Mobile Penetration under CPP and RPP

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Abstract

We analyze how termination charges and payment regimes affect usage and penetration rates. We assume that firms compete in non-linear tariffs and differentiate between on- and off-net calls. Consumers form passive expectations about network sizes. We show that an increase in the termination rate reduces call volume and penetration under the Calling Party Pays regime, but has the opposed effect under the Receiving Party Pays regime. We compare the market outcomes from the CPP regime when termination rates are regulated at cost with those generated under the RPP regime with Bill and Keep. For low values of the call externality CPP is far better while for high values the RPP regime does mildly better. We also find that increased product differentiation softens competition but produces more efficient result under either regime.

Key words: Bill and Keep; Call externality; Access Pricing; Interconnection; Receiver pays; Consumer Expectations

JEL classification: D43; K23; L51; L96

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1 Introduction

In this paper we examine how termination charges affect usage and penetration rates when call externalities are taken into account and mobile operators adopt either the "caller party pays" (CPP) or the "receiver party pays" (RPP) regime.

Under the CPP regime users pay for placing calls but not for receiving them. Mobile operators can then recover the cost of termination only through termination charges and tend to favor too high termination charges. In contrast, under the RPP regime users pay both for placing and receiving calls. Mobile operators do not need termination charges to recover the cost of termination and indeed tend to favor Bill and Keep agreements. CPP has been the typical payment regime adopted in most countries (including European countries, Australia and New Zealand), while the RPP regime has been adopted in countries such as the US and Canada, and also in Hong Kong, Singapore and China.[1]

These two payment regimes are generally believed and perceived to produce different results in terms of usage and adoption patterns. Under RPP there is competition for termination while under CPP there are competitive bottlenecks. This should favor lower call prices and higher usage under RPP. On the other hand, it has also been argued that undesired calls boosted by lower call prices could lead to a lower willingness to accept calls (so perhaps less usage) and fewer (pre-paid) contracts (and therefore lower penetration rates). In contrast, above-cost termination charges under the CPP regime may allow mobile operators to subsidize participation through lower rental charges or higher handset subsidies due to the "waterbed" effect. (See Dewenter and Kruse (2011); Genakos and Valletti (2011)).

The impact of the CPP and RPP regimes on consumer surplus and penetration has been the subject of debate but formal theoretical analysis is scarce. While several authors have examined the issue of pricing under RPP under the assumption of full participation, there has been no solid analysis of the issue of penetration under RPP. [2] Most articles on mobile diffusion are empirical case studies which involve either a CPP or a RPP regime. As far as we know, only three articles compared CPP and RPP countries. Littlechild (2006) makes an international cross-section comparison between countries, and finds lower usage prices and higher call volumes in RPP countries, but also lower penetration rates, which is consistent with higher handset subsidies or lower rental fees in CPP countries.[3] Dewenter and Kruse

[1] The question why countries have initially adopted one or the other payment regime is most likely explained by path dependence. Littlechild (2006) and Dewenter and Kruse (2011) argue that arrangements inherited from the fixed telephone market are possibly behind the chosen payment regime.

[2] Cunningham et al. (2010) do provide a theoretical framework of penetration but their model is somewhat unnatural as it assumes that consumers choose to which network to subscribe before firms set prices. Moreover, termination rates are set only after all other prices and subscription and usage decisions are taken.

[3] For example, Littlechild (2006, Table 6), using data in last quarter 2004, shows that the average revenue

(2011) estimate the impact of the payment regimes on mobile penetration rates using annual data of 84 countries from 1980 to 2003.[4] They find that growth rates increase by 2.17 basic points when countries switch from the receiver party pays to the caller party pays regime, although once they control for endogeneity in regulatory decisions the positive impact of CPP on mobile penetration disappear. Dewenter and Kruse do not use information about tariffs in their estimates. Finally, Veronese and Pesendorfer (2009) find higher penetration and lower usage in CPP countries. They did not find evidence that termination rates or payment regime affect average prices. However, they also warn that their results have to be taken with caution because of the limitations of the available data.

Our goal in this paper is to contribute to the debate over the impact of payment regimes and termination rates on usage and penetration with a formal theoretical analysis. For this purpose, we extend the traditional model of network competition with price discrimination between on- and off-net traffic (Laffont et al. (1998))[5] to allow for call externalities, reception charges and elastic subscription demand. We allow mobile operators to charge monthly fixed fees. In addition, we assume that consumers form passive expectations about network sizes (for a discussion on this assumption see Hurkens and López (2014a)).

We first consider competition under the CPP regime with call externalities and elastic participation, for any termination rate. As usual, on-net calls are efficiently priced below its marginal cost so as to internalize the call externality. Off-net calls are priced strictly above perceived marginal cost (as defined by the sum of origination cost and termination mark-up), which contrasts with the result obtained without call externality (Hurkens and Jeon (2012); Hurkens and López (2014a)). Firms raise the price above perceived marginal cost because doing so hurts subscribers to rival networks, and makes the own network relatively more attractive. However, they do not raise the price as much as under full participation because it also reduces penetration. Higher termination rates lead to higher off-net prices, lower call volume and lower fixed fees. However, despite the lower fixed fees, penetration decreases with higher termination rates. The waterbed effect exists but is partial and the reduction in fixed

per minute in countries where the receiver also pays is 9 US cents, whereas it reaches 23 US cents in countries where only the calling party pays. Accordingly, the mean of minutes of use (per month) is 415 in RPP countries and 178 in CPP countries. More importantly, the average mobile penetration rate is 76% in countries with RPP as compared to 89% in countries with CPP. However, not all countries present a similar pattern. For example, Hong Kong, where the receiver pays regime applies, has the second highest penetration rate. In addition, reported data face limitations: minutes of use in RPP countries and penetration figures in CPP countries may be overstated.

[4] In particular, Dewenter and Kruse note that 39 countries started with the caller party pays regime, 31 switched from the receiver party pays to the caller party pays regime, and 14 countries applied the receiver party pays regime up to 2003.

[5] A review of the literature on termination charges and network competition can be found in Armstrong (2002), Vogelsang (2003) and Peitz et al. (2004).

fee is not enough to compensate consumers for the less efficient call volume. This result is due to our assumption of passive expectations. (Compare with the results obtained without call externality obtained in Hurkens and Jeon (2012) and Hurkens and López (2014a)).

Next we consider competition under the RPP regime where consumers pay the same price for placing and receiving a call. In this case the call volume is determined by the receiver. Callers have higher demand for calls than receivers do, and consequently some calls are not answered or the receiver hangs up before the caller is willing to do so. This is consistent with the argument of subscribers turning of their phones under the RPP regime. When the call externality is low, this problem is severe because despite low off-net prices there may be connectivity breakdown. For higher values there is no connectivity breakdown. We show that prices decrease in termination rate so that Bill and Keep arrangements in fact lead to the highest price and the lowest call volume. For sufficiently (but not extremely) high call externality, firms maximize profits under Bill and Keep. We also show that penetration increases with termination rate so that Bill and Keep arrangements lead to the lowest consumer welfare.

Related literature. The literature that analyses the role of termination charges bifurcates into two bodies: one examines competition under the CPP regime and the other looks at the RPP regime.[6] We now briefly describe how our analysis relates and contributes to these two bodies.

Caller-Party-Pays Regime. Berger (2005), as we do, considers call externalities with termination-based price discrimination, though he assumes full participation. Dessein (2003) analyses elastic participation but without considering termination-based price discrimination or call externalities. Armstrong and Wright (2009) and Hurkens and Jeon (2012) examine mobile network competition with termination-based price discrimination and elastic participation, however call externalities are again left out in their analysis. In particular, Hurkens and Jeon (2012) show that a reduction in termination charge below cost provokes two opposing effects on penetration: it softens competition and therefore reduces penetration, and at the same time it helps mobile operators to internalize network externalities, which tends to increase penetration. The former effect was first identified in a setting of full participation by Gans and King (2001) and does depend on the assumption that consumers form responsive expectations about network sizes; with passive expectations mobile operators favor above-cost termination rates (see Hurkens and López (2014a)). The latter effect arises because mobile operators are aware that an increase in the rental charge will reduce the total

[6] An exception is a parallel work, Hurkens and López (2014b), where we integrate the two payment regimes in one economic model where mobile operators are free to charge only calls or, if they find it optimal, calls and call receptions.

number of subscribers and therefore the surplus of their own subscribers.[7] In our paper we assume passive expectations and a reduction in termination rate strengthens competition. However, a reduction in termination charge also helps to internalize the network externality as it increases penetration. Whether firms prefer above or below cost termination rates depends on the number of firms, the strength of the call externality and the strength of the network externality, which in turn depends on how differentiated the networks are. For most parameter value firms prefer above cost termination charges.

Jullien et al. (2013) consider competition between two mobile operators for two types of consumers: heavy or infra-marginal users and light or marginal users. Heavy users always subscribe to an operator, and derive utility from placing and receiving calls, although the latter is assumed to be constant. Light users, on the other hand, have elastic subscription demand, but they only receive calls, from which they obtain some (non-constant) utility. In our model, all consumers are assumed identical and all have elastic participation.

Receiver-Party-Pays Regime. Jeon et al. (2004) − hereafter JLT − is the article most closely related to ours.[8] JLT examine competition between two mobile operators under the RPP regime and inelastic subscription demand.[9] They show that when termination-based price discrimination is not allowed, operators set the prices for calling and reception at its off-net cost, i.e., as if they only had one consumer and therefore all incoming and outgoing traffic were off-net (which is the so-called off-net-cost pricing principle)[10]; however, they also show that when operators can set different prices for on-net and off-net calls, connectivity is prone to break down. López (2011b) extends JLT by allowing a non-vanishing noise in both the callers' and receivers' utility, and obtains the same result. Cambini and Valletti (2008) show that the incentives for breaking connectivity are reduced when there are interdependencies between incoming and outgoing calls in the form of return calls.[11] In effect, call propagation dilutes the incentives for breaking connectivity because by so doing mobile operators not only prevent their customers from receiving calls but also from deriving utility from any extra return call, which further harms them. In a similar vein, an

[7]Hurkens and Jeon (2012) also characterize the condition that determines which of the two effects is stronger.

[8]Some previous works that explore the RPP regime include Doyle and Smith (1998), Kim and Lim (2001), and Degraba (2003). For an overview of this literature see Jeon et al. (2004).

[9]JLT do discuss elastic participation in the particular case in which there is no termination-based price discrimination and the termination charge is set at the socially efficient level so that prices are set at their off-net cost (Section 4, p. 101).

[10]The off-net-cost pricing principle was first derived in a model of competition among Internet backbone operators with reciprocal and symmetric access pricing by Laffont et al. (2003). More recently, López (2011a) re-examines the off-net-cost pricing principle when operators are allowed to charge asymmetric (though reciprocal) access pricing.

[11]Cambini and Valletti (2008) also show that in the presence of such interdependencies the breakdown does not arise if operators can choose the level of the reciprocal termination charge.

increase in the number of mobile operators reduces the incentives for breaking connectivity, as shown in Hurkens and López (2011, 2014b) and Hoernig (2014).[12] In this paper, we show that an elastic subscription demand also weakens the incentives for creating a connectivity breakdown because this reduces total penetration (as participating becomes less appealing), and therefore consumers' surplus. Thus, the possibility of a connectivity breakdown seems to be an issue of little importance, as observed in practice indeed.

The rest of the paper is organised as follows. Section 2 introduces the model. Sections 3 and 4 derive the equilibria for the CPP and RPP regime, respectively. Comparative statics results are derived and the results are illustrated with numerical examples. Section 5 compares the outcomes obtained under the CPP regime with cost-based termination rates (approximately the future European situation) and those obtained under the RPP regime with Bill and Keep termination arrangements. Section 6 concludes. Proofs are relegated to the Appendix.

2 The model

Our model is built on the model of Laffont et al. (1998) where firms compete in non-linear prices and can discriminate between on- and off-net calls. The model is extended to include call externality (as in Berger (2004)), prices for receiving calls (as in Jeon et al. (2004)), to more than two networks and elastic subscription by using a Logit formulation for subscription choices (as in Cambini and Valletti (2008), Hurkens and Jeon (2012), and Hurkens and López (2014a)). The $n \geq 2$ symmetric network operators have complete coverage and compete for a continuum of consumers of unit mass. We make the standard assumption of a balanced calling pattern, which means that the fraction of calls from a given subscriber of a given network and completed on another given (including the same) network is equal to the fraction of consumers subscribing to the terminating network.

The fixed cost to serve each subscriber is f, whereas c_O and c_T denote the marginal cost of providing a telephone call borne by the originating and terminating networks. The marginal cost of an on-net call is $c \equiv c_O + c_T$. We let a denote the reciprocal access charge paid by the originating network to the terminating network.[13] The termination mark-up is

[12] Intuitively, with two mobile operators, as in JLT and López (2011b), a connectivity breakdown provoked through a too high reception charge reduces the utility from own subscribers to a lesser extent than that of rival's subscribers since receiving calls is assumed to generate lower utility than placing them. Thus, by increasing the reception charge, operators make their networks more appealing. However, for a larger number of operators, if one of them breaks connectivity, then it will harm the subscribers of other networks to a lower extent than its own subscribers since it only prevents calls made to subscribers of its network, but not between other networks.

[13] Reciprocity means that a network pays as much for termination of a call on the rival network as it

equal to:

$$m \equiv a - c_T.$$

Each firm $i \in N = \{1, 2, \ldots, n\}$ charges, in the most general setting, a tariff $T_i = (F_i, p_i, r_i, \hat{p}_i, \hat{r}_i)$, consisting of a fixed fee (F_i), per-unit call and reception charges for on-net traffic (p_i and r_i) and per-unit call and reception charges for off-net traffic ($\hat{p}_i$ and $\hat{r}_i$).[14] We will focus in this paper on two special but relevant tariff regimes: Under the CPP regime (T_{cpp}) reception charges are equal to zero ($r = \hat{r} = 0$) and under the RPP regime (T_{rpp}) call and reception charges are equal ($p = r$ and $\hat{p} = \hat{r}$).[15]

Subscribers obtain positive utility from placing and receiving calls. The caller's utility from making a call of length q minutes is $u(q)$, whereas the receiver's is $\beta u(q)$ with $0 < \beta < 1$ from receiving a call of that length. The caller's demand function is given by $u'(q(p)) = p$, whereas the receiver's demand function is given by $u'(q(r)) = \beta r$. When all firms use the same tariff T, under the CPP regime the length of an on-net call is thus $q(p)$, whereas the length of an off-net call is $q(\hat{p})$. Under the RPP regime, however, the length on an on-net call is $q(r/\beta)$, whereas the length of an off-net call is $q(\hat{r}/\beta)$.

We use the Logit formulation because it can readily deal both with multiple firms and elastic subscription.[16] Let w_i be the net value of subscribing to network i (as defined below). Not subscribing at all yields constant utility $w_0 = 0$. Consumers have idiosyncratic tastes for each operator. So we add a random noise term ε_i and define $U_i = w_i + \mu\varepsilon_i$. The parameter $\mu > 0$ reflects the degree of product differentiation in a Logit model. A high value of μ implies that most of the value is determined by a random draw so that competition between the firms is rather weak. The noise terms ε_k are random variables of zero mean and variance $\pi^2/6$, identically and independently double exponentially distributed. These terms reflect consumers' preference for one good over another (they are known to the consumer but are unobserved by the firms). A consumer will subscribe to network $i \in N$ if and only if $U_i = \max\{U_j\}$. The probability of subscribing to network i is denoted by α_i. The probability

receives for completing a call originated on the rival network.

[14]When $n \geq 3$, it would be even more general to allow each firm to set different prices for off-net traffic depending on which network is being called or is calling. However, since attention will be restricted to symmetric equilibria we lose nothing from imposing that there cannot be discrimination between the prices set for traffic terminating or originating at different rival networks. This reduces the burden of notation.

[15]Strictly speaking, any tariff in which consumers pay a positive price for receiving calls could be labeled as RPP. Nevertheless, in this paper we reserve this term for the tariffs in which calling and receiving calls are equally priced.

[16]See Anderson and De Palma (1992) and Anderson et al. (1992) for more details about the Logit model.

to remain unsubscribed is denoted by α_0. The probabilities are given by

$$\alpha_i = \frac{\exp[w_i/\mu]}{\sum_{k=0}^{n} \exp[w_k/\mu]}. \tag{1}$$

It is easily verified that for all $i, j \in N$, $t \in \{F, p, r, \hat{p}, \hat{r}\}$

$$\frac{\partial \alpha_i}{\partial t_j} = \frac{\alpha_i(1-\alpha_i)}{\mu} \frac{\partial w_i}{\partial t_j} - \frac{\alpha_i}{\mu} \sum_{k \in N \setminus \{i\}} \alpha_k \frac{\partial w_k}{\partial t_j}. \tag{2}$$

Consumer surplus in the Logit model has been derived by Small and Rosen (1981) as (up to a constant)

$$CS = \mu \ln \left(\sum_{k=0}^{n} \exp(w_k/\mu) \right) = w_0 - \mu \ln(\alpha_0), \tag{3}$$

where the right-hand side follows from (1). Clearly, consumer surplus is increasing in market penetration $1 - \alpha_0$.

We assume that the terms of interconnection are negotiated or established by a regulator first. Then firms choose simultaneously retail tariffs. Finally, consumers make rational subscription and consumption decisions. The presence of network effects implies that the optimal subscription decision of a consumer depends on her expectations with respect to market shares of the different networks, as well as the overall penetration rate. We assume that consumers form *passive* expectations as in Hurkens and López (2014a). Such expectations do not respond to the tariffs set by firms but turn out to be accurate in equilibrium.[17]

3 CPP regime

We will now consider the necessary conditions for a symmetric CPP type equilibrium, that is where reception prices are all exogenously fixed equal to zero. Suppose all firms $j \neq i$ use tariff $T^*_{cpp} = (F^*, p^*, \hat{p}^*)$ while firm i uses tariff $T_i = (F_i, p_i, \hat{p}_i)$. Assume that consumers expect all networks to be of size γ^*. The net surplus from subscribing to a network is the sum of the utility derived from placing and receiving on- and off-net calls, minus total payment. Hence, subscribing to network i yields

$$\begin{aligned} w_i = {} & \gamma^*[(1+\beta)u(q(p_i)) - p_i q(p_i)] + (n-1)\gamma^*[u(q(\hat{p}_i)) - \hat{p}_i q(\hat{p}_i)] \\ & + (n-1)\gamma^*[\beta u(q(\hat{p}^*))] - F_i, \end{aligned} \tag{4}$$

[17] For a more elaborate discussion of passive versus responsive beliefs we refer to Hurkens and López (2014a).

while subscribing to any network $j \neq i$ yields $w_j = w^*$ where

$$\begin{aligned} w^* = \gamma^*[(1+\beta)u(q(p^*)) - p^*q(p^*)] + (n-2)\gamma^*[(1+\beta)u(q(\hat{p}^*)) - \hat{p}^*q(\hat{p}^*)] \\ + \gamma^*[u(q(\hat{p}^*)) - \hat{p}^*q(\hat{p}^*) + \beta u(q(\hat{p}_i))] - F^*. \end{aligned} \tag{5}$$

Let $R(p) = (p-c)q(p)$. Let $p^M = \arg\max R(p)$ denote monopoly price and $q^M = q(p^M)$ monopoly volume. Profit of firm i equals

$$\pi_i = \alpha_i \left[\alpha_i R(p_i) + \sum_{j \in N \setminus \{i\}} \alpha_j (\hat{p}_i - c - m) q(\hat{p}_i) + \sum_{j \in N \setminus \{i\}} \alpha_j m q(\hat{p}^*) + F_i - f \right]. \tag{6}$$

Note that in equilibrium the on-net call price will be equal to

$$p^* = \frac{c}{1+\beta}. \tag{7}$$

Namely, firm i can vary p_i and F_i such that market shares of all networks remain constant, because the on-net price p_i only affects w_i and not w_j. It will thus be optimal for the firm to offer the efficient call volume (and extract additional surplus by increasing the fixed fee). Efficient on-net volume q^* is obtained by maximizing $(1+\beta)u(q) - cq$, or, equivalently, setting on-net price equal to p^*.

Unfortunately, the same trick cannot be used to determine the off-net price because varying $\hat{p}_i$ affects w_j through the call externality. To determine the off-net price one thus has to use the first-order condition $\partial \pi_i / \partial \hat{p}_i = 0$. The derivations are somewhat complex and are provided in the Appendix. In a symmetric equilibrium the first-order condition reads

$$0 = \frac{\partial \pi_i}{\partial \hat{p}_i} = (n-1)\alpha^{*2} q'(\hat{p}^*) \Phi(\alpha^*, \hat{p}^*), \tag{8}$$

where

$$\Phi(\alpha^*, \hat{p}^*) = \hat{p}^* - c - m + \frac{\alpha^* \beta \hat{p}^*}{1-\alpha^*} \left[-1 + (1 - n\alpha^*) \frac{R(\hat{p}^*)}{\mu} \right].$$

To determine the equilibrium fixed fee one has to use again the first-order condition. We prove in the Appendix that in a symmetric equilibrium we must have

$$F^* = f + \frac{\mu}{1-\alpha^*} - 2\alpha^* R(p^*) - R(\hat{p}^*)(n-1)\frac{\alpha^*(1-2\alpha^*)}{1-\alpha^*}. \tag{9}$$

For further reference let us denote the right-hand side of this equation by $F^{FOC}(\alpha^*, \hat{p}^*)$.

To determine the equilibrium number of subscribers per firm observe that from (1) we know that

$$\alpha^* = \frac{\exp[w^*/\mu]}{n\exp[w^*/\mu] + \exp[w_0/\mu]}$$

or, equivalently,

$$w^* = w_0 + \mu \log\left(\frac{\alpha^*}{1 - n\alpha^*}\right). \tag{10}$$

Denoting indirect utility by $v(p) = (1+\beta)u(q(p)) - pq(p)$, we can rewrite (10) as

$$F^* = \alpha^* v(p^*) + (n-1)\alpha^* v(\hat{p}^*) - w_0 - \mu \log\left(\frac{\alpha^*}{1 - n\alpha^*}\right). \tag{11}$$

We refer to this equation as the rational expectations condition and we denote the right-hand side by $F^{RE}(\alpha^*, \hat{p}^*)$.

The equilibrium is thus jointly determined by equations (7), (8), (9), and (11). The first equation gives us directly on-net price p^*, which can be substituted in the other equations. Furthermore, eliminating F^* from equations (9) and (11) yields an equation in $\hat{p}^*$ and α^*:

$$0 = \Psi(\alpha^*, \hat{p}^*),$$

where $\Psi = F^{FOC} - F^{RE}$. This new equation together with (8) yields a system of two equations with two unknowns. Any solution of this system of equations thus determines symmetric equilibrium candidates for market penetration and off-net call price. Under appropriate assumptions about the parameters the system of equations admits a unique solution. We will restrict attention to the cases where indeed a unique solution exists.[18]

Proposition 1 *In a symmetric interior CPP equilibrium, $p^* = c/(1+\beta)$ while number of subscribers α^* and off-net call price $\hat{p}^*$ are given by the following system of equations*

$$0 = \Psi(\alpha^*, \hat{p}^*) \tag{12}$$

$$0 = \Phi(\alpha^*, \hat{p}^*) \tag{13}$$

Equilibrium fixed fee is equal to

$$F^* = f + \frac{\mu}{1-\alpha^*} - 2\alpha^* R(p^*) - R(\hat{p}^*)(n-1)\frac{\alpha^*(1-2\alpha^*)}{1-\alpha^*}.$$

Equilibrium profit is equal to

[18] In particular, existence and uniqueness requires μ not to be too low.

$$\pi^* = \alpha^* \left(\frac{\mu}{1-\alpha^*} - \alpha^* R(p^*) + \frac{(n-1)\alpha^{*2}}{1-\alpha^*} R(\hat{p}^*) \right).$$

Note that $R(p^*) \leq 0$ because the efficient price is below cost. However, through the fixed fee the firms do extract part of the consumer surplus and on-net traffic does contribute positively to total profit.

Observe that for $m = 0$, the $\hat{p}^*$ that solves eq. (13) is strictly larger than c when $\beta > 0$. In particular, it is strictly larger than perceived marginal cost $c+m$. By continuity this must then also be true for $|m|$ not too large. By considering the expression for equilibrium profit it is thus clear that profit from off-net calls $R(\hat{p}^*)$ contributes positively to overall profit.

One sees immediately from (8) that without call externality (that is, $\beta = 0$) off-net calls would be priced at perceived marginal cost $c + m$. A positive call externality implies that these calls are priced above perceived marginal cost. The intuition for this is that an increase of the price hurts subscribers to rival networks because they will receive less calls. This makes the own network relatively more attractive for subscribers. If total subscription were inelastic, firms would increase the off-net call price up to $(n-1)(c+m)/(n-1-\beta)$. (See Jeon et al. (2004) and Hurkens and López (2014a).) For $n = 2$ and β very close to one, this price would thus choke off-net traffic for any termination markup. This asymptotic connectivity breakdown result does not obtain under elastic subscription: firms do not have such strong incentives to raise the off-net price above perceived marginal cost because it will hurt all subscribers and, consequently, penetration will decrease.

Proposition 2 *For $|m|$ not too large and μ sufficiently large the equilibrium off-net price satisfies*

$$c + m < \hat{p}^* < \frac{(n-1)(c+m)}{n-1-\beta}.$$

We illustrate the above results by plotting off-net call volume in Figure 1.[19] The dotted horizontal line on top depicts the efficient (on-net) call volume $q^{\text{eff}} = q(c/(1+\beta))$ while the lower dotted horizontal line depicts the monopoly call volume q^M. The dashed downward sloping lines show the call volume under perceived marginal cost pricing ($\hat{q}^{pmc} = q(c+m)$, top) and under inelastic subscription demand ($\hat{q}^{\text{inel}} = q((n-1)(c+m)/(n-1-\beta))$, bottom). The equilibrium off-net call volume $\hat{q}^*$ (thick blue) is in between these curves.

The observation from Prop. 2 is also helpful in performing some comparative statics on equilibrium off-net call price and penetration with respect to termination rates and product

[19] We use call volume rather than call price so as to facilitate later comparison with the RPP equilibrium. All our numerical examples are based on the following parameters, borrowed from the calibration performed in Hurkens and López (2012): $q(p) = a - bp$ with $a = 654.9$, $b = 2012.7$, $c = 2c_T = 0.049$, $f = 0$.

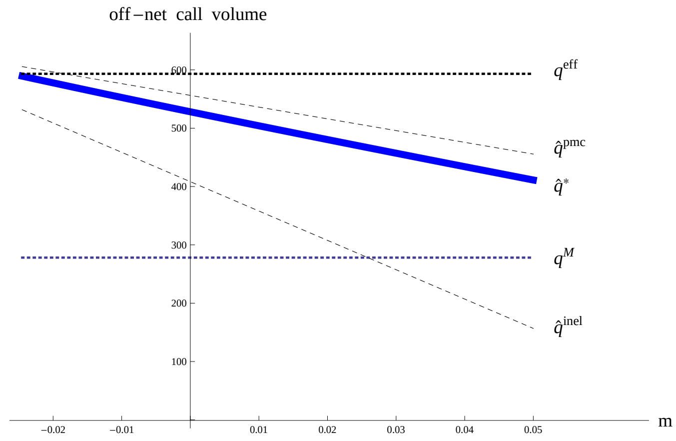

Figure 1: Off-net call volume. ($\beta = 0.6$, $n = 2$, $\mu = 80$).

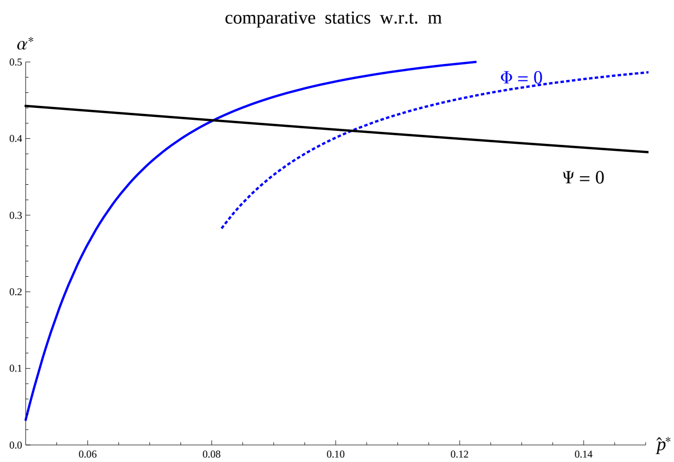

Figure 2: Increase in m leads to higher off-net price and lower penetration.

differentiation. Straightforward comparative statics exercises can be performed which give us the following results.

Proposition 3 (Comparative statics) *For $|m|$ not too large and μ sufficiently large, we have:*

(i) *An increase in m leads to higher $\hat{p}^*$ and lower α^**

(ii) *An increase in μ leads to lower $\hat{p}^*$ and lower α^**

Figures 2 and 3 illustrate Prop. 3. An increase in m shifts the Φ-curve down while it leaves the Ψ-curve unaltered. Consequently, penetration rate is decreasing in m (at least in the region where the comparative statics results apply). It follows immediately that lowering

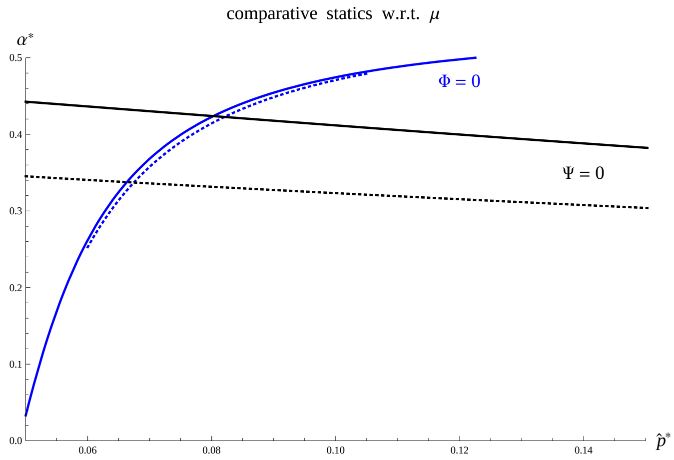

Figure 3: Increase in μ leads to lower off-net price and lower penetration.

the termination rate below the one that maximizes industry profit increases consumer and total welfare. Hence, regulators and firms have conflicting interest. Regulators favor lower termination rates than firms do. The argument occasionally employed by firms against lowering termination rates that such a policy would lead to less penetration is thus not valid in our model.[20]

Although Prop. 3 establishes that $\hat{p}^*$ is increasing in m, this does not mean that firms prefer the termination charge so high that $\hat{p}^* = p^M = \arg\max R(p)$. Although this would maximize profit for each off-net call ($R(\hat{p}^*)$), it would reduce penetration and thus number of subscribers. Under inelastic subscription demand firms would indeed prefer off-net price to be equal to monopoly price. (See Hurkens and López (2014b).) For relatively low levels of the call externality, the profit maximizing m^π is positive while for relatively high levels it is negative. In fact, for the example at hand in Figure 1 (with $\beta = 0.6$ and $n = 2$) the profit maximizing termination charge is Bill and Keep. Moreover, m^π appears to be increasing in the number of firms. The more firms there are, the more important is profit from off-net traffic relative to profit from on-net profit. See Figure 4.

Perhaps more surprising is the result that increased product differentiation leads to more efficient call prices. The reason is that when firms are more differentiated, they will act more like a monopolist who would offer efficient call volume but extract consumer surplus through the fixed fee. However, increased product differentiation leads to lower market penetration so that overall consumer surplus is reduced. See Figure 3.

Performing comparative statics with respect to the number of competitors is awkward

[20] The argument may be valid when the fixed line operators are taken into account because then mobile operators can subsidize the mobile subscribers from the termination profit earned from fixed line operators, the cost of which is ultimately borne by the fixed line subscribers.

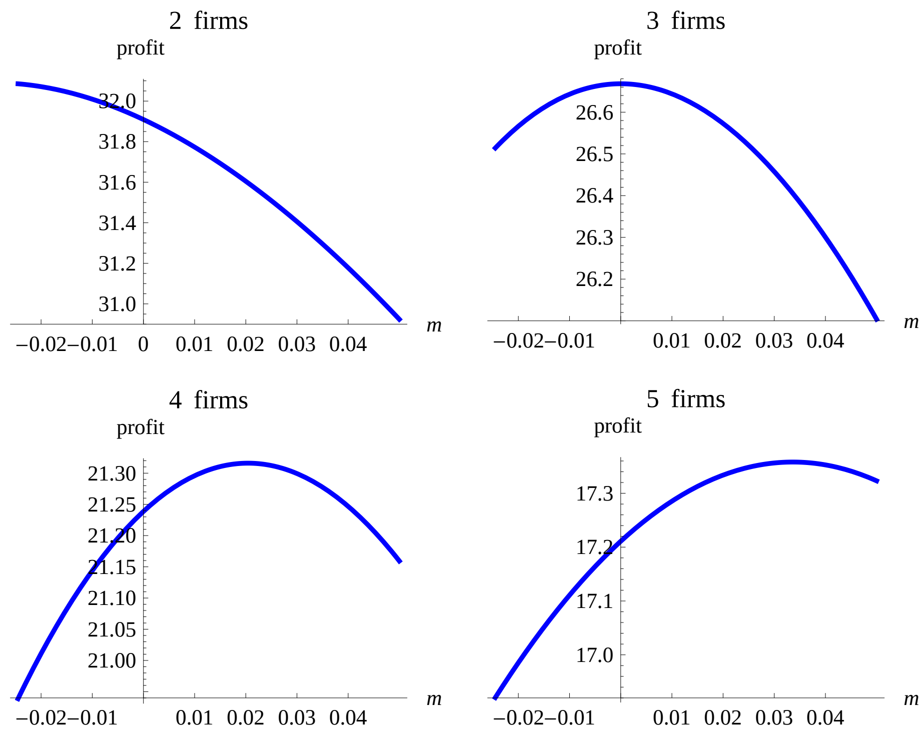

Figure 4: Comparing equilibrium profits. ($\beta = 0.6$, $\mu = 80$).

because it is meaningless to consider the effect of a marginal increase in n. Numerical examples suggest, however, that increasing the number of competitors reduces the off-net call price and increases market penetration. However, the larger the number of competitors, the larger is the termination markup favored by the industry. Hence, competition under the CPP regime is valuable but does not reduce the role of termination rate regulation. It rather strengthens the need for a strong regulatory intervention.

4 RPP regime

We will now consider the equilibrium conditions for the RPP type equilibrium, that is where prices for placing and receiving calls are the same ($p = r$ and $\hat{p} = \hat{r}$). In this case call volume is determined by the reception charge. In particular, on-net call volume equals $q(r/\beta)$ and off-net call volume equals $q(\hat{r}/\beta)$. Suppose that all firms $j \neq i$ use tariff $T^*_{rpp} = (\tilde{F}^*, r^*, \hat{r}^*)$ while firm i uses tariff $T_i = (\tilde{F}_i, r_i, \hat{r}_i)$. Assume again that consumers expect all networks to be of size γ^*. Subscribing to network i yields net surplus

$$\tilde{w}_i = \gamma^*[(1+\beta)u(q(r_i/\beta)) - 2r_i q(r_i/\beta)] + (n-1)\gamma^*[u(q(\hat{r}^*/\beta)) - \hat{r}_i q(\hat{r}^*/\beta)] + (n-1)\gamma^*[\beta u(q(\hat{r}_i)) - \hat{r}_i q(\hat{r}_i/\beta)] - \tilde{F}_i, \quad (14)$$

while subscribing to any network $j \neq i$ yields $\tilde{w}_j = \tilde{w}^*$ where

$$\tilde{w}^* = \gamma^*[(1+\beta)u(q(r^*/\beta)) - 2r^* q(r^*/\beta)] + (n-2)\gamma^*[(1+\beta)u(q(\hat{r}^*/\beta)) - 2\hat{r}^* q(\hat{r}^*/\beta)] + \gamma^*[u(q(\hat{r}_i/\beta)) - \hat{r}^* q(\hat{r}_i/\beta) + \beta u(q(\hat{r}^*/\beta)) - \hat{r}^* q(\hat{r}^*/\beta)] - \tilde{F}^*. \quad (15)$$

Note that these expressions are different from the ones obtained under CPP because call volume is determined by reception charge (and the call externality parameter β thus plays a major role) and because both placing and receiving calls are charged.

Let $\tilde{R}(r) = (2r - c)q(r/\beta)$. Let $\tilde{r}^M = \arg\max \tilde{R}(r)$ denote monopoly price and $\tilde{q}^M = q(\tilde{r}^M/\beta)$ monopoly volume. Profit of firm i equals

$$\tilde{\pi}_i = \alpha_i \left[\alpha_i \tilde{R}(r_i) + \sum_{j \in N \setminus \{i\}} \alpha_j (\hat{r}_i - c - m) q(\hat{r}^*/\beta) + \sum_{j \in N \setminus \{i\}} \alpha_j (\hat{r}_i + m) q(\hat{r}_i/\beta) + \tilde{F}_i - f \right]. \quad (16)$$

Note that in equilibrium the on-net price will be equal to

$$r^* = \frac{\beta c}{1+\beta}. \quad (17)$$

Namely, because on-net prices of network i do not affect $\tilde{w}_j$, network i can keep all market shares constant by adjusting its fixed fee when varying the on-net prices. It will there maximize on-net surplus by setting efficient on-net prices. Hence, on-net call volume will be the same as under CPP. Note, however, that the profit that the firm earns from on-net traffic is different because the margin is now $2r^* - c$ instead of $p^* - c$ and $2r^* - c > p^* - c$ if and only if $\beta > 1/2$.

Determining off-net price $\hat{r}^*$ and F^* relies again on first-order conditions. The analysis is similar. All details are provided in the Appendix. Let us define indirect utility as $\tilde{v}(r) = (1+\beta)u(q(r/\beta)) - 2rq(r/\beta)$. Let us also define

$$\widetilde{\Psi}(\alpha^*, \hat{r}^*) = \left[f + \frac{\mu}{1-\alpha^*} - 2\alpha^* \tilde{R}(r^*) - \tilde{R}(\hat{r}^*)(n-1)\frac{\alpha^*(1-2\alpha^*)}{1-\alpha^*}\right] - \left[\alpha^* \tilde{v}(r^*) + (n-1)\alpha^* \tilde{v}(\hat{r}^*) - w_0 - \mu \log\left(\frac{\alpha^*}{1-n\alpha^*}\right)\right] \quad (18)$$

$$\widetilde{\Phi}(\alpha^*, \hat{r}^*) = \frac{\hat{r}^* + m}{\beta} + \frac{\alpha^*(1-\beta)\hat{r}^*}{(1-\alpha^*)\beta^2}\left[-1 + (1-n\alpha^*)\frac{\tilde{R}(\hat{r}^*)}{\mu}\right] \quad (19)$$

We obtain

Proposition 4 *In a symmetric interior RPP equilibrium, on-net price equals $r^* = \beta c/(\beta + 1)$ while number of subscribers α^* and off-net call and reception price $\hat{r}^*$ are given by the following system of equations*

$$0 = \widetilde{\Psi}(\alpha^*, \hat{r}^*) \quad (20)$$

$$0 = \widetilde{\Phi}(\alpha^*, \hat{r}^*) \quad (21)$$

Equilibrium fixed fee is equal to

$$\tilde{F}^* = f + \frac{\mu}{1-\alpha^*} - 2\alpha^* \tilde{R}(r^*) - (n-1)\frac{\alpha^*(1-2\alpha^*)}{1-\alpha^*}\tilde{R}(\hat{r}^*).$$

Equilibrium profit is equal to

$$\tilde{\pi}^* = \alpha^* \left(\frac{\mu}{1-\alpha^*} - \alpha^* \tilde{R}(r^*) + \frac{(n-1)\alpha^{*2}}{1-\alpha^*}\tilde{R}(\hat{r}^*)\right).$$

Note that $\tilde{R}(r^*) \leq R(p^*)$ if and only if $\beta \geq 1/2$. Hence, for high values of the call externality the firms make higher on-net profit under RPP than under CPP (through the higher fixed fees).

Note that for $m = 0$ the solution entails free off-net calls ($\hat{r}^* = 0$). For $m > 0$ there is no interior solution if negative prices are not allowed. Free off-net calls would be part of a (constrained) equilibrium then as well, but we will henceforth restrict attention to $m < 0$. Observe that for $\beta = 1$, $\hat{r}^* = -m$ and that for $\beta < 1$ any solution must have $\hat{r}^* > -m$. Reception is charged above perceived marginal cost. The reason is that a raise in the reception charge hurts subscribers from rival networks as they can place less calls. However, under elastic subscription the incentive to raise price is not as strong as under the assumption of inelastic subscription. Hurkens and López (2014b) show that when total

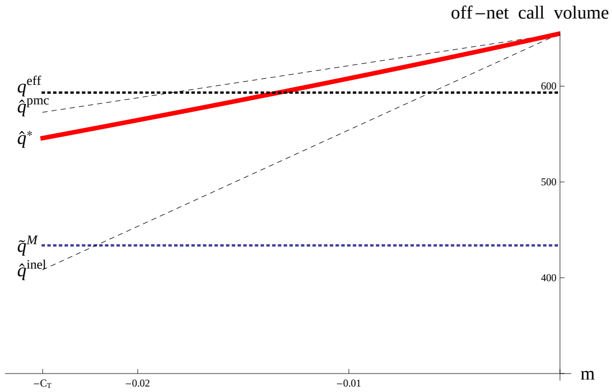

Figure 5: Off-net call volume. ($\beta = 0.6$, $n = 2$, $\mu = 80$).

subscription is inelastic, off-net reception would be charged at $\beta(n-1)m/(1-n\beta)$ (as long as this expression is positive). This does not mean, though, that under elastic subscription connectivity breakdown can never occur. For low values of the call externality it may be optimal to choke off-net traffic.

Proposition 5 *For $|m + c_T|$ not too large and μ sufficiently large the equilibrium off-net price is strictly between perceived and strategic marginal cost.*

$$-m < \hat{r}^* < \frac{\beta(n-1)m}{1-n\beta}.$$

We illustrate the above results by plotting off-net call volume in Figure 5. The dotted horizontal line on top depicts the efficient (on-net) call volume $q^{\text{eff}} = q(c/(1+\beta))$ while the lower dotted horizontal line depicts the monopoly call volume $\tilde{q}^M$. The dashed upward sloping lines show the call volume under perceived marginal cost pricing ($\hat{q}^{pmc} = q(-m/\beta)$, top) and under inelastic subscription demand ($\hat{q}^{\text{inel}} = q(\beta(n-1)m/(1-n\beta))$, bottom). The equilibrium off-net call volume $\hat{q}^*$ (thick red) is in between these curves.

We plot off-net call volumes for different values of β in Figure 6. Observe that for low call externality ($\beta = 0.25$) and low termination rates there is connectivity breakdown because off-net call volume is zero. Higher levels of call externality increase the volume. Note that for $\beta = 1$ off-net call volume is inefficiently high for any positive termination charge ($m > -c_T$). Recall that efficient call volume $q(c/(1+\beta)$ depends on te strength of the call externality. The grey rectangle indicates efficient call volumes for any $\beta \in (0, 1)$.

The observation from Prop. 5 is also helpful in performing some comparative statics on equilibrium off-net call price and penetration with respect to termination rates and product differentiation. Straightforward comparative statics exercises can be performed which give

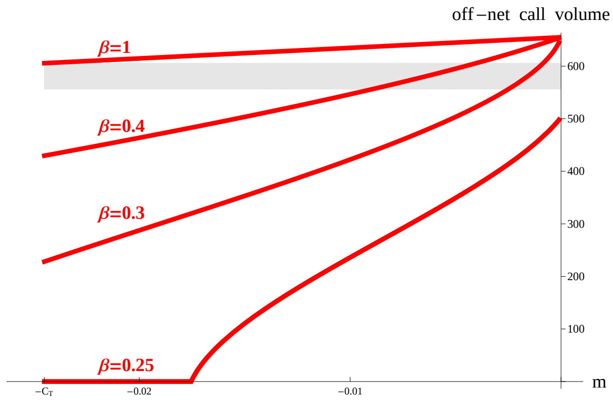

Figure 6: Off-net call volumes. ($\beta \in \{0.25, 0.3, 0.4, 1\}$, $n = 2$, $\mu = 80$).

us the following results.

Proposition 6 (Comparative statics) *For $|m+c_T|$ not too large and μ sufficiently large, we have:*

(i) *An increase in m leads to lower $\hat{r}^*$ and higher α^**

(ii) *An increase in μ leads to lower $\hat{r}^*$ and lower α^**

Reception price is decreasing in m. Hence higher termination rates (than Bill and Keep) are more efficient and lead to more penetration. However, firms may prefer to have Bill and Keep, especially when the call externality is relatively high. In any case, welfare maximizing termination rate is higher than the one that maximizes industry profit.

Although Prop. 6 establishes that $\hat{r}^*$ is decreasing in m, this does not mean that firms prefer the termination charge so low that $\hat{r}^* = \tilde{r}^M = \arg\max \tilde{R}(r)$. In fact, this may be impossible as it would require negative termination rates, that is, termination mark-up below $-c_T$. Although this would maximize profit for each off-net call ($\tilde{R}(\hat{r}^*)$), it would reduce penetration and thus number of subscribers.[21] For relatively low levels of the call externality, the profit maximizing $\tilde{m}^\pi$ is above $-c_T$ while for relatively high levels Bill and Keep maximizes profits. For the example at hand in Figure 5 (with $\beta = 0.6$ and $n = 2$) the profit maximizing termination charge is about $-0.012 > -c_T$. However, with more than 2 firms Bill and Keep maximizes profits. See Figure 7.

[21] Under inelastic subscription demand firms would indeed prefer off-net price to be equal to monopoly price. (See Hurkens and López (2014b).)

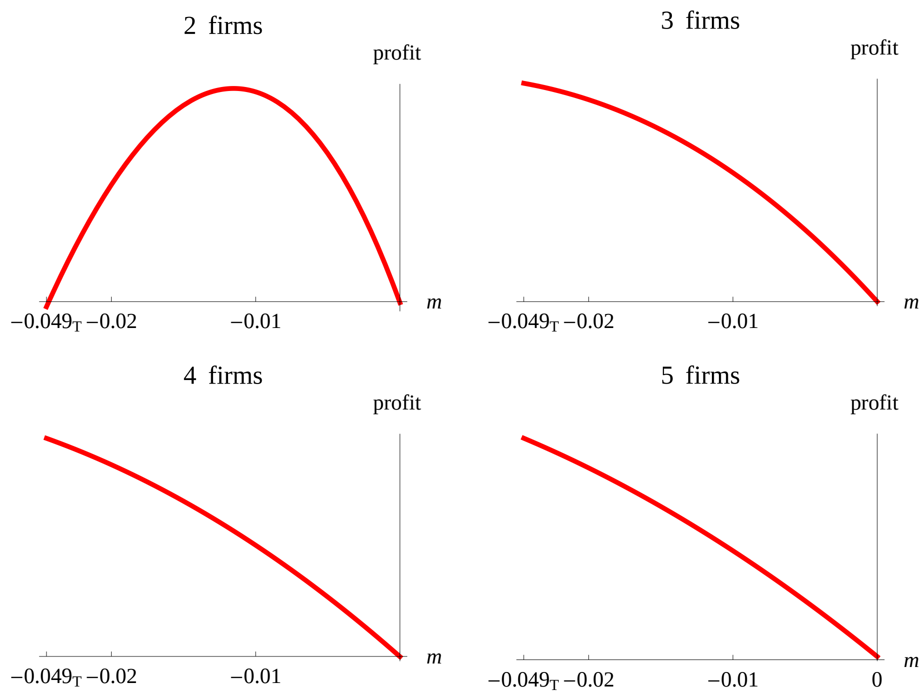

Figure 7: Comparing equilibrium profits. ($\beta = 0.6$, $\mu = 80$).

5 CPP vs RPP [INCOMPLETE]

The analysis in the previous sections has shown that for a wide range of parameter values that under CPP welfare increases and profits decrease when termination rates are pushed down toward cost; while under RPP welfare increases and profits decrease when termination rates are pushed upward toward cost. Regulation in Europe has pushed down termination rates down in the last 15 years or so from over 20 cents/minute to under 2 cents/minute. This has improved welfare considerably. But how does the enormous effort and burden of termination rate regulation in Europe compare to the situation in the US where firms often voluntarily agree on a Bill and Keep regime? In this section we compare the outcomes from CPP under cost-based regulation ($m = 0$) with those from RPP under Bill and Keep arrangements, using our numerical example. We will compare minutes of use[22], monthly consumer bill, penetration levels, industry profit and total welfare for different levels of call externality, different numbers of firms and different values for the product differentiation parameter. Results are reported in Tables 1, 2, and 3.

[22] We will count each minute of call placed and each minute of call received to make comparison useful.

β	0.2		0.4		0.6		0.8	
regime	CPP	RPP	CPP	RPP	CPP	RPP	CPP	RPP
MoU	840.78	274.84	920.11	630.82	946.93	964.06	909.31	1120.70
BILL	79.33	56.15	88.82	70.03	97.44	82.64	104.17	84.56
PEN	0.75	0.48	0.83	0.73	0.89	0.89	0.91	0.95
IND PROF	44.25	24.25	55.25	47.25	65.70	66.02	74.45	68.65
TW	93.27	47.13	118.03	92.49	141.43	142.43	158.43	175.98

Table 1: CPP vs. RPP in duopoly, $\mu = 35$

β	0.2		0.4		0.6		0.8	
regime	CPP	RPP	CPP	RPP	CPP	RPP	CPP	RPP
MoU	990.82	218.77	1032.40	772.07	1045.30	1069.40	1036.20	1159.80
BILL	76.08	51.30	80.35	63.62	83.64	67.97	86.29	67.84
PEN	0.89	0.57	0.94	0.89	0.96	0.96	0.98	0.98
IND PROF	46.18	26.84	51.55	53.28	55.86	55.44	59.52	53.48
TW	123.90	56.62	147.95	131.29	170.82	171.65	192.05	196.38

Table 2: CPP vs. RPP in triopoly, $\mu = 35$

β	0.2		0.4		0.6		0.8	
regime	CPP	RPP	CPP	RPP	CPP	RPP	CPP	RPP
MoU	862.19	206.50	925.28	745.68	966.84	990.92	984.38	1099.60
BILL	90.08	68.59	95.26	80.70	99.82	85.85	103.67	87.39
PEN	0.77	0.54	0.84	0.80	0.88	0.89	0.92	0.93
IND PROF	53.38	34.81	60.63	60.07	67.26	67.00	73.02	69.41
TW	127.76	73.73	150.80	140.11	174.72	175.75	197.98	203.27

Table 3: CPP vs. RPP in triopoly, $\mu = 50$

6 Concluding remarks (TO BE DONE)

Appendix

6.1 CPP

Proof of Proposition 1

A change in the fixed fee or the prices for on-net traffic of network i does not affect the expected net surplus from subscribing to network $j \neq i$ (i.e. $\partial w_j/\partial t_i = 0$ for $t \in \{F, p, r\}$). It follows that for $i \in N$

$$\frac{\partial \alpha_i}{\partial F_i} = -\frac{\alpha_i(1-\alpha_i)}{\mu}, \tag{22}$$

while for $j \in \{0, 1, ..., n\} \backslash \{i\}$

$$\frac{\partial \alpha_j}{\partial F_i} = \frac{\alpha_i \alpha_j}{\mu}. \tag{23}$$

Further,

$$\frac{\partial \alpha_i}{\partial p_i} = \frac{\alpha_i(1-\alpha_i)}{\mu}\frac{\partial w_i}{\partial p_i} \tag{24}$$

while for $j \in \{0, 1, ..., n\} \backslash \{i\}$

$$\frac{\partial \alpha_j}{\partial p_i} = -\frac{\alpha_i \alpha_j}{\mu}\frac{\partial w_i}{\partial p_i}. \tag{25}$$

Similarly,

$$\frac{\partial \alpha_i}{\partial r_i} = \frac{\alpha_i(1-\alpha_i)}{\mu}\frac{\partial w_i}{\partial r_i} \tag{26}$$

while for $j \in \{0, 1, ..., n\} \backslash \{i\}$

$$\frac{\partial \alpha_j}{\partial p_i} = -\frac{\alpha_i \alpha_j}{\mu}\frac{\partial w_i}{\partial p_i}. \tag{27}$$

On the other hand, off-net prices of network i may affect the net utility from subscribing to a different network, through the effect on the volume of off-net calls.

Note that

$$\frac{\partial w_i}{\partial p_i} = \gamma^*(\beta p_i q'(p_i) - q(p_i)) \tag{28}$$

$$\frac{\partial w_i}{\partial \hat{p}_i} = -(n-1)\gamma^* q(\hat{p}_i) \tag{29}$$

$$\frac{\partial w_i}{\partial F_i} = -1 \tag{30}$$

$$\frac{\partial w_j}{\partial p_i} = 0 \tag{31}$$

$$\frac{\partial w_j}{\partial \hat{p}_i} = \gamma^* \beta \hat{p}_i q'(\hat{p}_i) \tag{32}$$

$$\frac{\partial w_j}{\partial F_i} = 0. \tag{33}$$

We now consider the first-order condition with respect to F_i

$$\begin{aligned}
0 = \frac{\partial \pi_i}{\partial F_i} =& \frac{\partial \alpha_i}{\partial F_i}\left(\frac{\pi_i}{\alpha_i}\right) + \alpha_i \left(\frac{\partial \alpha_i}{\partial F_i} R(p^*) + \sum_{j\in N\setminus\{i\}} \frac{\partial \alpha_j}{\partial F_i} R(\hat{p}_i) + 1\right) \\
=& -\frac{\alpha_i(1-\alpha_i)}{\mu}(2\alpha_i R(p^*) + (1-\alpha_i-\alpha_0)R(\hat{p}_i) + F_i - f) \\
&+ \alpha_i\left(\frac{\alpha_i(1-\alpha_i-\alpha_0)}{\mu} R(\hat{p}_i) + 1\right).
\end{aligned}$$

It follows then that in a symmetric equilibrium fixed fee must satisfy eq. (9).

Let us now consider the first-order condition with respect to the off-net call price $\hat{p}_i$.

$$\begin{aligned}
0 = \frac{\partial \pi_i}{\partial \hat{p}_i} =& \frac{\partial \alpha_i}{\partial \hat{p}_i}\left(\frac{\pi_i}{\alpha_i}\right) + \alpha_i \left(\frac{\partial \alpha_i}{\partial \hat{p}_i} R(p^*) + \sum_{j\in N\setminus\{i\}} \frac{\partial \alpha_j}{\partial \hat{p}_i} R(\hat{p}_i)\right) \\
&+ \alpha_i \sum_{j\in N\setminus\{i\}} \alpha_j [q(\hat{p}_i) + (\hat{p}_i - c - m) q'(\hat{p}_i)] \\
=& \frac{\partial \alpha_i}{\partial \hat{p}_i}\left[2\alpha_i R(p^*) + \sum_{j\in N\setminus\{i\}} \alpha_j R(\hat{p}^*) + F_i - f\right] \\
&+ \alpha_i \sum_{j\in N\setminus\{i\}} \frac{\partial \alpha_j}{\partial \hat{p}_i} R(\hat{p}^*) \\
&+ \alpha_i \sum_{j\in N\setminus\{i\}} \alpha_j [q(\hat{p}_i) + (\hat{p}_i - c - m) q'(\hat{p}_i)]
\end{aligned}$$

Hence,

$$\begin{aligned}
0 =& \left(\frac{\alpha^*(1-\alpha^*)}{\mu}\frac{\partial w_i}{\partial \hat{p}_i} - \frac{(n-1)\alpha^{*2}}{\mu}\frac{\partial w_j}{\partial \hat{p}_i}\right)\left(\frac{\mu}{1-\alpha^*} + R(\hat{p}^*)\frac{(n-1)\alpha^{*2}}{1-\alpha^*}\right) \\
&+ (n-1)\alpha^* R(\hat{p}^*)\left(-\frac{\alpha^{*2}}{\mu}\frac{\partial w_i}{\partial \hat{p}_i} + \frac{\alpha^*(1-(n-1)\alpha^*)}{\mu}\frac{\partial w_j}{\partial \hat{p}_i}\right) \\
&+ (n-1)\alpha^{*2}[q(\hat{p}^*) + (\hat{p}^* - c - m) q'(\hat{p}^*)]
\end{aligned}$$

Straightforward algebra shows that this can be rewritten as

$$
\begin{aligned}
0 =& \frac{\partial w_i}{\partial \hat{p}_i}\alpha^* + (n-1)\alpha^{*2}[q(\hat{p}^*) + (\hat{p}^* - c - m)q'(\hat{p}^*)] \\
&+ \frac{(n-1)\alpha^{*2}}{\mu}\frac{\partial w_j}{\partial \hat{p}_i}\left(\frac{-\mu}{1-\alpha^*} + R(\hat{p}^*)\frac{1-n\alpha^*}{1-\alpha^*}\right)
\end{aligned}
$$

Substituting equations (29) and (32) this can then be rewritten as eq. (8). ■

Proof of Proposition 2

It is straightforward to check that substituting $\hat{p}^* = c + m$ in the right-hand side of eq. (13) yields a strictly negative number. Hence the equilibrium off-net price is strictly higher than $c+m$. On the other hand, substituting $\hat{p}^* = (n-1)(c+m)/(n-1-\beta)$ yields a strictly positive result. Hence, the equilibrium off-net price is below strategic marginal cost. ■

Proof of Proposition 3

It is straightforward to verify that (for small $|m|$, sufficiently large μ, $\hat{p}^* < p^M$ and $\alpha^* > 1/(n+1)$) partial derivatives satisfy

$$\Psi_{\alpha^*} > 0, \Psi_{\hat{p}^*} > 0, \Psi_m = 0, \Psi_\mu > 0$$

and

$$\Phi_{\alpha^*} < 0, \Phi_{\hat{p}^*} > 0, \Phi_m = -1, , \Phi_\mu < 0.$$

To be precise, we have

$$
\begin{aligned}
\Psi_{\alpha^*} =& \frac{\mu}{(1-\alpha^*)^2} - 2R(p^*) - v(p^*) - (n-1)\frac{1-4\alpha^* + 2\alpha^{*2}}{(1-\alpha^*)^2}R(\hat{p}^*) - (n-1)v(\hat{p}^*) + \frac{\mu}{\alpha^*(1-n\alpha^*)} > 0, \\
\Psi_{\hat{p}^*} =& -(n-1)\alpha^*\Big[q'(\hat{p}^*)[(1+\beta)\hat{p}^* - c]\frac{1-2\alpha^*}{1-\alpha^*} - \frac{\alpha^* q(\hat{p}^*)}{1-\alpha^*}\Big] > 0, \\
\Psi_\mu =& \frac{1}{1-\alpha^*} + \log\left(\frac{\alpha^*}{1-n\alpha^*}\right) > 0 \text{ if } \alpha^* > 1/(n+1). \\
\Phi_{\alpha^*} =& \frac{\beta\hat{p}^*}{(1-\alpha^*)^2}\Big[-1 + (1-2n\alpha^* + n\alpha^{*2})\frac{R(\hat{p}^*)}{\mu}\Big] < 0, \\
\Phi_{\hat{p}^*} =& \frac{c+m}{\hat{p}^*} + \frac{\alpha^*\beta\hat{p}^*}{1-\alpha^*}(1-n\alpha^*)\frac{R'(\hat{p}^*)}{\mu} > 0, \\
\Phi_\mu =& -\frac{\alpha^*\beta\hat{p}^*}{1-\alpha^*}(1-n\alpha^*)\frac{R(\hat{p}^*)}{\mu^2} < 0.
\end{aligned}
$$

Hence, in $(\hat{p}^*, \alpha^*)$-space the curve $\Phi(\alpha^*, \hat{p}^*) = 0$ is upward sloping and the curve $\Psi(\alpha^*, \hat{p}^*) = 0$ is downward sloping. The results follow then straightforwardly from analyzing how each curve shifts when one of the parameters is changed: An increase in m shifts the Φ curve down while holding the Ψ curve fixed, leading to an increase in $\hat{p}^*$ and a decrease in α^*, as illustrated in Figure 2. An increase in μ shifts both curves down, leading to a decrease in α^*. Careful consideration of the Jacobian of the system of equations yields that also $\hat{p}^*$ is decreased for large enough μ. In fact, Figure 3 suggests that the Φ-curve shifts only very little in comparison with the Ψ-curve. ■

6.2 RPP

In this case call volume is of course determined by the reception charge, i.e. $q(r/\beta)$. Note that in this case, at the symmetric equilibrium, we have

$$\frac{\partial \tilde{w}_i}{\partial r_i} = \gamma^* \left(-2q(r^*/\beta) + r^* q'(r^*/\beta) \frac{1-\beta}{\beta^2} \right) \tag{34}$$

$$\frac{\partial \tilde{w}_i}{\partial \hat{r}_i} = -2(n-1)\gamma^* q(\hat{r}^*/\beta) \tag{35}$$

$$\frac{\partial \tilde{w}_i}{\partial \tilde{F}_i} = -1 \tag{36}$$

$$\frac{\partial \tilde{w}_j}{\partial r_i} = 0 \tag{37}$$

$$\frac{\partial \tilde{w}_j}{\partial \hat{r}_i} = \gamma^* \hat{r}^* q'(\hat{r}^*/\beta) \frac{1-\beta}{\beta^2} \tag{38}$$

$$\frac{\partial \tilde{w}_j}{\partial \tilde{F}_i} = 0. \tag{39}$$

Let us now consider the first-order condition (evaluated at the symmetric equilibrium) with respect to the fixed fee $\tilde{F}_i$.

$$\begin{aligned} 0 = \frac{\partial \tilde{\pi}_i}{\partial \tilde{F}_i} =& \frac{\partial \alpha_i}{\partial \tilde{F}_i} \left(\frac{\pi_i}{\alpha_i} \right) + \alpha^* \left(\frac{\partial \alpha_i}{\partial \tilde{F}_i} \tilde{R}(r^*) + \sum_{j \in N \setminus \{i\}} \frac{\partial \alpha_j}{\partial \tilde{F}_i} \tilde{R}(\hat{r}^*) + 1 \right) \\ =& -\frac{\alpha^*(1-\alpha^*)}{\mu} (2\alpha^* \tilde{R}(r^*) + (n-1)\alpha^* \tilde{R}(\hat{r}^*) + \tilde{F}^* - f) \\ &+ \alpha^* \left(\frac{(n-1)\alpha^{*2}}{\mu} \tilde{R}(\hat{r}^*) + 1 \right). \end{aligned}$$

In a symmetric equilibrium we must thus have

$$\tilde{F}^* = f + \frac{\mu}{1-\alpha^*} - 2\alpha^* \tilde{R}(r^*) - \tilde{R}(\hat{r}^*)(n-1) \frac{\alpha^*(1-2\alpha^*)}{1-\alpha^*}. \tag{40}$$

Let us now consider the first-order condition with respect to the off-net price $\hat{r}_i$.

$$
\begin{aligned}
0 = \frac{\partial \pi_i}{\partial \hat{r}_i} =& \frac{\partial \alpha_i}{\partial \hat{r}_i}\left(\frac{\pi_i}{\alpha^*}\right) + \alpha^* \left(\frac{\partial \alpha_i}{\partial \hat{r}_i}\tilde{R}(r^*) + \sum_{j \in N\setminus\{i\}} \frac{\partial \alpha_j}{\partial \hat{r}_i}\tilde{R}(\hat{r}^*)\right) \\
&+ \sum_{j \in N\setminus\{i\}} \alpha_j [2q(\hat{r}^*/\beta) + (\hat{r}^* + m)q'(\hat{r}^*/\beta)/\beta] \\
=& \frac{\partial \alpha_i}{\partial \hat{r}_i}\left(2\alpha^*\tilde{R}(r^*) + (n-1)\alpha^*\tilde{R}(\hat{r}^*) + F^* - f\right) \\
&+ \alpha^*\left[(n-1)\left(\frac{\partial \alpha_i}{\partial \hat{r}_i}\right)\tilde{R}(r^*)\right] \\
&+ \alpha^{*2}(n-1)[2q(\hat{r}^*/\beta) + (\hat{r}^* + m)q'(\hat{r}^*/\beta)/\beta]
\end{aligned}
$$

Substituting equation (40), using equation (2) and considering being at a symmetric equilibrium we obtain

$$
\begin{aligned}
0 =& \left(\frac{\alpha^*(1-\alpha^*)}{\mu}\frac{\partial w_i}{\partial \hat{r}_i} - \frac{(n-1)\alpha^{*2}}{\mu}\frac{\partial w_j}{\partial \hat{r}_i}\right)\left(\frac{\mu}{1-\alpha^*} + \tilde{R}(r^*)\frac{(n-1)\alpha^{*2}}{1-\alpha^*}\right) \\
&+ (n-1)\alpha^*\tilde{R}(\hat{r}^*)\left(-\frac{\alpha^{*2}}{\mu}\frac{\partial w_i}{\partial \hat{r}_i} + \frac{\alpha^*(1-(n-1)\alpha^*)}{\mu}\frac{\partial w_j}{\partial \hat{r}_i}\right) \\
&+ (n-1)\alpha^{*2}[2q(\hat{r}^*/\beta) + \frac{\hat{r}^* + m}{\beta}q'(\hat{r}^*/\beta)]
\end{aligned}
$$

Straightforward algebra shows that this can be rewritten as

$$
\begin{aligned}
0 =& \frac{\partial w_i}{\partial \hat{r}_i}\alpha^* + (n-1)\alpha^{*2}\left[2q(\hat{r}^*/\beta) + \frac{\hat{r}^* + m}{\beta}q'(\hat{r}^*/\beta)\right] \\
&+ \frac{(n-1)\alpha^{*2}}{\mu}\frac{\partial w_j}{\partial \hat{r}_i}\left(\frac{-\mu}{1-\alpha^*} + \tilde{R}(\hat{r}^*)\frac{1-n\alpha^*}{1-\alpha^*}\right)
\end{aligned}
$$

Substituting equations (35) and (38) this can then be rewritten as

$$
0 = (n-1)\alpha^{*2}q'(\hat{r}^*/\beta)\left(\frac{\hat{r}^* + m}{\beta} + \frac{\alpha^*\beta\hat{r}^*}{1-\alpha^*}\left[-1 + (1-n\alpha^*)\frac{\tilde{R}(\hat{r}^*)}{\mu}\right]\right). \tag{41}
$$

From (1) we know that the number of subscribers per firm (denoted by α^*), must satisfy

$$
\alpha^* = \frac{\exp[w^*/\mu]}{n\exp[w^*/\mu] + \exp[w_0/\mu]}.
$$

Denoting indirect utility by

$$\tilde{v}(r) = (1+\beta)u(q(r/\beta)) - 2rq(r/\beta),$$

the above equation can be rewritten as

$$F^* = \alpha^*\tilde{v}(r^*) + (n-1)\alpha^*\tilde{v}(\hat{r}^*) - w_0 - \mu \log\left(\frac{\alpha^*}{1-n\alpha^*}\right), \tag{42}$$

The equilibrium is thus jointly determined by equations (17), (40), (41), (42).

The first equation gives us directly on-net price r^*, which can be substituted in the other equations. Furthermore, substituting (40) into (42) yields $\tilde{\Psi}(\alpha^*, \hat{r}^*) = 0$. Of course, (41) is equivalent to $\tilde{\Phi}(\alpha^*, \hat{r}^*) = 0$. Expressions for equilibrium fixed fee and profit follow from substitution. ■

Proof of Proposition 6

The comparative statics exercises are very similar to the case of CPP. We have now $\tilde{\Psi}_m = 0$ and $\tilde{\Phi}_m = 1/\beta > 0$ and

$$\begin{aligned}
\tilde{\Psi}_{\alpha^*} =& \frac{\mu}{(1-\alpha^*)^2} - 2\tilde{R}(r^*) - \tilde{v}(r^*) - (n-1)\frac{1-4\alpha^*+2\alpha^{*2}}{(1-\alpha^*)^2}\tilde{R}(\hat{r}^*) - (n-1)\tilde{v}(\hat{r}^*) + \frac{\mu}{\alpha^*(1-n\alpha^*)} > 0,\\
\tilde{\Psi}_{\hat{r}^*} =& -(n-1)\alpha^*\left[\frac{q'(\hat{r}^*/\beta)}{\beta}\left[[2\hat{r}^*-c]\frac{1-2\alpha^*}{1-\alpha^*} + \frac{1-\beta}{\beta}\hat{r}^*\right] - \frac{\alpha^* q(\hat{r}^*/\beta)}{1-\alpha^*}\right] > 0,\\
\tilde{\Psi}_{\mu} =& \frac{1}{1-\alpha^*} + \log\left(\frac{\alpha^*}{1-n\alpha^*}\right) > 0 \text{ if } \alpha^* > 1/(n+1).\\
\tilde{\Phi}_{\alpha^*} =& \frac{(1-\beta)\hat{r}^*}{(1-\alpha^*)^2\beta^2}\left[-1 + (1-2n\alpha^*+n\alpha^{*2})\frac{\tilde{R}(\hat{r}^*)}{\mu}\right] < 0,\\
\tilde{\Phi}_{\hat{r}^*} =& \frac{-m}{\beta\hat{r}^*} + \frac{\alpha^*(1-\beta)\hat{r}^*}{(1-\alpha^*)\beta^2}(1-n\alpha^*)\frac{\tilde{R}'(\hat{r}^*)}{\mu} > 0,\\
\tilde{\Phi}_{\mu} =& -\frac{\alpha^*(1-\beta)\hat{r}^*}{(1-\alpha^*)\beta^2}(1-n\alpha^*)\frac{\tilde{R}(\hat{r}^*)}{\mu^2} < 0.
\end{aligned}$$

■

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