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ABSTRACT

The Breakdown of Connectivity Breakdowns

We show that the prediction of a strategic connectivity breakdown under a receiving-party-pays (RPP) system and discrimination between on- and off-net prices does not hold up once more than two networks are considered. Indeed, equilibria with finite call and receiving prices exist for a large and realistic range of call externality values. This allows regulation of termination rates to achieve the socially optimal retail pricing structure under RPP.

JEL Classification: L13 and L51
Keywords: connectivity breakdown, mobile network competition, receiving party pays and termination rates

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1 Introduction

The regulation of mobile termination rates (MTRs or access charges) in the European Union has come a long way over the last decade, moving away from the paradigm of full network cost recovery towards an approach based on recovering only the incremental cost of termination. In particular, the advent of next-generation networks and IP interconnection have made the analysis of zero termination rates (Bill & Keep) on mobile networks more urgent. Indeed, in 2009 the communications regulator in the United Kingdom, Ofcom, held a consultation about the future regulation of MTRs, explicitly mentioning Bill & Keep as one of the options to consider.[1]

While charging very low MTRs is standard practice in the US, in Europe there has been some anxiety about the effects of MTR reductions on the mobile telephony market, in particular because the US has an RPP (receiving party pays) retail model. Contrary to the CPP (calling party network pays) model common in Europe, under RPP subscribers pay both for originating and receiving calls. While opponents of RPP claim that consumers should not pay for calls they receive if they already pay for making calls, they overlook that, in a nutshell, paying for reception tends to go together with paying less for making calls.

More worrying are theoretical results in the academic literature that indicate a high likelihood of connectivity breakdowns under RPP. These breakdowns occur under price discrimination between on- and off-net calls. Networks then have a strategic incentive to reduce the surplus of competing networks' subscribers by shutting off inter-network calls through prohibitively high call or receiving prices.

Results and Intuitions Until now connectivity breakdowns have only been considered for duopoly markets. We show in this paper that the breakdown result is not robust to an increase in the number of networks: With at least three networks there is a significant range of call externality values for which no breakdown occurs.[2] More precisely, if β measures the strength of the call externality on a scale from 0 (no call externality) through 1 (the receiver obtains the same utility as the caller), with $n \geq 2$ symmetric networks the range of β where strategic connectivity breakdowns do not occur is given

[1] See European Commission (2009) on incremental cost and Tera's (2010) report for the European Commission on Bill & Keep. The Ofcom consultation and responses are available at http://stakeholders.ofcom.org.uk/consultations/mobilecallterm (as of 27/09/2012).

[2] A trivial non-strategic breakdown equilibrium always exists, where a best response to other networks charging infinite prices is to do the same. What we show below is that non-trivial, i.e. strategic, breakdowns disappear.

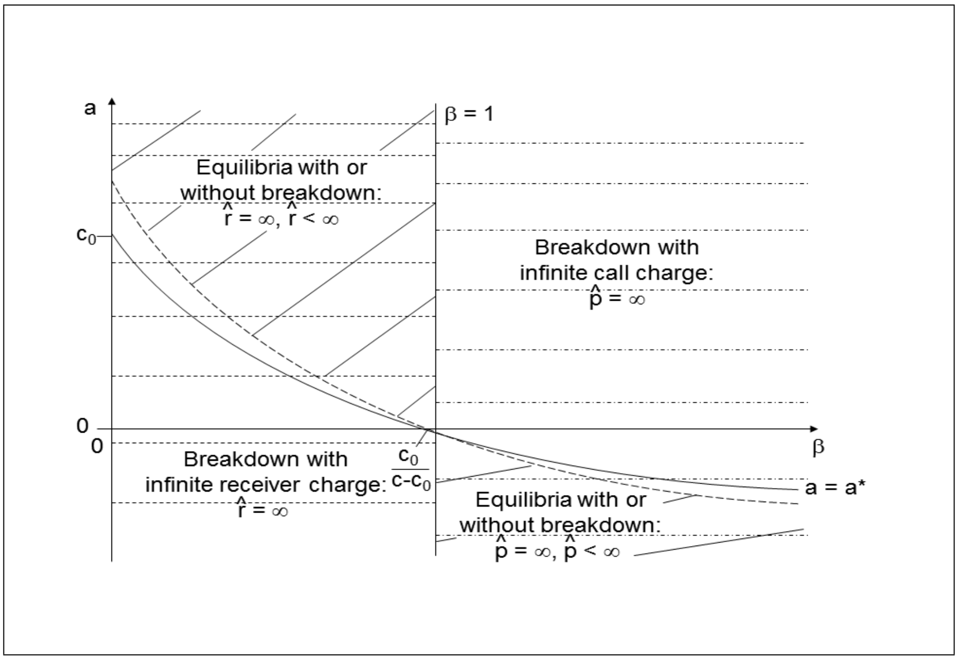

Figure 1: Equilibria in duopoly.

by

$$\frac{1}{n-1} < \beta < n-1. \tag{1}$$

In other words, while in duopoly ($n = 2$) no value of β satisfies this condition, already with three networks no breakdown occurs for $1/2 < \beta < 2$. The interval of call externalities without breakdown increases in size with the number of competing networks.

The configurations of equilibrium with $n = 2$ and $n > 2$ are depicted in Figures 1 and 2, respectively. With two networks, for all combinations of call externality values β and access charge levels a there are equilibria with connectivity breakdown. More precisely, for $\beta < 1$ the receiving price will be infinite, while for $\beta > 1$ the call price is infinite. Simultaneously, some equilibria may exist where no breakdown occurs (above the dashed line on the left and below on the right), but these never exist when the access charge would lead to the efficient retail pricing structure (on the line $a = a^*$).

With more than two networks, the previous structure of equilibria continues to exist for either very small β, i.e. $\beta < 1/(n-1)$, or very large β, i.e. $\beta > n-1$, while for intermediate values a whole new range of equilibria opens up. In this range, for $a > a^*$ callers hang up first, while for $a < a^*$ receivers hang up first. Crucially, no strategic connectivity breakdown occurs, and for all values of β a retail equilibrium with finite prices exists whenever

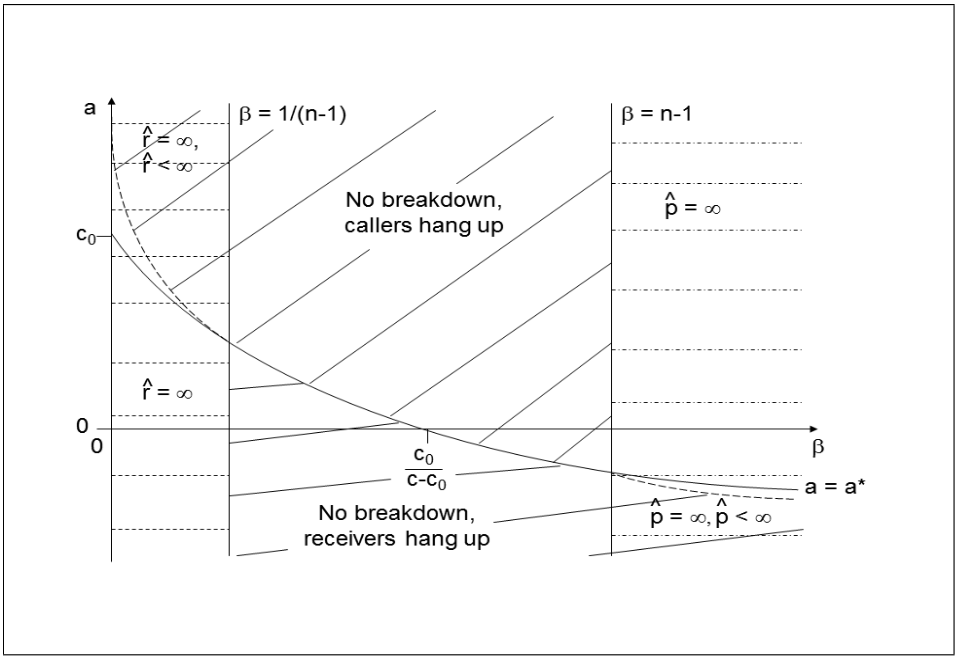

Figure 2: Equilibria with at least three networks.

the access charge is set efficiently at $a = a^*$.

The effect of an increase in the number of firms can be explained by considering networks' strategic marginal cost. If callers hang up first then from (6) below the expression (17) in JLT for the strategic marginal cost of off-net calls, given the off-net receiving price $\hat{r}$ on other networks, becomes

$$u'(q(\hat{p})) = c + m + \frac{1}{n-1}\left(\beta u'(q(\hat{p})) - \hat{r}\right).$$

Here u' and $\beta u'$ are the caller's and receiver's marginal utilities, respectively, and $c + m$ is perceived off-net cost. Connectivity breaks down only if $\beta/(n-1) > 1$, or $\beta > n - 1$. One sees clearly that the importance of direct and pecuniary externalities, as captured by the last term on the right-hand side, decreases in the number of networks.

Similarly, if callers hang up first then from (7) the strategic marginal cost for off-net reception, at call price $\hat{p}$, is given by

$$\beta u'(q(\hat{r}/\beta)) = -m + \frac{1}{n-1}\left(u'(q(\hat{r}/\beta)) - \hat{p}\right).$$

In this case breakdown occurs if $\beta < 1/(n-1)$. Again, the term on the right-hand side measuring the strategic externality decreases in the number of networks.

Since for call externality values in the range (1) no strategic connectivity breakdown occurs, we can start to consider the efficiency of retail prices and the access charge. We show that for $a > a^*$ call charges are above off-net cost but converge to the latter as the number of firms increases. The same holds for reception charges when $a < a^*$. Efficient call and receiving prices arise in equilibrium if a is set equal to a^*. In an extension section, we show that larger networks have higher incentives for provoking connectivity breakdowns, consider the efficiency of Bill & Keep, and investigate non-negative reception charges.

Related Literature Jeon *et al.* (2004, JLT) consider competition between two mobile networks under call externalities and two-part tariffs that include a payment for receiving calls. Under uniform pricing (the same price is charged for on-net and off-net calls) and full coverage, JLT find that call and reception charges are set at off-net cost, i.e. as if all calls were off-net, and that the socially optimal volume of calls can be achieved by setting the mobile termination rate (MTR) below termination cost. On the other hand, with discrimination between on-net and off-net calls, connection tends to break down in equilibrium, regardless of the strength of the call externality. In this case the strategic marginal cost of either making or receiving calls becomes so high that networks choose to set the corresponding prices at infinity, i.e. no off-net calls will be made. DeGraba (2003) already had determined socially optimal call and receiving prices and access charges, but did not check whether these could be implemented in market equilibrium.

Cambini and Valletti (2008) show that the possibility that calls spawn further calls, as measured by the propagation factor, reduces the probability of breakdowns while not eliminating them. On the other hand, Lopez (2011) confirms the result of JLT in a setting with noise in both caller and receiver utility. Hermalin and Katz (2011) assume that networks commit to subscriber numbers before setting retail prices, which decouples call pricing decisions from competition for subscribers. As a consequence, pricing is non-strategic and no connectivity breakdowns occur in their model. On the other hand, they allow for caller and receiver utility to vary independently, which implies that the first-best call and receiving prices cannot be implemented in market equilibrium.

Littlechild (2006) and Harbord and Pagnozzi (2010) present stylized facts and policy arguments concerning RPP versus CPP, while Dewenter and Kruse (2011) contains an econometric analysis of mobile penetration. Overall, their conclusions are that CPP and RPP lead to similar mobile penetration, while usage tends to be higher under RPP.

2 Model and Preliminary Results

The model setup is a generalization of JLT to many networks. We assume that there are $n \geq 2$ symmetric mobile networks $i = 1, ..., n$ who compete in multi-part tariffs of the form $(p_i, r_i, \hat{p}_i, \hat{r}_i, F_i)$, where p_i and r_i are the per-minute call and reception charges for on-net calls, $\hat{p}_i$ and $\hat{r}_i$ those for off-net calls, and F_i is a monthly fixed fee. Networks' marginal on-net cost of a call is $c > 0$, the cost of termination of an off-net call is $c_0 > 0$, and networks charge each other the mobile termination rate a per incoming call minute. Thus the marginal cost of an off-net call is $c + m$, where $m = a - c_0$ is the termination margin. There is also a monthly fixed cost f per customer.

Market shares are defined as follows.[3] If consumers obtain surplus w_i from subscribing to network i its market share is

$$\alpha_i = \frac{1}{n} + \sigma \sum_{j \neq i} (w_i - w_j), \tag{2}$$

where $\sigma > 0$ measures the degree of horizontal product differentiation. From making a call of length q, a consumer obtains utility $u(q)$, where $u(0) = 0$, $u' > 0$ and $u'' < 0$. For call price p, the corresponding call demand is defined by $u'(q(p)) = p$. As in JLT, receiving a call of length q yields utility $\tilde{u}(q) = \beta u(q) + \varepsilon q$, where $\beta \geq 0$ indicates the strength of the call externality and ε is a random noise term with $E[\varepsilon] = 0$, distribution function G and density g. Thus at a reception price r, the receiver demands a call of length $q((r - \varepsilon)/\beta)$. Both callers and receivers can hang up, thus for each caller and receiver pair the length of a call is given by $\min \{q(p), q((r - \varepsilon)/\beta)\}$. Since for high (small) values of ε the caller (receiver) hangs up first, the expected length of a call is given by

$$D(p, r) = (1 - G(r - \beta p)) q(p) + \int_{-\infty}^{r - \beta p} q\left(\frac{r - \varepsilon}{\beta}\right) g(\varepsilon)\, d\varepsilon.$$

The corresponding expected utilities for making and receiving calls are

$$\begin{aligned} U(p, r) &= (1 - G(r - \beta p)) u(q(p)) + \int_{-\infty}^{r - \beta p} u\left(q\left(\frac{r - \varepsilon}{\beta}\right)\right) g(\varepsilon)\, d\varepsilon, \\ \tilde{U}(p, r) &= \int_{r - \beta p}^{\infty} (\beta u(q(p)) + \varepsilon q(p)) g(\varepsilon)\, d\varepsilon \\ &\quad + \int_{-\infty}^{r - \beta p} \left(\beta u\left(q\left(\frac{r - \varepsilon}{\beta}\right)\right) + \varepsilon q\left(\frac{r - \varepsilon}{\beta}\right)\right) g(\varepsilon)\, d\varepsilon. \end{aligned}$$

[3] Armstrong and Wright (2007) introduced this demand specification, while Hoernig (2012) derives it from a generalized Hotelling model.

As in JLT we assume that calls between each pair of consumers are equally likely, so that a subscriber of network i obtains the following surplus:

$$w_i = \alpha_i \left(U_{ii} + \tilde{U}_{ii} - (p_i + r_i) D_{ii} \right) + \sum_{j \neq i} \alpha_j \left(U_{ij} - \hat{p}_i D_{ij} + \tilde{U}_{ji} - \hat{r}_i D_{ji} \right) - F_i,$$

where $D_{ii} = D(p_i, r_i)$, $D_{ij} = D(\hat{p}_i, \hat{r}_j)$, *etcetera*, for $j \neq i$. Network i's profits are

$$\begin{aligned} \pi_i &= \alpha_i [F_i - f + \alpha_i (p_i + r_i - c) D_{ii} \\ &\quad + \sum_{j \neq i} \alpha_j ((\hat{p}_i - c - m) D_{ij} + (\hat{r}_i + m) D_{ji})] \end{aligned} \tag{3}$$

As in JLT, we will consider equilibrium conditions for vanishing noise, i.e. for a sequence of distributions G_n whose support remains sufficiently large that both callers or receivers sometimes hang up but which converge to zero in probability. We also assume that this sequence is regular in the following sense: For $\bar{\varepsilon} > 0 > \underline{\varepsilon}$ we have [4]

$$\lim_{n \to \infty} E_n [\varepsilon | \varepsilon \geq \bar{\varepsilon}] = \bar{\varepsilon}, \ \lim_{n \to \infty} E_n [\varepsilon | \varepsilon \leq \underline{\varepsilon}] = \underline{\varepsilon}.$$

For each caller and receiver pair, the socially optimal call volume q is given by $u'(q) + \tilde{u}'(q) = c$. Since the latter depends on ε, in the presence of noise the social optimum cannot be achieved. If one considers vanishing noise, the condition for optimal call volume becomes $u'(q) = c/(1 + \beta)$. As JLT have pointed out, this optimal volume can be implemented if call and receiving prices $p^* = c/(1+\beta)$ and $r^* = \beta c/(1+\beta)$ are imposed, since both callers and receivers will then want to hang up simultaneously at the optimal quantity.

3 Market Equilibrium

We will now determine the call and reception charges that arise in a symmetric equilibrium, following as closely as possible the solution procedure in JLT, neglecting the equilibria in weakly dominated strategies that arise if both calling and reception charges are infinite in order to concentrate on the conditions under which no connectivity breakdown occurs. Furthermore, since we are interested principally in the latter, here we will omit the determination of equilibrium fixed fees.

[4] These assumptions imply that analogous conditions hold for any continuous and bounded function of ε (my thanks to Iliyan Georgiev for the proof).

An interesting new issue arises in the presence of multiple networks, as pointed out by Hoernig (2012): The standard procedure of finding profit-maximizing call prices by holding market shares constant and adjusting the network's fixed fee is no longer correct in general. More precisely, if one considers asymmetric networks, or even symmetric rival networks with non-identical tariffs, the shifts in markets shares will also be asymmetric. These asymmetric shifts then cannot be eliminated by adjusting a single network's fixed fee. There are two ways out: Either one considers the first-order conditions with respect to call prices and the fixed fee simultaneously as in Hoernig (2012), or one limits consideration to symmetric equilibria and assumes from the start that all rivals are identical and choose the same candidate tariff. For simplicity, we follow the latter route below, while following the former would lead to the same set of equilibria in this model.

Thus assume that all networks $j \neq i$ choose the same tariff $(p, r, \hat{p}, \hat{r}, F)$, resulting in identical market shares $\alpha_j = (1 - \alpha_i) / (n - 1)$, which we will hold constant together with α_i. Solving the market share condition (2) for F_i and substituting the result into (3) leads to the following profits of network i:

$$\begin{aligned} \pi_i &= \alpha_i^2 \left(U_{ii} + \tilde{U}_{ii} - cD_{ii} \right) \\ &\quad + \alpha_i (1 - \alpha_i) \left(U_{ik} - (c + m) D_{ik} + \tilde{U}_{ki} + mD_{ki} \right) \\ &\quad - \alpha_i^2 \left(U_{ki} - \hat{p} D_{ki} + \tilde{U}_{ik} - \hat{r} D_{ik} \right) + const. \end{aligned}$$

The first line contains the surplus and cost from making and receiving on-net calls, while the second line contains those for off-net calls. The third line indicates the direct and pecuniary externalities on customers of rival networks, as translated by the terms involving utilities or payments (plus a term that does not depend on network i's call prices).

The terms corresponding to on-net calls do not depend on the number of networks. Rather, network i will maximize $U_{ii} + \tilde{U}_{ii} - cD_{ii}$ as in the duopoly case, which leads to the efficient choices $p_i = p^*$ and $r_i = r^*$. This result arises because network i fully internalizes the externalities on callers and receivers.

For off-net calls, denote the partial profits related to call and receiving prices, respectively, by

$$\begin{aligned} \pi_i^{\hat{p}} (\hat{p}_i; \alpha_i, \hat{r}) &= \alpha_i \left\{ (1 - \alpha_i) \left(U_{ik} - (c + m) D_{ik} \right) + \alpha_i \left(\hat{r} D_{ik} - \tilde{U}_{ik} \right) \right\}, \\ \pi_i^{\hat{r}} (\hat{r}_i; \alpha_i, \hat{p}) &= \alpha_i \left\{ (1 - \alpha_i) \left(\tilde{U}_{ki} + mD_{ki} \right) + \alpha_i \left(\hat{p} D_{ki} - U_{ki} \right) \right\}. \end{aligned}$$

While these expressions are ostensibly identical to those found in the duopoly case, allowing for multiple networks will make all the difference.

Since infinite prices choke off demand we have $\pi_i^{\hat{p}}(\infty) = \pi_i^{\hat{r}}(\infty) = 0$, so that in equilibrium both $\pi_i^{\hat{p}}$ and $\pi_i^{\hat{r}}$ will be non-negative. The first derivatives with respect to p_i and r_i are

$$\begin{aligned}
\frac{\partial \pi_i^{\hat{p}}}{\partial \hat{p}_i} &= \alpha_i \left[1 - F\left(\hat{r} - \beta \hat{p}_i\right)\right] \times \{\left(1-\alpha_i\right)\left(\hat{p}_i - c - m\right) && (4)\\
&\quad -\alpha_i \left(\beta \hat{p}_i + E\left[\varepsilon | \varepsilon \geq \hat{r} - \beta \hat{p}_i\right] - \hat{r}\right)\} q'(\hat{p}_i), \\
\frac{\partial \pi_i^{\hat{r}}}{\partial \hat{r}_i} &= \alpha_i \frac{F\left(\hat{r}_i - \beta \hat{p}\right)}{\beta} \times E[\{\left(1-\alpha_i\right)\left(\hat{r}_i + m\right) && (5)\\
&\quad + \alpha_i (\hat{p} - u'(q\left(\frac{\hat{r}_i - \varepsilon}{\beta}\right)))\} q'\left(\frac{\hat{r}_i - \varepsilon}{\beta}\right) | \varepsilon \leq \hat{r}_i - \beta \hat{p}].
\end{aligned}$$

As noise vanishes, and assuming symmetric market shares $\alpha_i = \alpha_j = 1/n$ from now on, we can restate $\partial \pi_i^{\hat{p}} / \partial \hat{p}_i$, omitting positive leading factors, as

$$\begin{cases} \left(\hat{p}_i - c - m - \frac{1}{n-1}\left(\beta \hat{p}_i - \hat{r}\right)\right) q'\left(\hat{p}_i\right) & \text{if } \hat{r} \leq \beta \hat{p}_i \\ \left(\hat{p}_i - c - m - \frac{1}{n-1}\left(\beta \hat{p}_i + \hat{r} - \beta \hat{p}_i - \hat{r}\right)\right) q'\left(\hat{p}_i\right) & \text{if } \hat{r} \geq \beta \hat{p}_i \end{cases},$$

or

$$\begin{cases} \left(\left(1 - \frac{\beta}{n-1}\right) \hat{p}_i + \frac{1}{n-1} \hat{r} - c - m\right) q'\left(\hat{p}_i\right) & \text{if } \hat{r} \leq \beta \hat{p}_i \\ \left(\hat{p}_i - c - m\right) q'\left(\hat{p}_i\right) & \text{if } \hat{r} \geq \beta \hat{p}_i \end{cases}. \tag{6}$$

On the first branch, this derivative is positive (negative) before (after) the critical value if $\beta < n - 1$, while the same is true on the second branch regardless of the value of β. Thus in this case either critical value constitutes a local maximum if it falls on its branch, with $\pi_i^{\hat{p}}\left(\hat{p}_i\right) \geq 0$. If $\beta = n - 1$ then the derivative does not depend on $\hat{p}_i$ and indicates a maximum if and only if $\hat{r} = (n-1)(c+m)$.

Similarly, as noise vanishes we find that $\partial \pi_i^{\hat{r}} / \partial \hat{r}_i$ becomes

$$\begin{cases} \left(\left(\hat{r}_i + m\right) + \frac{1}{n-1}\left(\hat{p} - \hat{p}\right)\right) q'\left(\hat{p}\right) & \text{if } \hat{r}_i \leq \beta \hat{p} \\ \left(\frac{1}{n-1} \hat{p} + \left(1 - \frac{1}{(n-1)\beta}\right) \hat{r}_i + m\right) q'\left(\frac{\hat{r}_i}{\beta}\right) & \text{if } \hat{r}_i \geq \beta \hat{p} \end{cases}. \tag{7}$$

Again, the critical value is a local maximum on the first branch, and also on the second branch if $\beta > 1/(n-1)$, with $\pi_i^{\hat{r}}\left(\hat{r}_i\right) \geq 0$. If $\beta = 1/(n-1)$ then there is a local maximum if $\hat{p} = (n-1)m$.

Define the termination rate level

$$a^* = c_0 - \frac{\beta c}{1+\beta}. \tag{8}$$

We will see below that a^* is the efficient MTR independently of the number of networks, as in DeGraba (2003, p. 213) for a caller's share of benefits $1/(1+\beta)$. Now we have the following principal result.

Proposition 1 *Let ε be regularly distributed, and $n \geq 2$ networks compete in multi-part tariffs with on/off-net price discrimination. As the noise vanishes, for $\frac{1}{n-1} < \beta < n-1$ there is no strategic connectivity breakdown in symmetric equilibrium.*[5] *More precisely,*

1. *for $a > a^*$, callers hang up first, with $\hat{p} = \hat{p}^c \equiv \frac{(n-1)c+mn}{n-1-\beta} > p^*$ and $\hat{r} = \hat{r}^c \equiv -m < r^*$;*
2. *for $a = a^*$, callers and receivers hang up simultaneously, with $\hat{p} = p^*$ and $\hat{r} = r^*$;*
3. *for $a < a^*$, receivers hang up first, with $\hat{p} = \hat{p}^r \equiv c + m < p^*$ and $\hat{r} = \hat{r}^r \equiv -\frac{\beta(c+nm)}{(n-1)\beta-1} > r^*$.*

Proof. Assuming $\hat{r} \leq \beta\hat{p}$, the symmetric equilibrium candidate $(\hat{p}^c, \hat{r}^c)$ is given by the conditions

$$\left(1 - \frac{\beta}{n-1}\right)\hat{p}^c + \frac{1}{n-1}\hat{r}^c - c - m = 0,\ \ \hat{r}^c + m = 0.$$

The solution is $\hat{r}^c = -m$ and $\hat{p}^c = \frac{(n-1)c+nm}{n-1-\beta}$. We have $\hat{r}^c \leq \beta\hat{p}^c$ if and only if $m \geq -\frac{\beta c}{1+\beta}$, or $a \geq a^*$.

In a similar manner, assuming $\hat{r} \geq \beta\hat{p}$ the symmetric equilibrium candidate is $(\hat{p}^r, \hat{r}^r)$ with

$$\hat{p}^r - c - m = 0,\ \frac{1}{n-1}\hat{p}^r + \left(1 - \frac{1}{(n-1)\,\beta}\right)\hat{r}^r + m = 0,$$

with solution $\hat{p}^r = c + m, \hat{r}^r = -\beta\frac{c+mn}{(n-1)\beta-1}$. We have $\hat{r}^r \geq \beta\hat{p}^r$ if and only if $m \leq -\frac{\beta c}{1+\beta}$ or $a \leq a^*$. ■

At this point is it useful to remember that connectivity breakdowns can occur for two reasons. First, they can happen due to coordination failure, where networks set both call and receiving prices to infinity. These are mutually best responses, though in weakly dominated strategies, and this type of equilibrium always exists. Second, and more interestingly, connectivity can break down for strategic reasons. This happens whenever setting a finite

[5] Similar to JLT, these equilibria exist if either m or σ are sufficiently small.

call or receiver charge benefits the rival too much, as shown in JLT. In this case it is optimal to choke off calls through an infinite charge. What we have shown in Proposition 1 is that once more than two competing networks are considered, a whole new region of equilibria opens up where connectivity breakdowns due to strategic reasons simply cannot happen. Moreover, this region includes reasonable values for the call externality at the prevailing number of networks in most countries. For example, with three or four networks, there is no connectivity breakdown for $1/2 < \beta < 2$ and $1/3 < \beta < 3$, respectively (Evidently, if one follows the common assumption that $\beta \leq 1$ then only the lower bound is relevant in practice).

An additional significant piece of good news is that with more than two networks the efficient call volumes can be achieved by setting the mobile termination rate equal to a^*, without having to fear connectivity breakdowns. Indeed, a look at Figure 1 shows that the same is not true in duopoly: The line indicating $a = a^*$ only passes through areas where breakdown is unavoidable. This implies that while in duopoly efficient call volumes can only be achieved if MTRs *and* receiver charges are regulated, with more networks it is enough to set the MTR at the right level and let the market choose equilibrium retail prices.

For small values of β, i.e. $\beta < 1/(n-1)$, the same result as in JLT obtains, i.e. connectivity breakdown can only be avoided if a is sufficiently above a^* (above the dashed line in Figures 1 and 2, which corresponds to the condition $\pi_i^{\hat{r}}(\hat{r}^r) = 0$). But even then there is an equilibrium with strategic connectivity breakdown due to $\hat{r} = \infty$ which exists for all MTR values. Equally, if $\beta > n - 1$ then for all MTR values there is always an equilibrium with connectivity breakdown due to $\hat{p} = \infty$, while for a sufficiently below a^* (below the dashed line indicating $\pi_i^{\hat{p}}(\hat{p}^c) = 0$) there is also an equilibrium without breakdown. Thus what is special for β between these extremes is that connectivity breakdowns due to strategic reasons will not arise.

As a last point, we consider how call and receiver charges change as a function of the number of networks:

Corollary 2 *Let $\frac{1}{n-1} < \beta < n - 1$. For all n, $\hat{r}^c$ and $\hat{p}^r$ are equal to off-net cost. As n increases, $\hat{p}^c$ and $\hat{r}^r$ converge from above to off-net cost.*

Proof. Follows from the expressions in Proposition 1. ■

This Corollary implies that the relevant charges, i.e. $\hat{p}^c$ when callers hang up first and $\hat{r}^r$ when receivers hang up first, are higher than they would be under uniform pricing, where even with many networks charges continue to be equal to off-net cost as in JLT.[6] In other words, if there is no connectivity breakdown, for strategic reasons fewer off-net calls will be made with discrimination between on-net and off-net calls, just as in the case without receiver charges. As the number of networks increases, though, more calls will be made off-net and therefore it pays off less to distort call off-net prices upwards.

4 Additional Issues

Asymmetric Networks Here we give a quick stab at the question of how strategic connectivity breakdown depends on networks' relative sizes. For simplicity, we continue to assume that networks $j \neq i$ are symmetric, thus derivatives (4) and (5) still apply for network i even if α_i is different from $1/n$ in equilibrium.

For vanishing noise, the derivatives defining the off-net call and receiver charges that influence call duration, i.e. $\hat{p}_i^c$ and $\hat{r}_i^r$, become

$$\begin{aligned} \frac{\partial \pi_i^{\hat{p}}}{\partial \hat{p}_i} &\sim \left(\left(1 - \frac{\beta \alpha_i}{1-\alpha_i}\right)\hat{p}_i + \frac{\alpha_i}{1-\alpha_i}\hat{r} - c - m\right) q'(\hat{p}_i) \\ \frac{\partial \pi_i^{\hat{r}}}{\partial \hat{r}_i} &\sim \left(\frac{\alpha_i}{1-\alpha_i}\hat{p} + \left(1 - \frac{\alpha_i}{(1-\alpha_i)\beta}\right)\hat{r}_i + m\right) q'\left(\frac{\hat{r}_i}{\beta}\right) \end{aligned}$$

Reframing the conditions for the existence of local maxima in terms of market share α_i (i.e. the sign of the derivative must change from positive to negative at the solution), the condition for a finite call charge becomes $\alpha_i < \frac{1}{1+\beta}$, while the condition for a finite receiver charge becomes $\alpha_i < \frac{\beta}{1+\beta}$. The latter condition is stricter in the more relevant case $\beta < 1$, while the former is stricter for $\beta > 1$.

Thus we find in this indicative example that larger networks have a stronger incentive to cause strategic connectivity breakdowns, by setting a high off-net receiver charge. In other words, for any given number of networks, the risk of connectivity breakdown increases with the relative asymmetry between networks, much as is the case without receiver charges.

Optimality of Bill & Keep An unavoidable question is whether and when Bill & Keep ($a = 0$) can achieve the social optimum. This question has been hotly discussed in Europe under the CPP system, and now we pose it assuming RPP. First of all, even at the danger of repeating ourselves,

[6] The proof is straightforward and therefore omitted.

we would like to stress that this question could not have been meaningfully posed in the duopoly case. With multiple networks, though, there is a large and reasonable parameter region where call and receiver charges are finite in equilibrium and fine-tuning of the termination rate becomes possible in the first place.

Corollary 3 *Let* $\frac{1}{n-1} < \beta < n-1$*. Bill & Keep is efficient if and only if* $\beta = c_0/(c-c_0)$*.*

Proof. Follows from the definition of (8) and $a^* = 0$. ■

This condition for optimality of Bill & Keep has been proven before by DeGraba (2003, p. 213), but without considering whether an equilibrium without breakdown exists at all. We add to this condition the certainty that for reasonable values of β no strategic connectivity breakdown occurs.

On the other hand, it may be that the marginal cost of both origination and termination are effectively zero, and any positive values ventilated only arise due to the accounting practice of attributing common costs. This argument is only bound to get stronger with the routing of traffic over cheaper IP-based networks. In this case, we find the following, again similar to DeGraba (2003):

Corollary 4 *If the marginal costs calls are zero then Bill & Keep is efficient, with equilibrium retail charges* $\hat{p} = \hat{r} = 0$*.*

Proof. Immediate from (8) and $p^* = r^* = 0$. ■

In other words, if marginal costs are indeed zero, under Bill & Keep the market would move to "pure bucket pricing", where consumers pay a subscription fee and then costlessly make and receive calls.

Non-Negative Reception Charges As several authors have pointed out (e.g. Cambini and Valletti 2008 and Lopez 2011), networks may not find it possible to set negative reception charges, since the latter may invite arbitrage or opportunistic behaviour by clients. In this case the restriction $\hat{r} \geq 0$ is binding whenever the termination rate is high enough.

Corollary 5 *Networks will choose positive reception charges if and only if* $a < c_0$*. If networks cannot set negative reception charges then if* $a > c_t$ *the symmetric market equilibrium involves the off-net call charge*

$$\tilde{p} = \frac{c+m}{1-\beta/(n-1)}$$

if $\beta < n-1$*, and* $\tilde{p} = \infty$ *if* $\beta > n-1$*.*

Proof. In the unconstrained equilibrium, $\hat{r} < 0$ only occurs in the case $a > a^*$, where $\hat{r} = -m$. Thus $\hat{r} < 0$ if and only if $m > 0$. The expression for $\tilde{p}$ follows from the first-order condition for the off-net price in Proposition (1) with $\hat{r} = 0$. ■

JLT derive the corresponding formula for $n = 2$ under the assumption that reception charges are absent, while Hoernig (2012) derived the latter result for the more general case of many asymmetric networks under CPP.

5 Conclusions

In this paper we have shown that the stark prediction in Jeon *et al.* (2004) of a strategic connectivity breakdown under RPP and discrimination between on- and off-net prices does not hold up once more than two networks are considered in the model. Indeed, for reasonable values of the call externality, connectivity breakdowns for strategic reasons do not arise in symmetric equilibrium. Intuitively, in the presence of multiple rivals it becomes essential that off-net calls, both incoming and outgoing, are priced reasonably, while strategic externalities lose importance.

The take-away from a policy perspective is that if competition is sufficiently effective in the sense that at least three similar-sized networks exist, then direct regulation of receiver charges is not necessary. The reverse side of the medal is that if networks are few or sufficiently asymmetric then regulatory intervention is still needed under RPP in order to avoid connectivity breakdowns.

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