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Asymmetric Network Interconnection⋆

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Abstract. We develop a model of competition between interconnected networks, that allows for carriers to differ in size. Under two-part pricing, we show that because of asymmetry the larger network will always prefer a reciprocal interconnection charge be set at cost. For sufficiently large asymmetry the smaller network will have the same preference. Under the assumptions of our model a particularly simple regulation is optimal – if carriers cannot agree on the terms of interconnection, the larger carrier is entitled to select the access price which is then applied reciprocally.

Key words: Interconnection, networks, reciprocity, telecommunications.

JEL Classifications: D41, K21, L41, L43, L51.

I. Introduction

Many countries around the world are engaged in deregulation of network industries. Previous national monopolies are being privatized, regulatory oversight reduced and competition encouraged. One of the biggest challenges is achieving competition in local telecommunications markets. Local telecommunications networks have in the past been viewed as natural monopolies, exhibiting network externalities on the demand side and economies of scale on the cost side. Duplication of the local loop is now feasible with new technologies. However, carriers require access to each other's networks in order to compete. This need for interconnection raises concerns regarding anticompetitive behavior since interconnection requires cooperation between competing networks. These potential difficulties have stimulated research into the means of achieving effective competition in local telecommunications markets. A key question is whether the need for interconnection undermines retail competition in a deregulated environment and what regulations are needed in this new environment.

Some guidance to these questions is provided by the burgeoning literature on interconnection. This literature shares a common framework. Once the terms for interconnection are agreed, the competing networks play a standard Bertrand pricing game, where the consumers choose networks according to the Hotelling model of

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product differentiation. Assuming reciprocal (i.e., equal) access charges and linear retail pricing, Armstrong (1998) and Laffont et al. (1998) show that symmetric local networks will set the common access charge above the cost of providing access to lessen retail price competition. By agreeing to high interconnection charges, firms reduce the incentive to undercut each other in an endeavor to increase market share. If either firm lowers its retail price, it will face a net outflow of calls which, given sufficiently high interconnection charges, will reduce its profits. In this way, competition in the retail market can be undermined by collusion over the access charge. Carter and Wright (1999) allow for unequal-sized firms by providing for brand loyalty, showing that the ability to use interconnection charges to facilitate collusion is retained with asymmetry, and that with non-reciprocal access prices the terms of interconnection can be used by the incumbent as a barrier to entry.

The benefits of deregulation appear stronger once non-linear (e.g., two-part) retail prices are allowed. Provided that networks are restricted to charge each other reciprocal per-minute access charges, Laffont et al. (1998) show that the firms cannot use access charges to lessen competition.[1] Higher access charges push up per-minute retail prices, but this is offset by a reduction in fixed fees. Because lower fixed fees do not lead to a net outflow of calls, higher access charges do not reduce a firm's incentive to compete on fixed fees. In particular, Laffont et al. show that symmetric firms will be indifferent to the level of the reciprocal access charge.

This indifference result is striking. Dessein (2002) considers whether the result still holds when customers are heterogeneous and firms can price discriminate. He shows that in a symmetric model, equilibrium profits remain independent of the reciprocal access charge. Hahn (1999) obtains similar conclusions with a continuous distribution of consumer demand.

In this paper, we extend the non-linear pricing model of Laffont et al. (1998) in another direction. As in Carter and Wright (1999) we allow for brand loyalty, so that one firm can have a greater market share than the other, even when their prices are the same. This could capture the asymmetry between incumbent and entrant in terms of size, or the possibility that firms may offer a vertically differentiated service. This single change when applied to a Hotelling model with two-part pricing produces dramatically different results. We show that the standard result that with non-linear pricing networks are indifferent to the level of the access charge depends critically on the symmetry of the networks. Providing for asymmetry implies that the incumbent strictly prefers the reciprocal access charge to be set at the marginal cost of providing the local loop.

To understand this result, consider the incentives facing the incumbent when it has larger market share. The only reason for it to set an above-cost reciprocal access price is if this can generate net interconnection revenue, since with two-part

[1] This assumes that access charges are linear. Allowing two-part access charges that incorporate a per-customer charge as well as a per-minute charge would restore the collusive potential of interconnection pricing. It remains for future research to explore the effects of other forms of non-linear access prices.

pricing high per-minute prices will be offset by lower line rentals. If it sets the reciprocal access price above cost, it will face a net outflow of calls as the smaller rival firm will face a higher effective marginal cost for calls and thus set higher per-minute prices. The higher effective marginal cost faced by the smaller rival firm results from the fact the smaller firm faces a higher proportion of *inter*-network calls which attract the above-cost access charge, whereas the larger firm faces a higher proportion of *intra*-network calls which are free from the above-cost access charge. A net outflow of calls with above-cost access prices is unambiguously bad for the incumbent. Similarly, if the incumbent sets the reciprocal access price below cost, it will face a net inflow of calls as the smaller rival firm will face a lower effective marginal cost for calls and thus set lower per-minute prices. A net inflow of calls with below-cost access prices is also unambiguously bad for the incumbent. Thus, the incumbent will always prefer reciprocal access charges set at cost. The incentives facing the smaller entrant will generally be the opposite of those faced by the incumbent. The smaller firm will want to either have below-cost access charges in which case it faces a net outflow of calls or above-cost access charges in which case it faces a net inflow of calls.[2]

The result suggests a very simple policy can achieve the welfare maximizing outcome. If the firms cannot agree on the level of interconnection charges between themselves, the regulator should require that the incumbent and entrant interconnect at some reciprocal price, but leave the incumbent free to set this price. Because the incumbent's preferred reciprocal interconnection price is equal to its own cost of originating and terminating calls, we show in the context of our model that this achieves the welfare maximizing outcome without any need for the regulator to determine costs or prices.[3]

This differs from the standard reciprocity principle, enshrined in the 1996 U.S. Telecommunications Act, in two fundamental respects. First, the reciprocity principle requires the two parties to establish reciprocal compensation arrangements, which we do not require. Second, the reciprocity principle has the regulator or arbitrator determine the outcome if the two parties cannot agree. Given the likelihood for disagreement, this places a higher burden on regulators than we require.[4]

If firms set non-reciprocal interconnection prices, we show that each firm will prefer to unilaterally increase their charge for local call interconnection. In this

[2] The only reason for firms to not want such access charges is if these induce a change in market share which more than offsets the change in net interconnection revenue. We show for the Hotelling model with two-part pricing, changes in market share only affect the behavior of entrants and then only when its market share is sufficiently small. In this case the entrant's incentives become aligned with the incumbent.

[3] The model we use to derive this result is a very standard one in the literature, with the main point of departure being the introduction of a simple form of asymmetry. Section IV discusses some complications that arise for interpreting optimal policy once other realistic extensions such as cost asymmetries are introduced.

[4] Economides et al. (1996) provides an analysis of the reciprocity principle, although in a model that assumes market shares do not respond to prices.

case, non-reciprocal local interconnection agreements allow the incumbent to use its greater bargaining power to charge more for incoming calls than it pays for outgoing calls. This can act as a barrier to entry for competitors to the extent it is not justified by cost differentials. Non-reciprocal interconnection agreements can also be used by firms to increase their joint profits at the expense of consumers, by increasing the difference between the interconnection price set by the large firm and that set by the small firm. We argue these results reinforce the desirability of requiring the incumbent choose a reciprocal interconnection fee in the advent of a breakdown in negotiations.

The rest of the paper proceeds as follows. In Section II we model network competition under two-part pricing and reciprocal access prices, allowing for asymmetry between the participants. In Section III we consider what would happen without reciprocity. Section IV discusses a number of extensions and practical considerations that are relevant to interpreting the implications of the model for policy. Finally, Section V briefly concludes.

II. Network Competition with Brand Loyalty

Our model of local competition follows the framework developed in Section VIII of Laffont et al. (1998). There are two networks, each providing full local coverage. Each network incurs a marginal cost c per minute for originating or terminating a call.[5] The total marginal cost of a call is $2c$. In addition, there is a fixed cost of f in serving a customer, which reflects the costs of connecting the customer to the network, as well as billing and servicing the customer.

The utility derived by a consumer who subscribes to network i is $u(q_i)+\theta_i+v_0$, where q_i is the volume of calls and θ_i measures the additional benefits of belonging to network i. v_0 represents a fixed surplus from being connected to either network and it is assumed to be large enough so that all consumers choose to be connected to a network at equilibrium prices.

To model asymmetry between the networks, we follow Carter and Wright (1999). Customers are endowed with a value of x drawn from a uniform distribution on the interval [0,1], with the networks 1 and 2 located at either end of the interval. A consumer with value x receives extra benefits

$$\theta_1 = \frac{1-x}{2\sigma} + \frac{\beta}{2\sigma} \quad \text{and} \quad \theta_2 = \frac{x}{2\sigma}$$

from subscribing to networks 1 and 2 respectively. The parameter σ measures the degree of substitutability between the networks. For low values of σ, a firm can price higher than its rival without losing all its market share. As σ tends to infinity, only price differentials matter and the firm with the lowest prices captures the whole market.

[5] This is denoted c_0 in Laffont et al. (1998).

The parameter β measures the degree of asymmetry between the networks. When $\beta > 0$, firm 1 has a greater market share than firm 2 when prices are equal. For example, when $\beta = 1$, firm 2 cannot attract any customers unless it undercuts firm 1. Whenever $\beta > 0$, we refer to firm 1 as the "incumbent" and firm 2 as the "entrant". In other words, β represents the extra benefits that the entrant must offer to persuade consumers to switch from the incumbent. Such brand loyalty can capture the superior services (or complementary services) provided by the incumbent. Alternatively, brand loyalty can proxy for switching costs faced by customers, in which case the extra β term should be subtracted from θ_2 rather than added to θ_1. In either case, the implication of brand loyalty is that an entrant will have to undercut the incumbent to achieve an equal share of the market, so that other things equal the incumbent has the greater market share.

Given that all households' marginal willingness to pay for calls is the same, firms can do no better than offer two-part tariffs. Each firm charges a per-unit price p_i and a lump-sum fee (line charge or rental) r_i. Let

$$v(p_i) = \max_q\{u(q) - p_i q\}.$$

A consumer's net surplus of belonging to network i is $w_i = v(p_i) - r_i$. A consumer located at x will be indifferent between the two networks if

$$w_1 + \frac{\beta}{2\sigma} + \frac{1-x}{2\sigma} = w_2 + \frac{x}{2\sigma}.$$

Solving for x, the market share of network 1 is

$$s_1 = \frac{1}{2} + \frac{\beta}{2} + \sigma(w_1 - w_2).$$

The market share of network 2 is $s_2 = 1 - s_1$.

Let a denote the reciprocal per-unit access charge to be paid for interconnection by a network to its competitor. The profit function of firm i is

$$\begin{aligned}\pi_i &= s_i(p_i - 2c)q(p_i) + s_i(r_i - f) \\ &\quad + s_i s_j(a - c)\big(q(p_j) - q(p_i)\big). \qquad (1)\end{aligned}$$

The first term represents retail profit from customer usage, where marginal costs are $2c$ (since calls within a firm's network consists of both an originating and terminating component). We assume symmetric costs for simplicity and discuss the implications of cost differentials later. The second term represents profit from line rentals. The last term represents net interconnection revenue. A proportion $s_i s_j$ of all calls require interconnection. The average length of calls originating in each network depends on the per-minute price charged in each network, and so under the isotropic calling pattern which we assume, the relative per-minute prices determine whether there will be a net inflow or outflow of calls from firm i. Where there is a net flow of calls from one network to the other, the net access provider receives an access payment a from the net access seeker, but incurs additional network costs of c from completing calls. The net access seeker pays out a but saves c.

We assume that the terms of interconnection are negotiated first. Given these, we look for a Bertrand equilibrium in the second-stage pricing game.[6] Since market shares are determined directly by net surpluses w_i, it is analytically convenient to consider the networks as competing over p_i and w_i rather than p_i and r_i. Substituting $r_i = v(p_i) - w_i$, the profit function for firm i can be rewritten as

$$\pi_i = s_i(p_i - 2c)q(p_i) + s_i(v(p_i) - w_i - f) + s_i s_j(a - c)\big(q(p_j) - q(p_i)\big).$$

The first-order conditions for profit maximization with respect to p_i and w_i are

$$\begin{aligned}\frac{\partial \pi_i}{\partial p_i} &= s_i q(p_i) + s_i(p_i - 2c)q'(p_i) + s_i v'(p_i) - s_i s_j(a - c)q'(p_i) = 0,\\ \frac{\partial \pi_i}{\partial w_i} &= -s_i + \sigma\Big((p_i - 2c)q(p_i)\\ &\quad +(v(p_i) - w_i - f) + (s_j - s_i)(a - c)(q(p_j) - q(p_i))\Big) = 0.\end{aligned}$$

Using the fact that $v'(p_i) = -q(p_i)$, the first-order condition with respect to p yields the equilibrium pricing condition

$$p_i = 2c + s_j(a - c). \tag{2}$$

The smaller a network's market share, the more its usage prices will depend on the terms of interconnection since the proportion of off-net calls is larger. The price differential is proportional to the difference in market shares and the margin between access price and cost, that is

$$p_i - p_j = -(s_i - s_j)(a - c). \tag{3}$$

Note that the larger firm will price below the smaller firm if the access charge exceeds cost ($a > c$). This is because the larger firm has a smaller proportion of calls terminating on the rival network, and consequently a lower average marginal cost. Conversely, if the access charge is set below cost ($a < c$), the larger firm will price above the smaller firm. This simple implication of different market sizes underlies our results below.

The equilibrium rental rate is

$$r_i = f + \frac{s_i}{\sigma} - (p_i - 2c)q_i - (s_i - s_j)(a - c)(q_i - q_j), \tag{4}$$

[6] We implicitly assume that the parameters are such that a pure-strategy equilibrium exists. For the symmetric case ($\beta = 0$), Laffont et al. (1998, Appendix B) show that a unique equilibrium exists when $a = c$. When $a \neq c$, there may be no equilibrium when either σ or $|a - c|$ is large.

where the last term is the same for both firms. Further, it follows from (3) that

$$\text{sign}(q_i - q_j) = \text{sign}(s_i - s_j)(a - c) \tag{5}$$

so that the last term in (4) is always nonnegative.

Substituting in the optimal price and rental using (2) and (4), equilibrium profit for firm i is

$$\pi_i = \frac{s_i^2}{\sigma} - s_i^2(a - c)(q_i - q_j) \tag{6}$$

The relationship in Equation (5) implies that the term in Equation (6) that follows the minus sign is positive for the larger firm and negative for the smaller firm. This seems to suggest that the larger firm would strictly prefer $a = c$ while the smaller firm would prefer $a \neq c$. However, the situation is a little more complicated, since the market shares also vary with a. When s_i is sufficiently low, an increase in a can reduce s_i to such an extent that it more than offsets the gain from the second term. We now make this conclusion explicit. (Propositions are proven in Appendix A.)

PROPOSITION 1. *When the firms share the market equally, both firms are indifferent over the reciprocal interconnection charge a. Otherwise, the larger firm always prefers $a = c$, while the smaller firm prefers $a = c$ if its market share is less than one-third.*

Some insight into this result can be obtained by examining Equations (2) and (4). An increase in the access charge a leads to an increase in the usage charges p_i, but this is more or less offset by a reduction in rentals r_i. The overall effect depends upon net interconnection payments; the last term in Equation (4). When $s_i = 1/2$, call volumes balance, there are no net interconnection payments (the last term in Equation (4) is zero) and the reduction in rentals precisely offsets the increase in revenue from usage prices.[7] Otherwise ($s_1 > 1/2$), when $a > c$, the larger firm has a net outflow of calls from Equation (5), and therefore it has an incentive to reduce the margin $a - c$. Similarly, when $a < c$, the larger firm has a net inflow of calls which is unprofitable since a is less than cost. Thus the larger firm always prefers $a = c$.

The converse applies to the smaller firm provided $s_1 < 2/3$. As a is increased above cost c, the larger firm 1 undercuts firm 2 on call price p. Therefore firm 1 experiences higher call volumes, which means that firm 2 gains net interconnection revenue. On the other hand, firm 2's market share falls. Although it reduces its rental r_2, this is not sufficient to offset firm 1's price advantage. Provided firm 2 has more than 1/3 of the market ($s_1 < 2/3$), the first effect (gain in interconnection revenue) outweighs the second (loss of market share), and firm 2's profit increases

[7] This is the case analyzed by Laffont et al. (1998).

with $|a - c|$. However, when $s \geq 2/3$ so that the smaller firm has less than 1/3 of the market, second order changes in the market share become sufficient to overcome the favorable balance in interconnection revenue, aligning the interests of the smaller firm with those of its larger rival.

With cost-based access charges, equilibrium market shares depend solely on brand loyalty, being

$$s_1 = \frac{1}{2} + \frac{\beta}{6} \quad \text{and} \quad s_2 = \frac{1}{2} - \frac{\beta}{6}.$$

Since

$$\frac{2}{3} \leq s_1 < 1 \iff 1 \leq \beta < 3$$

the lower bound $s_1 = 2/3$ corresponds to $\beta = 1$, the value at which network 2 must undercut its rival to gain any market share.

Before considering policy implications we first derive profit maximizing and welfare maximizing access pricing. As Proposition 2 below shows, $a = c$ maximizes total industry profits $\pi_1 + \pi_2$ regardless of the degree of asymmetry. Cost based access prices also maximize total welfare, subject to one qualification. Total welfare is measured by the sum of producer and consumer surplus, plus the aggregate benefits derived from product differentiation, which we denote by B. Since marginal cost access pricing induces the firms to set retail prices at marginal cost, it maximizes the sum of producer and consumer surplus. However, competition for market share induces some customers to subscribe to their less favored network. For example, with $\beta = 1$, everyone would prefer *ceteris paribus* to belong to network 1. However, firm 2 manages to secure 1/3 of the market by undercutting the rental rate of firm 1. These customers gain on price but lose on network specific benefits. The reduction in benefits occurs either because they are induced to switch to a less favored network or simply because they incur the cost of switching networks. If the access price is set above marginal cost, firm 1's market share increases which raises aggregate network specific benefits (B). However, it comes at the cost of reducing the volume of calls below the socially optimal level. Typically, in our model, the aggregate deadweight loss outweighs the benefits of belonging to the most appropriate network. However, for sufficiently high asymmetry, network specific benefits outweigh the deadweight loss and total welfare increases as the access price is increased above cost. Proposition 2 confirms these results formally.

PROPOSITION 2. *Producer surplus is always maximized for $a = c$. Total surplus is maximized for $a = c$ provided β is smaller than $\sqrt{\frac{27}{7}}$.*

We conclude that, with moderate asymmetry ($0 < \beta \leq 1$), firms will have opposing interests, with the incumbent preferring cost-based interconnection and the entrant preferring access prices that deviate from costs. In this case welfare will be maximized when access prices are set at cost. With larger asymmetry ($\beta > 1$), the firms should agree to $a = c$ since it is in their mutual interests, although for even larger asymmetry ($\beta > \sqrt{\frac{27}{7}}$), this may not achieve the first-best outcome.

III. Non-Reciprocal Access Prices

In this section, we explore the ramifications of allowing the firms to independently impose different access charges on one another. Not surprisingly, we find that each firm has a unilateral incentive to set an access price above marginal cost (for the calls it terminates), and would prefer to face an access price below cost (for calls that are terminated by the rival firm). This suggests that requiring the incumbent set *reciprocal* terms of interconnection in the case negotiations fail, is needed to constrain the ability of the incumbent to obtain more favorable outcomes at the expense of the entrant.

Using the model of local competition analyzed in Section II, assume that reciprocity is not imposed so that the networks independently set access charges a_1 and a_2 respectively. The profit function of firm i is then

$$\pi_i = s_i(p_i - 2c)q(p_i) + s_i(r_i - f) + s_i s_j((a_i - c)q(p_j) - (a_j - c)q(p_i))$$

and the equilibrium prices, rentals, shares, and profits are

$$\begin{aligned} p_i &= 2c + s_j(a_j - c), \\ r_i &= f + \frac{s_i}{\sigma} - s_j(a_j - c)q_i - (s_j - s_i)((a_i - c)q_j - (a_j - c)q_i), \\ s_i &= \frac{1}{2} + \frac{\beta}{6} + \frac{\sigma}{3}\Big(v(p_i) - v(p_j) + s_j(a_j - c)q_i - s_i(a_i - c)q_j\Big), \\ \pi_i &= \frac{s_i^2}{\sigma} - s_j^2\big((a_j - c)q_i - (a_i - c)q_j\big). \end{aligned}$$

Totally differentiating the equilibrium share function we get that

$$\frac{ds_i}{da_i} = \frac{-\sigma s_i^2(a_i - c)\frac{\partial q_j}{\partial p_j}}{3 + \sigma(s_i(a_i - c)^2\frac{\partial q_j}{\partial p_j} + s_j(a_j - c)^2\frac{\partial q_i}{\partial p_i})},$$

which implies

$$\frac{ds_j}{da_i} = \frac{\sigma s_i^2(a_i - c)\frac{\partial q_j}{\partial p_j}}{3 + \sigma(s_i(a_i - c)^2\frac{\partial q_j}{\partial p_j} + s_j(a_j - c)^2\frac{\partial q_i}{\partial p_i})}.$$

These derivatives suggest that if firm i increases its access charge unilaterally, its market share will increase at the expense of its competitor. However, at the point of cost-based access charges both derivatives are zero.

Differentiating the equilibrium profit function, we find

$$\begin{aligned}\frac{d\pi_i}{da_i} &= 2s_i\left(\frac{1}{\sigma}+(a_i-c)q_j-(a_j-c)q_i\right)\frac{ds_i}{da_i}\\ &\quad +s_i^2\left(q_j+(a_i-c)\frac{\partial q_j}{\partial p_j}\left(s_i+(a_i-c)\frac{ds_i}{da_i}\right)-(a_j-c)^2\frac{\partial q_i}{\partial p_i}\frac{ds_j}{da_i}\right),\\ \frac{d\pi_j}{da_i} &= 2s_j\left(\frac{1}{\sigma}+(a_j-c)q_i-(a_i-c)q_j\right)\frac{ds_j}{da_i}\\ &\quad +s_j^2\left(-q_j-(a_i-c)\frac{\partial q_j}{\partial p_j}\left(s_i+(a_i-c)\frac{ds_i}{da_i}\right)+(a_j-c)^2\frac{\partial q_i}{\partial p_i}\frac{ds_j}{da_i}\right).\end{aligned}$$

Evaluated at marginal cost access prices, these simplify to

$$\frac{d\pi_i}{da_i} = s_i^2 q_j > 0. \tag{7}$$

$$\frac{d\pi_j}{da_i} = -s_j^2 q_j < 0. \tag{8}$$

This implies that, starting from the point of cost-based access prices, both firms would like to unilaterally raise the access price they charge and lower the access charge they face. Marginal cost access pricing is not a Nash equilibrium of this game. In negotiation an incumbent may be able to achieve a higher access rate than its rival, which could be used as a barrier to entry. Whether this is actually the case depends on the underlying regulations in place as well as the alternative to a negotiated outcome.[8] In general, imposing reciprocity in the case of negotiation failure guards against an incumbent using market power to obtain favorable interconnection terms.

Equations (7) and (8) also imply that starting from the point where both firms set access prices at cost, joint profits can be increased by raising the large firm's access price and lowering the small firm's access price. Since we rule out lump-sum transfers between firms (these correspond to two-part access prices), the small firm will not benefit from this collusive outcome which requires it sets an access price below cost. Rather, the small firm will prefer to have negotiations fail, at which point it is assured of the reciprocal outcome with $a = c$. Knowing this, the incumbent will agree to reciprocal access prices set at cost. Given that marginal cost pricing maximizes welfare in the model, this result further underscores the value of requiring that any interconnection fee chosen by the incumbent be applied reciprocally in case private negotiations fail.[9]

[8] Carter and Wright (1999) model the negotiation of interconnection outcomes with linear retail pricing and consider the possibility of no interconnection agreement in the event of a negotiation failure. They find that the terms of interconnection can be used as a barrier to entry in this case.

[9] In the presence of lump-sum transfers, this result also suggests there may be added value in restricting private negotiations to reciprocal agreements so to prevent firms using non-reciprocal access prices as a form of collusion. The next section, however, suggests there are also drawbacks of any such restriction.

IV. Policy Implications and Extensions

Whenever mandatory interconnection is legislated, as it was in the 1996 United States Telecommunications Act, some principle must be used to determine access prices in the case parties fail to privately negotiate terms. Our model suggests a very simple principle can achieve desirable outcomes for local exchange carrier interconnection – let the incumbent pick the access price and apply it reciprocally. The incumbent will not pick an access price above cost, since this will lead to its smaller rivals competing with high usage prices but lower rentals. The end result will be an outflow of calls from the larger firm and an access deficit. Similarly, the incumbent will not pick an access price below cost, since this will lead to its smaller rivals competing with low usage prices and higher rentals. The end result will be an inflow of calls to the larger firm, which given the below cost access prices will also imply an access deficit.

The above result was derived by extending a very stylized, albeit standard, model of network interconnection to allow for one form of asymmetry. This section discusses the likely robustness of the derived policy to a number of important practical considerations. While the discussion is very much preliminary, it suggests some reasons why the policy rule might not be appropriate, as well as how it can be made more robust to some realistic extensions of the model.

The existence of heterogeneous calling patterns may strengthen the case for the policy rule derived. In this case, if the incumbent sets a high reciprocal access price, entrants will have an incentive to set their pricing so as to attract customers who generate a lot of incoming calls, implying an incumbent will not want access prices to be above cost in the first place. The implication is that reciprocity in itself puts considerable constraints on the incumbent's ability to seek anticompetitive outcomes – whenever reciprocal access prices deviate from costs, arbitrage opportunities are created in one direction, either for the origination or termination of calls.[10]

Our model assumed costs were symmetric across firms. Where per-customer costs differ across firms, these will affect the equilibrium rentals charged by each firm in our model in exactly the same way as our brand loyalty parameter. For instance, where the incumbent has lower costs per-customer, this will have the same effect as increased brand loyalty for the incumbent, and our results will continue to hold.

In the case that the per-minute costs of originating calls differ across the two networks, it can still be shown that the reciprocal access prices based on the cost of terminating calls will be socially optimal in our model. However, in this case the firm with the higher costs of origination will set a higher per-minute retail price. This will, other things equal, lead to a net inflow of calls to the high cost firm, which will then want a reciprocal access price above the cost of terminating calls. Thus,

[10] Haring and Rohlfs (1997) use arbitrage type arguments to justify a similar policy proposal.

to the extent to which the incumbent has higher origination costs than the entrant, reciprocity alone will not constrain it from setting the access price too high.

The policy rule we derived might also not be appropriate when the per-minute costs of termination differ across the two networks, although for quite different reasons. In this case, neither reciprocity nor cost-based access prices will necessarily maximize welfare. With different costs of terminating calls, clearly reciprocity will not generally be first-best.[11] Less obviously, setting termination charges at cost will not generally maximize welfare either.

Some intuition for the welfare properties of different access prices can be obtained by noting that with access prices set at the cost of termination, per-minute retail prices will be equal.[12] However, equal per-minute retail prices are not generally welfare maximizing. When a subscriber joins the low-cost network they lower the costs of calls to them. Since under uniform pricing such subscribers will not face this reduction in costs, it might be beneficial to subsidize them. This can be achieved by having the low-cost network set a higher access price than the high-cost network. Thus, one cannot conclude that in the face of asymmetric termination costs, regulating access prices for each network at respective termination costs is necessarily better than allowing the incumbent and entrant to negotiate a non-reciprocal agreement, with the option that the incumbent picks a reciprocal access price if they cannot agree. Clearly, more analysis is needed of such situations.

One important reason for cost differences is the universal service obligations faced by the incumbent. If policy makers wish to compensate the incumbent for these obligations, this may be best addressed separately from the interconnection agreement. Our model shows that under reciprocity, a high interconnection charge will not in general provide any compensation for these obligations.

A key requirement for our model to apply is that there is two-way interconnection and firms compete over the same service for a given population.[13] Where firms offer quite different services (fixed versus mobile service), or where traffic is essentially one-way (ISP-bound call termination), the policy of allowing the larger firm to pick the reciprocal access price in the event of a breakdown of private negotiations is unlikely to be appropriate. For instance, in many countries mobile penetration is much less than 100%, and so as Wright (2002) argues, subsidizing elastic mobile subscriptions through high termination charges for inelastic fixed-to-cellular calls can be welfare enhancing. Mobile termination may also be much more costly than fixed-line termination, further explaining why reciprocity is inappropriate. Similarly, a reciprocal rate is likely to be undesirable for ISP-bound

[11] Since in the policy proposed firms are still free to negotiate non-reciprocal agreements, they should still be able to capture the efficiency gains from non-reciprocal access prices.

[12] This assumes firms set a uniform price for outgoing calls. Discriminatory on- and off-net pricing is discussed later in this section.

[13] This may explain why in many jurisdictions, incumbents appear to favor high reciprocal access charges, while entrants call for cost based rates. Where the incumbent still has a monopoly over part of the local loop, and sells access to this, it may well have an incentive to inflate the price of access above cost.

calls. These calls are not equivalent to regular local calls since they are not calls between two calling parties. Thus the principles of two-way interconnection do not apply. Rather, the above-cost termination charges for ISP-bound calls which would result from treating them reciprocally with local fixed-line calls, will lead to arbitrage opportunities for firms to specialize in terminating such calls.[14]

Throughout our analysis we assumed, in line with common practice for local calls, that firms could not set their retail prices in a discriminatory fashion. With discriminatory on and off-net retail prices the incumbent firm will no longer induce a net outflow of calls by setting an above-cost reciprocal access price. This follows because the per-minute price of off-net calls will equal $c + a$ regardless of the direction of the traffic. For this reason, the rationale for the incumbent to prefer cost-based access prices no longer applies. On the other hand, if firms set discriminatory retail prices, Gans and King (2000) have argued in the context of a model of interconnection with symmetric firms and non-linear retail pricing that firms will opt for bill and keep, in which the reciprocal access price is set at zero. To the extent to which this result also applies to asymmetric networks, it suggests our policy proposal will lead networks to agree to bill and keep, which is likely to be viewed as an acceptable outcome by policy makers.

Given that there may be more than two competing local exchange carriers requiring interconnection, the question of how to apply our results arises. The reason reciprocity constrains the anti-competitive incentives of the incumbent in our model is that both firms face the same access charges for accessing the same service. With multiple competitors, reciprocity can be interpreted in two ways. In the first way, the incumbent gets to pick an access price but this access price is that which the incumbent must also pay for the equivalent service. Under this interpretation, the reciprocal access price is applied in a non-discriminatory way across competing carriers as an option for them in the case that private negotiations fail.[15] Alternatively, reciprocity can be interpreted to mean that when the incumbent cannot agree with a particular competitor, the incumbent has the right to pick a reciprocal access charge that applies only to this competitor. This second approach puts substantially less constraints on the ability of the incumbent to obtain favorable outcomes at the expense of competitors, since under this approach the incumbent can set a low reciprocal access price for a competitor which has a net inflow of calls and a high reciprocal access price for a competitor which has a net outflow of calls. Given this, we interpret reciprocity with multiple firms to mean interconnection prices that are available on a non-discriminatory basis if firms cannot agree privately.

[14] Wright (2001) analyzes this situation.

[15] This does not prevent the incumbent agreeing on different reciprocal access rates with different competitors. However, where private negotiations fail with a particular competitor so that the incumbent gets to choose the reciprocal access rate unilaterally, we would require that the same rate be made available to all other competitors.

The time taken for facilities to be built raises another concern with giving the incumbent the right to pick the reciprocal interconnection charge. Once an entrant has invested in building a network which is optimal given a particular reciprocal access charge, the incumbent can reduce the value of the entrant's network ex-post if it can freely change the access charge. For example, suppose the entrant targets consumers who receive a lot of calls because access prices are set high initially. By lowering interconnection charges to eliminate the entrant's termination revenue from incoming calls after the entrant has built its network and customer base, the incumbent can seriously impair the entrant's profitability. This suggests that the incumbent should not be allowed to change the reciprocal access charge once set unless there are good reasons. This requirement may be stronger than necessary. Provided that entrants' anticipate such expropriation from an incumbent, they will avoid targeting an unbalanced customer base, trying instead to achieve roughly balanced traffic with the incumbent. Moreover, to the extent an incumbent faces a mix of entrants (in terms of the types of subscribers they have) and provided the non-discrimination interpretation of reciprocity is applied, the incumbent's incentive to engage in such behavior will be limited.

Although the reciprocity principle put forward would seem to be robust across a number of practical considerations, we have also noted scenarios in which giving the incumbent the right to pick the reciprocal rate unchecked is likely to be undesirable. Regulators should safeguard against such outcomes. This could be done by limiting the reciprocal access charge that incumbents can choose to lie within a reasonable range. This range is presumably bounded below by bill-and-keep. The remaining job of the regulator would then be to determine the upper limit of this range, which if chosen appropriately, would only become binding when the conditions of our benchmark model do not apply.

V. Conclusion

This paper is motivated by a simple policy question: Does the need for interconnection undermine local retail competition in a deregulated environment? We have answered this question by making an extension to the standard model of network competition with reciprocal access prices and two-part retail prices, namely allowing for asymmetry in demand (brand loyalty).

We found that introducing a small degree of asymmetry can lead to a divergence of interests between the incumbent and the entrant. In particular the incumbent (and industry) profits are maximized for access charges equal to cost, while the entrant would like a higher or lower common access charge. Given this, one way to ensure cost-based interconnection without regulatory intervention is through a simple regulation whereby if the parties cannot agree, the incumbent gets to choose the interconnection price which is then applied reciprocally. This gives all the bargaining power to the incumbent, but constrains the ability of the incumbent to use this power to anticompetitive effect by imposing the reciprocity requirement.

Because reciprocity implies the incumbent's interests coincide with society's interests, this approach is able to deliver desirable outcomes with minimal regulatory intervention and informational requirements.

To understand why our results apply, consider the incentives facing the incumbent in such a case. The only reason for it to set an above-cost reciprocal access price is if this can generate net interconnection revenue, since high per-minute prices will be offset by competition over the line rentals. If it sets the reciprocal access price higher than cost, it will face a net outflow of calls as the smaller rival firm will face a higher effective marginal cost for calls and thus set higher per-minute prices. A net outflow of calls with high reciprocal access prices lowers the incumbent's profit.

We discussed how this principle might apply more generally. We noted that an above-cost access price that is applied reciprocally Will encourage entrants to target incoming calls, and thus will often be self-defeating. By analyzing the outcomes without reciprocity, we showed that non-reciprocal terms of interconnection can still be used as a barrier to entry by the incumbent, as well as a form of collusion between networks. Despite this, cost differences may justify non-reciprocal access charges. We discussed some implications of cost differences for policy, as well as a number of other practical considerations, but left a thorough treatment of these extensions for future research.

Appendix A: Proofs of Propositions

Proof of Proposition 1

The market share of firm 1 in equilibrium satisfies the equation

$$s_1 = \frac{1}{2} + \frac{\beta}{6} + \frac{\sigma}{3}\Big(v(p_1) - v(p_2) + (a-c)\big(s_2 q(p_1) - s_1 q(p_2)\big)\Big),$$

which we can rewrite as

$$s_1 = \frac{1}{2} + \frac{\beta}{6} + \frac{\sigma}{3}\Big(v(p_1) - v(p_2) + (a-c)\Delta\Big), \tag{A.1}$$

where $\Delta = s_2 q_1 - s_1 q_2$. Using (2) and remembering that $s_2 = 1 - s_1$,

$$\begin{aligned}\frac{dp_1}{da} &= s_2 + (a-c)\frac{ds_2}{da} = s_2 - (a-c)\frac{ds_1}{da}\\ \frac{dp_2}{da} &= s_1 + (a-c)\frac{ds_1}{da}\end{aligned}$$

and

$$\frac{d\Delta}{da} = s_2\frac{dq_1}{dp_1}\frac{dp_1}{da} + q_1\frac{ds_2}{da} - s_1\frac{dq_2}{dp_2}\frac{dp_2}{da} - q_2\frac{ds_1}{da}$$

$$\begin{aligned}
&= s_2 q'(p_1)\left(s_2 - (a-c)\frac{ds_1}{da}\right) - q_1\frac{ds_1}{da}\\
&\quad -s_1 q'(p_2)\left(s_1 + (a-c)\frac{ds_1}{da}\right) - q_2\frac{ds_1}{da}\\
&= s_2^2 q'(p_1) - s_1^2 q'(p_2) - \Big(q_1 + q_2 + (a-c)\big(s_2 q'(p_1) + s_1 q'(p_2)\big)\Big)\frac{ds_1}{da}.
\end{aligned}$$

Totally differentiating (9), using (2) and $v'(p_1) = -q_1$,

$$\begin{aligned}
\frac{ds_1}{da} &= \frac{\sigma}{3}\left(v'(p_1)\frac{dp_1}{da} - v'(p_2)\frac{dp_2}{da} + (a-c)\frac{d\Delta}{da} + \Delta\right)\\
&= \frac{\sigma}{3}\left(-q_1\left(s_2 - (a-c)\frac{ds_1}{da}\right) + q_2\left(s_1 + (a-c)\frac{ds_1}{da}\right)\right.\\
&\quad \left. +(a-c)\frac{d\Delta}{da} + \Delta\right)\\
&= \frac{\sigma}{3}\left(s_1 q_2 - s_2 q_1 + (a-c)(q_1+q_2)\frac{ds_1}{da} + (a-c)\frac{d\Delta}{da} + \Delta\right)\\
&= \frac{\sigma}{3}\left(-\Delta + (a-c)(q_1+q_2)\frac{ds_1}{da} + (a-c)\frac{d\Delta}{da} + \Delta\right)\\
&= \frac{\sigma}{3}(a-c)\left(s_2^2 q'(p_1) - s_1^2 q'(p_2) - (a-c)\big(s_2 q'(p_1) + s_1 q'(p_2)\big)\frac{ds_1}{da}\right)
\end{aligned}$$

so that

$$\Big(3 + \sigma(a-c)(a-c)\big(s_2 q'(p_1) + s_1 q'(p_2)\big)\Big)\frac{ds_1}{da} = \sigma(a-c)\big(s_2^2 q'(p_1) - s_1^2 q'(p_2)\big)$$

and therefore

$$\frac{ds_1}{da} = \frac{\sigma(a-c)\big(s_2^2 q'(p_1) - s_1^2 q'(p_2)\big)}{3 + \sigma(a-c)^2(s_2 q'(p_1) + s_1 q'(p_2))}.$$

Using the identity $s_2 = 1 - s_2$,

$$\frac{ds_2}{da} = -\frac{ds_1}{da} = \frac{\sigma(a-c)\big(s_1^2 q'(p_2) - s_2^2 q'(p_1)\big)}{3 + \sigma(a-c)^2(s_1 q'(p_2) + s_2 q'(p_1))}.$$

Thus, we have that

$$\left(\frac{ds_i}{da}\right)_{a=c} = 0 \quad i = 1, 2. \tag{A.2}$$

Profits in equilibrium are given by (6)

$$\pi_i = \frac{s_i^2}{\sigma} - s_i^2(a-c)(q_i - q_j).$$

Totally differentiating with respect to the common access charge a

$$\begin{aligned}\frac{d\pi_i}{da} &= \frac{2s_i}{\sigma}\frac{ds_i}{da} - s_i^2(a-c)\left(\frac{dq_i}{dp_i}\frac{dp_i}{da} - \frac{dq_j}{dp_j}\frac{dp_j}{da}\right) \\ &\quad -s_i^2(q_i - q_j) - 2s_i(a-c)(q_i - q_j)\frac{ds_i}{da} \\ &= 2s_i\left(\frac{1}{\sigma} - (a-c)(q_i - q_j)\right)\frac{ds_i}{da} \\ &\quad -s_i^2\Big((q_i - q_j) + (a-c)\Big[\left(s_j - (a-c)\frac{ds_i}{da}\right)q'(p_i) \\ &\quad -\left(s_i + (a-c)\frac{ds_i}{da}\right)q'(p_j)\Big]\Big),\end{aligned}$$

where we again used (2). Evaluating this derivative at $a = c$ using (5) and (A.2) yields

$$\left(\frac{d\pi_i}{da}\right)_{a=c} = 0, \quad i = 1, 2. \tag{A.3}$$

Thus $a = c$ satisfies the first-order condition for maximizing the equilibrium profits of both networks.

Differentiating again and evaluating at $a = c$, we find that

$$\begin{aligned}\left(\frac{d^2 s_i}{da^2}\right)_{a=c} &= \frac{\sigma}{3}\left(s_j^2 q'(p_i) - s_i^2 q'(p_j)\right), \\ \left(\frac{d^2\pi_i}{da^2}\right)_{a=c} &= s_i q'(p_i)\left(4s_i^2 - \frac{10}{3}s_i + \frac{2}{3}\right).\end{aligned}$$

We note that the term in brackets is negative if and only if $\frac{1}{3} < s_i < \frac{1}{2}$, so that

$$\left(\frac{d^2\pi_i}{da^2}\right)_{a=c} \begin{cases} > 0 & \text{if } \frac{1}{3} < s_i < \frac{1}{2} \\ = 0 & \text{if } s_i = \frac{1}{2}. \\ < 0 & \text{otherwise} \end{cases}$$

Proof of Proposition 2

We measure total surplus as

$$TS = PS + CS + B,$$

where producer surplus is

$$PS = \pi_1 + \pi_2,$$

consumer surplus from phone calls is

$$CS = s_1(v_1 - r_1) + s_2(v_2 - r_2)$$

and network specific benefits are

$$\begin{aligned} B &= \int_0^{s_1} \frac{\beta}{2\sigma} + \frac{1-x}{2\sigma} dx + \int_{s_1}^{1} \frac{x}{2\sigma} dx \\ &= \frac{0.5 + (1+\beta)s_1 - s_1^2}{2\sigma} \end{aligned}$$

From (11), we observe that

$$\left(\frac{d\pi_1}{da}\right)_{a=c} + \left(\frac{d\pi_2}{da}\right)_{a=c} = 0$$

so that $a = c$ satisfies the first-order condition for a maximum of producer surplus $\pi_1 + \pi_2$. Further, $a = c$ satisfies the second-order condition for a maximum since

$$\left(\frac{d^2\pi_1}{da^2}\right)_{a=c} + \left(\frac{d^2\pi_2}{da^2}\right)_{a=c} = \frac{16}{3}\frac{\partial q}{\partial p}\left[s^2 - s + \frac{1}{4}\right] \tag{A.4}$$

is negative for all $0 \leq s \leq 1$, except when $s = \frac{1}{2}$ (where it is zero). Thus, producer surplus is maximized when the access charge is set equal to cost.

Differentiating consumer surplus gives

$$\begin{aligned} \frac{dCS}{da} &= \frac{ds_1}{da}(v_1 - r_1) + \frac{ds_2}{da}(v_2 - r_2) - s_1\left(q_1\frac{dp_1}{da} + \frac{dr_1}{da}\right) \\ &\quad -s_2\left(q_2\frac{dp_2}{da} + \frac{dr_2}{da}\right) \end{aligned}$$

Note that

$$\frac{dp_i}{da} = s_j + \frac{ds_j}{da}(a - c)$$

and

$$\begin{aligned} \frac{dr_i}{da} &= \frac{1}{\sigma}\frac{ds_i}{da} - (a-c)q_i\frac{ds_j}{da} - s_j q_i - s_j(a-c)\frac{\partial q_i}{\partial p_i}\frac{dp_i}{da} \\ &\quad -\left(\frac{ds_i}{da} - \frac{ds_j}{da}\right)(a-c)(q_i - q_j) - (s_i - s_j)(q_i - q_j) \\ &\quad -(s_i - s_j)(a-c)\left(\frac{\partial q_i}{\partial p_i}\frac{dp_i}{da} - \frac{\partial q_j}{\partial p_j}\frac{dp_j}{da}\right) \end{aligned}$$

Since when $a = c$, $\frac{ds_i}{da} = 0$ and $q_i = q_j$, we get that

$$\left(\frac{dCS}{da}\right)_{a=c} = -s_1(q_1 s_2 - s_2 q_1) - s_2(q_2 s_1 - s_1 q_2) = 0.$$

Twice differentiating consumer surplus implies

$$\begin{aligned}\frac{d^2CS}{da^2} = {} & \frac{d^2 s_1}{da^2}(v_1 - r_1) + 2\frac{ds_1}{da}\left(-q_1\frac{dp_1}{da} - \frac{dr_1}{da}\right) + \frac{d^2 s_2}{da^2}(v_2 - r_2) \\ & +2\frac{ds_2}{da}\left(-q_2\frac{dp_2}{da} - \frac{dr_2}{da}\right) - s_1\left(\frac{\partial q_1}{\partial p_1}\left(\frac{dp_1}{da}\right)^2 + q_1\left(\frac{d^2 p_1}{da^2}\right)\right. \\ & \left. +\frac{d^2 r_1}{da^2}\right) - s_2\left(\frac{\partial q_2}{\partial p_2}\left(\frac{dp_2}{da}\right)^2 + q_2\left(\frac{d^2 p_2}{da^2}\right) + \frac{d^2 r_2}{da^2}\right).\end{aligned}$$

Note that

$$\left(\frac{d^2 p_i}{da^2}\right)_{a=c} = 0$$

and

$$\left(\frac{d^2 r_i}{da^2}\right)_{a=c} = \frac{1}{\sigma}\left(\frac{d^2 s_i}{da^2}\right)_{a=c} + 2s_i^2\frac{\partial q}{\partial p} - 4s_i s_j\frac{\partial q}{\partial p}.$$

Since when $a = c$, $d^2 s_i/da^2 = \frac{\sigma}{3}(s_j^2 - s_i^2)\frac{\partial q}{\partial p}$, we get that

$$\begin{aligned}\left(\frac{d^2CS}{da^2}\right)_{a=c} = {} & \frac{\partial q}{\partial p}\left[-\frac{\beta}{9}(s_2^2 - s_1^2) + s_1\left(-\frac{4}{3}s_2^2 - \frac{5}{3}s_1^2 + 4s_1 s_2\right)\right. \\ & \left. +s_2\left(-\frac{4}{3}s_1^2 - \frac{5}{3}s_2^2 + 4s_1 s_2\right)\right], \qquad \text{(A.5)}\end{aligned}$$

which is negative provided β is not too large. Moreover,

$$\left(\frac{dB}{da}\right)_{a=c} = 0$$

and

$$\left(\frac{d^2 B}{da^2}\right)_{a=c} = \frac{\beta}{9}(s_2^2 - s_1^2)\frac{\partial q}{\partial p} > 0 \qquad \text{(A.6)}$$

for β positive.

Combining Equations (A.4), (A.5) and (A.6), it follows that

$$\left(\frac{d^2TS}{da^2}\right)_{a=c} = \frac{\partial q}{\partial p}\left(-\frac{5}{3}s_1^3 - \frac{5}{3}s_2^3 + \frac{8}{3}s_1^2 s_2 + \frac{8}{3}s_1 s_2^2 + \frac{16}{3}s_1^2 - \frac{16}{3}s_1 + \frac{16}{12}\right)$$
$$= \frac{1}{3}\frac{\partial q}{\partial p}\left(-7s_1^2 + 7s_1 - 1\right)$$
$$= \frac{1}{12}\frac{\partial q}{\partial p}\left(3 - \frac{7}{9}\beta^2\right).$$

Since

$$\left(\frac{dTS}{da}\right)_{a=c} = 0,$$

this implies that cost-based access charges are (locally) welfare maximizing provided $\beta < \sqrt{\frac{27}{7}} \simeq 1.964$.

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