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Going beyond Duopoly: Connectivity Breakdowns under Receiving Party Pays

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Going beyond Duopoly: Connectivity Breakdowns under Receiving Party Pays*

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Abstract

We show that the prediction of strategic connectivity breakdowns under a receiving-party-pays system and discrimination between on- and off-net prices does not hold up once more than two mobile networks are considered. Indeed, if there are at least three competing networks and enough utility is obtained from receiving calls, only equilibria with finite call prices and receiving prices exist. Private negotiations over access charges then achieve the efficient outcome. Bill & keep (zero access charges) and free outgoing and incoming calls are efficient if and only if marginal costs of calls are zero.

Keywords: Mobile network competition; Receiving party pays; Connectivity breakdown; Termination rates

JEL: L13, L51.

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1 Introduction

The regulation of mobile termination rates (MTRs or access charges, the fees that networks receive from their competitors to terminate calls) 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 access charges (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 making 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 that under RPP there is a high likelihood that strategic considerations will lead "connectivity breakdowns". These breakdowns are predicted to occur under price discrimination between on- and off-net calls and duopolistic competition. Each of the two networks has a strategic incentive to reduce the surplus of its rival network's subscribers by shutting off inter-network calls through prohibitively high call or receiving prices. That this kind of pricing behavior has not been observed in reality may well be due to regulatory pressure, but it seems important to check whether the theoretical prediction is robust in the first place. In this paper we show that it is not, and that going beyond duopoly leads to a major change in predictions.

Results and Intuitions Below we show that the result in the duopoly case is not robust to an increase in the number of networks, as there is a significant range of fundamental parameter values for which no strategic breakdown occurs if and only if the number of networks is larger than two. This range

¹See 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).

depends on the relation between the strength of the "call externality", i.e. the utility that call receivers obtain, and the number of networks. More precisely, if the parameter 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 no strategic connectivity breakdowns occur is given by

$$\frac{1}{n-1} < \beta < n-1. \quad (1)$$

Clearly, in duopoly ($n = 2$) the lower and upper bounds are equal and no value of β satisfies this condition. Already with three networks no strategic breakdown occurs for $1/2 < \beta < 2$, and the interval of call externalities without breakdown increases with the number of competing networks.

The intuition behind the effect of the number of networks is the following. First consider an equilibrium in a duopoly market where the breakdown is caused by a very large price for making off-net calls, while at the corresponding receiving price subscribers would accept to receive calls.² This high calling price is the result of very high "strategic marginal cost", i.e. the combined value of the marginal cost of network usage and the externalities bestowed on rival networks' customers. This latter externality consists of the call externality from receiving the call and a "pecuniary externality" from paying for receiving it. The key to understanding the pricing incentives in this case is the size of the externality as compared to the marginal utility of the caller. Indeed, as the number of networks grows, the total externality for any specific rival network becomes smaller, and thus the externality component of strategic marginal cost declines. Once strategic marginal cost falls below a certain level (we show below that this happens when $n-1 > \beta$) the call price will be set at a finite level and no strategic breakdown occurs.

In a similar fashion, consider now a strategic breakdown caused by a very large receiving price, while the off-net call price is finite. In this case the strategic marginal cost of receiving calls must be very high. The latter consists of (minus) the termination margin and the externality caused on rival networks' customers by accepting an incoming call. This externality consists of the utility from making the call and the pecuniary externality from paying for it. As in the previous case, as the number of networks increases, the externality on each rival network becomes smaller, and below a certain level the receiver price takes on a finite value. The exact condition for this to happen in this case is $\beta > 1/(n-1)$, or that $n > 1 + 1/\beta$.

²There are also non-strategic equilibria where both prices are infinite, due to a coordination failure between networks. One can imagine that joint interest or a nudge by a regulator would move networks out of these equilibria.

Some authors, such as Littlechild (2006) and Dewenter and Kruse (2011), interpret "RPP" as conflating payment for incoming calls and the imposition of bill & keep, resulting in the idea that the receivers of calls pay "termination charges". The latter are then subject to consumer choice and competition, which helps to keep them low. Here we interpret RPP differently: The receiver price is a "missing price" under CPP, while it is charged under RPP; simultaneously, the access charge is a wholesale price that is either chosen by networks or set by a regulator. Indeed, since for call externality values in the range (1) no strategic connectivity breakdown occurs, we can meaningfully study the negotiated and efficient levels of the access charge. We find that the latter coincide, at a level below termination cost but generally different from zero. This implies on the one hand that under RPP regulation of access charges would no longer be necessary, but on the other that the outcome of these negotiations is not bill & keep unless the marginal costs of origination and terminating calls are effectively zero. Indeed, in the latter case the market would settle on both bill & keep and free incoming and outgoing calls ("bucket pricing").

Finally, in an extension section, i) we show that larger networks have higher incentives for provoking connectivity breakdowns, ii) consider the efficiency of bill & keep, and iii) investigate non-negative reception charges.

Related Literature Jeon *et al.* (2004, JLT) consider competition between two mobile networks under call externalities and where networks charge their customers for receiving calls. Under uniform pricing (the same price is charged for on-net and off-net calls, i.e. calls within the same network or between networks), 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 access charges 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: For strategic reasons networks choose to set either call or receiver charges so high that no off-net calls will occur. Lopez (2011) confirms this result in a setting with noise in both caller and receiver utility. On the other hand, Kim and Lim (2001) assume that the originating network sets the price for receiving calls and show that in this (unrealistic) case no breakdown occurs. We show that the duopoly model does not lead to a robust prediction of market outcomes, as with more than two networks a new class of equilibria appears that takes the place of breakdowns for reasonable values of the call externality parameter.

Cambini and Valletti (2008) show that the possibility that call receivers

phone back reduces the probability of breakdowns in duopoly while not eliminating them unless networks can jointly agree on access charges. They also show that if callers end calls first then networks will jointly choose the efficient access charge.³ Our paper obtains the same result for the more general case where either callers or receivers end calls, and for more than two firms.⁴

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, strategic considerations are reflected only in setting the fixed part of tariffs, and no connectivity breakdowns occur in their model. In our model we underline the logic of strategic call pricing, while pointing out the reasons why breakdowns may or may not occur.

DeGraba (2003) determines socially optimal call prices and receiving prices and access charges, but does not check whether these could actually be implemented in market equilibrium. We show that indeed if the call externality value is in the correct range then the market equilibrium at the efficient access charges implies that both call and receiver prices are set efficiently. But our work also shows that it is necessary to consider both the number of networks and the strength of the call externality to come to this conclusion.

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. There is no mentioning of breakdowns having ever happened, which underlines the need to have theory models such as ours that predict finite (or even zero) call prices.

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 $i = 1, \dots, n$ 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 calling and reception charges for on-net calls, \hat{p}_i and \hat{r}_i those for

³Lopez (2011) shows that profits do not depend on access charges if networks do not price discriminate between on- and off-net calls.

⁴Combining a larger number of networks with the possibility of calling back further increases the range of equilibria.

off-net calls, and F_i is a monthly fixed fee.⁵ 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 access charge 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. If consumers obtain surplus w_i from subscribing to networks $i = 1, \dots, n$, the market share of network i is

$$\alpha_i = A(w_i - w_1, \dots, w_i - w_n),$$

where $A : \mathbb{R}^n \rightarrow \mathbb{R}$ is strictly increasing and symmetric in its arguments, with $0 \leq \alpha_i \leq 1$, $\sum_{i=1}^n \alpha_i = 1$ and $A(0, \dots, 0) = 1/n$.⁶

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 $q(p)$ is defined implicitly by $u'(q) = p$. 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 .⁷ Thus at a reception price r , receiver demand is determined by $\beta u'(q) + \varepsilon = r$ and the receiver demands a call of length $q((r - \varepsilon)/\beta)$. Both callers and receivers can end the call, 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

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

In the first term on the right we have $p < (r - \varepsilon)/\beta$ or $\varepsilon > r - \beta p$, and thus a call of length $q(p)$, while the second term contains the expected length of the call for $p \geq (r - \varepsilon)/\beta$. The corresponding expected utilities for making

⁵Thus networks set uniform off-net call (receiver) charges, i.e. do not price discriminate between calls to (from) rival networks. One can show that allowing for price discrimination leads to the same equilibrium charges in symmetric equilibrium.

⁶This demand specification encapsulates both the generalized Hotelling model of Hoernig (2014) and the logit model $\alpha_i = \exp(w_i) / \sum_{j=1}^n \exp(w_j)$. Thus we allow for a much more general discrete choice setup than JLT.

⁷The existence of randomness in receiver utility implies that both callers and receivers determine the length of different calls. If call length was determined by only callers or receivers then the equilibrium then either the calling or receiving price would be indeterminate.

and receiving calls are

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

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 expected 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 $D_{ii} = D(p_i, r_i)$, $D_{ij} = D(\hat{p}_i, \hat{r}_j)$, etc., for $j \neq i$. The first term on the right-hand side contains the utility and payments for making and receiving on-net calls, while the second term refers to off-net calls.

Network i 's profits are

$$\begin{aligned}
\pi_i &= \alpha_i [F_i - f + \alpha_i (p_i + r_i - c) D_{ii}] \\
&\quad + \sum_{j \neq i} \alpha_j ((\hat{p}_i - c - m) D_{ij} + (\hat{r}_i + m) D_{ji}),
\end{aligned} \tag{2}$$

where the line contains the profits from fixed fees and on-net calls, and the line line those from incoming and outgoing off-net calls. 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 end the call but which converges to zero in probability. We also assume that this sequence is regular in the following sense: For $\underline{\varepsilon} < 0 < \bar{\varepsilon}$ we have ⁸

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

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 pointed out, this optimal volume can be implemented if call prices and receiving prices $p^* = c/(1 + \beta)$ and $r^* = \beta c/(1 + \beta)$ are imposed, since both callers and receivers will then want to end the call simultaneously at the optimal quantity.

⁸These assumptions imply that analogous conditions hold for any continuous and bounded function of ε (my thanks to Iliyan Georgiev for this observation).

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. We neglect the equilibria in weakly dominated strategies that arise if both calling and reception charges are infinite.⁹ Rather, we concentrate on strategic connectivity breakdown, where one network wants to exchange off-net calls and some other network effectively refuses to do so. Furthermore, we will omit the determination of equilibrium fixed fees in order to concentrate on call prices.

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 while determining call prices. For these symmetric tariffs we have $w_j = w$ for all $j \neq i$ and some expected surplus w . Thus we can state network i 's market share as

$$\alpha_i = A(w_i - w, \dots, w_i - w) = \bar{A}(w_i - w),$$

for some strictly increasing function \bar{A} . Solving the latter condition for F_i and substituting the result into (2) leads to the following profits of network i :

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

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 externalities on customers of rival networks, direct ones via the utilities U_{ki} and \tilde{U}_{ik} , and pecuniary ones via the payments $\hat{p}D_{ki}$ and $\hat{r}D_{ik}$. Finally, there is a term that does not depend on network i 's call prices. The expressions 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.

⁹The existence of these equilibria is a natural consequence of the application of the Nash equilibrium concept. We can imagine, though, that coordination or regulatory pressure could nudge firms away from this equilibrium.

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

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

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

Since infinite calling or receiving 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 $\pi_i^{\hat{r}}$ must be non-negative. The first derivatives with respect to p_i and r_i are

$$\frac{\partial \pi_i^{\hat{p}}}{\partial \hat{p}_i} = \alpha_i [1 - F(\hat{r} - \beta \hat{p}_i)] \times \{ (1 - \alpha_i) (\hat{p}_i - c - m) - \alpha_i (\beta \hat{p}_i + E[\varepsilon | \varepsilon \geq \hat{r} - \beta \hat{p}_i] - \hat{r}) \} q'(\hat{p}_i), \quad (3)$$

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

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

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

or

$$\begin{cases} ((1 - \frac{\beta}{n-1}) \hat{p}_i + \frac{1}{n-1} \hat{r} - c - m) q'(\hat{p}_i) & \text{if } \hat{r} \leq \beta \hat{p}_i \\ (\hat{p}_i - c - m) q'(\hat{p}_i) & \text{if } \hat{r} \geq \beta \hat{p}_i \end{cases}. \quad (5)$$

On the first branch, this derivative is positive before the critical value if $\beta < n - 1$, and negative thereafter, 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 the corresponding branch, with $\pi_i^{\hat{p}}(\hat{p}_i) \geq 0$. 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

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

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

Define the access charge level

$$a^* = c_0 - \frac{\beta c}{1 + \beta}. \quad (7)$$

We will see below that a^* is the efficient access charge independently of the number of networks, as in DeGraba (2003) for a caller's share of benefits $1/(1+\beta)$, or Cambini and Valletti (2008) with two networks. 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 ε vanishes, for $\frac{1}{n-1} < \beta < n-1$ there is no strategic connectivity breakdown in symmetric equilibrium.¹⁰ More precisely,*

1. for $a > a^*$, callers end the call 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 end the call simultaneously, with $\hat{p} = p^*$ and $\hat{r} = r^*$;
3. for $a < a^*$, receivers end the call 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

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

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

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

¹⁰Similar to JLT, these equilibria exist if either m or σ are sufficiently small.

where networks set both call prices and receiving prices to infinity. These are mutually best responses, though in weakly dominated strategies, and this type of equilibrium always exists due to the Nash equilibrium assumption. Second, and more interestingly, connectivity can break down for strategic reasons. This happens whenever setting a finite call or receiver price benefits the rival too much. In this case it is optimal to choke off calls through an infinite charge. What we have shown in Proposition 1 is that if 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 access charge equal to a^* , without having to fear strategic 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 access *and* receiver charges are regulated, with more networks it is enough to set the access charge at the right level and let the market choose equilibrium retail prices.

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

Corollary 1 *Let $\frac{1}{n-1} < \beta < n - 1$. For all $n > 2$, \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 end the call first and \hat{r}^r when receivers do so, 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.¹¹ 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

¹¹The proof is straightforward and therefore omitted.

will be made off-net and therefore there are fewer incentives to distort off-net call prices upwards.

Finally, we consider which access charge networks would jointly agree on. To our knowledge, only Cambini and Valletti (2008) have considered this issue before under RPP with discriminatory pricing, since all other authors found that only equilibria with connectivity breakdowns existed. They found that if there is a positive probability that call receivers make return calls then equilibria without breakdown exist, and that if callers end calls first then a network duopoly would agree on the efficient access charge. We show that this finding carries over the case of multiple firms, even if the probability of return calls is zero and if either callers or receivers end calls (The proof is relegated to the Appendix):

Proposition 2 *Let $\frac{1}{n-1} < \beta < n - 1$. For all $n > 2$, networks jointly agree on an access charge equal to the efficient one, i.e. $a = a^*$, in which case both call and receiver prices are set at the efficient levels, too.*

This result implies that if mobile networks were to adopt RPP, regulatory determination of termination charges would no longer be necessary, as the outcome would be efficient. Contrary to what some authors have claimed (e.g. Littlechild 2006, or Dewenter and Kruse 2011), networks in general would not agree on bill & keep, though, as the efficient access charge a^* is different from zero.

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 (3) and (4) 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 prices 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 price becomes $\alpha_i < \frac{1}{1+\beta}$, while the condition for a finite receiver price 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 price. 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 risk of repeating ourselves, 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 prices are finite in equilibrium and fine-tuning of the access charge becomes possible in the first place.

Corollary 2 *Let $\frac{1}{n-1} < \beta < n - 1$. If $c > 0$ then bill & keep is efficient iff $\beta = c_0/(c - c_0)$. If $c = c_0 = 0$ then bill & keep is efficient for all $\beta \geq 0$, and equilibrium retail prices are $\hat{p} = \hat{r} = 0$.*

Proof. Follows from the definition of (7) 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 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 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 make and receive calls for free.

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 behavior by clients. In this case the restriction $\hat{r} \geq 0$ is binding whenever the access charge is high enough.

Corollary 3 *Networks will choose positive reception charges if and only if $a < c_0$. If networks cannot set negative reception charges then if $a > c_0$ the symmetric market equilibrium involves off-net receiving price $\tilde{r} = 0$ and the call price*

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

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 $\tilde{r} = 0$. ■

Assuming CPP from the outset, JLT and Hoernig (2014) derive the same pricing formula for $n = 2$ and arbitrary $n \geq 2$, respectively.

5 Conclusions

In this paper we have shown that the stark prediction in Jeon *et al.* (2004) of a strategic connectivity breakdown under RPP (receiving party pays, i.e. subscribers also pay for receiving calls) 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 pressure is still needed under RPP in order to avoid connectivity breakdowns.

We have also found that an access charge below cost is socially optimal in the presence of RPP, and that bill & keep is exactly socially optimal if marginal costs are zero. This lends further support to regulatory policies that induce access charges at or close to zero.

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Appendix

Proof of Proposition 2:

Proof. From (2), the first-order condition for profit-maximizing fixed fees is

$$0 = \frac{\partial \pi_i}{\partial F_i} = \frac{\partial \alpha_i}{\partial F_i} \pi_i + \alpha_i \left[1 + \frac{\partial \alpha_i}{\partial F_i} (p_i + r_i - c) D_{ii} + \sum_{j \neq i} \frac{\partial \alpha_j}{\partial F_i} ((\hat{p}_i - c - m) D_{ij} + (\hat{r}_i + m) D_{ji}) \right],$$

from which we obtain equilibrium profits

$$\pi_i = -\alpha_i^2 \left[\frac{1}{\frac{\partial \alpha_i}{\partial F_i}} + (p_i + r_i - c) D_{ii} + \sum_{j \neq i} \frac{\frac{\partial \alpha_j}{\partial F_i}}{\frac{\partial \alpha_i}{\partial F_i}} ((\hat{p}_i - c - m) D_{ij} + (\hat{r}_i + m) D_{ji}) \right].$$

In order to determine the derivatives of market shares we write consumers' benefits of subscribing to network i as

$$w_i = \sum_{j=1}^n h_{ij} \alpha_j - F_i,$$

where $h_{ii} = U_{ii} + \tilde{U}_{ii} - (p_i + r_i) D_{ii}$ and, for $j \neq i$, $h_{ij} = U_{ij} - \hat{p}_i D_{ij} + \tilde{U}_{ji} - \hat{r}_i D_{ji}$. Letting h be the $n \times n$ -matrix of h_{ij} and w, F the $n \times 1$ -vectors of w_i and F_i , we can write $w = h\alpha - F$. Write market shares as $\alpha_i = D_i(w)$ and $\alpha = D(w) = D(h\alpha - F)$ for a function $D : \mathbb{R}^n \rightarrow \mathbb{R}^n$, then we obtain the market share derivatives

$$\frac{d\alpha}{dF} = D_w \left(h \frac{d\alpha}{dF} - I \right) \iff \frac{d\alpha}{dF} = -(I - D_w h)^{-1} D_w,$$

where D_w is the Jacobian of D , and I is the identity matrix. Since market shares sum to 1 we have $\frac{\partial D_i}{\partial w_i} + \sum_{j \neq i} \frac{\partial D_i}{\partial w_j} = 0$ for all i , which in a symmetric

equilibrium implies that $\frac{\partial D_i}{\partial w_i} = -(n-1) \frac{\partial D_i}{\partial w_j}$ for all i and $j \neq i$. As for the latter, we have

$$\sigma \equiv -\frac{\partial D_i}{\partial w_j} = \frac{\partial A(x, 0, \dots, 0)}{\partial x} \Big|_{x=0} > 0,$$

i.e. σ is the partial derivative of A at equal surplus on all networks (and as such is a constant). Furthermore, in symmetric equilibrium all h_{ii} are identical, and so are all h_{ij} , for $j \neq i$. After some tedious computations we find

$$\frac{d\alpha_i}{dF_i} = -\frac{(n-1)\sigma}{1 - \sigma n(h_{ii} - h_{ij})}, \quad \frac{d\alpha_i}{dF_j} = \frac{\sigma}{1 - \sigma n(h_{ii} - h_{ij})}.$$

Substitute these into profits, apply symmetry via $D_{ji} = D_{ij}$, $\hat{p}_i = \hat{p}$, $\hat{r}_i = \hat{r}$ and $\alpha_i = 1/n$ to obtain equilibrium profits

$$\pi_i = \frac{1}{n^2} \left[\frac{1}{(n-1)\sigma} - \frac{n((1+\beta)U_{ii} - (p_i + r_i)D_{ii})}{n-1} - (p_i + r_i - c) D_{ii} \right. \\ \left. + \frac{n(1+\beta)U_{ij}}{n-1} - \left(\frac{\hat{p} + \hat{r}}{n-1} + c \right) D_{ij} \right].$$

In order to see the effect of the access charge a , or equivalently the access margin m , on profits we need to consider both the case where callers end calls first and the case where receivers end calls first.

Case 1: $\beta\hat{p} \geq \hat{r}$, i.e. callers end calls first ($a \geq a^*$ or $m \geq m^* = -\frac{\beta c}{1+\beta}$): In this case we have $D_{ij} = q(\hat{p})$, $U_{ij} = u(q(\hat{p}))$, $\hat{p} = \frac{(n-1)c + mn}{n-1-\beta}$ and $\hat{r} = -m$. The derivative of profits with respect to the access margin m becomes

$$\frac{d\pi_i}{dm} = \frac{1}{n^2} \left(n(1+\beta)\hat{p} + \frac{1+\beta}{n\eta}\hat{p} - (\hat{p} - m) - (n-1)c \right) \frac{q'(\hat{p})}{n-1} \frac{n}{n-1-\beta},$$

with the demand elasticity $\eta = -\hat{p}q'(\hat{p})/q(\hat{p})$, which at the lower bound becomes

$$\frac{d\pi_i}{dm} \Big|_{m=m^*} = \frac{1}{n^2} \frac{c}{\eta} \frac{q'(\hat{p})}{(n-1)(n-1-\beta)}.$$

If no breakdown occurs, i.e. $\beta < n-1$, the latter is negative. There is a unique solution to the first-order condition $d\pi_i/dm = 0$, at

$$m = -(n-1)c \frac{1+\beta + (n+1)n\eta\beta}{n(n^2\eta - \eta + 1)(1+\beta)}.$$

The latter lies below m^* if and only if $\beta < n-1$. Thus on this branch of profits there is a unique global maximum at $m = m^*$ if $\beta < n-1$.

Case 2: $\beta\hat{p} \leq \hat{r}$, i.e. receivers end calls first ($a \leq a^*$ or $m \leq m^* = -\frac{\beta c}{1+\beta}$): In this case we have $D_{ij} = q\left(\frac{\hat{r}}{\beta}\right)$, $U_{ij} = u\left(q\left(\frac{\hat{r}}{\beta}\right)\right)$, $\hat{p} = c+m$ and $\hat{r} = \frac{\beta(c+nm)}{(n-1)\beta-1}$.

The derivative of profits with respect to the access margin m now becomes

$$\frac{d\pi_i}{dm} = -\frac{1}{n^2} \left(\frac{n(1+\beta)\frac{\hat{r}}{\beta} + \frac{1+\beta}{n\eta}\frac{\hat{r}}{\beta}}{-(c+m+\hat{r}) - (n-1)c} \right) \frac{q'\left(\frac{\hat{r}}{\beta}\right)}{n-1} \frac{n}{(n-1)\beta-1},$$

with $\eta = -(\hat{r}/\beta)q'(\hat{r}/\beta)/q(\hat{r}/\beta)$, which at the upper border $m = m^*$ simplifies to

$$\left. \frac{d\pi_i}{dm} \right|_{m=m^*} = -\frac{1}{n^2} \frac{c}{\eta(n-1)} \frac{q'\left(\frac{\hat{r}}{\beta}\right)}{((n-1)\beta-1)}.$$

If no breakdown occurs, i.e. $\beta > 1/(n-1)$, the latter is positive. The unique solution to $d\pi_i/dm = 0$ is

$$m = -c \frac{1+\beta + (n^2-1)n\eta\beta}{n((n^2-1)\eta+1)(1+\beta)},$$

which lies above m^* if and only if $\beta > 1/(n-1)$. Thus on the second branch of profits there is a unique global maximum at $m = m^*$ if $\beta > 1/(n-1)$.

Finally, we can conclude that the profits are indeed maximized at $m = m^*$. Using any of the expressions for call prices it then follows immediately that $\hat{p} = p^*$ and $\hat{r} = r^*$, i.e. call and receiver prices are efficient. ■