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Mobile telephony in emerging markets: the importance of dual-SIM phones *

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Abstract

A substantial share of customers in emerging markets use dual-SIM phones and subscribe to two mobile networks. A primary motive for so called multi-simming is to take advantage of cheap on-net services from both networks. In our modelling effort, we augment the seminal model of competing telephone networks á la Laffont, Rey and Tirole (1998b) by a segment of flexible price hunters that may choose to multi-sim. According to our findings, in equilibrium, the networks set a high off-net price in the linear tariffs to achieve segmentation. This induces the price hunters to multi-sim. We show that increased deployment of dual-SIM phones may induce a mixing equilibrium with high expected on-net prices. Thus, somewhat paradoxically, deployment of a technology that increases substitutability, and thereby competition, may end up raising prices.

Keywords: Network competition, multi-sim, dual-SIM phones, price discrimination

JEL-Classification: D43, L13, L96

1 Introduction

Most major mobile hand-set manufacturers now offer dual-sim versions of their hand-sets, i.e. phones that support two (or more) SIM cards.¹ Modern dual-SIM

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¹For instance, Huawei, Motorola, Nokia, Oppo, Samsung, Sony, Vivo and several other brands offer dual-sim versions. A notable exception at the time of writing is Apple, even though rumors of a coming dual-SIM iPhone have appeared in the business press from time to time.

phones are typically dual-standby, that is, both SIM cards can receive calls and messages at any time.²

The owner of a dual-SIM phone may thus subscribe to two different mobile networks (and may have two telephone numbers), and choose either SIM for any particular service. Dual-SIM phones are typically much more popular in emerging markets than in mature economies. For example, a recent analysis tracking web traffic according to hand-set type finds that in India, Nigeria, and Brazil, the percentage of mobile web traffic from dual SIM phones is 68, 49, and 43, respectively. The corresponding figures for the UK and US are only 7.5 and 4.1, respectively.³ In the mobile industry, a customer who uses subscriptions from two or more networks is referred to as a *multi-simmer*, a term we adopt hereafter. Multi-simming has been an important phenomenon in emerging markets for more than a decade. Prior to the widespread deployment of multi-SIM phones, multi-simmers used two single-SIM phones, or physically switched SIM cards in a single-SIM phone. Dual-SIM phones make switching between SIMs much more convenient.

Customers in emerging markets have several reasons for using dual-SIM phones, or more generally, for holding mobile subscriptions from two different providers. First, and most relevant for the present paper, having two SIMs allows a customer to choose the lowest price alternative for any particular service. This is especially important when networks charge lower prices for on-net services, that is calls (or texts) between customers who subscribe to the same network.⁴ A multi-simmer can thus avoid making expensive off-net calls by selecting the SIM from the same network as the recipient when originating a call. Second, being connected to two networks is useful when the networks do not have full coverage, or when the network quality is unstable. Moreover, having a separate private and mobile subscriptions is more common in emerging markets than in mature markets.

In our paper, we depart from the seminal model of competing telephone networks by Laffont, Rey and Tirole (1998b) and Gans and King (2001), and relax the assumption that all customers subscribe to only one network. We assume that the networks have full coverage and hence focus on the first incentive for multi-simming, i.e., that the customers multi-sim to avoid making expensive off-net calls. There are two types of customers: The high types (henceforth H-types),

²See e.g. https://en.wikipedia.org/wiki/Dual_SIM for a brief introduction on dual-SIM phones.

³The figures are from 2017 Q2 and collected by DeviceAtlas, a device intelligence firm, see <https://deviceatlas.com/blog/dual-sim-smartphone-usage-2017>. An illustration of multiple SIM ownership is also given in international statistics on mobile subscription penetration, i.e. the number of mobile subscriptions in percent of the population. About half of the countries included in the International Telecommunication Union's database have mobile subscription penetration above 100 percent in 2013, and one third of the countries have had so for five years or more. The data comprises mobile penetration rates in 229 countries measured yearly in the period from 2000 to 2013. 117 countries had penetration rates above 1 in 2013, and 75 countries had had it for 5 or more years. The metrics are calculated from the data published at <http://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx>.

⁴Large price differentials between on-net and off-net calls are frequently observed in practice in emerging economies. For instance, the telecom regulator in India reports that off-net prices were 5 times higher than on-net prices, see Sarma (2011).

who exhibit a high demand for calls, and the low types (henceforth L-types) with a lower call demand. Moreover, the two types differ in their brand preferences. The H-types have idiosyncratic brand preferences, whereas the L-types are price hunters without brand preferences. The two networks offer a linear and a two-part tariff. In our model, the L-types cannot use the two-part tariffs. Such an assumption makes sense in emerging economies: The income of the L-types is not only low, but also irregular and uncertain, see e.g. Collins et.al. (2009). Hence, signing up to a tariff with a (in practice, recurring) subscription fee is unattractive, or even unfeasible.

We find that a pooling equilibrium cannot exist. Intuitively this is easy to explain since, in a pooling equilibrium, the two-part tariffs are unused. A network could thus, as a deviation, introduce a two-part tariff with slightly lower calling prices and a small but positive subscription fee that is as attractive to the H-types as the linear tariff. Since our calling prices are above marginal cost, this deviation is profitable for the deviator: Its profit increases because the positive subscription fee and the higher call volume outweighs the loss in profit that accrues due to the lower calling prices. In our model, the networks set the off-net calling prices in the linear tariffs sufficiently high, so that a symmetric equilibrium emerges in which the H-types single-sim on the networks' two-part tariffs and the L-types multi-sim on the networks' linear tariffs. Intuitively, the high off-net prices act as a segmentation device since it makes the linear tariffs unattractive for the H-types. This is beneficial for the networks since they can siphon more profit from the H-type segment when the H-types use the two-part tariffs.

Perhaps most importantly, our model suggests that an increased deployment of dual-SIM phones will only initially benefit the L-types. To see this, note that the deployment increases the substitutability of the networks' call offerings, which in turn increases competition. Moreover, a network's on-net price must cater to two types of calls: i) from the multi-simming L-types to the network's single-simming H-types and ii) from the multi-simmers to other multi-simmers. For the first type of calls the network has a monopoly, whereas the second type is subject to competition from the other network's SIM. If using different SIMs for the second type of calls are not too strong substitutes, the networks set the on-net price according to a Lerner rule using the aggregate of these calls. This on-net price becomes lower as the substitutability of the call offerings increases. However, when the substitutability increases beyond a certain threshold, the profit the networks can extract from the calls between the L-types becomes negligible compared to the profit they gain from the calls from the L-types to the H-types. This implies that it becomes optimal for a network to charge the monopoly price, effectively giving up on the calls between the L-types. This situation can, however, not be part of an equilibrium since the other network then has an incentive to undercut the now high on-net price of its competitor in order to obtain a high profit from the calls between the L-types. Finally, we can establish that a mixing equilibrium emerges, in which the expected on-net prices are substantially higher compared to the prices, which the networks set just before they start mixing. Thus, somewhat paradoxically, the deployment of a technology that increases substitutability, and

thereby competition, may end up raising prices and may thus hurt the L-types.

The literature on network competition building on the seminal works by Laffont, Rey and Tirole (1998a, 1998b) and Armstrong (1998) is large and covers a range of extensions. Hurkens and Lopez (2014), Armstrong and Wright (2009), and Hoernig (2014) are recent contributions that generalize and extend this literature. Our paper is related to Dessein [2003, 2004] who considers heterogeneous usage and second degree price-discrimination. This literature assumes, however, that all customers single-sim. In the equilibrium of our model, where the L-types multi-sim and the networks use the off-net price in the linear tariff as a segmentation device, the H-types incentive compatibility constraint is not binding. Thus, our equilibrium exhibits third-degree price discrimination, with a high off-net price, and possibly, as explained above, mixing in the on-net price. However, since the L-types can reach every other customer on-net, the high off-net prices do not lead to a communication breakdown as in Jeon, Laffont and Tirole (2004). Also contrary to Hoernig (2007), our high off-net prices do not depend on asymmetric market shares or predatory pricing. In sum, our model shows that multi-homing may have a profound effect on how networks set linear prices. That multi-homing seriously affects competition is well documented in the literature, see e.g. Rochet and Tirole (2003), Doganoglu and Wright (2006) and Armstrong and Wright (2007). In the literature on competing telecommunication networks, single-homing has, to our knowledge, been universally assumed. This makes existing results less applicable for emerging markets where a substantial share of customers multi-sim. Our paper aims at filling this gap.

The rest of our paper is organized as follows: In the next section we present our model. In Section 3, we derive the networks' equilibrium pricing and resulting consumer-configuration. In Section 4, we discuss our results and provide a brief application to the deployment of dual-SIM phones.

2 A model with multi-simming customers

We consider a market where subscriptions for mobile calls are offered by two competing, interconnected mobile networks (i, j) with full coverage. There are two types of customers; high income (H-types) and low income (L-types). The H-types have a high demand for calls, and the L-types have low demand for calls. Moreover, the two groups differ in their brand (network) preferences. The H-types have idiosyncratic brand preferences à la Hotelling, i.e., they have transportation cost, $t > 0$. In contrast, our L-types are price hunters without brand preferences. They do not incur transportation cost, $t^L = 0$. The number of H-types and L-types are normalized to 1 and λ , respectively, both with perfectly divisible mass. The number of H-types subscribing to networks i and j is denoted n_i and, n_j respectively.

The timing of the model is as follows: At date 0, the networks negotiate, or the regulator sets, a reciprocal termination charge, a - the fee paid by the network i for a call to a customer at network j . At date 1, each network offers a linear *and* a two-part tariff, targeted at the L-types and H-types, respectively. The customers

observe the tariffs at date 2 and sign up to one or both tariffs. We denote the non-linear and linear tariff offered by network i as

$$T_i = \{r_i, p_i, p_{ij}\} \text{ and } \bar{T}_i = \{\bar{p}_i, \bar{p}_{ij}\},$$

respectively. Here, p_i and \bar{p}_i are the prices of calls between customers connected to the same network, hereafter called on-net calls, whereas p_{ij} and \bar{p}_{ij} are the prices of calls from a customer connected to network i to a customer connected to network j , hereafter called off-net calls. Finally, r_i represents the subscription fee in the two-part tariff offered by network i .

Before we impose further restrictions, a customer has three different homing possibilities, with several tariff combinations within each category: i) he or she can single-home on each of the networks' tariffs, ii) he can multi-home on both networks' tariffs, and iii) he can subscribe to both tariffs offered by the same network.⁵ In the following, we will refer to a customer in the second category as a multi-simmer. In the model we are about to set up, the only motive to multi-sim arises from different on and off-net prices. A multi-simmer can reach all customers on-net and hence can avoid making expensive off-net calls. Note that there cannot exist an equilibrium consumer configuration were all customers multi-sim.⁶ A H-type could then save transportation cost (and one subscription fee if he subscribes to a two-part tariff) by unsubscribing one of the tariffs, and still be able to call all other customers at the lowest possible price. Consequently, in a model where multi-simming occurs in equilibrium, some of the customers must single-sim. In our model these will be the H-types. To avoid specifying an overly complicated model, in which e.g. some H-types single-sim and some multi-sim, we simply assume that

Assumption 1 (H-type) *The H-types do not subscribe to more than one tariff.*

In reality, the H-types may be wealthy customers and/or regular customers who want to avoid the hassle of having to deal with more than one subscription. The L-types, on the other hand, having zero transportation costs, may find it beneficial to multi-sim if the price of off-net calls is too high. To further simplify our model, we consider the financial situation of low-income customers in emerging economies: Incomes are not only low, but also irregular and uncertain, see e.g. Collins et.al. (2009). Hence, signing up to a tariff with a (in practice, recurring) subscription fee is unattractive, or even unfeasible. We impose this stylized fact as an assumption in our model:

Assumption 2 (L-type) *The L-types cannot subscribe to a two-part tariff.*

Thus, if multi-simming occurs, then it will be the L-types that multi-sim on the linear tariffs. Finally, to rule out some particular odd calling configurations, as for instance L-types calling each other off-net instead of on-net, we assume that

⁵In principle a customer has 10 different possibilities: To singlehome on T_1, T_2, \bar{T}_2 or \bar{T}_1 ; to multi-home (multi-sim) on $(T_1, T_2), (T_1, \bar{T}_2), (\bar{T}_1, T_2),$ or (\bar{T}_1, \bar{T}_2) , and to have two SIMs on the same network (T_1, \bar{T}_1) or (T_2, \bar{T}_2) .

⁶This point is well known in the literature on multihoming, see e.g. Doganoglu and Wright (2006).

Assumption 3 (Price-structure) *A network may not set its off-net price strictly below its on-net price within the same tariff.*

None of the assumptions above are crucial for the equilibrium we are going to establish below. However, they considerably simplify the model's primitives and reduce the number of possible deviations, we have to consider in the subsequent analysis. A H-type now has four tariff choices, i.e., to single-sim on either of the four tariffs offered by the networks. A L-type has three choices: to single-sim on either of the networks' linear tariffs or to multi-sim on both networks' linear tariffs. Thus, the third homing category described above - having two SIMs from the same network - cannot occur in our model.

In section 3, we explain that pooling cannot be an equilibrium in our model. Presuming this is the case, the networks then design tariffs to induce the H-types to self-select into the two-part tariffs. The possibility that the L-types may choose to multi-sim generates a twist to this price-discrimination problem. In particular, a network may use the off-net price in the linear tariff as a segmentation device. If a network sets this price sufficiently high, it induces the L-types to multi-sim to avoid making expensive off-net calls, *and* prevents the H-types to take the linear tariff. This does not distort the consumption of the multi-simming L-types since they can call all customers on-net. We make use of this when we present the model below:

Remark 1 *The utility functions and incentive compatibility constraints in this section are conditional on each network using the off-net price in their respective linear tariffs as a segmentation device, i.e. \bar{p}_{ij} is (much) higher than \bar{p}_i for each network $i \in \{1, 2\}$. Market shares and profit functions are written given that the H-types single-sim on the non-linear tariffs and the L-types multi-sim on the linear tariffs.*

In section 3 we will prove that - put loosely - if t is sufficiently large, and λ is not too large, then this is indeed an equilibrium in our model.

Utilities of the L-types

The L-types may either multi-sim on (\bar{T}_i, \bar{T}_j) , or single-sim on either one of these tariffs. We assume that a multi-simming L-type has both SIM cards active for receiving calls, which means that either he uses a dual-sim phone or he carries two active single-sim phones. In our subsequent specification of the L-type's indirect utility of making calls, we consider three cases: (i) calls from single-simming L-types, (ii) calls from multi-simming L-types to other L-types and (iii) calls from multi-simming L-types to H-types.

(i) A single-simming L-type's utility from making a call is given by the indirect utility function $v(p)$, so that call demand is given by $q(p) = -v'(p)$.

(ii) When a multi-simming L-type calls another multi-simmer, he can use either the tariff of network 1 or network 2. Due to Remark 1, he will not make off-net calls. We denote the indirect utility a L-type derives from a call to another multi-simmer by $v^m(\bar{p}_1, \bar{p}_2)$. We assume that $v^m(\bar{p}_1, \bar{p}_2)$, is a well behaved, continuously

differentiable, indirect utility function. The demand for using SIM 1 to call another multi-simmer is $q_1(\bar{p}_1, \bar{p}_2) = -\partial v^m(\bar{p}_1, \bar{p}_2)/\partial \bar{p}_1$, and the demand for using SIM 2 to call another multi-simmer is $q_2(\bar{p}_1, \bar{p}_2) = -\partial v^m(\bar{p}_1, \bar{p}_2)/\partial \bar{p}_2$. For symmetric prices, $\bar{p}_1 = \bar{p}_2 = \bar{p}$, the customer is indifferent with regard to which SIM card to use. Her or his call utility is then identical to a single-simmer's, and the total number of calls is split evenly between the two SIMs, i.e.

$$v^m(\bar{p}, \bar{p}) = v(\bar{p}), \quad q_1(\bar{p}, \bar{p}) = q_2(\bar{p}, \bar{p}) = \frac{1}{2}q(\bar{p}). \quad (1)$$

In the appendix we show that, for example, the Shubik-Levitan utility function, see Shubik and Levitan (1980), satisfies (1). In principle, the indirect utility function $v^m(\bar{p}_1, \bar{p}_2)$ may exhibit any substitution patterns from indepenence to perfect substitutes. In practice, we would expect calling with SIM 1 or SIM 2 for a L-type customer to be substitutes, where the degree of substitutability depends on the hassle involved in selecting the right SIM for a particular call (in a symmetric situation it does not matter). For instance, if a customer multi-sims by carrying two phones, we would expect substitutability to be lower than in the case of a customer owning a dual-SIM phone. In the case where the dual-SIM phone automatically chooses the SIM with the lowest price for any particular call, the two SIMs would be perfect substitutes.

(iii) When a multi-simming L-type calls a H-type connected to network i , he can do so by using either the on-net price of network i , \bar{p}_i , or the off-net price of network j , \bar{p}_{ji} . Recall from Remark 1 that each network sets \bar{p}_{ji} (much) higher than \bar{p}_i . In our symmetric equilibrium we shall focus on in the next section, this will then also imply that \bar{p}_{ji} is (much) higher than \bar{p}_i . In the specification below, we disregard possible out-of-equilibrium asymmetric situations where this is not the case and we assume that a multi-simming L-type always make on-net calls when calling a H-type customer. His call-utility function is then as in (i).

In line with the literature, calls are made according to a balanced calling pattern. Each customer calls all other customers (not SIM cards) with equal probability.⁷ The utility of a multi-simming L-type, given that all other L-types multi-sim, can then be written as

$$U^L(\bar{T}_1, \bar{T}_2) = v_0 + n_1 v(\bar{p}_1) + n_2 v(\bar{p}_2) + \lambda v^m(\bar{p}_1, \bar{p}_2), \quad (2)$$

whereas it is given by

$$U^L(\bar{T}_i) = v_0 + (n_i + \lambda) v(\bar{p}_i) + (1 - n_i) v(\bar{p}_{ij}), \quad (3)$$

if he single-sims using network $i \in \{1, 2\}$ given that all other L-types multi-sim. Here, v_0 is the intrinsic utility of being connected, which in our model does not depend on whether the customer is a multi or a single-simmer. Throughout, we assume that v_0 is sufficiently large so that all customers choose to be connected to at least one network.

⁷Dessein (2003, 2004) and Hoernig et al. (2014), consider network competition with non-balanced calling patterns.

The second term in (2), $n_1 v(\bar{p}_1)$, is then a multi-simming L-type's utility of using SIM 1 to call the n_1 H-types connected to network 1 at on-net price \bar{p}_1 , the third term, $n_2 v(\bar{p}_2)$, is the utility of using SIM 2 to call the n_2 H-types connected to network 2 at on-net price \bar{p}_2 , and the last term, $\lambda v^m(\bar{p}_1, \bar{p}_2)$, is the utility of calling the other multi-simming L-types. The second term in (3), $(n_i + \lambda) v(\bar{p}_i)$, is the utility of a L-type who single-sims at network i and thus calls $n_i + \lambda$ customers on-net, and the last term, $(1 - n_i) v(\bar{p}_{ij})$, is the utility of calling the $(1 - n_i)$ H-types connected to network j .

A L-type prefers to multi-sim whenever $U^L(\bar{T}_1, \bar{T}_2) > \max[U^L(\bar{T}_1), U^L(\bar{T}_2)]$. Let \bar{T}_i be the tariff that provides the largest single-sim utility. A L-type will thus prefer to multi-sim if

$$(1 - n_i)(v(\bar{p}_j) - v(\bar{p}_{ij})) + \lambda(v^m(\bar{p}_1, \bar{p}_2) - v(\bar{p}_i)) > 0. \quad (4)$$

In our symmetric equilibrium with $\bar{p}_j = \bar{p}_i$ the last term on the l.h.s of this inequality is zero due to (1), and all L-types will then choose to multi-sim since $v(\bar{p}_j) - v(\bar{p}_{ij}) = v(\bar{p}_i) - v(\bar{p}_{ij}) > 0$ due to Remark 1. Conversely, if network i deviates to a flat linear tariff, $\bar{p}_i = \bar{p}_{ij}$, it will induce all L-types to single-sim on its network. In section 3, we show that deviating to a flat tariff, combined with lowering the subscription fee in the non-linear tariff, is the optimal deviation when termination rates are cost based. In addition, we detail the instances under which our symmetric equilibrium is robust to this deviation.⁸

Utilities of the H-types

The H-types are uniformly distributed on a Hotelling line with support $[0, 1]$. The networks are situated at the extremes, i.e., network 1 is located at point 0 and network 2 is located at point 1. When a H-type located at x subscribes to a tariff offered by network i , she incurs transportation costs of $t|x - x_i|$, where $x_i \in \{0, 1\}$ is the location of networks 1 and 2, respectively.

A H-type's utility from making a call is given by the indirect utility function $v^H(p)$ so that the demand for calls is given by $q^H(p) = -\partial v^H / \partial p$. Calls are made according to a balanced calling pattern, and the H-types have a higher call utility than the L-types, i.e., $v^H(p) > v(p)$ and $q^H(p) > q(p)$.

We write the H-types' utility under the presumption that condition (4) holds. A H-type who subscribes to network i then calls the H-types connected to the same network and the multi-simming L-types, $n_i + \lambda$ in total, on-net. The H-types connected to network j , $1 - n_i$ in total, are called off-net. Consequently, a H-type located at x on the Hotelling line, who uses network i 's non-linear tariff, has utility

$$U^H(T_i) = v_0 + (n_i + \lambda)v^H(p_i) + (1 - n_i)v^H(p_{ij}) - r_i - t|x - x_i|. \quad (5)$$

If he uses network i 's linear tariff, the utility is

$$U^H(\bar{T}_i) = v_0 + (n_i + \lambda)v^H(\bar{p}_i) + (1 - n_i)v^H(\bar{p}_{ij}) - t|x - x_i|.$$

⁸If instead we assume that there is a cost, $h > 0$, of multi-simming, the condition for multi-simming in a symmetric equilibrium would be $v(\bar{p}_i) - v(\bar{p}_{ij}) > 2h$. In that case a network would not need to go all the way down to a flat tariff to induce single-simming.

Hence, she will use the non-linear tariff when $U^H(T_i) \geq U^H(\bar{T}_i)$, which after inserting from the two equations above, simplifies to

$$(n_i + \lambda)(v^H(p_i) - v^H(\bar{p}_i)) + (1 - n_i)(v^H(p_{ij}) - v^H(\bar{p}_{ij})) \geq r_i. \quad (6)$$

Given that $r_i > 0$, the H-types' incentive compatibility constraint given in (6) holds when a H-type derives a sufficient utility gain from calling at lower prices using the non-linear tariff. A key property of the symmetric equilibrium, we are going to derive in the next section, is that there exist reasonable parameter configurations for which this incentive compatibility constraint is not binding when the network sets \bar{p}_{ij} at a high level, as described in Remark 1. The intuition for this is that a high \bar{p}_{ij} makes the linear tariff unattractive for the H-types, who do not multi-SIM, but does not affect the multi-simming L-types who only make on-net calls. However, as we will show below, equation (6) will come into play when we derive a network's optimal deviation.

Market shares and firms' profit

Let us consider our candidate equilibrium's consumer configuration, in which the H-types single-sim on the non-linear tariffs and the L-types multi-sim on the linear tariffs. Network i 's share of H-types is found by solving $U^H(T_i) = U^H(T_j)$ for the indifferent customer, x . After rearranging, the market share of network i can be written as

$$n_i = \frac{t + r_j - r_i + v^H(p_{ij}) - v^H(p_j) + \lambda(v^H(p_i) - v^H(p_j))}{2t - v^H(p_i) - v^H(p_j) + v^H(p_{ij}) + v^H(p_{ji})}, \quad (7)$$

which simplifies to $n_1 = n_2 = 1/2$ in a symmetric equilibrium.⁹

Except for the different locations on the Hotelling line, we assume that the networks are identical. A network's fixed cost of serving a customer is f per contract - this also includes the cost of issuing a SIM card for the customer's chosen tariff. A network has a cost of c per call it originates or terminates, such that the marginal cost of an on-net call is $2c$. Since off-net calls terminate on the rival's network, the originating network pays a termination fee, a , to the other network for such a call. A network's perceived marginal cost for an off-net call is then $a + c$. It follows that a network's margin on an incoming call from the rival is $a - c$. Consequently, network i 's profit, π_i , amounts to

$$\pi_i = \lambda\pi_i^L + n_i\pi_i^H, \quad (8)$$

where

$$\begin{aligned} \pi_i^L &= -f + (n_i q(\bar{p}_i) + \lambda q_i(\bar{p}_1, \bar{p}_2))(\bar{p}_i - 2c), \text{ and} \\ \pi_i^H &= r_i - f + (n_i + \lambda)q^H(p_i)(p_i - 2c) + (1 - n_i)(q^H(p_{ij})(p_{ij} - c - a) + q^H(p_{ji})(a - c)). \end{aligned}$$

Here, π_i^H and π_i^L are the profits made on a H-type and a L-type, respectively.

⁹Note that we are working under the presumption that hotelling is stable, i.e., we only consider parameter constellations in which the hotelling game does not have corner solutions, in which one network has all customers in the H-type segment.

3 Equilibrium pricing and consumer configuration

Let us now establish that the price structure and consumer configuration described in Remark 1 is an equilibrium. To derive our separating equilibrium, we proceed in four steps. First, we establish that the H-types use the two-part tariffs and recall from (4) that for symmetric prices, the L-types multi-sim on the linear tariffs. Second, we derive the optimal pricing in both the linear and the two-part tariffs, given what we stated in Remark 1. Third, we find the best possible deviation from our candidate equilibrium. Fourth, we derive when this deviation is not profitable. As it will turn out, this will crucially depend on λ . Let us begin by establishing the following proposition:

Proposition 1 *A pooling equilibrium in which both the L and the H-types use the linear tariffs cannot exist.*

The reasoning is straightforward. In a pooling equilibrium the two-part tariff is not being used. Consequently, a network could deviate to a two-part tariff which offers calling prices slightly below the calling prices in the linear tariff and a subscription fee that is slightly above zero so that the H-types switch to the two-part tariff. Then, the increase in profit due to the higher subscription fee *and* the higher call volume outweighs the loss in profit that accrues due to the lower calling price. This result is closely related to the well known result that the subscription fee of a two-part tariff is strictly positive, see e.g. Laffont et al. (1998b), so we do not prove it formally.

Corollary 1 *In our equilibrium candidate, the two-part tariff calling prices are $p_1^* = p_2^* = 2c$, and $p_{12}^* = p_{21}^* = a + c$.*

The rationale is similar to the one underlying Proposition 1. A situation where one or more of the calling prices in the two-part tariff are above marginal cost cannot be part of a symmetric equilibrium. In that case, a network can keep its market shares, in the H-type segment, constant by simultaneously increasing the subscription fee and decreasing a calling price. This is a profitable deviation because the increase in profit due to the higher subscription fee *and* the higher call volume outweighs the loss in profit that accrues due to the lower calling price. Because this argument holds for any calling prices above perceived marginal cost, we can directly conclude that $p_1^* = p_2^* = 2c$ and $p_{12}^* = p_{21}^* = a + c$. Whereas the calling prices do not depend on what is going on in the L-type segment, this is not so for the subscription fee, r_i . Let us establish that

Proposition 2 *In our equilibrium candidate, the networks set $r_1^* = r_2^* = r^* = f + t - v^H(2c) + v^H(a + c) - (\bar{p}_{on}^* - 2c)\lambda q(\bar{p}_{on}^*)$, where p_{on}^* is the equilibrium on-net price of Proposition 3.*

PROOF: See Appendix.

Except for the last term, the expression for r^* is identical to Laffont et al.(1998b). Similarly to their model, the networks use the subscription fee, r , as an instrument to attract the H-types. The last term, $-(\bar{p}_{on}^* - 2c)\lambda q(\bar{p}_{on}^*)$ is negative and decreasing in the number of L-types. It represents that, compared to Laffont et al.(1998b), the networks have an additional incentive to lower the subscription fee. More precisely, this additional incentive arises due to the calls, that are being made, from the multi-simming L-types to the H-types. Thus, the existence of multi-simmers increases competition for market shares in the H-type segment, which results in a lower equilibrium subscription fee.

Let us now consider the linear-tariff segment. Recall from Assumption 2 that the L-types are financially constrained. Thus they cannot use the two-part tariffs. In the equilibrium we are going to establish, the networks set the off-net prices sufficiently high so that it acts as a segmentation device. This allows the networks to set the subscription fee, r , without having to worry that the H-types switch to the linear tariffs. The high off-net prices also ensure that the networks have a quasi monopoly on the calls from the L-types to their own H-types. This is so since it is prohibitively expensive for the L-types to call the H-types of, say, network 1 off-net using network 2's sim card. The role of the on-net prices in the linear tariff segment is twofold. First, the networks have an incentive to undercut the competitor in order to get more calls from L-types to L-types. Thus networks have an incentive to choose a "low" on-net price. Second, the L-types use the on-net prices to call the H-types. Since, as mentioned, the networks have a quasi monopoly on the calls from the L-types to their own H-types, they have an incentive to choose a "high" on-net price. Which of these two effects dominates depends on how elastic the call demand of the L-types is. We can establish that:

Proposition 3 *There is a critical value k , such that if $|\partial q_i(\bar{p}_i, \bar{p}_{on}^*)/\partial \bar{p}_i| \leq k$, the optimal on-net price of network i , $i \in \{1, 2\}$, $\bar{p}_i^* = \bar{p}_{on}^*$, is implicitly defined by*

$$\frac{\bar{p}_{on}^* - 2c}{\bar{p}_{on}^*} = -\frac{(1 + \lambda)q(\bar{p}_{on}^*)}{\bar{p}_{on}^*(q'(\bar{p}_{on}^*) + 2\lambda\partial q_i(\bar{p}_{on}^*, \bar{p}_{on}^*)/\partial \bar{p}_i)} > 0. \quad (9)$$

If $|\partial q_i(\bar{p}_{on}^, \bar{p}_{on}^*)/\partial \bar{p}_i| > k$ there exists a symmetric mixed strategy equilibrium, in which the networks, $i \in \{1, 2\}$, choose \bar{p}_i from a probability distribution with support $[\bar{p}_{on}^*, \bar{p}_{on}^M]$, where \bar{p}_{on}^M is implicitly defined as*

$$\frac{\bar{p}_{on}^M - 2c}{\bar{p}_{on}^M} = -\frac{q(\bar{p}_{on}^M)}{\bar{p}_{on}^M(q'(\bar{p}_{on}^M))} > \frac{\bar{p}_{on}^* - 2c}{\bar{p}_{on}^*}.$$

PROOF: See Appendix.

The multi-simming L-types make two types of calls that are relevant for network i , (i) to network i 's H-types and (ii) to other L-types. For the first type of calls the network has a monopoly, whereas the second type is subject to competition from the other SIM. If using SIM i or SIM j for the second type of calls

is perceived as "not too close substitutes", i.e., when $|\partial q_i(\bar{p}_i, \bar{p}_{on}^*)/\partial \bar{p}_i| \leq k$, the network sets \bar{p}_i according to a Lerner rule using the aggregate of these calls as in (9). When the substitutability is strong, a mixed strategy equilibrium similar to Varian (1980) emerges.

Interestingly, with increasing substitutability, the prices first decrease until the profit from the calls to the other L-types becomes so low that it is optimal for a network, say network 1, to deviate and charge the monopoly price. Network 1 then gets zero revenue from the calls between the L-types but earns a substantial profit on the calls between the L-types and its own H-types, on which it has a monopoly. However, this situation cannot be part of an equilibrium either. Network 2 then has an incentive to also raise its on-net price in order to get a higher profit from the calls between the L-types. Then, network 1 has an incentive to undercut network 2's price in order to compete for the now expensive calls between the L-types. Since the same argument is true for network 2, we obtain that no equilibrium in pure strategies exists and that a mixing equilibrium emerges. The expected price, that emerges when the networks mix, is much higher than the prices the networks set just before they begin to mix. Hence, with increasing substitutability prices first decrease and then jump up once the networks begin to mix. In the next section, we elaborate on this with respect to the deployment of multi-sim phones.

Above, we have established the optimal pricing for both the linear and the two-part tariffs, given that the networks use the off net price in the linear tariffs as a segmentation device as described in Remark 1. Let us now establish that this equilibrium candidate is indeed an equilibrium. Since the networks can deviate in two tariffs simultaneously, there is a multitude of possible deviations. To keep the formulae tractable, we assume cost-based termination rates, i.e. $a = c$, and fixed cost $f = 0$.¹⁰ Now, let us establish what is the best possible deviation for a network, say network 1, from our candidate equilibrium. There are two cases we need to distinguish:

Lemma 1 *When $r_1^d < r_1^*$, the optimal deviation is to offer a flat linear tariff so that*

$$\bar{p}_1^d = \bar{p}_{12}^d = \bar{p}_{on}^*,$$

and to simultaneously set the subscription fee in the non-linear tariff to

$$r_1^d = (1 + \lambda)(v^H(2c) - v^H(\bar{p}_{on}^*)).$$

The reasoning is straightforward. First, if a profitable deviation in which the H-types use the linear tariff exists, there must also exist an even more profitable deviation in which they use the two-part tariffs. The reasoning for this is very similar to the one in Proposition 1 and Corollary 1. Hence, under the best possible deviation, the L-types use the linear tariffs and the H-types use the two-part tariffs. There are then two possible customer-tariff configurations that may be optimal for the deviator. (i) The deviator deviates so that the L-types multisim and the

¹⁰Our main objective is to prove that our equilibrium exist *even* for $a = c$. The long and quite tedious general version for small deviations from cost based termination is available upon request.

H-types use the two-part tariffs or (ii) the deviator deviates in order to induce the L-types to single sim on its network. We can directly conclude that the first type cannot be a profitable deviation. Given that the L-types multisim and the H-types use the two-part tariffs, the tariffs described in Propositions 3 , 2 and Corollary 1 are optimal.

Let us now show that the optimal deviation of type (ii) is to deviate to the flat tariff in Lemma 1: The deviators off-net price could potentially be used for calls between the L-types and/or for calls from the L-types to the H-types connected to network 2. Since we do not consider the case that a network undercuts its own on-net price with its off-net price, Assumption (3), the only relevant question is whether network 1's off-net price is used for calls from the L-types to network 2's H-types. This is the case when network 1's off-net price is strictly lower than network 2's on-net price, otherwise it remains unused. From the multisim condition, (4), we know that reducing the off-net prices down to \bar{p}_{on}^* induces the L-types to single sim on the deviator's network. This increases call revenues for the deviator. Moreover, it makes no sense to deviate to a linear tariff in which either only the on-net price or both the on-net and the off-net prices are below \bar{p}_{on}^* . This is so, since by deviating to the aforementioned flat tariff, the deviator already obtains all calls from the L-types and because \bar{p}_{on}^* is below the monopoly price. Thus, the deviator has no incentive to go below the flat linear tariff stated in Lemma (1).

Let us now turn to the question on how the deviator optimally sets its subscription fee. To ensure that the H-types' incentive compatibility constraint holds under the deviation, see equation (6), the deviator has to set the fee so that $(n_1^d + \lambda)v^H(2c) + (1 - n_1^d)v^H(2c) - r_1^d = (1 + \lambda)v^H(\bar{p}_{on}^*)$. This simplifies to r_1^d in lemma (1), where n_1^d is network 1's market share under the optimal deviation, i.e.,

$$n_1^d = \frac{1}{2} + \frac{r^* - r_1^d}{2t}. \quad (10)$$

We have two cases. First, if $r_1^d < r^*$, the deviator has to lower its subscription fee to r_1^d in order to prevent its H-types from switching to its linear tariff. Furthermore, it has no incentive to reduce the fee below r_1^d . To see this, note that this would reduce profits since r_1^d is below the monopoly level. Second, if $r_1^d \geq r^*$, we can directly conclude that to deviate to the aforementioned flat tariff and to set the subscription fee to r^* is profitable, which means that our equilibrium does not exist. To see this, note that the deviator deviates to a flat tariff, inducing all L-types to single sim on its network while keeping all its H-types on the old non-linear tariff without having to reduce its subscription fee. Then, subscription revenues are the same but call revenues have increased. Hence, we can establish that:

Proposition 4 *i) A necessary condition for the existence of an equilibrium in which the networks use the off net price in the linear tariffs as a segmentation device as described in Remark 1, and set the prices as described in Corollary 1, Proposition 2 and Proposition 3, is that*

$$(1 + \lambda)(v^H(2c) - v^H(\bar{p}_{on}^*)) < t - \lambda(\bar{p}_{on}^* - 2c)q(\bar{p}_{on}^*) \quad (11)$$

or equivalently $r_1^d < r^*$.

ii) If condition (11) holds and λ is not too large, deviating to the flat tariff of Lemma 1 is not a profitable deviation.

Proof. i) As we discussed in the main text below Lemma 1, to deviate to the flat tariff is profitable when $r_1^d \geq r^*$.

ii) Let us now compare the deviator's profit at our candidate equilibrium, π_1^* , to the one under the optimal deviation, π_1^d . When $a = c$ and $f = 0$ these are

$$\pi_1^* = \frac{1}{2}r^* + \lambda\left(\frac{1}{2}q(\bar{p}_{on}^*) + \lambda q_1(\bar{p}_{on}^*, \bar{p}_{on}^*)\right)(\bar{p}_{on}^* - 2c)$$

and

$$\pi_1^d = n_1^d r_1^d + \lambda(1 + \lambda)q(\bar{p}_{on}^*)(\bar{p}_{on}^* - 2c).$$

Using $q_1(\bar{p}_{on}^*, \bar{p}_{on}^*) = q(\bar{p}_{on}^*)/2$, we get, after some manipulation, that $\pi_1^* - \pi_1^d > 0$ when

$$\frac{1}{2}r^* - n_1^d r_1^d > \frac{\lambda}{2}(1 + \lambda)(\bar{p}_{on}^* - 2c)q(\bar{p}_{on}^*). \quad (12)$$

In words, the deviation is not profitable when the parameters are such that the loss in subscription revenue, is larger than the gain in call revenues. When λ is 0, the r.h.s. of equation (12) is zero. The l.h.s. is positive when condition (11) holds: To see this let us define $R(\bar{p}_{on}^*) := (\bar{p}_{on}^* - 2c)q(\bar{p}_{on}^*)$ and $dv^H := v^H(2c) - v^H(\bar{p}_{on}^*)$. After some manipulation, using the expressions for r^* , r_1^d and n_1^d , we find that

$$\frac{1}{2}r^* - n_1^d r_1^d = \frac{t - \lambda R(\bar{p}_{on}^*)}{2} - \frac{(1 + \lambda)dv^H(2t - \lambda R(\bar{p}_{on}^*) - (1 + \lambda)dv^H)}{2t}. \quad (13)$$

The expression on the l.h.s. of equation (12) is positive when (11) holds. ■

In Proposition 4, we have established when our equilibrium candidate is indeed an equilibrium. As mentioned, it is crucial that condition (11) holds since it ensures that the deviating network loses subscription revenues by deviating, that is, $\frac{1}{2}r^* - n_1^d r_1^d > 0$. This loss of revenues must be large enough so that it offsets the gain in call revenues the deviator accrues from the now single simming L-types, $\frac{\lambda}{2}(1 + \lambda)(\bar{p}_{on}^* - 2c)q(\bar{p}_{on}^*)$. For a given net income per L-type, $R(\bar{p}_{on}^*)$, whether this is the case or not crucially depends on λ : When λ is not too large, the former effect dominates the latter. When λ gets “large”, our equilibrium breaks down. The rationale behind this is that the r.h.s. of condition (12) is continuously increasing in λ whereas the l.h.s. depends on λ in a complicated way. How large λ can be depends on the size of $R(\bar{p}_{on}^*)$ and other parameters in our model.

4 Discussion

We have shown that there exists a symmetric separating equilibrium where the networks use the off-net price in the linear tariff as a segmentation device when

$r_1^d < r^*$ and the number of low types, λ , is "not too large". To illustrate what "not too large" might mean in our model, we give a numerical example, in which we use the Shubik-Levitan (SL) utility function specified in the Appendix.

Under SL utility, the demand function for the L-types' calls to the H-types at network i is given by $q(\bar{p}_i) = b - \bar{p}_i$, and for calls to other L-types it is $q_i(\bar{p}_i, \bar{p}_j, z) = (b - \bar{p}_i)/2 + (z/4(1 - z))(\bar{p}_j - \bar{p}_i)$. The H-types call demand is given by $q(p_i) = b^H - p_i$, where $b^H > b$. The parameter $z \in [0, 1)$ directly measures the degree of substitutability between using SIM i and SIM j for the calls between the L-types. When $z = 0$, the SIM cards are independent, and when $z \rightarrow 1$ the SIM cards are perfect substitutes. As we show in the Appendix, when $0 < z \lesssim 0.94$, we have a pure strategy equilibrium. Let us consider the following set of parameters: When $\{a = c = 1, b^H = 6, b = 3, z = 0.9, t = 4\}$, our equilibrium exists if $\lambda \lesssim 1.66$. If the net income per L-type, $R(\bar{p}_{on}^*)$ is smaller, for instance because b is lower or z is larger (but still below 0.94), the critical λ will be larger. For instance, if $b = 2.5$, all else equal, the critical λ where our equilibrium breaks down raises to 4.66.

Whether our model has relevance for a particular market, with multi-simming customers, is of course an empirical question. In any case, our model shows that if the net incomes from the multisimming segment is not too large, there exists a separating equilibrium where the networks accomodate multisimming by using the off-net price as a segmentation device. Our model thus gives an explanation for high off-net prices in such markets. If, however, the net incomes from the multi-sim segment is large, either because the margin is high and/or λ is large, our equilibrium breaks down. To deviate to a flat linear tariff while simultaneously lowering the subscription fee then becomes profitable. Note however that a situation where both networks set a flat linear tariff, and the single-simming L-types distribute themselves between the networks, cannot be an equilibrium either. A network could then lower the on-net price, or both the on-net and off-net price by a small amount, and attract all the L-types. This would be a profitable deviation. We leave it to future research to describe the equilibria occurring when our equilibrium breaks down.

Our model can be linked to the deployment of dual-SIM phones in emerging markets. As mentioned in the introduction, countries like India have experienced a massive increase in dual-SIM phones over the last decade. Suppose an economy starts out in a pure strategy equilibrium, and deployment of dual-SIM phones among the λ L-types increases. We would then expect that the aggregate substitutability in the L-types' call demand function increases since multi-simming with a dual sim phone involves less hassle. Initially then, an increased deployment of multi-sim phones would benefit all L-types in terms of lower on-net call prices. Paradoxically, though, if the number of dual-SIM users becomes large, the aggregate substitutability may become so large that the networks switch to mixing, confer Proposition 3. If so, the expected price would shift up compared to the price just before the networks start mixing. Thus, an increased deployment of multi-sim phones might eventually hurt the poor customers (the L-types). Another possibility is that our equilibrium breaks down once the aggregate substitutability is so large that the networks start mixing. This is so because the expected revenues in

the L-type segment increase in the mixing case and deviating to a flat tariff might then become a profitable option.

Much of the literature on competing mobile networks have focused on the welfare effects of the termination rate level. For some recent analyses, see e.g. Genakos and Valletti (2015), Armstrong and Wright (2009), Harbord and Hornig (2015) and Hurkens and Lopez (2014). In our paper we have disregarded this question altogether and focused on cost-based termination rates in our main proofs. Allowing $a \neq c$ would substantially increase the complexity of our analysis, even if small departures from a cost based reciprocal termination rate would not alter the general conclusions.¹¹ We leave the general analyses for future research.

Appendix

Shubik Levitan call utility

The point of this subsection is to demonstrate that the quadratic Shubik-Levitan utility function satisfies (1). Recall that a multi-simmer makes two types of calls: calls to single-simmers and calls to other multi-simmers. Suppose that a multi-simmer's utility of a call to a singlesimmer at network i is given by $bq - q^2/2$, where b is a positive constant so that the indirect utility amounts to $v(\bar{p}_1) = (b - \bar{p}_1)^2/2$ and the call demand is $q(\bar{p}_1) = b - \bar{p}_1$. Moreover, suppose that for calls to other multi-simmers the L-types have a Shubik Levitan utility function, or more precisely $u(q_1, q_2) = b(q_1 + q_2) - (z(q_1 + q_2)^2 + 2(1 - z)(q_1^2 + q_2^2))$. Here, q_1 and q_2 are the calls made with SIM 1 and SIM 2, respectively, and z is a constant satisfying $0 \leq z < 1$. The parameter z reflects to which degree a L-type considers the two SIMs as substitutes: Calling with SIM 1 and SIM 2 are independent when $z = 0$, and perfect substitutes when $z \rightarrow 1$. Indirect utility is given by $\text{Max}_{q_1, q_2} \{u(q_1, q_2) - \bar{p}_1 q_1 - \bar{p}_2 q_2\}$, which after some manipulation can be written as

$$v^m(\bar{p}_1, \bar{p}_2, z) = \frac{2b^2 + \bar{p}_1^2 + \bar{p}_2^2 - 2b(\bar{p}_1 + \bar{p}_2) - \frac{z}{2}(2b - \bar{p}_1 - \bar{p}_2)^2}{4(1 - z)}.$$

Hence, the demand for calls with the two SIMs amounts to

$$q_1(\bar{p}_1, \bar{p}_2, z) = -\frac{\partial v^m(\bar{p}_1, \bar{p}_2, z)}{\partial \bar{p}_1} = \frac{b - \bar{p}_1}{2} + \frac{z}{4(1 - z)}(\bar{p}_2 - \bar{p}_1), \text{ and}$$

$$q_2(\bar{p}_1, \bar{p}_2, z) = -\frac{\partial v^m(\bar{p}_1, \bar{p}_2, z)}{\partial \bar{p}_2} = \frac{b - \bar{p}_2}{2} + \frac{z}{4(1 - z)}(\bar{p}_1 - \bar{p}_2).$$

Inserting symmetric prices in the above functions, we see directly that our call assumptions, (1), are satisfied for all $z \in [0, 1]$.

In the main part of the paper we argued that with increasing substitutability of the call offerings the on-net prices in the L-type segment first decrease before

¹¹The proofs for the case for small departures from cost based termination rates are available upon request.

we arrive at a jump that occurs because the networks begin to mix. Let us now shed some more light on this by using the Shubik-Levitan (SL) utility functions. After some straightforward, but very tedious, algebra, it can be shown that, when network j sets $\bar{p}_j^* = \bar{p}_{on}^*$,

$$\pi_i^L(\bar{p}_{on}^M, \bar{p}_{on}^*) - \pi_i^L(\bar{p}_{on}^*, \bar{p}_{on}^*) = v[2c]\delta(z, \lambda),$$

where $v[2c] = (b - 2c)^2/2$ and

$$\delta(z, \lambda) = -\lambda^2(16(1+\lambda)^2 - 8z(4+7\lambda+3\lambda^2) + z^2(16+23\lambda+8\lambda^2))/4(-4(1+\lambda) + z(4+3\lambda))^2.$$

Thus, since $v[2c]$ is a positive constant, whether we have a pure or a mixed strategy equilibrium depends on $\delta(z, \lambda)$ only. It can be shown that for $0 < z \lesssim 0.94$, $\delta(z, \lambda)$ is always negative.¹² In this case, network i 's best response is to set $\bar{p}_i = \bar{p}_{on}^*$, and we arrive at the pure strategy equilibrium of Proposition 3. For $0.95 \lesssim z < 1$, $\delta(z, \lambda)$ is always positive. In this case, network i 's best response is to set $\bar{p}_i = \bar{p}_{on}^M$, and we arrive at the mixed strategy equilibrium.¹³

Proof of Proposition 2

Proof. Given that the networks set the calling prices in the two-part tariffs equal to perceived marginal cost, the profit of network i can be written as

$$n_i(r_i - f) + (a - c)(1 - n_i)n_i q^H(a + c) + \lambda(-f + (\bar{p}_i^* - 2c)(n_i q(\bar{p}_i^*) + \lambda q_i(\bar{p}_i^*, \bar{p}_j^*))).$$

Let us insert the right-hand side of (7) for n_i and maximize the above equation with respect to r_i . Then, we obtain the following best response function:

$$r_i = \frac{1}{D}[(t - v^H(2c) + v^H(a + c) + (a - c)q^H(a + c))r_j + (t - v^H(2c) + v^H(a + c))(f + t - (\bar{p}_i^* - 2c)\lambda q(\bar{p}_i^*) - v^H(2c) + v^H(a + c))],$$

where $D = 2(t - v^H(2c) + v^H(a + c)) + (a - c)q^H(a + c) > 0$. The best response is upward sloping when $a \geq c$ since stability in the H-type segment requires $t - v^H(2c) + v^H(a + c) > 0$. Solving the networks' best responses yields the equilibrium subscription fees

$$r_1^* = r_2^* = t + f - v^H(2c) + v^H(a + c) - (\bar{p}_i^* - 2c)\lambda q(\bar{p}_i^*).$$

■

Proof of Proposition 3

Proof. The proposition states that if $|\partial q_i(\bar{p}_{on}^*, \bar{p}_{on}^*)/\partial \bar{p}_i| \leq k$, it is a best reply for network i to charge \bar{p}_{on}^* , given that network j also charges \bar{p}_{on}^* . After taking

¹²The details are available upon request.

¹³For $0.94 \lesssim z \lesssim 0.95$, the sign depends on λ in a complicated way. Details are available upon request.

the derivative of (8) with respect to \bar{p}_i , plugging in \bar{p}_{on}^* for both \bar{p}_i and \bar{p}_j and some reorganization of terms, we obtain (9). Note that to set $\bar{p}_i^* = \bar{p}_{on}^*$ is only a local maximum of network i 's profit function, given that network j also charges \bar{p}_{on}^* . There may exist a second local maximum, which may emerge when network i sets a very high price as a best reply to $\bar{p}_j^* = \bar{p}_{on}^*$. In that case, $q_i(\bar{p}_i, \bar{p}_{on}^*) = 0$ and hence $\partial q_i(\bar{p}_i, \bar{p}_{on}^*)/\partial \bar{p}_i = 0$. Less formally, this means that all L-types use network j 's tariff to call one another. However, by setting a high on-net price, network i capitalizes on the $\lambda q(p_i)/2$ number of calls from the L to the H-types, where it has a monopoly. The second local maximum (best reply candidate) is found by maximizing π_i^L under the constraints that $q_i(\bar{p}_i, \bar{p}_j) = 0$ and $\bar{p}_j^* = \bar{p}_{on}^*$. After reorganizing terms, the optimal price \bar{p}_{on}^M is given by

$$\frac{\bar{p}_{on}^M - 2c}{\bar{p}_{on}^M} = -\frac{q(\bar{p}_{on}^M)}{\bar{p}_{on}^M(q'(\bar{p}_{on}^M))} > \frac{\bar{p}_{on}^* - 2c}{\bar{p}_{on}^*}.$$

Note, however, that to set $\bar{p}_j^* = \bar{p}_{on}^*$ cannot be a best reply for network j , given that network i charges $\bar{p}_j^* = \bar{p}_{on}^M$. In that case, network j could increase its on-net price by a small amount to increase the profit it derives from the calls from L-types to L-types, hence increasing its total profit. Likewise, $\bar{p}_i = \bar{p}_{on}^M$ cannot be a best reply to $\bar{p}_j^* = \bar{p}_{on}^M$, because a small decrease in price would yet again increase network i 's profit. Consequently, a mixing equilibrium candidate emerges in which the networks choose their prices from a probability distribution with support $[\bar{p}_{on}^*, \bar{p}_{on}^M]$. We can conclude that the pure strategy equilibrium emerges if

$$\begin{aligned} \pi_i^L(\bar{p}_{on}^*, \bar{p}_{on}^*) &\geq \pi_i^L(\bar{p}_{on}^M, \bar{p}_{on}^*) \Leftrightarrow \\ (\frac{1}{2}q(\bar{p}_{on}^*) + \lambda q_i(\bar{p}_{on}^*, \bar{p}_{on}^*))(\bar{p}_{on}^* - 2c) &\geq \frac{1}{2}q(\bar{p}_{on}^M)(\bar{p}_{on}^M - 2c). \end{aligned}$$

Whether or not $\pi_i^L(\bar{p}_{on}^*, \bar{p}_{on}^*) \geq \pi_i^L(\bar{p}_{on}^M, \bar{p}_{on}^*)$ depends on how elastic the call demand $q_i(\bar{p}_i, \bar{p}_{on}^*)$ is to changes in \bar{p}_i . For instance, when $|\partial q_i(\bar{p}_{on}^*, \bar{p}_{on}^*)/\partial \bar{p}_i|$ approaches infinity, the margin and profits from the L-type segment approach zero, if network i sets its on-net prepaid price according to (9). Consequently, there exists a critical value k above which \bar{p}_{on}^M and not \bar{p}_{on}^* is a best reply to \bar{p}_{on}^* . ■

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