has increased by approximately 50% in recent years (from 3.2% in 2001 to 4.8% in 2014 according to the Swedish regulator PTS). The above results indicate that such legal proposals should be viewed with skepticism. One solution would be to require all NRAs to restrict regulation to rate ceilings. Any attempt by an NRA to force termination rates above the profit-maximizing level would be futile under a termination rate ceiling because the regulation would then become nonbinding. However, deregulation would still be welfare improving because regulation would be ineffective and could be rolled back to save on the regulatory burden.

The policy conclusions depend on the strength δ of the waterbed affect and the degree θ of internationalization. Most countries do not release traffic data that allow us to calculate θ, and δ is not directly observable. Note, however, that termination rates in most countries are regulated by means of binding price caps. Furthermore, off-net calls typically are more expensive than on-net calls under price discrimination. The joint implication of those two observations is that $0 < m^R_{NNO} \leq m^*$ in the benchmark case of national network ownership (assuming symmetry and $\alpha = 0$). This configuration of equilibrium termination rates occurs in the model if and only if $\delta < 1/2$ and $\theta \leq \frac{1-2\delta}{4\delta}$; see Lemma 2 and Proposition 1. In this parameter range, symmetric consolidation is unambiguously welfare improving when it occurs, but deregulation is not necessarily welfare improving. This does not necessarily mean that deregulation is irrelevant, as it can be the only way to induce consolidation ($\pi^R_{INO} < 2\pi^R_{NNO}$, but $\tilde{\pi}_{INO}(m^*) > 2\pi_{NNO}(m^*)$ if $\delta < 1/2$ and $\theta \leq \frac{1-2\delta}{3+2\delta}$). In principle, the increased call price efficiency could be sufficient to outweigh the cost of a higher termination rate (such that $\tilde{w}_{INO}(m^*) > w^R_{NNO}$).

4.3 Discussion

The European Commission has recently proposed steps to harmonize the European telecommunication markets. These include measures aimed at reducing the margins on international calls within Europe.[9] The proposed regulation would mean that *"companies cannot charge more for a*

[8] There is a theoretical case for setting a termination rate floor at termination cost in the workhorse model of network competition because the profit-maximizing termination rate is below the efficient level (Gans and King, 2001). On-net and off-net prices would then be the same. In reality, off-net calls are more expensive than on-net calls under price discrimination, such that termination markups are positive. The present model can explain termination rate floors above cost.

[9] See http://europa.eu/rapid/press-release_IP-13-828_en.htm. Accessed January 2016.

fixed intra-EU call than they do for a long-distance domestic call. For mobile intra-EU calls, the price could not be more than 0.19 euro per minute (plus VAT)". The proposal further states that this measure would ensure that *"companies could recover objectively justified costs, but arbitrary profits from intra-EU calls would disappear"*. The present analysis points to measures that are less intrusive than the direct regulation of retail prices that EU authorities could invoke to accomplish reduced international call prices. In this model, the price of an international call is exactly the same as the price of a national off-net call in the terminating country. This result occurs because consumers in our framework base their choice of operator on its full range of call prices, both national and international, and no additional costs are associated with international traffic. Non-linear pricing then lowers all call prices to the perceived marginal cost. Hence, increased consumer awareness, price transparency and harmonization of termination rates across the EU would probably do a great deal to reduce the prices of international calls to the level of national off-net calls, even without any direct regulation of retail prices. Notably, the large pan-European carrier T-Mobile already treats intra-EU calls on equal terms with national off-net calls in its German "Complete Premium" contract.[10] Authorities could thus achieve the desired reduction in international (and national) call prices by focusing on reducing termination rates. Additional costs associated with international calls would tend to increase the price of international relative to national off-net calls. The profit-maximizing termination rate would remain the same, at least under national network ownership, because network profit would then be independent of international termination profit. The regulated termination rate would also have the same qualitative properties as before.

Our analysis takes an industry perspective by comparing national network ownership with symmetric consolidation by which the four national networks merge into two international network operators. A complementary analysis would involve considering partial consolidation. The resulting retail equilibrium would be asymmetric, but retail prices would still be priced at perceived marginal cost. Such partial consolidation would probably trigger asymmetric regulatory responses. Compared with the NRA in the host country, the NRA in the country in which a national network was taken over by a foreign network operator would be more inclined to reduce its domestic termination rate to extract operator rent if we assume an incomplete waterbed effect. The increased call price efficiency implies that mergers to full monopoly would be socially efficient in a market with full participation if we assume that increases in the equilibrium subscription fee have no aggregate welfare effect. Still, there could be reasons for not allowing market concentration to increase by that much. Today's high-capacity telecommunication networks were launched under network competition, not in the era of national monopolies. One limitation of consolidation could be a weaker incentive to innovate and improve network performance. We leave it for future research to undertake an analysis of partial mergers and network investment in an international setting.

[10] See www.t-mobile.de/tarife. Accessed January 2016.

We have assumed that consumers make only mobile calls. This simplification is a realistic approximation of some national telecommunication markets. In Finland and the Czech Republic, for instance, approximately 85% of households have access to mobile telephony only (Eurobarometer, 2014). These examples are extreme; thus, it would still be interesting to determine how the inclusion of a fixed network might affect the analysis. A standard way of incorporating fixed telephony is to assume a given number of fixed subscribers and to assume that all calls are either fixed to mobile (F2M) or mobile to mobile (M2M). For arbitrage reasons, F2M calls cost the same as off-net M2M calls (Armstrong and Wright, 2009). F2M termination profit increases the value of attracting mobile subscribers, which serves to increase network competition and thereby reduce equilibrium subscription fees. In this model, the entire F2M termination profit would be passed on to consumers, thus leaving mobile network profit independent of F2M termination–at least under national network ownership. With respect to regulation, on the one hand, adding F2M calls increases the cost of retail price distortions. On the other hand, an increasing volume of incoming international F2M calls serves to increase the value of foreign rent extraction. Whether fixed telephony would increase or decrease regulated termination rates generally depends on the relative size of the domestic and foreign fixed networks.

We have assumed that consumers attach a positive value to initiating calls but assign no value to receiving them. Alternatively, one could let consumers benefit also from incoming calls, which would give rise to positive call externalities. Such call externalities would tend to reduce the regulated termination rate in an effort to increase call volumes, thereby counteracting rent extraction on international call termination. A problem with call externalities in a setting with call price discrimination is that networks have an incentive to increase off-net call prices to a level that chokes all off-net calls (Jeon et al., 2004). Hoernig (2015) shows that such connectivity breakdown can sometimes be avoided if there are more than two networks. Extending the current analysis to the case of $n > 2$ networks and call externalities is beyond the scope of this paper.

Our paper excludes several other interesting dimensions of national and international regulations of the telecommunication sector. Mobile roaming, network neutrality, and spectrum allocations could be fruitful avenues for further research in the context of the present framework, in addition to those mentioned above.

5 Conclusion

Motivated by the globalization of telecommunication markets, we have developed a framework to analyze the consequences and welfare implications of national regulation, international network ownership and deregulation in an international market in a model of network competition. We have shown that NRAs have incentives to set excessive rates to extract rent from international termination. Our results suggest that initiatives to facilitate cross-border network ownership would increase aggregate welfare if the share of international calls is sufficiently small. Full deregulation of telecommunication markets can further improve welfare when the share of international calls is larger. Direct regulation of retail prices seems less important for increasing market performance if authorities can achieve price transparency and appropriate termination rates.

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A Mathematical Appendix

A.1 Notation

Notation	Description
$k \neq l \in \{H, F\}$	Country: home and foreign.
$i \neq j \in \{1, 2\}$	National networks.
t_{ki}	Subscription fee.
λ	Size of personal network.
q_{ki}, $\widehat{q}_{ki}$	Number of calls to own and other national network.
p_{ki}, $\widehat{p}_{ki}$	Price per call to own and other national network.
$\bar{s}_{ki}$, $\bar{s}_{kj}$	Expected number of consumers in own and other national network.
x_{ki}, $\widehat{x}_{ki}$	Number of calls to foreign network li and lj.
r_{ki}, $\widehat{r}_{ki}$	Price for calls to foreign network li and lj.
$\bar{s}_{li}$, $\bar{s}_{lj}$	Expected number of consumers in foreign country in network li and lj.
θ_k	Degree of internationalization of the telecommunication market in country k.
y	Amount of numeraire good.
u	Call utility.
$v(p)$	Indirect call utility.
v_0	Standalone utility of holding a subscription.
I	Income.
b	Consumer location on the unit interval.
σ	Virtual transportation cost on the unit interval.
δ	Share of consumers with responsive expectations.
π_{NNOki}	Profit of national network operator ki.
c	Marginal cost of on-net call.
c_O	Marginal cost of call origination.
c_T	Marginal cost of call termination.
a_k	Domestic termination rate in country k.
$\widehat{a}_k$	International termination rate in country k.
m_k	Markup on termination in country k.
f	Marginal subscription cost.
CS_{NNOk}	Consumer surplus in country k with national network operators.
$1-\alpha$	Weight on industry profit relative to consumer surplus.
w_{NNOk}	Total surplus in country k with national network operators.
π_{INOki}	Profit of international network operator ki.
CS_{INOk}	Consumer surplus in country k with international network operators.
w_{INOk}	Total surplus in country k with international network operators.

A.2 Proof of Lemma 1

This is a generalization of Proposition 1 in Hurkens and López (2014), taking into account that only a share $1-\delta$ of consumers have passive beliefs and that network operators also compete in international calls, $\theta_k > 0$. Using (1), we explicitly solve for the subscription demand for network *ki*

$$s_{ki}+\frac{1-\delta}{\delta}\bar{s}_{ki} = \frac{(1-2\delta\sigma\lambda\psi_l)\left[\frac{1}{2}+\sigma\lambda(v(\widehat{p}_{ki})-v(p_{kj}))+\sigma\lambda\theta_k(v(\widehat{r}_{ki})-v(r_{kj}))+\sigma(t_{kj}-t_{ki})+\frac{1-\delta}{\delta}\bar{s}_{ki}\right]}{(1-2\delta\sigma\lambda\psi_H)(1-2\delta\sigma\lambda\psi_F)-4(\delta\sigma\lambda\theta_k)^2\widehat{\psi}_H\widehat{\psi}_F} + \frac{2\delta\sigma\lambda\theta_k\widehat{\psi}_k\left[\frac{1}{2}+\sigma\lambda(v(\widehat{p}_{li})-v(p_{lj}))+\sigma\lambda\theta_k(v(\widehat{r}_{li})-v(r_{lj}))+\sigma(t_{lj}-t_{li})+\frac{1-\delta}{\delta}\bar{s}_{li}\right]}{(1-2\delta\sigma\lambda\psi_H)(1-2\delta\sigma\lambda\psi_F)-4(\delta\sigma\lambda\theta_k)^2\widehat{\psi}_H\widehat{\psi}_F} \tag{23}$$

if both networks have a positive market share. $\psi_k=\frac{1}{2}(v(p_{k1})+v(p_{k2})-v(\widehat{p}_{k1})-v(\widehat{p}_{k2}))$ is the domestic network externality, and $\widehat{\psi}_k=\frac{1}{2}(v(r_{k1})+v(r_{k2})-v(\widehat{r}_{k1})-v(\widehat{r}_{k2}))$ is the international network externality in country k. Through the differentiation of subscription demand (23),

$$\frac{\partial s_{ki}/\partial p_{ki}}{\partial s_{ki}/\partial t_{ki}}=\frac{\partial s_{li}/\partial p_{ki}}{\partial s_{li}/\partial t_{ki}}=(\delta s_{ki}+(1-\delta)\bar{s}_{ki})\,\lambda q_{ki}, \tag{24}$$

$$\frac{\partial s_{ki}/\partial \widehat{p}_{ki}}{\partial s_{ki}/\partial t_{ki}}=\frac{\partial s_{li}/\partial \widehat{p}_{ki}}{\partial s_{li}/\partial t_{ki}}=(1-\delta s_{ki}-(1-\delta)\bar{s}_{ki})\lambda \widehat{q}_{ki}, \tag{25}$$

$$\frac{\partial s_{ki}/\partial r_{ki}}{\partial s_{ki}/\partial t_{ki}}=\frac{\partial s_{li}/\partial r_{ki}}{\partial s_{li}/\partial t_{ki}}=(\delta s_{li}+(1-\delta)\bar{s}_{li})\lambda\theta_k x_{ki}, \tag{26}$$

$$\frac{\partial s_{ki}/\partial \widehat{r}_{ki}}{\partial s_{ki}/\partial t_{ki}}=\frac{\partial s_{li}/\partial \widehat{r}_{ki}}{\partial s_{li}/\partial t_{ki}}=(1-\delta s_{li}-(1-\delta)\bar{s}_{li})\lambda\theta_k\widehat{x}_{ki}, \tag{27}$$

which we can use to generate the marginal profit expressions for NNO_{ki} under full market participation:

$$\begin{aligned}&\frac{\partial \pi_{NNOki}}{\partial p_{ki}}-(\delta s_{ki}+(1-\delta)\bar{s}_{ki})\,\lambda q_{ki}\frac{\partial \pi_{NNOki}}{\partial t_{ki}}\\ =\;&\lambda s_{ki}[(1-\delta)(s_{ki}-\bar{s}_{ki})q_{ki}+s_{ki}\,(p_{ki}-c)\,q'(p_{ki})]\end{aligned} \tag{28}$$

$$\begin{aligned}&\frac{\partial \pi_{NNOki}}{\partial \widehat{p}_{ki}}-(1-\delta s_{ki}-(1-\delta)\bar{s}_{ki})\lambda\widehat{q}_{ki}\frac{\partial \pi_{NNOki}}{\partial t_{ki}}\\ =\;&\lambda s_{ki}[(1-\delta)(\bar{s}_{ki}-s_{ki})\widehat{q}_{ki}+s_{kj}\,(\widehat{p}_{ki}-c-m_k)\,\widehat{q}'(\widehat{p}_{ki})]\end{aligned} \tag{29}$$

$$\begin{aligned}&\frac{\partial \pi_{NNOki}}{\partial r_{ki}}-(\delta s_{li}+(1-\delta)\bar{s}_{li})\lambda\theta_k x_{ki}\frac{\partial \pi_{NNOki}}{\partial t_{ki}}\\ =\;&\lambda\theta_k s_{ki}[(1-\delta)(s_{li}-\bar{s}_{li})x_{ki}+s_{li}\,(r_{ki}-c-m_l)\,x'(r_{ki})]\end{aligned} \tag{30}$$

$$\begin{aligned}&\frac{\partial \pi_{NNOki}}{\partial \widehat{r}_{ki}}-(1-\delta s_{li}-(1-\delta)\bar{s}_{li})\lambda\theta_k\widehat{x}_{ki}\frac{\partial \pi_{NNOki}}{\partial t_{ki}}\\ =\;&\lambda\theta_k s_{ki}[(1-\delta)(\bar{s}_{li}-s_{li})\widehat{x}_{ki}+s_{lj}\,(\widehat{r}_{ki}-c-m_l)\,\widehat{x}'(\widehat{r}_{ki})].\end{aligned} \tag{31}$$

Let $\mathbf{s}^*=(s^*_{H1},s^*_{H2},s^*_{F1},s^*_{F2})$ be an arbitrary, full-participation, equilibrium distribution of market shares. If $s_{ki}\geq s^*_{ki}>0$ or $s_{ki}>s^*_{ki}=0$, then the right-hand side of (28) is strictly positive for all

$p_{ki} < c$ and strictly negative for $p_{ki} = P$. In this case,

$$(1-\delta)(s_{ki} - s_{ki}^*)q(\mathscr{P}) + s_{ki}(\mathscr{P} - c)q'(\mathscr{P}) = 0 \tag{32}$$

uniquely defines the optimal national on-net price $\mathscr{P}(s_{ki}) \in [c, P)$. If $0 < s_{ki} < s_{ki}^*$, then (28) is strictly negative for all $p_{ki} \in [c, P]$. Given the compactness of $[0, c]$ and the continuity of network profit in p_{ki}, an optimum does exist and is defined by (32) if $\mathscr{P}(s_{ki}) > 0$. The optimal domestic off-net price $\widehat{\mathscr{P}}(s_{ki})$ is similarly defined, with one exception: profit is monotonically increasing in $\widehat{p}_{ki}$ if $s_{ki}s_{kj} > 0$, $s_{ki} \leq \bar{s}_{ki}$ and $P < c + m_k$. In this case, $\widehat{\mathscr{P}}(s_{ki}) = c + m_k$ is a profit-maximizing off-net price. Let the international prices $\mathscr{R}(s_{li})$ and $\widehat{\mathscr{R}}(s_{li})$ be defined in an analogous manner to the domestic off-net price.

Marginal cost pricing of calls in interior equilibrium. Beliefs are consistent in equilibrium: $s_{ki}^* = \bar{s}_{ki}$. Given (32), the on-net equilibrium price satisfies $p_{ki}^* = \mathscr{P}(s_{ki}^*) = c$ for $s_{ki}^* > 0$. By the same token, $s_{k1}^* s_{k2}^* > 0$ implies $\widehat{p}_{ki}^* = c + m_k$, $s_{Hi}^* s_{Fi}^* > 0$ implies $r_{ki}^* = c + m_l$ and $s_{H1}^* s_{F2}^* > 0$ implies $\widehat{r}_{ki}^* = c + m_l$.

There are no cornered market equilibria. Suppose that $s_{ki}^* = 1$. Given the above optimality conditions, $p_{ki}^* = c$, international calls are priced at marginal cost $s_{li}^* r_{ki}^* + s_{lj}^* \widehat{r}_{ki}^* = c + m_l$, whereas $\widehat{p}_{ki}^*$ remains undefined. Let $\pi_{ki}^* = t_{ki}^* - f + \lambda \theta_l m_k \hat{x}(c + m_k) \geq 0$ be the corresponding monopoly network profit. Assume that NNO_{kj} deviates from the proposed equilibrium by entering market k at $p_{kj} = \widehat{p}_{kj} = c$, $r_{kj} = \widehat{r}_{kj} = c + m_l$ and $t_{kj} = t_{ki}^* + 1/2\sigma - \lambda$. Because NNO_{kj} does not price-discriminate between on-net and off-net calls, the consumer net surplus at NNO_{kj} is independent of actual and expected market shares and equal to $\lambda v(c) + \theta_k \lambda v(c + m_l) - t_{ki}^* - 1/2\sigma + \lambda$ for a consumer located at b_{kj}. The consumer net surplus when NNO_{ki} corners the market equals $\lambda v(c) + \theta_k \lambda v(c + m_l) - t_{ki}^* - 1/2\sigma$ for the same consumer. Hence, it is a dominant strategy for a positive mass of consumers to choose network j: $s_{kj} > 0$. Network profit

$$\pi_{NNOkj} = \lambda s_{kj}[s_{ki} m_k(\widehat{q}(\widehat{p}_{ki}) - \widehat{q}(c)) - 1 + 1/2\sigma\lambda + \pi_{ki}^*/\lambda]$$

is strictly positive when $\sigma\lambda$ is sufficiently small (recall the assumption that $\widehat{q}(p)$ is bounded). Hence, for a sufficiently small $\sigma\lambda$, there exists no equilibrium in which a national network operator corners the market.

There exists at most one shared market equilibrium. Consider an interior, shared-market equilibrium $s_{ki}^* \in (0, 1)$ for all $k = H, F$, $i = 1, 2$. Given marginal cost pricing and the first-order condition (3), the equilibrium subscription fee equals

$$t_{ki}^* = f + \frac{1}{2\sigma}[1 - 2\delta\sigma\lambda(v(c) - v(c+m_k))]2s_{ki}^*$$
$$- \lambda m_k[(1-2s_{ki}^*)\widehat{q}(c+m_k) + \theta_l \hat{x}(c+m_k)].$$

We substitute back into (23) and rearrange to obtain the equilibrium subscription demand:

$$(s_{ki}^* - \tfrac{1}{2})[3 - 2(1+2\delta)\sigma\lambda(v(c) - v(c+m_k)) + 4\sigma\lambda m_k \widehat{q}(c+m_k)] = 0.$$

Hence, $s_{ki}^* = 1/2$ in interior equilibrium if $\sigma\lambda$ is sufficiently small. Moreover, $s_{ki}^* = 1/2$ implies $t_{ki}^* = t_{NNOk}^*$; thus, $(\mathbf{p}_{NNOk}^*, t_{NNOk}^*)$ is the unique interior equilibrium candidate.

Existence. The above results demonstrated that $(\mathbf{p}_{NNOk}^*, t_{NNOk}^*)$ is the unique equilibrium candidate if $\sigma\lambda$ is sufficiently small. We now show that this constitutes an equilibrium for a sufficiently small $\sigma\lambda$. Assume that NNO_{kj} charges $(\mathbf{p}_{NNOk}^*, t_{NNOk}^*)$, whereas NNO_{l1} and NNO_{l2} both charge $(\mathbf{p}_{NNOl}^*, t_{NNOl}^*)$. Assume also that $\bar{\mathbf{s}} = \mathbf{s}^*$.

Consider a deviation by NNO_{ki}. First, $s_{l1} = s_{l1}^* = 1/2$ and $s_{l2} = s_{l2}^* = 1/2$ independently of NNO_{ki}'s strategy. Hence, $r_{ki} = \widehat{r}_{ki} = c + m_l$ is optimal for any deviation by NNO_{ki}. For any interior deviation $s_{ki} = 1 - s_{kj} \in (0,1)$, the optimal national call prices are $\mathscr{P}(s_{ki})$ and $\widehat{\mathscr{P}}(s_{ki})$. The corresponding subscription fee that generates s_{ki} is given by the following:

$$\mathscr{T}(s_{ki}) = t_{NNOk}^* - (s_{ki} - \tfrac{1}{2})(\tfrac{1}{\sigma} - \delta\lambda(v(\mathscr{P}(s_{ki})) + v(c) - v(\widehat{\mathscr{P}}(s_{ki})) - v(c+m_k)))$$
$$+ \tfrac{1}{2}\lambda(v(\mathscr{P}(s_{ki})) + v(\widehat{\mathscr{P}}(s_{ki})) - v(c) - v(c+m_k)).$$

Substitute $\mathscr{P}(s_{ki})$, $\widehat{\mathscr{P}}(s_{ki})$ and $\mathscr{T}(s_{ki})$ into π_{NNOki} in (2) to obtain the profit of NNO_{ki}:

$$\breve{\pi}(s_{ki}) = s_{ki}\lambda[s_{ki}(\mathscr{P}(s_{ki}) - c)q(\mathscr{P}(s_{ki})) + (\delta s_{ki} + \tfrac{1}{2}(1-\delta))(v(\mathscr{P}(s_{ki})) - v(c+m_k))]$$
$$+ s_{ki}\lambda[s_{kj}(\widehat{\mathscr{P}}(s_{ki}) - c - m_k)\widehat{q}(\widehat{\mathscr{P}}(s_{ki})) + (\delta s_{kj} + \tfrac{1}{2}(1-\delta))(v(\widehat{\mathscr{P}}(s_{ki})) - v(c))]$$
$$+ s_{ki}[t_{NNOk}^* - f + \tfrac{1}{\sigma}(\tfrac{1}{2} - s_{ki}) + \sigma\lambda m_k(s_{kj}\widehat{q}(c+m_k) + \theta_l x(c+m_k))].$$

The marginal effect of increasing the market share is

$$\sigma\breve{\pi}'(s_{ki}) = \sigma\lambda[2s_{ki}(\mathscr{P}(s_{ki}) - c)q(\mathscr{P}(s_{ki})) + (2\delta s_{ki} + \tfrac{1}{2}(1-\delta))(v(\mathscr{P}(s_{ki})) - v(c+m_k))]$$
$$+ \sigma\lambda[(s_{kj} - s_{ki})(\widehat{\mathscr{P}}(s_{ki}) - c - m_k)\widehat{q}(\widehat{\mathscr{P}}(s_{ki})) + (\delta(s_{kj} - s_{ki}) + \tfrac{1}{2}(1-\delta))(v(\widehat{\mathscr{P}}(s_{ki})) - v(c))]$$
$$+ \sigma(t_{NNOk}^* - f) + \tfrac{1}{2} - 2s_{ki} + \sigma\lambda m_k((s_{kj} - s_{ki})\widehat{q}(c+m_k) + \theta_l x(c+m_k)).$$

$\mathscr{P}(s_{ki})$ and $\widehat{\mathscr{P}}(s_{ki})$ are independent of $\sigma\lambda$. Hence, $\lim_{\sigma\lambda\to 0}\sigma\breve{\pi}'(s_{ki}) = \sigma(t_k^* - f) + \frac{1}{2} - 2s_{ki}$, and therefore, $\lim_{\sigma\lambda\to 0}\sigma\breve{\pi}''(s_{ki}) = -2$. It follows that $\breve{\pi}(s_{ki})$ is strictly concave in $s_{ki} \in (0,1)$ for a sufficiently small $\sigma\lambda$. The best reply is then uniquely defined by the solution $\breve{\pi}'(1/2) = 0$ to the first-order condition. Moreover, $s_{ki} = 1/2$ implies $\mathscr{P}(1/2) = c$, $\widehat{\mathscr{P}}(1/2) = c + m_k$, and $\mathscr{T}(1/2) = t^*_{NNOk}$. Hence, $(\mathbf{p}^*_{NNOk}, t^*_{NNOk})$, $k = H,F$ indeed represents a retail equilibrium for a sufficiently small $\sigma\lambda$.

A.3 Proof of Lemma 4

Let $\mathbf{s}^* = (s^*_{H1}, s^*_{H2}, s^*_{F1}, s^*_{F2})$ be an arbitrary, full-participation equilibrium distribution of market shares, and assume that $\bar{\mathbf{s}} = \mathbf{s}^*$. Given the comparative statics (24)-(27), it is straightforward to verify that the marginal profit functions (28), (29) and (31) apply even to INO_i. Hence, the optimal national on-net price in country k equals $\mathscr{P}(s_{ki})$, and the optimal national off-net price is $\widehat{\mathscr{P}}(s_{ki})$, while the optimal international off-net price is $\widehat{\mathscr{R}}(s_{li})$. However, international on-net calls now have a perceived marginal cost c; hence,

$$\frac{\partial \pi_{ki}}{\partial r_{ki}} - (\delta s_{li} + (1-\delta)\bar{s}_{li})\lambda\theta x_{ki}\frac{\partial \pi_{ki}}{\partial t_{ki}} = s_{ki}\lambda\theta[(1-\delta)(s_{li} - \bar{s}_{li})x_{ki} + s_{li}(r_{ki} - c)x'(r_{ki})], \qquad (33)$$

which implies $\mathscr{R}(s_{li})$ implicitly defined by

$$(1-\delta)(s_{li} - s^*_{li})x(\mathscr{R}) + s_{li}(\mathscr{R} - c)x'(\mathscr{R}) = 0$$

in interior equilibrium, or $\mathscr{R}(s_{li}) = 0$ for $s_{Hi}s_{Fi} > 0$. With an argument analogous to that made in the proof of Lemma 1, $s^*_{k1} > 0$ implies $p^*_{ki} = c$, $s^*_{k1}s^*_{k2} > 0$ implies $\widehat{p}^*_{ki} = c + m_k$, $s^*_{Hi}s^*_{Fi} > 0$ implies $r^*_{ki} = c$ and $s^*_{H1}s^*_{F2} > 0$ implies $\widehat{r}^*_{ki} = c + m_l$.

There exists no equilibrium in which one INO corners both markets. Suppose that INO_i corners both markets: $s^*_{Hi} = s^*_{Fi} = 1$. Monopoly entails marginal cost pricing of on-net calls, $p^*_{ki} = r^*_{ki} = c$, while off-net prices $\widehat{p}^*_{ki}$ and $\widehat{r}^*_{ki}$ remain undefined by the first-order conditions (29) and (31). Let $\pi^*_i = \pi^*_{Hi} + \pi^*_{Fi} \geq 0$ be the corresponding equilibrium network profit, and assume (without loss of generality) that $\pi^*_{ki} \geq 0$. Suppose that INO_j deviates from the proposed equilibrium by entering country k at $p_{kj} = \widehat{p}_{kj} = c$, $r_{kj} = \widehat{r}_{kj} = c$ and $t_{kj} = t^*_{ki} + 1/2\sigma - \lambda$. Because INO_j does not price-discriminate between on-net and off-net calls, the consumer net surplus at INO_j is independent of actual and expected market shares and is equal to $\lambda(1+\theta)v(c) - t^*_{ki} - 1/2\sigma + \lambda$ for a consumer located at b_{kj}. The consumer net surplus when INO_i corners both markets equals $\lambda(1+\theta)v(c) - t^*_{ki} - 1/2\sigma$ for the same consumer. Hence, it is a dominant strategy for a positive mass of consumers in both countries to choose network j: $s_{kj} > 0$. Network profit

$$\pi_{kj} = \lambda s_{kj}[s_{ki}m_k(\widehat{q}_{ki} - \widehat{q}(c)) + \theta s_{li}(m_k\widehat{x}_{li} - m_l\widehat{x}(c)) - 1 + 1/2\sigma\lambda + \pi^*_{ki}/\lambda]$$

of INO_j is strictly positive for a sufficiently small $\sigma\lambda$. We conclude that for a sufficiently small $\sigma\lambda$, there exists no equilibrium in which one INO corners both markets.

There exists no equilibrium in which the two INOs corner one market each. Suppose that $s^*_{ki} = 1$ ($s^*_{lj} = 1$). Monopoly entails marginal cost pricing of national on-net and international off-net calls, $p^*_{ki} = c$ and $\widehat{r}^*_{ki} = c + m_l$, while the other prices, $\widehat{p}^*_{ki}$ and r^*_{ki}, remain undefined by the first-order conditions (29) and (33). Let $\pi^*_i \geq 0$ be the corresponding monopoly network profit of INO_i. Assume that j enters market k at $p_{kj} = \widehat{p}_{kj} = c$, $r_{kj} = \widehat{r}_{kj} = c + m_l$ and $t_{kj} = t^*_{ki} + 1/2\sigma - \lambda$. Assume also that network j charges $r_{lj} = c + m_k$.

Because INO_j does not locally price-discriminate between on-net and off-net calls, the consumer net surplus of subscribing to INO_j in country k is equal to $\lambda v(c) + \lambda\theta v(c + m_l) - t^*_{ki} - 1/2\sigma + \lambda$ for a consumer located at b_{kj}, independent of actual and expected market shares. Consumer net surplus at i when i holds the monopoly position in k equals $\lambda v(c) + \lambda\theta v(c + m_l) - t^*_{ki} - 1/2\sigma$ for the same consumer. Hence, it is a dominant strategy for a positive mass of consumers in country k to choose network j: $s_{kj} > 0$. Subscribers in country l remain unaffected by the change and obtain the same consumer net surplus $\lambda v(c) + \lambda\theta v(c + m_k) - t^*_{kj}$ as before. Hence, the monopoly position of INO_j in l remains unchallenged by its entry into country k.

The net profitability

$$\pi_j - \pi^*_j = \lambda s_{kj}[s_{ki} m_k(\widehat{q}(c + m_k) - \widehat{q}(c)) - 1 + 1/2\sigma\lambda + \pi^*_i/\lambda]$$

of entering the competitor's market is strictly positive for a sufficiently small $\sigma\lambda$. We conclude that for a sufficiently small $\sigma\lambda$, there exists no equilibrium in which the two INOs corner one market each.

There exists no equilibrium in which one INO corners one market and both INOs share the other market. Suppose that INO_i has a monopoly in country k, $s^*_{ki} = 1$, but both INOs share the market in country l: $s^*_{li} = 1 - s^*_{lj} \in (0, 1)$. With the proposed market structure, $p^*_{Hi} = p^*_{Fi} = c$, $r^*_{Hi} = r^*_{Fi} = c$ and $\widehat{r}^*_{ki} = \widehat{p}^*_{li} = c + m_l$, while $\widehat{p}^*_{ki}$ and $\widehat{r}^*_{li}$ are undefined by the first-order conditions (29) and (31). Moreover, $p^*_{lj} = c$, $\widehat{p}^*_{lj} = c + m_l$, $\widehat{r}^*_{lj} = c + m_k$ while r^*_{lj} and the prices of INO_j in country k are undefined.

INO_i corners market k if and only if the consumer at b_{kj} weakly prefers INO_i to INO_j:

$$\begin{aligned} &\lambda v(c) + \lambda\theta s^*_{li} v(c) + \lambda\theta s^*_{lj} v(c + m_l) - t^*_{ki} - 1/2\sigma \\ &\geq \lambda v(\widehat{p}^*_{kj}) + \lambda\theta s^*_{lj} v(r^*_{kj}) + \lambda\theta s^*_{li} v(\widehat{r}^*_{kj}) - t^*_{kj}. \end{aligned} \tag{34}$$

If the inequality was strict, then INO_i could raise its profit without jeopardizing its monopoly position by increasing t^*_{ki} to the point at which (34) was strictly binding. Hence, (34) holds with equality at the proposed equilibrium.

Consider a deviation by i in k to $s_{ki} = 1 - s_{kj} \in (0,1)$, maintaining equilibrium market shares $s^*_{li} = 1 - s^*_{lj} \in (0,1)$ in the other country. Assume also that $\bar{\mathbf{s}} = \mathbf{s}^*$. The optimal call prices are defined by $\mathscr{P}(s_{ki})$, $\widehat{\mathscr{P}}(s_{ki})$, $\mathscr{R}(s_{li})$ and $\widehat{\mathscr{R}}(s_{li})$ in country k. The subscription fees are set at $\mathscr{T}_{ki}(s_{ki}, s^*_{li})$ and $\mathscr{T}_{li}(s^*_{li}, s_{ki})$ to achieve the desired distribution of market shares, where

$$\begin{aligned}\mathscr{T}_{ki}(s_{ki}, s_{li}) = t^*_{kj} &+ \tfrac{1-2s_{ki}}{2\sigma} + \lambda(\delta s_{ki} + (1-\delta)s^*_{ki})(v(\mathscr{P}(s_{ki})) - v(\widehat{p}^*_{kj}))\\ &+ \lambda(\delta s_{kj} + (1-\delta)s^*_{kj})(v(\widehat{\mathscr{P}}(s_{ki})) - v(p^*_{kj}))\\ &+ \lambda\theta(\delta s_{li} + (1-\delta)s^*_{li})(v(\mathscr{R}(s_{li})) - v(\widehat{r}^*_{kj}))\\ &+ \lambda\theta(\delta s_{lj} + (1-\delta)s^*_{lj})(v(\widehat{\mathscr{R}}(s_{li})) - v(r^*_{kj})).\end{aligned}$$

Substitute the optimal prices and subscription fees into network profit to obtain $\check{\pi}_i(s_{ki}, s^*_{li}) = \check{\pi}_{ki}(s_{ki}, s^*_{li}) + \check{\pi}_{li}(s^*_{li}, s_{ki})$, where

$$\begin{aligned}\check{\pi}_{ki}(s_{ki}, s_{li}) = s_{ki}\lambda&[s_{ki}(\mathscr{P}(s_{ki}) - c)q(\mathscr{P}(s_{ki})) + (\delta s_{ki} + (1-\delta)s^*_{ki})(v(\mathscr{P}(s_{ki})) - v(\widehat{p}^*_{kj}))]\\ &+ s_{ki}\lambda[s_{kj}(\widehat{\mathscr{P}}(s_{ki}) - c - m_k)\widehat{q}(\widehat{\mathscr{P}}(s_{ki})) + (\delta s_{kj} + (1-\delta)s^*_{kj})(v(\widehat{\mathscr{P}}(s_{ki})) - v(p^*_{kj}))]\\ &+ s_{ki}\lambda\theta[s_{li}(\mathscr{R}(s_{li}) - c)x(\mathscr{R}(s_{li})) + (\delta s_{li} + (1-\delta)s^*_{li})(v(\mathscr{R}(s_{li})) - v(\widehat{r}^*_{kj}))]\\ &+ s_{ki}\lambda\theta[s_{lj}(\widehat{\mathscr{R}}(s_{li}) - c - m_l)\widehat{x}(\widehat{\mathscr{R}}(s_{li})) + (\delta s_{lj} + (1-\delta)s^*_{lj})(v(\widehat{\mathscr{R}}(s_{li})) - v(r^*_{kj}))]\\ &+ s_{ki}(t^*_{kj} - f + \tfrac{1-2s_{ki}}{2\sigma}) + s_{ki}\lambda m_k(s_{kj}\widehat{q}(\widehat{p}^*_{kj}) + \theta s_{lj}\widehat{x}(c + m_k)).\end{aligned} \tag{35}$$

Marginal profit equals

$$\begin{aligned}\sigma\frac{\partial\check{\pi}_{ki}}{\partial s_{ki}} = \sigma\lambda&[2s_{ki}(\mathscr{P}(s_{ki}) - c)q(\mathscr{P}(s_{ki})) + (2\delta s_{ki} + (1-\delta)s^*_{ki})(v(\mathscr{P}(s_{ki})) - v(\widehat{p}^*_{kj}))]\\ &+ \sigma\lambda[(s_{kj} - s_{ki})(\widehat{\mathscr{P}}(s_{ki}) - c - m_k)\widehat{q}(\widehat{\mathscr{P}}(s_{ki})) + (\delta(s_{kj} - s_{ki}) + (1-\delta)s^*_{kj})(v(\widehat{\mathscr{P}}(s_{ki})) - v(p^*_{kj}))]\\ &+ \sigma\lambda\theta[s_{li}(\mathscr{R}(s_{li}) - c)x(\mathscr{R}(s_{li})) + (\delta s_{li} + (1-\delta)s^*_{li})(v(\mathscr{R}(s_{li})) - v(\widehat{r}^*_{kj}))]\\ &+ \sigma\lambda\theta[s_{lj}(\widehat{\mathscr{R}}(s_{li}) - c - m_l)\widehat{x}(\widehat{\mathscr{R}}(s_{li})) + (\delta s_{lj} + (1-\delta)s^*_{lj})(v(\widehat{\mathscr{R}}(s_{li})) - v(r^*_{kj}))]\\ &+ \sigma(t^*_{kj} - f) + \tfrac{1}{2} - 2s_{ki} + \sigma\lambda m_k((s_{kj} - s_{ki})\widehat{q}(\widehat{p}^*_{kj}) + \theta s_{lj}\widehat{x}(c + m_k))\end{aligned} \tag{36}$$

and

$$\begin{aligned}\sigma\frac{\partial\check{\pi}_{li}}{\partial s_{ki}} &= s_{li}\sigma\lambda\theta[(\mathscr{R}(s_{ki}) - c)x(\mathscr{R}(s_{ki})) + \delta(v(\mathscr{R}(s_{ki})) - v(c + m_k)) - m_l\widehat{x}(\widehat{r}^*_{kj})]\\ &\quad - s_{li}\sigma\lambda\theta[(\widehat{\mathscr{R}}(s_{ki}) - c - m_k)\widehat{x}(\widehat{\mathscr{R}}(s_{ki})) + \delta(v(\widehat{\mathscr{R}}(s_{ki})) - v(r^*_{lj}))].\end{aligned} \tag{37}$$

The deviation by INO_i in country k is unprofitable only if $\lim_{s_{ki}\to 1} \partial\check{\pi}_i/\partial s_{ki}|_{s_{li}=s^*_{li}} \geq 0$. Through a similar argument, a deviation by j in country k to $s_{kj} = 1 - s_{ki} \in (0,1)$, while keeping $s^*_{lj} =$

$1-s_{li}^{*}\in(0,1)$ fixed, is unprofitable only if $\lim_{s_{kj}\to 0}\partial\check{\pi}_j/\partial s_{kj}|_{s_{lj}=s_{lj}^{*}}\leq 0$. Hence, the equilibrium is sustainable only if

$$\begin{aligned}
&\sigma\left(\lim_{s_{kj}\to 0}\frac{\partial\check{\pi}_j}{\partial s_{kj}}|_{s_{lj}=s_{lj}^{*}}-\lim_{s_{ki}\to 1}\frac{\partial\check{\pi}_i}{\partial s_{ki}}|_{s_{li}=s_{li}^{*}}\right)\\
&=\tfrac{3}{2}+\sigma\lambda[(\widehat{\mathscr{P}}(1)-c-m_k)\widehat{q}(\widehat{\mathscr{P}}(1))+\delta(v(\widehat{\mathscr{P}}(1))-v(p_{kj}^{*}))]\\
&+s_{lj}^{*}\sigma\lambda\theta[(\mathscr{R}(0)-c)x(\mathscr{R}(0))+\delta(v(\mathscr{R}(0))-v(\widehat{r}_{li}^{*}))]\\
&+s_{li}^{*}\sigma\lambda\theta[(\widehat{\mathscr{R}}(1)-c-m_k)\widehat{x}(\widehat{\mathscr{R}}(1))+\delta(v(\widehat{\mathscr{R}}(1))-v(r_{lj}^{*}))]\\
&+\sigma\lambda\theta(s_{lj}^{*}-s_{li}^{*})[v(c)-v(c+m_l)+\delta(v(c)-v(c+m_k))]\\
&-\sigma\lambda[v(c)-v(c+m_k)+\delta(v(c)-v(\widehat{p}_{kj}^{*}))]\\
&+\sigma\lambda\theta m_l(s_{li}^{*}\widehat{x}(\widehat{r}_{kj}^{*})-s_{lj}^{*}\widehat{x}(c+m_l))\\
&+\sigma\lambda m_k(\widehat{q}(\widehat{p}_{ki}^{*})+\widehat{q}(\widehat{p}_{kj}^{*})+\theta s_{li}^{*}\widehat{x}(\widehat{r}_{li}^{*})-\theta s_{lj}^{*}\widehat{x}(c+m_k))
\end{aligned}$$

is non-positive, which is violated for sufficiently small $\sigma\lambda$. Hence, there exists no equilibrium in which one *INO* corners one market and both *INO*s share the other market for sufficiently small $\sigma\lambda$.

There exists at most one shared market equilibrium. Consider an interior, shared-market equilibrium $s_{ki}^{*}=\bar{s}_{ki}\in(0,1)$ for all $k=H,F$, $i=1,2$. By utilizing marginal cost pricing, the first-order condition (16) and the appropriate subscription elasticities, we can express the equilibrium subscription fee as

$$\begin{aligned}
&t_{ki}^{*}-f+\lambda\left[s_{lj}^{*}\theta m_k\widehat{x}(c+m_k)-s_{li}^{*}\theta m_l\widehat{x}(c+m_l)-m_k(s_{ki}^{*}-s_{kj}^{*})\widehat{q}_{kj}\right]\\
&=\frac{s_{ki}^{*}-2\delta\sigma\lambda(s_{ki}^{*}+\theta s_{li}^{*})(v(c)-v(c+m_k))}{\sigma}
\end{aligned}\tag{38}$$

after simplifications. Moreover,

$$\begin{aligned}
t_{kj}^{*}-t_{ki}^{*}&=2\lambda\theta\left(2\delta(v(c)-v(c+m_k))-m_k\widehat{x}(c+m_k)-m_l\widehat{x}(c+m_l)\right)(s_{li}^{*}-\tfrac{1}{2})\\
&-2\left(\frac{1-2\delta\sigma\lambda(v(c)-v(c+m_k))}{\sigma}+2\lambda m_k\widehat{q}(c+m_k)\right)(s_{ki}^{*}-\tfrac{1}{2}).
\end{aligned}$$

Notably, $t_{kj}^{*}-t_{ki}^{*}$ is linear in s_{Hi}^{*} and s_{Fi}^{*}. Using marginal cost pricing in (23), we can rewrite equilibrium subscription demand as

$$s_{ki}^* - \frac{1}{2} = \frac{(1-2\delta\sigma\lambda\psi_l)[\delta\sigma(t_{kj}^* - t_{ki}^*) + (1-\delta)(s_{ki}^* - \frac{1}{2})]}{(1-2\delta\sigma\lambda\psi_H)(1-2\delta\sigma\lambda\psi_F) - 4(\delta\sigma\lambda\theta)^2\psi_H\psi_F}$$
$$+ \frac{2\delta\sigma\lambda\theta\psi_l\left[\delta\sigma(t_{lj}^* - t_{li}^*) + (1-\delta)(s_{li}^* - \frac{1}{2})\right]}{(1-2\delta\sigma\lambda\psi_H)(1-2\delta\sigma\lambda\psi_F) - 4(\delta\sigma\lambda\theta)^2\psi_H\psi_F}$$

Note that subscription demand is linear in s_{Hi}^* and s_{Fi}^* as well as in $t_{Hj}^* - t_{Hi}^*$ and $t_{Fj}^* - t_{Fi}^*$. Hence, s_{Hi}^* and s_{Fi}^* are solutions to two linear equations with a unique solution for generic termination rates (a_H, a_F). The generic solution is $s_{Hi}^* = s_{Fi}^* = 1/2$. $t_{ki}^* = t_{INOk}^*$, which can easily be verified by entering the equilibrium market shares into (38) and simplifying. We conclude that $(\mathbf{p}_{INO}^*, \mathbf{t}_{INO}^*)$ is the unique candidate for a shared market equilibrium for generic termination rates.

Existence. The above results have established that $(\mathbf{p}_{INO}^*, \mathbf{t}_{INO}^*)$ is the unique equilibrium candidate for generic termination rates if $\sigma\lambda$ is sufficiently small. Assume that INO_j charges this tariff. Consider an interior deviation by INO_i to $s_{Hi} = 1 - s_{Hj} \in (0,1)$ and $s_{Fi} = 1 - s_{Fj} \in (0,1)$. Network profit is then $\breve{\pi}_i(s_{Hi}, s_{Fi}) = \breve{\pi}_{Hi}(s_{Hi}, s_{Fi}) + \breve{\pi}_{Fi}(s_{Fi}, s_{Hi})$ with $\breve{\pi}_{ki}(s_{ki}, s_{li})$ defined in (35). All optimal call prices are independent of $\sigma\lambda$; hence, all terms in $\sigma\partial\breve{\pi}_{ki}/\partial s_{ki}$ defined in (36) but $1/2 + \sigma(t_{INOk}^* - f) - 2s_{ki}$ converge to zero as $\sigma\lambda \to 0$, while $\sigma\partial\breve{\pi}_{li}/\partial s_{ki}$ defined in (37) converges to zero as $\sigma\lambda \to 0$. Thus, $\lim_{\sigma\lambda\to 0}(\sigma\partial^2\breve{\pi}_i/\partial s_{ki}^2) = -2$, $k = H, F$, whereas

$$\lim_{\sigma\lambda\to 0} \sigma^2 \left(\frac{\partial^2\breve{\pi}_i}{\partial s_{Hi}^2}\frac{\partial^2\breve{\pi}_i}{\partial s_{Fi}^2} - \frac{\partial^2\breve{\pi}_i}{\partial s_{Hi}\partial s_{Fi}}\frac{\partial^2\breve{\pi}_i}{\partial s_{Fi}\partial s_{Hi}} \right) = 4.$$

Network profit $\breve{\pi}_i(s_{Hi}, s_{Fi})$ is strictly concave in (s_{Hi}, s_{Fi}) for sufficiently small $\sigma\lambda$, in which case the optimal strategy is characterized by the solution to the first-order condition. As is easily verified, $\partial\breve{\pi}_i/\partial s_k|_{s_{Hi}=s_{Fi}=1/2} = 0$, $k = H, F$. At $s_{Hi} = s_{Hi}^* = 1/2$ and $s_{Fi} = s_{Fi}^* = 1/2$, all calls are priced at marginal cost. Moreover, $t_{ki} = t_{INOk}^*$.