IFN Working Paper No. 1005, 2014

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11th February 2014

Abstract

We analyse network competition in a market with international calls. National regulatory agencies (NRAs) have incentives to set regulated termination rates above marginal cost to extract rent from international call termination. International network ownership and deregulation are alternatives to combat the incentives of NRAs to distort termination rates. We provide conditions under which each of these policies increase efficiency and aggregate welfare. Our findings provide theoretical support for recent policy initiatives by the European Commission.

Keywords: Cross-border ownership, decentralized regulation, international markets, network competition, telecoms, termination rates.
JEL classification: L51, L96.

*We thank Tommaso Valletti and seminar participants at IFN and Imperial College for helpful comments, and Fredrik Andersson and Dina Neiman for research assistance. Financial support from the Marianne and Marcus Wallenberg Foundation is gratefully acknowledged.

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1 Introduction

Telecoms markets have gone global over the last decades, both in terms of traffic and ownership structure. Annual international call volumes, for example, grew at a rate of around 15% per year between 1992 and 2007.[1] Former national telecoms champions have expanded abroad and merged to create international network operators. Four big international network operator groups, Vodafone, Telefonica/O2, T-mobile and Orange, now hold a 78% market share of EU-wide mobile subscriptions (Benzoni et al., 2011).

The internationalisation of telecoms markets has motivated policy initiatives to coordinate sector-specific regulation across borders. At a general level, a single European telecoms market is part of the Europe 2020 agenda. The Body of European Regulators for Electronic Communications (BEREC) was established in 2009 as a part of the Telecom Reform Package, to help national regulatory authorities (NRAs) coordinate and implement the EU regulatory framework for electronic communications. At a more specific level, efforts have been undertaken to coordinate regulation of the termination rates operators charge for completing calls from external networks. These are regulated in most developed countries because termination rates are viewed as central in determining market performance. In an attempt to "realise the full potential of a single telecoms market", the European Commission in 2009 set out cost factors that all EU national telecoms regulators should take account of when setting termination rates. The objective was to equalise differing regulatory approaches thought to "undermine the Single Market and Europe's competitiveness".[2] Apparently, the NRAs had not done enough to bring national termination rates close to an efficient level. This concern raises policy questions as to whether the incentives of the NRAs are indeed distorted, and, if so, what can be done at a central level to increase regulatory efficiency. The goal of the present paper is to shed light on these questions.

Despite increased globalization of telecoms markets and supranational policy initiatives to cope with it, conceptual frameworks for thinking about telecoms regulation in the face of increased internationalisation are scarce. Our contribution is to extend the workhorse model of network competition to include international calls. This framework allows to analyse the properties and welfare consequences of national termination rate regulation in an international market

[1] According to market research firm TeleGeography, see http://www.telegeography.com/research-services/telegeography-report-database. Accessed November 2013. Since 2007, however, growth has slowed due to an increase in international VOIP traffic.

[2] See Telecoms: Commission acts on termination rates to boost competition. http://europa.eu/rapid/press-release_IP-09-710_en.htm#PR_metaPressRelease_bottom and the frequently asked questions supplementary material at http://europa.eu/rapid/press-release_MEMO-09-222_en.htm?locale=en. Accessed November 2013.

of network competition.

Our main result points to a regulatory failure which distorts regulated termination rates in international telecoms markets. If markets are entirely national, in the sense that there are no international calls and network ownership is national, then NRAs implement the first-best optimal policy by requiring operators to set termination rates equal to the marginal termination costs (Laffont, Rey and Tirole, 1998,a,b). In an international market, NRAs have a unilateral incentive to deviate from this first-best policy by increasing the regulated termination rate thereby extracting termination rent from international calls. As distortions are exacerbated the more international are telecoms markets, the European Commission's concern with excessive domestic termination rates appears warranted.

A supranational and benevolent regulatory agency could implement the first-best policy in this complete information framework by requiring all network operators to set termination rates equal to their marginal termination cost. But centralised regulation may not be feasible, either because it violates some principle of decentralised policy making, e.g. the subsidiarity principle in the EU, or because there is no centralised regulatory agency to implement the first-best policy (e.g., for EU-US termination). Under incomplete information, centralised regulation would also be informationally demanding in the sense that it requires accurate and detailed information about the cost structures of all domestic and international network operators. If NRAs were the ones furnished with the task of collecting this information, they would have an incentive to exaggerate marginal costs in order to defend high domestic termination rates. In view of the problems of centralised regulation, we maintain the assumption of decentralised regulation and consider instead structural remedies which do not rely on any information about costs. The first remedy is to facilitate cross-border consolidation of network operations, and is one of the policies currently under consideration in the EU.[3] The second remedy is full deregulation of telecoms markets, which is one of the long-term policy objectives of the EU.

Cross-border consolidation of the telecoms market—a shift from national to international network ownership—has two primary effects on consumers and industry for given termination rates. If termination markups are positive, then international network ownership drives down the perceived marginal cost of those outgoing international calls which are now terminated on-net. This cost reduction benefits consumers because calls are priced at perceived marginal cost. But

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

consolidation could also soften network competition and increase the equilibrium subscription fees to the benefit of networks and the detriment of consumers. Hence, consumers could benefit or suffer from international consolidation. Subscription fees merely represent transfers between consumers and firms at an aggregate level. International ownership therefore has a direct and positive welfare effect through more efficient pricing. But also the regulated termination rate change as a result of consolidation. An NRA concerned with the maximization of domestic welfare will shift its focus more towards domestic consumer surplus because some of the domestic profit now floats out of the country as a consequence of international ownership. If network profit is negatively affected by lower termination rates, then international ownership drives NRAs to reduce regulated termination rates, which can have an additional positive welfare effect. Because of more efficient call pricing and potentially more efficient termination rate regulation, increased market concentration through cross-border consolidation can have a positive aggregate welfare effects even absent any cost synergies associated with consolidated network ownership. However, networks may have insufficient incentives to consolidate if they anticipate stricter regulation as a consequence. In this case, deregulation may be an option.

In a national market without international calls, unregulated network operators have an incentive to soften retail competition by distorting the termination rate (Armstrong, 1998; Laffont, Rey and Tirole, 1998a,b). However, NRAs also have incentives to distort termination rates in international markets. Hence, termination rates are distorted in an international setting both when they are unregulated and when they are subject to regulation by NRAs. When telecoms markets become more international, the incentives of national regulatory authorities to distort the termination rate are stronger. Meanwhile, the incentives of unregulated national network operators to distort the termination rate are independent of the degree of internationalisation because of profit neutrality on the international segment.[4] So decentralised termination rate regulation by NRAs becomes an increasingly unattractive policy relative to deregulation from an aggregate welfare perspective when markets become increasingly international.

We have organised the paper as follows. The next section discusses related literature. Section 3 develops the baseline framework for analysing network competition and regulation in the presence of international calls. We show how international call externalities cause national regulatory authorities to set too high termination rates from an aggregate welfare perspective

[4]Increased internationalisation has a direct effect on termination profit, however there is also an indirect effect on the equilibrium subscription fee because internationalisation intensifies network competition. These two effects cancel out in equilibrium.

under national network ownership. Section 4 considers the consequences of international network ownership for regulation and welfare, while Section 5 compares deregulation with decentralised regulation. In Section 6, we analyse the profitability of network consolidation and discuss implications of our results for telecoms policy. Section 7 concludes the paper. Some tedious proofs not contained in the main text are in the appendix.

2 Related literature

Our framework is related to two separate strands of literature.

Network competition The workhorse model of network competition was developed by Armstrong (1998) who considered linear and non-discriminatory call prices, and Laffont, Rey and Tirole (1998a,b) who allowed also two-part call tariffs and price discrimination between on-net and off-net calls. The emergence of formal models of network competition was a response to a technological development which had lead network operators to roll-out their own mobile networks and opened the possibility for facilities-based competition in the telecoms sector. A key policy question was whether the termination rates networks negotiated for connecting calls from each other could be used to soften retail competition. This literature is now extensive; see Armstrong (2002), Vogelsang (2003), and Hoernig and Valletti (2012) for surveys. Recent contributions include Hoernig (2012), López and Rey (2012), Jullien et al. (2013), Hoernig et al. (forthcoming), Hurkens and López (forthcoming) and Tangerås (forthcoming). A common feature of this entire research is the restriction to domestic markets in which national network operators compete for national consumers. All calls are initiated and terminated domestically. Either termination rates are negotiated to maximize industry profit, or a single regulatory authority sets termination rates to maximize total surplus. Our paper extends the workhorse model to an international setting by letting domestic consumers initiate and receive international calls priced differently from national calls. We allow for international network operators as well as multiple national regulatory agencies located in different countries. These extensions make it possible to analyse cross-border externalities associated with competition and national regulation.

International traffic termination The literature on international traffic termination peaked during the turn of the century when the FFC imposed rate caps on international termination settlements. A central issue was the asymmetric call pattern from national operators in rich countries to national operators in developing countries, which meant that the (negotiated and regulated) international settlement payments flowed from rich to poor countries (hence the cap imposed to protect the domestic network operators from excessive fees). The academic literature on this issue is broad and surveyed in Einhorn (2002) and Jakopin (2008). Our paper is related by the international dimension, but is otherwise fundamentally different. First, we depart from the (partially) monopolistic setting by considering national and international network competition. Network competition is more in line with how modern telecoms markets operate. Second, the historical emphasis on asymmetric call patterns and different termination rates for domestic and international calls appear less relevant today. Internationalisation has led to more symmetric call patterns. Termination rates for national and international calls are the same in most countries, not least owing to arbitrage possibilities by rerouting calls domestically or abroad.

3 Benchmark case: National network operators

This section develops the baseline framework for analysing national regulation in the presence of international calls and competing network operators. It also solves for equilibrium retail prices given termination rates at home and abroad.

3.1 The model

Demand The 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 at most 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 $\widehat{s}_{ki}$ 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 $\lambda\widehat{s}_{kj}$ 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 $\lambda\theta\widehat{s}_{li}$ ($\lambda\theta\widehat{s}_{lj}$) 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 that consumers may have a personal network which is (much) smaller than the total network.[5] The parameter $\theta \in (0, 1]$ captures the size of the

[5] Allowing λ to be small guarantees the existence of a retail equilibrium.

international network, and measures the degree of internationalisation of the telecoms market.

Consumers with income I and call utility u maximize utility

$$\lambda\widehat{s}_{ki}u(q_{ki}) + \lambda\widehat{s}_{kj}u(\widehat{q}_{ki}) + \lambda\theta\widehat{s}_{li}u(x_{ki}) + \lambda\theta\widehat{s}_{lj}u(\widehat{x}_{ki}) + y \tag{1}$$

subject to the budget constraint

$$\lambda\widehat{s}_{ki}p_{ki}q_{ki} + \lambda\widehat{s}_{kj}\widehat{p}_{ki}\widehat{q}_{ki} + \lambda\theta\widehat{s}_{li}r_{ki}x_{ki} + \lambda\theta\widehat{s}_{lj}\widehat{r}_{ki}\widehat{x}_{ki} + y + t_{ki} \leq I. \tag{2}$$

Assume that call utility u is twice continuously differentiable, increasing and strictly concave ($u' > 0$ and $u'' < 0$) and that income I is sufficiently high that call demand depends entirely on the own-call price: $q(p) = u'^{-1}(p)$, $q(0) < \infty$. We can then 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

$$v_0 + \lambda\widehat{s}_{ki}v(p_{ki}) + \lambda\widehat{s}_{kj}v(\widehat{p}_{ki}) + \lambda\theta\widehat{s}_{li}v(r_{ki}) + \lambda\theta\widehat{s}_{lj}v(\widehat{r}_{ki}) + I - t_{ki} - \frac{|b_{ki} - b|}{2\sigma} \tag{3}$$

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 is σ, the more differentiated are the networks. 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 realised 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 $\widehat{s}_{k1}$ and $\widehat{s}_{k2}$ 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 now also depends on the expected distribution $\widehat{s}_{l1}$ and $\widehat{s}_{l2}$ of market shares abroad.

To determine subscription demand, let $\hat{\mathbf{s}} = (\widehat{s}_{H1}, \widehat{s}_{H2}, \widehat{s}_{F1}, \widehat{s}_{F2})$ be the expected distribution of market shares at home and abroad. Expectations are required to be fulfilled at equilibrium: $\hat{\mathbf{s}} = \mathbf{s}$, where $\mathbf{s} = (s_{H1}, s_{H2}, s_{F1}, s_{F2})$ is the realised distribution of market shares. A share $\delta \in [0, 1]$ of consumers have responsive expectations (Hoernig, 2012; Hurkens and López, forthcoming) in the sense that they correctly anticipate and take network effects into account when they choose which network to subscribe to: $\hat{\mathbf{s}} = \mathbf{s}$. The other $1-\delta$ share of consumers have passive expectations.[6] Subscription demand for network ki equals

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

if both networks have a positive market share. It is a function of the expected distribution of market shares, $\hat{\mathbf{s}}$, subscription fees $(t_{H1}, t_{H2}, t_{F1}, t_{F2})$ and call prices $(\mathbf{p}_{H1}, \mathbf{p}_{H2}, \mathbf{p}_{F1}, \mathbf{p}_{F2})$, where $\mathbf{p}_{ki} = (p_{ki}, \hat{p}_{ki}, r_{ki}, \hat{r}_{ki})$ is the menu of call prices charged by network ki, $\psi_k = \frac{1}{2}(v(p_{k1}) + v(p_{k2}) - v(\widehat{p}_{k1}) - v(\widehat{p}_{k2}))$ 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.

Network profit There are four national network operators (NNOs). NNO_{ki} derives its profits from three sources: initiated calls (call profit), subscription fees (subscription profit) and termination of received calls (termination profit):

$$\begin{aligned} \pi_{ki} = & \underbrace{s_{ki}\lambda[s_{ki}(p_{ki}-c)q_{ki} + s_{kj}(\widehat{p}_{ki}-c-m_k)\widehat{q}_{ki} + \theta s_{li}(r_{ki}-c-m_l)x_{ki} + \theta s_{lj}(\widehat{r}_{ki}-c-m_l)\widehat{x}_{ki}]}_{\text{Call profit}} \\ + & \underbrace{s_{ki}(t_{ki}-f)}_{\text{Subscription profit}} + \underbrace{s_{ki}\lambda m_k(s_{kj}\widehat{q}_{kj} + \theta(s_{li}x_{lj} + s_{lj}\hat{x}_{lj}))}_{\text{Termination profit}}. \end{aligned} \tag{5}$$

The marginal cost of an on-net call equals $c = c_O + c_T$, where c_O (c_T) is the marginal cost of call origination (termination). The marginal cost of call origination plus the domestic termination rate a_k yield the 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 the marginal cost $c_O + a_l = c + m_l$. Marginal subscription cost is f. Termination profit is positive if and only if the domestic termination rate is higher than the marginal termination cost: $m_k > 0$.

[6] We assume that a share of consumers have passive expectations to align our model predictions with observed price patterns. As is well known, unregulated network operators soften retail competition in the standard model of network competition by negotiating a termination rate below marginal termination cost (Gans and King, 2001). Negative termination markups imply that the perceived marginal cost of off-net calls is lower than for on-net calls. Hence, the workhorse model predicts off-net prices below on-net prices. In reality, off-net calls are nearly always more expensive than on-net calls under price discrimination. Positive unregulated termination markups emerge if, for example, a large enough share of share of consumers have passive expectations; see Hoernig (2012) and Hurkens and López (forthcoming).

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 termination $\widehat{a}_k$ of international calls is substantially cheaper than domestic termination: $\widehat{a}_k < a_k - \varepsilon$. In the opposite case of $\widehat{a}_k > a_k + \varepsilon$, foreign networks can bypass the international termination rate by transiting calls destined for NNO_{ki} through NNO_{kj}. Hence, termination arbitrage implies $\widehat{a}_k \in [a_k - \varepsilon, a_k + \varepsilon]$. Marginal rerouting costs are tiny in modern telecoms networks, so we set $\varepsilon = 0$, and therefore $\widehat{a}_k = a_k$. Note also that $a_k \geq -c_O$ because network ki could make infinite profits by initiating an unbounded amount of off-net calls to network kj if it were the case that $a_k < -c_O$.

To ensure equilibrium existence and uniqueness, we assume throughout that $(p-c)q'(p)$ is weakly decreasing in p and that $2q(p) + (p-c)q'(p) \leq 0$ for some $p > c$. These assumptions are met by standard utility functions, such as the linear-quadratic and the exponential.[7]

3.2 Retail equilibrium

NNO_{ki} chooses the menu of call prices $\mathbf{p}_{ki}$ and the subscription fee t_{ki} to maximize network profit π_{ki}. The marginal value of raising the subscription fee t_{ki} is

$$\begin{aligned}
\frac{\partial \pi_{ki}}{\partial t_{ki}} = & \underbrace{\tfrac{\partial s_{ki}}{\partial t_{ki}} \lambda [s_{ki}(p_{ki} - c)q_{ki} + s_{kj}(\widehat{p}_{ki} - c - m_k)\widehat{q}_{ki} + \theta s_{li}(r_{ki} - c - m_l)x_{ki} + \theta s_{lj}(\widehat{r}_{ki} - c - m_l)\widehat{x}_{ki}]}_{\text{Marginal call profit}} \\
+ & \underbrace{s_{ki}\lambda \left[\tfrac{\partial s_{ki}}{\partial t_{ki}}[(p_{ki} - c)q_{ki} - (\widehat{p}_{ki} - c - m_k)\widehat{q}_{ki}] + \theta \tfrac{\partial s_{li}}{\partial t_{ki}}[(r_{ki} - c - m_l)x_{ki} - (\widehat{r}_{ki} - c - m_l)\widehat{x}_{ki}]\right]}_{\text{Composition effect}} \\
+ & \underbrace{s_{ki} + \tfrac{\partial s_{ki}}{\partial t_{ki}}(t_{ki} - f)}_{\text{Marginal subscription profit}} + \underbrace{\lambda m_k [\tfrac{\partial s_{ki}}{\partial t_{ki}}(s_{kj} - s_{ki})\widehat{q}_{kj} + \theta[\tfrac{\partial s_{ki}}{\partial t_{ki}}(s_{li}x_{li} + s_{lj}\widehat{x}_{lj}) + \tfrac{\partial s_{li}}{\partial t_{ki}} s_{ki}(x_{li} - \widehat{x}_{lj})]]}_{\text{Marginal termination profit}}.
\end{aligned} \quad (6)$$

The first term is the *marginal call profit*, which reflects that a higher subscription fee t_{ki} reduces call profit because of a loss in subscribers. The second term is a domestic and international *composition effect*. As the number of subscribers falls, more national calls are terminated outside than inside the network. The domestic composition effect is negative if and only if on-net calls are more profitable than off-net calls. The third term is the *marginal subscription profit*. It captures the trade-off between higher subscription markup and the marginal loss in subscribers.

[7] The CES utility function violates monotonicity, but satisfies the boundary condition for high enough elasticities. It can be shown that all propositions hold even with CES utility.

The final term is the *marginal termination profit.* It captures the effect on termination profit of charging a higher subscription fee through the effect on marginal termination demand. The effect from marginal domestic termination demand 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, marginal domestic termination demand is positive if and only if network ki initially has more than 50 percent of the subscribers: $s_{ki} > s_{kj}$. Marginal termination demand of international calls tends to be negative if incoming calls do not vary to much across foreign networks ($x_{li} \approx \widehat{x}_{lj}$) because then a loss in 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*

$$t^*_{NNOk} - f + \lambda\theta m_k \hat{x}(c + m_k) = \frac{1 - 2\sigma\lambda\delta(v(c) - v(c + m_k))}{2\sigma} \quad (7)$$

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

Proof. See the appendix. □

The network operator sets the on-net price and all other call prices equal to perceived marginal costs at equilibrium. To see the intuition, note that a small reduction in the on-net price p_k has marginal benefit $\lambda q_k/2$ to every consumer in the network. This allows the operator to raise the subscription fee by $\lambda q_k/2$ while keeping all consumers equally well off as before. Hence, market shares 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. But as total call demand increases, the price reduction is strictly profitable if the markup on call prices is positive ($p_k > c$). In the opposite case of a negative markup on on-net calls, the network operator strictly profits from increasing p_k, thereby contracting call demand. At optimum, therefore, the network operator sets the on-net price and all other call prices equal to perceived marginal cost. As a consequence of marginal pricing of calls, marginal call profit and the composition effect in (6) are zero. The optimal subscription fee, $t^*_{NNOk} = t^*_{NNO}(m_k, \theta)$, therefore trades off a higher subscription markup against the loss in subscribers, taking into account also the effect on marginal termination profit. The marginal domestic termination demand is zero at symmetric equilibrium, leaving only marginal termination profit on international calls.

The subscription fee is set according to a modified Ramsey rule. The left-hand side of (7) is the markup of the subscription fee over the marginal subscription cost adjusted by the marginal termination profit. The right-hand side is the inverse of the semi-elasticity of subscription demand

$$-\frac{\partial s_{ki}}{\partial t_{ki}}\frac{1}{s_{ki}}\bigg|_{\mathbf{p}_{k1}=\mathbf{p}_{k2}=\mathbf{p}^*_{NNOk},t_{k1}=t_{k2}=t^*_{NNOk}} = \frac{2\sigma}{1-2\sigma\lambda\delta(v\left(c\right)-v(c+m_k))} \tag{8}$$

and is a measure of the intensity of competition for subscribers at equilibrium. A higher degree of network substitutability (σ) intensifies network competition and drives down the subscription fee because tariffs then matter more for the choice of the network. A larger share of responsive consumers (δ) or a larger personal network (λ) reinforces any positive network externality ($v\left(c\right) > v(c+m_k)$) and similarly intensifies network competition.

If the termination markup is positive ($m_k > 0$), then increased internationalisation implies that subscribers become more valuable to networks because they generate more international termination revenue. In this case, increased internationalisation drives down the equilibrium subscription fee; as is obvious from an inspection of (7).

3.3 Regulation

This section derives the social optimum and analyses national regulation of termination rates in the presence of national network operators. We show how international call externalities cause NRAs to set termination rates that are too high from an aggregate welfare perspective.

Social optimum Consumer surplus in country k is the value of national on-net calls, national off-net calls and international calls, less the subscription fee:

$$\tfrac{\lambda}{2}v\left(c\right)+\tfrac{\lambda}{2}v(c+m_k)+\lambda\theta v(c+m_l)-t^*_{NNO}(m_k,\theta). \tag{9}$$

For simplicity, we have normalised consumer surplus by eliminating the utility v_0 of holding a subscription and the cost $1/8\sigma$ of differentiation, both of which are constant throughout. Industry profit

$$t^*_{NNO}(m_k,\theta)+m_k\lambda(\tfrac{1}{2}\widehat{q}(c+m_k)+\theta\hat{x}(c+m_k)). \tag{10}$$

in country k consists entirely of subscription profit and termination profit because network operators set call prices equal to marginal cost (we have removed the total subscription cost, f).

The sum of consumer surplus and the profit of the two national network operators gives welfare in country k:

$$w_{NNOk} = \underbrace{\tfrac{\lambda}{2}(v(c) + v(c+m_k) + 2\theta v(c+m_l))}_{\text{Consumer net surplus}} + \underbrace{\tfrac{\lambda}{2}m_k(\widehat{q}(c+m_k) + 2\theta \hat{x}(c+m_k))}_{\text{Termination profit}}. \tag{11}$$

The subscription fee merely represents a transfer between firms and consumers and therefore vanishes from the welfare function.

Under the assumption of unregulated retail competition, the benevolent social planner chooses the markups m_H and m_F to maximize aggregate consumer surplus and industry profit:

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

The marginal overall welfare effect of raising the termination rate in country k is

$$\frac{\partial w_{NNO}}{\partial m_k} = \underbrace{\tfrac{\lambda}{2}m_k(\widehat{q}'(c+m_k) + 2\theta\hat{x}'(c+m_k))}_{\text{Aggregate price distortion}}. \tag{12}$$

At the aggregate level, deviations from marginal costs only serve to distort retail prices of national and international calls. As a result, the social optimum is to set termination rates at marginal termination cost in both countries: $m^{soc} = 0$.

National regulation Let us now contrast the socially optimal termination rate with the termination rate set by a national regulatory agency in country k, NRA_k. By assumption, NRA_k chooses the termination markup m_k to maximize the 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

$$\frac{\partial w_{NNOk}}{\partial m_k} = \underbrace{\tfrac{\lambda}{2}m_k\widehat{q}'(c+m_k)}_{\text{Domestic price distortion}} + \underbrace{\lambda\theta(m_k\hat{x}'(c+m_k) + \hat{x}(c+m_k))}_{\text{Marginal international termination rent}}. \tag{13}$$

A termination rate different from marginal termination cost ($m_k \neq 0$) distorts both domestic and international call prices. The first term identifies the domestic inefficiency associated with price distortions. If there was no international dimension to network competition, i.e. $\theta = 0$, then

NRA_k would set the termination markup equal to zero, and the regulated termination rate would therefore coincide with the socially optimal one. The second term identifies a *rent extraction effect on international termination*, which tends to drive up the termination rate. While changes to the foreign termination rate have consequences for welfare at home ($\frac{\partial w_{NNOk}}{\partial m_l} = -\lambda\theta\hat{x}(c+m_l)$), there is no effect on the marginal benefit of changing the domestic termination rate ($\frac{\partial^2 w_{NNOk}}{\partial m_k \partial m_l} = 0$). Additive separability of the domestic welfare function implies that there is no strategic interaction among regulatory agencies here. Hence, the NRA behaves as a regulatory monopoly and sets the termination rate to balance the domestic price distortion against the marginal rent extraction from international calls:

Proposition 1. *A national regulatory authority maximizing domestic welfare sets a positive termination markup*

$$\frac{m^R_{NNO}}{c + m^R_{NNO}} = \frac{2\theta}{1+2\theta}\frac{1}{\eta(c + m^R_{NNO})} \tag{14}$$

under national network ownership, where $\eta(p) = -q'(p)p/q$ is the price elasticity of call demand. The regulated termination rate (and therefore the aggregate welfare distortion) is larger when the market is more international ($dm^R_{NNO}/d\theta > 0$).

Proof. $\frac{\partial w_{NNO_k}}{\partial m_k} > 0$ for all $m_k < 0$, and therefore $m^R_{NNO} \geq 0$. Domestic welfare is strictly quasi-concave by the assumption that $(p-c)q'(p)$ is weakly decreasing in p (recall marginal cost pricing of calls). Hence, the optimum is uniquely defined by $\frac{\partial w_{NNO_k}}{\partial m_k} = 0$, which is equivalent to (14). This optimum exists because w_{NNOk} is continuous, $\frac{\partial w_{NNO_k}}{\partial m_k}|_{m_k=0} = \theta\lambda\hat{x}(c + m_k) \geq 0$, and $\frac{\partial w_{NNO_k}}{\partial m_k} \leq 0$ for some $m_k > 0$ by the boundary condition $q(p) + (p - c)q'(p) \leq 0$ for some $p > c$. The comparative statics result follows from strict concavity of w_{NNOk} at the optimum and $\frac{\partial^2 w_{NNO_k}}{\partial m_k \partial\theta}|_{m_k=m^R_{NNO}} = \frac{\lambda}{1+2\theta}\hat{x}(c + m^R_{NNO}) > 0$. Aggregate welfare is single-peaked at $m^{soc} = 0$, and therefore the welfare distortion is monotonically increasing in m^R_{NNO}. □

Proposition 1 shows that the exploitation of market power on international termination prevents national regulatory agencies from bringing termination rates down to marginal cost. Standard arguments would attribute this exercise of trade policy to an incentive to promote or to protect the domestic industry profit. This is not the case here. A marginal increase in the degree of internationalization, θ, has two countervailing effects on industry profit; see (10). For any positive termination markup $m_k > 0$, there is a positive effect owing to increased termination of international calls. But there is also a negative effect because internationalisation intensifies domestic competition for subscribers and pushes down the equilibrium subscription fee. To evaluate the net effect of internationalization, substitute the equilibrium subscription fee (7) into (10) to get:

$$\pi_{NNO}(m_k) = \underbrace{\tfrac{1}{2\sigma}[1 - 2\sigma\lambda\delta(v\,(c) - v(c + m_k))]}_{\text{Subscription markup}} + \underbrace{\tfrac{\lambda}{2} m_k \widehat{q}(c + m_k).}_{\text{Domestic termination profit}} \tag{15}$$

The two effects of internationalisation cancel out, leaving domestic industry profit independent of θ. Hence, it is not a concern for domestic industry profit which drives policy makers to distort termination rates. Rather, domestic consumers are the ones who benefit from internationalisation because of the reduction in the subscription fee. Network operators abroad are not affected by any changes to the domestic termination rate, so the exercise of market power on international termination effectively transfers rent from consumers abroad (through higher international call prices) to domestic consumers (through lower subscription fees).

4 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 structural remedy of encouraging international network consolidation. Our main finding is that cross-border consolidation—a shift from national to international ownership of networks—can incentivize national regulatory authorities to set regulated termination rates closer to marginal cost. International ownership increases aggregate welfare if network externalities are weak and markets are characterized by an intermediate degree of internationalisation.

4.1 The model

Call demand and subscription demand are the same as in the Section 3. The difference is that we now assume the two national networks Hi and Fi to be owned by international network operator INO_i, $i \in \{1, 2\}$. We can think of each country having one INO each as result of previous national monopolies having expanded abroad. The profit of INO_i equals $\pi_i = \pi_{Hi} + \pi_{Fi}$, where national profit in country k now equals

$$\pi_{ki} = \underbrace{s_{ki}\lambda[s_{ki}(p_{ki}-c)q_{ki} + s_{kj}(\widehat{p}_{ki}-c-m_k)\widehat{q}_{ki} + \theta s_{li}(r_{ki}-c)x_{ki} + \theta s_{lj}(\widehat{r}_{ki}-c-m_l)\widehat{x}_{ki}]}_{\text{Call profit}}$$
$$+ \underbrace{s_{ki}(t_{ki}-f)}_{\text{Subscription profit}} + \underbrace{s_{ki}\lambda m_k(s_{kj}\widehat{q}_{kj} + \theta s_{lj}\widehat{x}_{lj})}_{\text{Termination profit}}. \tag{16}$$

Compared to the profit of network ki under national ownership, see (5), the perceived marginal cost of an international call now depends on whether the call is terminated in 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 perceived marginal call cost implies that the INO engages in termination-based price discrimination even on international calls. Second, international termination profit falls (if $m_k > 0$) because INO_i now is paid only to terminate calls from one of the two foreign networks. Third, operator profit now depends on the termination rate in both countries. Hence, the international network operator is a common agency.

4.2 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 profit π_i. By increasing the subscription fee t_{Hi} in the home country, INO_i affects marginal profit as follows

$$\underbrace{\sum_k \frac{\partial s_{ki}}{\partial t_{Hi}}\lambda[s_{ki}(p_{ki}-c)q_{ki} + s_{kj}(\widehat{p}_{ki}-c-m_k)\widehat{q}_{ki} + \theta s_{li}(r_{ki}-c)x_{ki} + \theta s_{lj}(\widehat{r}_{ki}-c-m_l)\widehat{x}_{ki}]}_{\text{Marginal call profit}}$$
$$+ \underbrace{\sum_k s_{ki}\lambda\left[\frac{\partial s_{ki}}{\partial t_{Hi}}[(p_{ki}-c)q_{ki} - (\widehat{p}_{ki}-c-m_k)\widehat{q}_{ki}] + \theta\frac{\partial s_{li}}{\partial t_{Hi}}[(r_{ki}-c)x_{ki} - (\widehat{r}_{ki}-c-m_l)\widehat{x}_{ki}]\right]}_{\text{Composition effect}}$$
$$+ \underbrace{s_{Hi} + \sum_k \frac{\partial s_{ki}}{\partial t_{Hi}}(t_{ki}-f)}_{\text{Marginal subscription profit}} + \underbrace{\sum_k \lambda m_k[\frac{\partial s_{ki}}{\partial t_{Hi}}(s_{kj}-s_{ki})\widehat{q}_{kj} + \theta(\frac{\partial s_{ki}}{\partial t_{ki}}s_{lj} - s_{ki}\frac{\partial s_{li}}{\partial t_{ki}})\widehat{x}_{lj}]}_{\text{Marginal termination profit}} \tag{17}$$

with a similar effect of increasing t_{Fi}.

Lemma 2. *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*

$$t^*_{INOk} - f + \frac{\lambda}{2}\theta(m_k\widehat{x}(c+m_k) - m_l\widehat{x}(c+m_l)) = \frac{1-2(1+\theta)\sigma\lambda\delta(v\,(c) - v(c+m_k))}{2\sigma} \quad (18)$$

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

Proof. See the appendix. □

As in the case of national network operators, each operator sets call prices at perceived marginal cost domestically and on international calls. Hence, marginal call profit and the composition effect both disappear in the first-order conditions for the optimal subscription fee. At optimum, the operator balances a higher subscription markup against lower subscription demand, accounting also for the effect of a higher subscription fee on international marginal termination profit.

The shift from national to international network operations implies that the call prices of all international calls originating and terminating inside the multinational network fall (if termination markups are positive) because the perceived marginal costs of those calls fall 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 creates international call externalities in addition to the domestic ones. If on-net calls are cheaper than off-net calls, then positive international network externalities provide an additional benefit to network operators of cutting subscription fees, namely the possibility of attracting additional subscribers abroad through a larger international network. But because the total size of the market is constant, these additional network externalities only serve to intensify competition and drive down subscription fees. This competition effect materialises as an international semi-elasticity

$$-\frac{\left[s_{ki}\frac{\partial s_{li}}{\partial t_{li}} - s_{li}\frac{\partial s_{li}}{\partial t_{ki}}\right]}{\left[\frac{\partial s_{ki}}{\partial t_{ki}}\frac{\partial s_{li}}{\partial t_{li}} - \frac{\partial s_{li}}{\partial t_{ki}}\frac{\partial s_{ki}}{\partial t_{li}}\right]}\Big|_{\mathbf{p}_1=\mathbf{p}_2=\mathbf{p}^*_{INO},\mathbf{t}_1=\mathbf{t}_2=\mathbf{t}^*_{INO}} = \frac{2\sigma}{1-2(1+\theta)\sigma\lambda\delta(v\,(c) - v(c+m_k))}, \quad (19)$$

which is higher than the national semi-elasticity (8). Recall that a higher profitability of international call termination intensifies retail competition at home and drives down subscription fees under national network ownership. This incentive is comparatively weaker under international ownership because there is less termination of international off-net calls to begin with, and because a loss of subscribers at home now 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, an issue we shall return to.

4.3 Regulation

Social optimum Consumer net surplus in country k is given by

$$\tfrac{\lambda}{2}v\left(c\right)+\tfrac{\lambda}{2}v(c+m_k)+\tfrac{\lambda}{2}\theta v(c)+\tfrac{\lambda}{2}\theta v(c+m_l)-t^*_{INO}(m_k,m_l,\theta) \qquad (20)$$

under international ownership and differs from consumer surplus (9) under national network ownership in two ways. Consumers benefit from lower call prices on international off-net calls if termination markups are positive. But the different mode of competition affects also the equilibrium subscription fee, $t^*_{INOk}=t^*_{INO}(m_k,m_l,\theta)$, which could be higher or lower under international than national network ownership. Hence, the effect of international ownership on consumers is ambiguous. The profit of the international network operator equals $\pi_{INO}=\pi_{INOH}+\pi_{INOF}$ and consists entirely of subscriber and termination profit because calls are priced at perceived marginal cost:

$$\pi_{INOk}(m_k,m_l,\theta)=\tfrac{1}{2}[t^*_{INO}(m_k,m_l,\theta)+\tfrac{\lambda}{2}m_k(\hat{q}(c+m_k)+\theta\hat{x}(c+m_k))]. \qquad (21)$$

Under the assumption that one international network operator is located in each country, welfare in country k equals

$$\begin{aligned} w_{INOk}(m_k,m_l,\theta) \;=\; & \underbrace{\tfrac{\lambda}{2}(v\left(c\right)+v(c+m_k)+\theta v(c)+\theta v(c+m_l))}_{\text{Consumer net surplus}} \\ & +\underbrace{\tfrac{\lambda}{2}m_k(\widehat{q}(c+m_k)+\theta\hat{x}(c+m_k))}_{\text{Termination profit}} \\ & +\underbrace{\pi_{INOl}(m_l,m_k,\theta)}_{\text{Ownerhip abroad}}-\underbrace{\pi_{INOk}(m_k,m_l,\theta)}_{\text{Domestic profit loss}}. \end{aligned} \qquad (22)$$

Domestic welfare under international ownership differs from domestic welfare (11) under national ownership in a number of important aspects. First, price discrimination in the international segment implies higher consumer net surplus because of lower international call prices if termination markups are positive. But there is also a loss in termination profit owing to less international termination. The third line above is new. The first term represents the profit on operations abroad, and the second term represents the part of domestic profit which floats out of the country owing to foreign ownership of one of the domestic networks.

The distribution of profits does not matter at the aggregate level, only retail prices:

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

Hence, the socially optimal termination rate is equal to marginal termination cost even under international ownership.

National regulation The national regulatory agency 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

$$\frac{\partial w_{INOk}}{\partial m_k} = \underbrace{\tfrac{\lambda}{2} m_k \widehat{q}'(c+m_k)}_{\text{Domestic price distortion}} + \underbrace{\lambda\tfrac{\theta}{2}(m_k\hat{x}'(c+m_k) + \hat{x}(c+m_k))}_{\text{Marginal international termination rent}} \tag{23}$$
$$+ \underbrace{\lambda\tfrac{\theta}{4}(m_k\widehat{x}'(c+m_k) + \widehat{x}(c+m_k))}_{\text{Marginal international profit}} - \underbrace{\tfrac{\lambda}{4}[(1-2\delta(1+\theta))\hat{q}(c+m_k) + m_k\hat{q}'(c+m_k)]}_{\text{Domestic profit extraction from foreign INO}}.$$

The first two terms are qualitatively similar to the case with national network operators, see (13), except marginal international termination rent is lower because of the smaller share of international off-net termination. The first term on the second line is the marginal effect on INO profit abroad of increasing the domestic termination rate. Changes in the domestic termination rate matter because the magnitude of international termination profit affects competition abroad. Still, indirect rent extraction running through foreign profits is not enough to offset the direct loss of termination profit. If the first three effects were all that mattered, then regulated termination rates would be unambiguously lower under international than 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. INO profit consists of subscriber and termination profit. Network competition is intense for positive termination markups if network externalities are strong (δ is large) or markets are international (θ is large); see eq. (19). NRA_k extracts INO profit by setting a high termination rate in this case and above the level that would prevail under national ownership. In the opposite case of weak network externalities and a small degree of internationalisation, the best way for NRA_k to regulate INO profit is by slicing the termination profit through a low termination rate. In this case, international ownership drives down the regulated termination rate. Domestic welfare is additively separable in termination rates even under international ownership, so the fact that the INOs are common agencies does affect regulation in the present context:

Proposition 2. *A national regulatory authority maximizing domestic welfare sets a non-negative termination markup*

$$\frac{m^R_{INO}}{c+m^R_{INO}}=\frac{4\theta-(1+\theta)(1-2\delta)}{1+3\theta}\frac{1}{\eta(c+m^R_{INO})} \tag{24}$$

under international network ownership if and only if markets are sufficiently international ($\theta \geq max\{0;\frac{1-2\delta}{3+2\delta}\}$). The regulated termination rate is smaller under international than national network ownership if and only if network externalities are weak enough and the degree of internationalisation is small enough ($m^R_{INO} \leq m^R_{NNO}$ if and only if $\delta \leq 1/2$ and $\theta \leq \frac{1-2\delta}{4\delta}$).

Proof. The first part of the proof is analogous to the proof of Proposition 1, hence omitted. Strict quasi-concavity of w_{NNOk} and $\frac{\partial w_{NNOk}}{\partial m_k}|_{m_k=m^R_{INO}}=\frac{\lambda}{2}\frac{1+\theta}{1+3\theta}(1-2\delta-4\delta\theta)\hat{x}(c+m^R_{INO})$ yield the second result. □

4.4 The welfare effects of international network ownership

Let $\hat{w}_{INO}(m)=w_{INO}(m,m,\theta)$ be aggregate welfare under international ownership when the termination markup m is the same in both countries, and define $\hat{w}_{NNO}(m)$ correspondingly. Then, $w^R_{INO}=\hat{w}_{INO}(m^R_{INO})$ and $w^R_{NNO}=\hat{w}_{NNO}(m^R_{NNO})$ define aggregate equilibrium welfare under international and national ownership, respectively. International ownership has two welfare effects:

$$\begin{aligned} w^R_{INO}-w^R_{NNO}=&\underbrace{\lambda\theta[v(c)-v(c+m^R_{NNO})-m^R_{NNO}\hat{x}(c+m^R_{NNO})]}_{\text{Less call price distortions}} \\ &+\underbrace{w^R_{INO}-\hat{w}_{INO}(m^R_{NNO})}_{\text{Regulatory response}} \end{aligned} \tag{25}$$

Holding the termination rate fixed at m^R_{NNO}, there is a direct welfare benefit stemming from the fact that international call prices are less distorted under international ownership. Second, regulated termination rates are likely to change as a response to the change in ownership structure, i.e., $m^R_{INO}\neq m^R_{NNO}$. The regulatory response increases welfare if network externalities are weak ($\delta \leq 1/2$) and markets are characterized by an intermediate degree of internationalisation ($\frac{1-2\delta}{3+2\delta} \leq \theta \leq \frac{1-2\delta}{4\delta}$) because then the regulated termination rate is less distorted under international than national ownership: $m^{soc} \leq m^R_{INO} \leq m^R_{NNO}$. The aggregate welfare effect is ambiguous if network externalities are strong ($\delta > 1/2$) or markets are very international ($\theta > \frac{1-2\delta}{4\delta}$) because then call prices are less distorted whereas termination rates are more distorted, $m^{soc} < m^R_{NNO} < m^R_{INO}$, under international network ownership. We collect these observations in a proposition:

Proposition 3. *International ownership has a positive effect on aggregate welfare under weak network externalities and intermediate degrees of internationalisation ($w^R_{INO} \geq w^R_{NNO}$ if $\delta \leq 1/2$ and $\theta \in [\frac{1-2\delta}{3+2\delta}, \bar{\theta}]$, where $\bar{\theta} > \frac{1-2\delta}{4\delta}$).*

5 Deregulation

This section discusses deregulation, one of the long-term policy objectives of the EU, as an alternative remedy to the problem of excessive rate setting by NRAs. When network operators are free to set termination rates, then the deregulated termination rate is preferable from an aggregate welfare viewpoint to the regulated termination rate set by national regulatory authorities if markets are sufficiently international.

5.1 The profit maximizing termination rate

Call demands, subscription demands and retail equilibria are the same as in the previous two sections. Assume first that two NNOs in country k negotiate the reciprocal markup m_k to maximize domestic industry profit; see (15). The trade-off facing NNOs in raising the termination rate above termination cost is between a higher termination profit and intensified retail competition through a stronger network externality:

$$\begin{aligned}\pi'_{NNO}(m_k) &= \underbrace{\tfrac{\lambda}{2}\widehat{q}(c+m_k) + \tfrac{\lambda}{2}m_k\widehat{q}'(c+m_k)}_{\text{Marginal termination profit}} + \underbrace{\tfrac{\lambda}{2}2\delta v'(c+m_k)}_{\text{Marginal network externality}} \qquad (26)\\ &= \tfrac{\lambda}{2}((1-2\delta)\widehat{q}(c+m_k) + m_k\widehat{q}'(c+m_k)).\end{aligned}$$

If the share of responsive consumers is large enough, i.e. $\delta > 1/2$, then the network externality dominates the trade-off for all termination rates above marginal termination cost. In this case, networks prefer a termination rate below cost. In the opposite case, when the share of consumers with passive expectations is large enough, i.e. $\delta \leq 1/2$, then marginal termination profit dominates for small termination rates, and unregulated networks negotiate a termination rate at or above termination cost. The profit maximizing termination rate is independent of the degree of internationalisation. Hence, a profit neutrality result obtains on the international call segment. Profit neutrality has shown to be robust to a number of generalizations of the workhorse model such as consumer heterogeneity (Dessein, 2003, 2004; Hahn, 2004) and call externalities (e.g. Armstrong, 2002; Jeon et al. 2004; Hurkens and López, forthcoming), so we expect even the above profit neutrality result to be robust to generalisations in the same dimensions.

Consider next the case of two INOs jointly negotiating termination markups (m_H, m_F) to maximize overall industry profit. By symmetry, this is the same as maximizing network profit

$$\pi_{INO}(m_H, m_F, \theta) = \sum_{k=H,F} \tfrac{1}{2}[t^*_{INO}(m_k, m_l, \theta) - f + \tfrac{\lambda}{2} m_k(\hat{q}(c+m_k) + \theta\hat{x}(c+m_k))] \tag{27}$$

$$= \sum_{k=H,F} \tfrac{1}{2}[\tfrac{1}{2\sigma}(1 - 2(1+\theta)\sigma\lambda\delta(v(c) - v(c+m_k))) + \tfrac{\lambda}{2} m_k(\hat{q}(c+m_k) + \theta\widehat{x}(c+m_k))], \tag{28}$$

where in the second row, we have substituted the equilibrium subscription fee (18) into network profit and simplified.

The marginal effect on profit of increasing the termination markup rate in country k is

$$\frac{\partial \pi_{INO}}{\partial m_k} = \tfrac{\lambda}{4}(1+\theta)((1-2\delta)\widehat{q}(c+m_k) + m_k\widehat{q}'(c+m_k)), \tag{29}$$

which is proportional to the trade-off facing the NNOs. Although the presence of an international network externality intensifies network competition and tends to drive down the profit maximizing termination rate, there is a countervailing effect of an increased marginal termination profit which goes in the opposite direction. Owing to the balanced call pattern, these two effects cancel out. By inspection of marginal profits above, we immediately note that unregulated international network operators negotiate the same termination rate as unregulated national network operators, which is, moreover, independent of the degree of internationalisation.

Proposition 4. *The profit maximizing termination markup is independent of ownership struc-*

ture and the degree of internationalisation. It is non-negative and characterized by

$$\frac{m^*}{c+m^*} = \frac{1-2\delta}{\eta(c+m^*)}. \tag{30}$$

if and only if network externalities are weak enough ($\delta \leq 1/2$). The profit maximizing termination rate is above the regulated termination rate if and only if network externalities are weak enough and the degree of internationalisation is small enough ($m^* \geq m^R_{NNO}$ and $m^* \geq m^R_{INO}$ if and only if $\delta \leq 1/2$ and $\theta \leq \frac{1-2\delta}{4\delta}$).

Proof. We prove the result for the INO case only, as the NNO case is analogous. If $\delta > 1/2$, then $\frac{\partial \pi_{INO}}{\partial m_k} < 0$ for all $m_k \geq 0$ such that $\pi_{INO} > 0$ by $\widehat{q}' < 0$, and therefore networks maximize profit by a negative termination markup. An optimum exists by continuity of π_{INO} and compactness: $m_k \in [-c, 0]$. If $\delta = 1/2$, then π_{INO} is single-peaked with optimum $m^* = 0$. If $\delta < 1/2$, then $\frac{\partial \pi_{INO}}{\partial m_k} > 0$ for all $m_k \leq 0$, so networks maximize profit by a positive termination markup: $m^* > 0$. Network profit is strictly quasi-concave by the assumption that $(p-c)q'(p)$ is weakly decreasing in p. Hence, the optimum is uniquely defined by $\frac{\partial \pi_{INO}}{\partial m_k} = 0$, which is equivalent to (30). This optimum exists because π_{INO} is continuous, $\frac{\partial \pi_{INO}}{\partial m_k}|_{m_k=0} = \lambda(1+\theta)(1-2\delta)\widehat{q}(c)/4 > 0$, and $\frac{\partial \pi_{INO}}{\partial m_k} \leq 0$ for some $m_k > 0$ by the boundary condition $q(p) + (p-c)q'(p) \leq 0$ for some $p > c$. If $\delta > 1/2$, then $m^* < 0 < m^R_{INO}$. Hence, $m^* \geq m^R_{INO}$ only if$\delta \leq 1/2$. Let $\delta \leq 1/2$. Strict quasi-concavity of π_{INO} and $\frac{\partial \pi_{INO}}{\partial m_k}|_{m_k=m^R_{INO}} = \frac{\lambda}{2}\frac{1+\theta}{1+3\theta}(1-2\delta-4\delta\theta)\widehat{q}(c+m^R_{INO})$ imply $m^* \geq a^R_{INO}$ if and only if $\theta \leq \frac{1-2\delta}{4\delta}$. □

The unregulated termination rate converges to marginal cost as the share of responsive consumers increases and network externalities become increasingly important, i.e. $\delta \to 1/2$ implies $m^* \to 0$. The network externality vanishes completely in the opposite case when the share of passive consumers becomes very large, i.e. $\delta \to 0$. Termination rates are then set to maximize termination profit by inducing the monopoly off-net price: $(\widehat{p}^* - c)/\widehat{p}^* = 1/\eta(\widehat{p}^*)$. These results were established by Hoernig (2012) and Hurkens and López (forthcoming) for the case of national network competition. Proposition 4 shows that the results hold even if we allow international calls and different ownership structures. Also, the regulated termination rates are increasing in the degree of internationalisation while the profit maximizing termination rates are independent of it. Therefore, the regulated termination rates surpass the deregulated ones if and only if markets are sufficiently international.

5.2 The welfare effects of deregulation

Unregulated network operators distort termination rates in a collusive effort to raise profit, and the unregulated termination rate is excessive from a welfare viewpoint if network externalities are weak ($\delta \leq 1/2$). But even national regulatory authorities have incentives to distort termination rates. In particular, the regulated termination rates are excessive, independently of the ownership structure, if the degree of internationalisation is strong enough ($\theta \geq \frac{1-2\delta}{3+2\delta}$). And because the aggregate welfare functions $\hat{w}_{INO}(m)$ and $\hat{w}_{NNO}(m)$, are single peaked in m, the welfare maximizing regime is the one that yields the smallest equilibrium termination rate. In light of Proposition 4:

Proposition 5. *Hold the ownership structure fixed. Assume that network externalities are weak enough ($\delta \leq 1/2$) and the degree of internationalisation strong enough ($\theta \geq \frac{1-2\delta}{3+2\delta}$) that the equilibrium termination markups are non-negative independently of whether they are regulated or not. Deregulation then welfare dominates regulation ($w^*_{INO} = \hat{w}_{INO}(m^*) \geq w^R_{INO}$ and $w^*_{NNO} = \hat{w}_{NNO}(m^*) \geq w^R_{NNO}$) if and only if markets are sufficiently international ($\theta > \frac{1-2\delta}{4\delta}$).*

Proposition 5 underscores that deregulation may be preferable to decentralized regulation even if unregulated network operators have an incentive to agree on excessive termination rates.

6 Policy discussion

Our analysis has centered around the consequences of decentralised regulation and whether changes in network ownership structure and deregulation can be desirable from a welfare viewpoint. Deregulation is a political decision which in principle can be imposed upon the market participants if deemed optimal, but network consolidation is not. For sure, regulators and competition authorities can sometimes block undesirable cross-border mergers, but they cannot force private companies to merge. Also, the anticipation that ownership changes may subsequently affect regulation can have implications for the incentives to consolidate.

Let (full) consolidation refer to the case when the four national network operators merge into two international network operators. Define by $\widehat{\pi}_{INO}(m) = \pi_{INO}(m, m, \theta)$ the profit of an international network operator when the termination rate m is the same in both countries. Then, $\pi^R_{INO} = \widehat{\pi}_{INO}(m^R_{INO})$ characterizes its equilibrium profit under decentralised regulation, whereas $\pi^R_{NNO} = \pi_{NNO}(m^R_{NNO})$ is the corresponding domestic equilibrium industry profit under national network ownership. The net effect of consolidation on network profit is $\pi^R_{INO} - \pi^R_{NNO}$.

Holding the termination rate fixed at m^R_{NNO}, consolidation has two effects on network profit:

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

The first term in the first line above is the effect of network consolidation on network competition, as reflected in the change to the subscription fee. The second term is the negative effect of consolidation on international termination profit. If the share of responsive consumers is large enough ($\delta > 1/2$), then intensified network competition resulting from the international network externalities is sufficient to render consolidation weakly unprofitable at the termination rate m^R_{NNO}: $\hat{\pi}_{INO}(m^R_{NNO}) \leq \pi^R_{NNO}$. Cross-border consolidation also triggers a regulatory response which drives up the termination rate, i.e. $m^R_{INO} > m^R_{NNO} \geq 0$; see Proposition 2. This regulatory response reduces network profit, $\pi^R_{INO} < \hat{\pi}_{INO}(m^R_{NNO})$, because the profit maximizing termination rate is below cost and network profit is strictly decreasing for all non-negative termination rates, see eq. (29). Hence, consolidation reduces industry profit under strong network externalities. Network consolidation is unprofitable also under weak network externalities and a small degree of internationalisation because the regulated termination rate then falls to such an extent as to wipe out all anti-competitive benefits.

Lemma 3. *Full consolidation increases total industry profit relative to national network ownership under decentralised regulation ($\pi^R_{INO} \geq \pi^R_{NNO}$) only if network externalities are weak enough ($\delta \leq 1/2$) and markets are sufficiently international ($\theta \geq \frac{1-2\delta}{3+2\delta}$).*

Proof. We have shown in the main text that $\pi^R_{INO} < \hat{\pi}_{INO}(m^R_{NNO})$ if $\delta > 1/2$. Define $H(m) = m\hat{x}(c + m) - 2\delta(v(c) - v(c + m))$. $H'(m) = (1 - 2\delta)\hat{x}(c + m) + m\hat{x}'(c + m) < 0$ for all $m \geq 0$ if $\delta > 1/2$ implies $\hat{\pi}_{INO}(m^R_{NNO}) - \pi^R_{NNO} = \frac{\lambda\theta}{2}H(m^R_{NNO}) \leq \frac{\lambda\theta}{2}H(0) = 0$ in this case. Hence, $\pi^R_{INO} \geq \pi^R_{NNO}$ only if $\delta \leq 1/2$. If $\delta < 1/2$ and $\theta < \frac{1-2\delta}{3+2\delta}$, then $\pi^R_{INO} - \pi_{NNO}(m^R_{INO}) = \frac{\lambda\theta}{2}H(m^R_{INO}) \leq \frac{\lambda\theta}{2}H(0) = 0$ because then $m^R_{INO} < 0$, see Proposition 2, and $H'(m) > 0$ for all $m \leq 0$. Furthermore, $m^R_{INO} < 0 \leq m^R_{NNO} \leq m^*$ and strict quasi-concavity of π_{NNO} imply $\pi_{NNO}(m^R_{INO}) < \pi^R_{NNO}$ in this parameter range. □

Proposition 3 suggests that international ownership can have negative consequences for aggregate welfare. This problem can occur if, for example, network externalities are strong ($\delta > 1/2$) or markets are not particularly international ($\theta < \frac{1-2\delta}{3+2\delta}$) because the regulatory response then conceivably distorts termination rates enough to outweigh the benefits of increased call price efficiency. But Lemma 3 shows that these concerns are exaggerated if one accounts for the incentives to consolidate. For network consolidation is unprofitable precisely in circumstances under which the regulatory response is likely to reduce aggregate welfare. By a combination of Proposition 3 and Lemma 3:

Corollary 1. *Assume that national network operators consolidate under decentralised regulation if and only if doing so increases aggregate industry profit ($\pi^R_{INO} \geq \pi^R_{NNO}$). If the degree of internationalisation is small enough ($\theta \leq \frac{1-2\delta}{4\delta}$), then a regulatory policy which facilitates cross-border consolidation increases aggregate welfare compared to a policy under which consolidation is prohibited.*

This corollary shows that a first step towards increasing aggregate welfare under decentralised regulation would be to facilitate cross-border consolidation. This result is driven by an increased efficiency in international call prices and an improved regulatory performance and arises independently of any additional cost synergies associated with cross-border consolidation. But consolidation is not enough when markets become very globalized ($\theta > \bar{\theta} > \frac{1-2\delta}{4\delta}$) because then the regulated termination rates become so distorted after consolidation that aggregate welfare falls. A second step to increasing aggregate welfare would be full deregulation:

Corollary 2. *Assume that national network operators have consolidated under decentralised regulation. Deregulation then leads to an additional increase in aggregate welfare ($w^*_{INO} > w^R_{INO}$) if markets are very international ($\theta > \frac{1-2\delta}{4\delta}$).*

Proof. Lemma 3 states that networks consolidate under decentralized regulation only if $\delta \leq 1/2$ and $\theta \geq \frac{1-2\delta}{3+2\delta}$. If $\delta \leq 1/2$ and $\theta > \frac{1-2\delta}{4\delta}$, then ($w^*_{INO} > w^R_{INO}$); see Proposition 5. □

Our result that decentralised regulation is worse than deregulation from an aggregate welfare viewpoint when markets are very international relies on the assumption that the national regulatory agencies can force network operators to charge higher termination rates than what are privately profitable, for example by means of a termination rate floor. It is then interesting to note that the Swedish Ministry of Enterprise recently has proposed that termination rates in Sweden should be subject precisely to a regulated floor and not only a ceiling, as is currently the case. The above results indicate that the EU should view such legal proposals with skepticism. One solution would be to require of all NRAs that they 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 non-binding. However, deregulation would still be welfare improving in this case because decentralised regulation would be ineffective and could be rolled back to save on the regulatory burden. Note also that deregulation can be socially optimal even if termination rates would become more distorted as a consequence. For weak network externalities and intermediate degrees of internationalisation ($\delta < 1/2$ and $\theta \gtrsim \frac{1-2\delta}{3+2\delta}$), the only way to induce international consolidation and thereby increase call price efficiency would be through deregulation ($\pi^R_{INO} < \pi^R_{NNO}$, but $\pi^*_{INO} > \pi^*_{NNO}$). In principle, this welfare gain could be enough to outweigh the cost of a higher termination rate.

The incentive for firms to consolidate arises in the present context from relaxed network competition. The associated increase in the equilibrium subscription fee has no aggregate welfare effect by the assumptions that markets are fully covered, so that there are no resulting deadweight losses, and that consumer and producer surpluses have equal weights, so that redistribution from subscribers to network operators does not matter. Market coverage now exceeds 100 percent in most OECD countries in terms of mobile subscriptions per capita (OECD, 2011). Deadweight losses arising from excessive subscription fees thus seem to be a minor problem in mature telecoms markets. The regulatory emphasis on cost-based termination rates suggests that efficiency, and not redistributional, concerns play the major role in shaping EU telecoms policy. Still, there could be reasons for not allowing market concentration to increase by too much. Today's high capacity telecoms networks were rolled out under network competition and not in the era of national monopolies. One limitation of consolidation could be a weaker incentive to innovate and improve network performance.

Our analysis takes an industry perspective by comparing national network ownership with full consolidation whereby the four national networks merge into two international network operators. A complementary analysis would be to consider the unilateral merger incentives to get a fuller picture of the consolidation process. The retail equilibrium would be asymmetric under an asymmetric ownership structure, but retail prices would still be priced at perceived marginal cost. Full consolidation would be welfare optimal for fixed termination rates because international call prices would become increasingly efficient with additional consolidation. A unilateral cross-border merger would probably trigger asymmetric regulatory responses. 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 than the NRA in the host country, assuming weak network externalities. But an analysis of how asymmetric retail equilibria and asymmetric regulatory responses affect merger incentives is beyond the scope of this paper, and we leave it for future research.[8]

The European Commission has recently proposed steps to harmonise the European telecoms markets. These include measures aimed at reducing the margins on international phone calls within Europe.[9] The proposed regulation would mean that "companies cannot charge more for a 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 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 less intrusive measures than direct regulation of retail prices which the 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 happens because consumers in our framework base their choice of operator on its full range of call prices, national as well as international. Non-linear pricing then drives all call prices down to perceived marginal cost. Hence, increased consumer awareness, price transparency and harmonisation of termination rates across the EU would probably do a lot to reduce the price of international calls down to the level of national off-net calls even absent any direct regulation of retail prices. In this respect, it is interesting to note that 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 (www.t-mobile.de/tarife; accessed February 2014). Authorities could then achieve the desired reduction of international (and national) call prices by focusing on reducing termination rates.

7 Conclusion

Motivated by the globalisation of telecoms markets, we have developed a framework to analyse the consequences and welfare implications of decentralised regulation, international network ownership and deregulation in an internationalised market. We have shown that national regulatory authorities have incentives to set termination rates above marginal costs to extract rents

[8]This paper excludes also several other interesting dimensions of national and international regulations of the telecoms sector. Mobile roaming, network neutrality, and spectrum allocations could be fruitful avenues for further research in the context of the present framework.

[9]See http://europa.eu/rapid/press-release_IP-13-828_en.htm. Accessed November 2013.

from international termination. The efforts by EU policy makers to improve regulatory performance in the member countries are therefore warranted. Our results suggest that the initiatives to facilitate cross-border network ownership can increase aggregate welfare in international markets. Full deregulation of telecoms markets, a long-term policy objective of the EU, can further improve welfare when markets are very international. Direct regulation of retail prices seems less important if the authorities achieve price transparency and manage to get termination rates right.

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A Appendix

A.1 Proof of Lemma 1

This is a generalisation of Proposition 1 in Hurkens and López (forthcoming), taking into account that only a share $1-\delta \leq 1$ of consumers have passive beliefs and that network operators also compete in international calls, $\theta \geq 0$. By differentiation of subscription demand (4)

$$\frac{\partial s_{ki}/\partial p_{ki}}{\partial s_{ki}/\partial t_{ki}} = \frac{\partial s_{li}/\partial p_{ki}}{\partial s_{li}/\partial t_{ki}} = \left(\delta s_{ki} + (1-\delta)\widehat{s}_{ki}\right)\lambda q_{ki}, \tag{31}$$

$$\frac{\partial s_{ki}/\partial \widehat{p}_{ki}}{\partial s_{ki}/\partial t_{ki}} = \frac{\partial s_{li}/\partial \widehat{p}_{ki}}{\partial s_{li}/\partial t_{ki}} = (1 - \delta s_{ki} - (1-\delta)\widehat{s}_{ki})\lambda \widehat{q}_{ki}, \tag{32}$$

$$\frac{\partial s_{ki}/\partial r_{ki}}{\partial s_{ki}/\partial t_{ki}} = \frac{\partial s_{li}/\partial r_{ki}}{\partial s_{li}/\partial t_{ki}} = (\delta s_{li} + (1-\delta)\widehat{s}_{li})\lambda\theta x_{ki}, \tag{33}$$

$$\frac{\partial s_{ki}/\partial \widehat{r}_{ki}}{\partial s_{ki}/\partial t_{ki}} = \frac{\partial s_{li}/\partial \widehat{r}_{ki}}{\partial s_{li}/\partial t_{ki}} = (1 - \delta s_{li} - (1-\delta)\widehat{s}_{li})\lambda\theta \widehat{x}_{ki}, \tag{34}$$

which generate the aggregate first-order conditions:

$$\frac{\partial \pi_{ki}}{\partial p_{ki}} - \left(\delta s_{ki} + (1-\delta)\widehat{s}_{ki}\right)\lambda q_{ki}\frac{\partial \pi_{ki}}{\partial t_{ki}} = s_{ki}\lambda[(1-\delta)(s_{ki}-\widehat{s}_{ki})q_{ki} + s_{ki}\left(p_{ki}-c\right)q'(p_{ki})] \leq 0, \tag{35}$$

$$\frac{\partial \pi_{ki}}{\partial \widehat{p}_{ki}} - (1-\delta s_{ki} - (1-\delta)\widehat{s}_{ki})\lambda \widehat{q}_{ki}\frac{\partial \pi_{ki}}{\partial t_{ki}} = s_{ki}\lambda[(1-\delta)(\widehat{s}_{ki}-s_{ki})\widehat{q}_{ki} + s_{kj}\left(\widehat{p}_{ki}-c-m_k\right)\widehat{q}'(\widehat{p}_{ki})] \leq 0, \tag{36}$$

$$\frac{\partial \pi_{ki}}{\partial r_{ki}} - (\delta s_{li} + (1-\delta)\widehat{s}_{li})\lambda\theta x_{ki}\frac{\partial \pi_{ki}}{\partial t_{ki}} = s_{ki}\lambda\theta[(1-\delta)(s_{li}-\widehat{s}_{li})x_{ki} + s_{li}\left(r_{ki}-c-m_l\right)x'(r_{ki})] \leq 0, \tag{37}$$

$$\frac{\partial \pi_{ki}}{\partial \widehat{r}_{ki}} - (1-\delta s_{li} - (1-\delta)\widehat{s}_{li})\lambda\theta \widehat{x}_{ki}\frac{\partial \pi_{ki}}{\partial t_{ki}} = s_{ki}\lambda\theta[(1-\delta)(\widehat{s}_{li}-s_{li})\widehat{x}_{ki} + s_{lj}\left(\widehat{r}_{ki}-c-m_l\right)\widehat{x}'(\widehat{r}_{ki})] \leq 0 \tag{38}$$

for NNO_{ki} under full market coverage.

Let $\mathbf{s}^* = (s^*_{H1}, s^*_{H2}, s^*_{F1}, s^*_{F2})$ be an arbitrary, full coverage, equilibrium distribution of market shares, and assume that $\widehat{\mathbf{s}} = \mathbf{s}^*$. If $s_{ki} \geq s^*_{ki} > 0$ or $s_{ki} > s^*_{ki} = 0$, then (35) is strictly positive for all $p_{ki} < c$. In this case

$$(1-\delta)(s_{ki} - s^*_{ki})q\left(\mathcal{P}\right) + s_{ki}\left(\mathcal{P} - c\right)q'(\mathcal{P}) = 0 \tag{39}$$

uniquely defines the optimal national on-net price $\mathcal{P}(s_{ki}) \geq c$. By weak monotonicity of $(p - c)q'(p)$, (39) has at most one solution $\mathcal{P} \geq c$. A solution exists by the boundary condition $q(p) + (p - c)q'(p) \leq 0$ for some $p > c$. If $0 < s_{ki} < s^*_{ki}$, then (35) is strictly negative for all $p_{ki} > c$. Hence, $\mathcal{P}(s_{ki}) \in [0, c]$ in this case. By compactness of $[0, c]$ and continuity of network profit in p_{ki}, an optimum does exist and is defined by (39) if $\mathcal{P}(s_{ki}) > 0$. The optimal national off-net price $\widehat{\mathcal{P}}(s_{ki})$, and international prices $\mathcal{R}(s_{li})$ and $\widehat{\mathcal{R}}(s_{li})$ are correspondingly defined.

Marginal cost pricing of calls at interior equilibrium. Consider the equilibrium on-net price p^*_{ki}. Beliefs are consistent at equilibrium: $s^*_{ki} = \widehat{s}_{ki}$. If $s^*_{ki} > 0$, then (35) is strictly positive (negative) for all $p^*_{ki} < c$ ($p^*_{ki} > c$) by $q' < 0$. The first-order condition (35) holds with equality if $s^*_{ki}p^*_{ki} > 0$. Hence, $s^*_{ki} > 0$ implies $p^*_{ki} = c$. 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 $s^*_{ki} = 1$. By the above optimality conditions, $p^*_{ki} = c$, international calls are priced at marginal cost $s^*_{li}r^*_{ki} + s^*_{lj}\widehat{r}^*_{ki} = c + m_l$, while $\widehat{p}^*_{ki}$ remains undefined. Let $\pi^*_{ki} = t^*_{ki} - f + \lambda\theta m_k \hat{x}(c + m_k) \geq 0$ 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 $t_{kj} = t^*_{ki} + 1/2\sigma - \lambda$. Since NNO_{kj} does not price discriminate between on-net and off-net calls, consumer net surplus at NNO_{kj} is independent of actual and expected market shares and equal to $\lambda v(c) + \theta\lambda v(c + m_l) - t^*_{ki} - 1/2\sigma + \lambda$ for a consumer located at b_{kj}. Consumer net surplus when NNO_{ki} corners the market equals $\lambda v(c) + \theta\lambda v(c + m_l) - t^*_{ki} - 1/2\sigma$ 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

$$\pi_{kj} = \lambda s_{kj}[s_{ki}m_k(\widehat{q}(\widehat{p}_{ki}) - \widehat{q}(c)) - 1 + 1/2\sigma\lambda + \pi^*_{ki}/\lambda] \tag{40}$$

is strictly positive for $\sigma\lambda$ small enough (recall the assumption that $\widehat{q}(p)$ is bounded). We conclude that for $\sigma\lambda$ small enough, 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 $k = H, F$, $i = 1, 2$. By utilizing marginal cost pricing and the first-order condition (6), the equilibrium subscription fee equals

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

Substitute back into (4) and rearrange to get equilibrium subscription demand:

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

For generic termination rates, therefore, $s_{ki}^{*} = 1/2$ at interior equilibrium. Furthermore, $s_{ki}^{*} = 1/2$ implies $t_{ki}^{*} = t_{NNOk}^{*}$, so $(\mathbf{p}_{NNOk}^{*}, t_{NNOk}^{*})$ is the unique interior equilibrium candidate.

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

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 $\mathcal{P}(s_{ki})$ and $\widehat{\mathcal{P}}(s_{ki})$. The corresponding subscription fee which generates s_{ki} is given by:i

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

Substitute $\mathcal{P}(s_{ki})$, $\widehat{\mathcal{P}}(s_{ki})$ and $\mathcal{T}(s_{ki})$ into π_{ki} in (5) to get the profit of NNO_{ki} as a function of s_{ki}:

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

The marginal effect of increasing the market share is

$$\sigma\widehat{\pi}'(s_{ki}) = \sigma\lambda[2s_{ki}\left(\mathcal{P}(s_{ki}) - c\right)q(\mathcal{P}(s_{ki})) + (2\delta s_{ki} + \tfrac{1}{2}(1-\delta))(v\left(\mathcal{P}(s_{ki})\right) - v(c+m_k))]$$
$$+ \sigma\lambda[(s_{kj} - s_{ki})(\widehat{\mathcal{P}}(s_{ki}) - c - m_k)\widehat{q}(\widehat{\mathcal{P}}(s_{ki})) + (\delta(s_{kj} - s_{ki}) + \tfrac{1}{2}(1-\delta))(v(\widehat{\mathcal{P}}(s_{ki})) - v\left(c\right))]$$
$$+ \sigma(t^*_{NNOk} - f) + \tfrac{1}{2} - 2s_{ki} + \sigma\lambda m_k((s_{kj} - s_{ki})\widehat{q}(c+m_k) + \theta x(c+m_k)).$$

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

A.2 Proof of Lemma 2

Let $\mathbf{s}^* = (s^*_{H1}, s^*_{H2}, s^*_{F1}, s^*_{F2})$ be an arbitrary, full coverage equilibrium distribution of market shares, and assume that $\widehat{\mathbf{s}} = \mathbf{s}^*$. By utilizing the comparative statics (31)-(34), it is straightforward to verify that aggregate first-order conditions identical to (35), (36) and (38) apply even to INO_i. Hence, the optimal national on-net price in country k equals $\mathcal{P}(s_{ki})$, the optimal national off-net price is $\widehat{\mathcal{P}}(s_{ki})$, while the optimal international off-net price is $\widehat{\mathcal{R}}(s_{li})$. However, international on-net calls now have perceived marginal cost c, hence

$$\frac{\partial\pi_i}{\partial r_{ki}} - (\delta s_{li} + (1-\delta)\widehat{s}_{li})\lambda\theta x_{ki}\frac{\partial\pi_i}{\partial t_{ki}} = s_{ki}\lambda\theta[(1-\delta)(s_{li} - \widehat{s}_{li})x_{ki} + s_{li}(r_{ki} - c)x'(r_{ki})] \leq 0, \quad (41)$$

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

$$(1-\delta)(s_{li} - s^*_{li})x(\mathcal{R}) + s_{li}(\mathcal{R} - c)x'(\mathcal{R}) = 0 \quad (42)$$

or $\mathcal{R}(s_{li}) = 0$ for $s_{Hi}s_{Fi} > 0$. By an argument analogous to the one 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 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

(36) and (38). 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 $t_{kj} = t_{ki}^* + 1/2\sigma - \lambda$. Since INO_j does not price discriminate between on-net and off-net calls, consumer net surplus at INO_j is independent of actual and expected market shares and equal to $\lambda(1+\theta)v(c) - t_{ki}^* - 1/2\sigma + \lambda$ for a consumer located at b_{kj}. 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

$$\pi_{kj} = \lambda s_{kj}[s_{ki}m_k(\widehat{q}_{ki} - \widehat{q}(c)) + \theta s_{li}(m_k\widehat{x}_{li} - m_l\widehat{x}(c)) - 1 + 1/2\sigma\lambda + \pi_{ki}^*/\lambda] \tag{43}$$

of INO_j is strictly positive for $\lambda\sigma$ small enough. We conclude that for $\sigma\lambda$ small enough, 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 (36) and (41). 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 $r_{lj} = c + m_k$.

Since INO_j does not locally price discriminate between on-net and off-net calls, 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}, independently 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

$$\pi_j - \pi_j^* = \lambda s_{kj}[s_{ki}m_k(\widehat{q}(c + m_k) - \widehat{q}(c)) - 1 + 1/2\sigma\lambda + \pi_i^*/\lambda] \tag{44}$$

of entering the competitor's market is strictly positive for $\lambda\sigma$ small enough. We conclude that for $\sigma\lambda$ small enough, 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 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 (36) and (38). 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:

$$\begin{aligned} &\lambda v\,(c) + \lambda\theta s^*_{li} v(c) + \lambda\theta s^*_{lj} v(c + m_l) - t^*_{ki} - 1/2\sigma \\ &\quad \geq \lambda v(\widehat{p}^*_{kj}) + \lambda\theta s^*_{lj} v(r^*_{kj}) + \lambda\theta s^*_{li} v(\widehat{r}^*_{kj}) - t^*_{kj}. \end{aligned} \tag{45}$$

If the inequality was strict, then INO_i could raise its profit without jeopardising its monopoly position by increasing t^*_{ki} up until the point at which (45) was strictly binding. Hence, (45) 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 $\widehat{\mathbf{s}} = \mathbf{s}^*$. The optimal call prices are defined by $\mathcal{P}(s_{ki})$, $\widehat{\mathcal{P}}(s_{ki})$, $\mathcal{R}(s_{li})$ and $\widehat{\mathcal{R}}(s_{li})$ in country k, while the subscription fees are set at $\mathcal{T}_{ki}(s_{ki}, s^*_{li})$ and $\mathcal{T}_{li}(s^*_{li}, s_{ki})$ to achieve the desired distribution of market shares, where

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

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

$$\begin{aligned} \widetilde{\pi}_{ki}(s_{ki}, s_{li}) &= s_{ki}\lambda[s_{ki}\,(\mathcal{P}(s_{ki}) - c)\,q(\mathcal{P}(s_{ki})) + (\delta s_{ki} + (1-\delta)s^*_{ki})(v\,(\mathcal{P}(s_{ki})) - v(\widehat{p}^*_{kj}))] \\ &\quad + s_{ki}\lambda[s_{kj}(\widehat{\mathcal{P}}(s_{ki}) - c - m_k)\widehat{q}(\widehat{\mathcal{P}}(s_{ki})) + (\delta s_{kj} + (1-\delta)s^*_{kj})(v(\widehat{\mathcal{P}}(s_{ki})) - v(p^*_{kj}))] \\ &\quad + s_{ki}\lambda\theta[s_{li}(\mathcal{R}(s_{li}) - c)x(\mathcal{R}(s_{li})) + (\delta s_{li} + (1-\delta)s^*_{li})(v(\mathcal{R}(s_{li})) - v(\widehat{r}^*_{kj}))] \\ &\quad + s_{ki}\lambda\theta[s_{lj}(\widehat{\mathcal{R}}(s_{li}) - c - m_l)\widehat{x}(\widehat{\mathcal{R}}(s_{li})) + (\delta s_{lj} + (1-\delta)s^*_{lj})(v(\widehat{\mathcal{R}}(s_{li})) - v(r^*_{kj}))] \\ &\quad + s_{ki}(t^*_{kj} - f + \tfrac{1-2s_{ki}}{2\sigma}) + s_{ki}\lambda m_k(s_{kj}\widehat{q}(\widehat{p}^*_{kj}) + \theta s_{lj}\widehat{x}(c + m_k)). \end{aligned} \tag{46}$$

Marginal profit equals

$$
\begin{aligned}
\sigma\frac{\partial\widetilde{\pi}_{ki}}{\partial s_{ki}} &= \sigma\lambda[2s_{ki}\left(\mathcal{P}(s_{ki})-c\right)q(\mathcal{P}(s_{ki}))+(2\delta s_{ki}+(1-\delta)s_{ki}^{*})(v\left(\mathcal{P}(s_{ki})\right)-v(\widehat{p}_{kj}^{*}))] \qquad (47)\\
&+\sigma\lambda[(s_{kj}-s_{ki})(\widehat{\mathcal{P}}(s_{ki})-c-m_k)\widehat{q}(\widehat{\mathcal{P}}(s_{ki}))+(\delta(s_{kj}-s_{ki})+(1-\delta)s_{kj}^{*})(v(\widehat{\mathcal{P}}(s_{ki}))-v(p_{kj}^{*}))]\\
&+\sigma\lambda\theta[s_{li}(\mathcal{R}(s_{li})-c)x(\mathcal{R}(s_{li}))+(\delta s_{li}+(1-\delta)s_{li}^{*})(v(\mathcal{R}(s_{li}))-v(\widehat{r}_{kj}^{*}))]\\
&+\sigma\lambda\theta[s_{lj}(\widehat{\mathcal{R}}(s_{li})-c-m_l)\widehat{x}(\widehat{\mathcal{R}}(s_{li}))+(\delta s_{lj}+(1-\delta)s_{lj}^{*})(v(\widehat{\mathcal{R}}(s_{li}))-v(r_{kj}^{*}))]\\
&+\sigma(t_{kj}^{*}-f)+\tfrac{1}{2}-2s_{ki}+\sigma\lambda m_k((s_{kj}-s_{ki})\widehat{q}(\widehat{p}_{kj}^{*})+\theta s_{lj}\widehat{x}(c+m_k))
\end{aligned}
$$

and

$$
\begin{aligned}
\sigma\frac{\partial\widetilde{\pi}_{li}}{\partial s_{ki}} &= s_{li}\sigma\lambda\theta[(\mathcal{R}(s_{ki})-c)x(\mathcal{R}(s_{ki}))+\delta(v(\mathcal{R}(s_{ki}))-v(c+m_k))-m_l\widehat{x}(\widehat{r}_{kj}^{*})] \qquad (48)\\
&- s_{li}\sigma\lambda\theta[(\widehat{\mathcal{R}}(s_{ki})-c-m_k)\widehat{x}(\widehat{\mathcal{R}}(s_{ki}))+\delta(v(\widehat{\mathcal{R}}(s_{ki}))-v(r_{lj}^{*}))].
\end{aligned}
$$

The deviation by INO_i in country k is unprofitable only if $\lim_{s_{ki}\to 1}\partial\widetilde{\pi}_i/\partial s_{ki}|_{s_{li}=s_{li}^{*}}\geq 0$. By a similar argument, a deviation by j in country k to $s_{kj}=1-s_{ki}\in(0,1)$, keeping $s_{lj}^{*}=1-s_{li}^{*}\in(0,1)$ fixed is unprofitable only if $\lim_{s_{kj}\to 0}\partial\widetilde{\pi}_j/\partial s_{kj}|_{s_{lj}=s_{lj}^{*}}\leq 0$. Hence, the equilibrium is sustainable only if

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

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

There exists at most one shared market equilibrium. Consider an interior, shared market equilibrium $s_{ki}^{*}=\widehat{s}_{ki}\in(0,1)$ for all $k=H,F$, $i=1,2$. By utilizing marginal cost pricing, the first-order condition (17) and the appropriate subscription elasticities, the equilibrium subscription fee can be written as

$$
\begin{aligned}
&t_{ki}^* - f + \lambda \left[s_{lj}^* \theta m_k \widehat{x}(c+m_k) - s_{li}^* \theta m_l \widehat{x}(c+m_l) - m_k (s_{ki}^* - s_{kj}^*) \widehat{q}_{kj} \right] \\
&= \frac{s_{ki}^* - 2\delta\sigma\lambda(s_{ki}^* + \theta s_{li}^*)(v(c) - v(c+m_k))}{\sigma}
\end{aligned}
\tag{49}
$$

after simplifications. Moreover,

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

The important thing to note here is that $t_{kj}^* - t_{ki}^*$ is linear in s_{Hi}^* and s_{Fi}^*. Using marginal cost pricing in (4), we can rewrite equilibrium subscription demand as

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

Notice 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 $s_{Hi}^* = s_{Fi}^* = 1/2$. $t_{ki}^* = t_{INOk}^*$ as can easily be verified by plugging the equilibrium market shares into (49) 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 $\lambda\sigma$ is small enough. 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 then is $\widetilde{\pi}_i(s_{Hi}, s_{Fi}) = \widetilde{\pi}_{Hi}(s_{Hi}, s_{Fi}) + \widetilde{\pi}_{Fi}(s_{Fi}, s_{Hi})$ with $\widetilde{\pi}_{ki}(s_{ki}, s_{li})$ defined in (46). All optimal call prices are independent of $\sigma\lambda$, hence all terms in $\sigma\partial\widetilde{\pi}_{ki}/\partial s_{ki}$ defined in (47) but $1/2 + \sigma(t_{INOk}^* - f) - 2s_{ki}$ converge to zero as $\sigma\lambda \to 0$, while $\sigma\partial\widetilde{\pi}_{li}/\partial s_{ki}$ defined in (48) goes to zero as $\sigma\lambda \to 0$. Thus $\lim_{\sigma\lambda\to 0}(\sigma\partial^2\widetilde{\pi}_i/\partial s_{ki}^2) = -2$, $k = H, F$ while

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

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