Pricing Access in Network Competition*

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Abstract

We compare various access pricing rules in the two-way access model. We show that the Generalized Efficient Component Pricing Rule leads to a lower equilibrium price than does the Efficient Component Pricing Rule, marginal cost pricing, and any non-negative fixed access charges.

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I. INTRODUCTION

Due to technological advances, substantial changes have occurred in telecommunications over the last decade. All stages of production, including local network service, which was long thought to be a natural monopoly, are now open to competition. Now that interconnection between competing networks is mandatory, networks must negotiate to gain access to each other. Such a two-way access problem differs considerably from the conventional, one-way access problem, where an integrated monopolist alone owns the essential facility and any entrant must acquire access to it in order to compete with the monopolist. In the one-way access case, regulatory concerns focus on how to enable entrants to compete without being handicapped by the incumbent's reluctance to provide access to its network at a reasonable price. However, in the two-way access case, competing networks do have their own facility. They require access to the rival's network to compete for network subscribers. The danger is not so much one of foreclosure, as in the one-way pricing case, but of collusion between networks. Naturally, the crux of the matter is how access charges affect market competition.

Armstrong (1998) and Laffont, Rey, and Tirole (1998) first identified the problem that competing networks might use a high access charge as a collusive device. Since the seminal work of Laffont *et al*. (1998), several authors have examined whether interconnected networks can use access charges to facilitate collusion in different models. For example, Dessein (2003) finds that it is difficult to collude using the access charge in non-linear pricing. Hahn (2004) considers two-part tariffs with heterogeneous consumers and shows that, under certain conditions, firms' profit is independent of access charges and thus collusion using access charges is not sustainable. Berger (2004) shows that even below-cost access charges may be used as a collusive device in discriminatory pricing in the presence of a call externality. Yet no consensus has been reached on optimal two-way access fees.

In this paper, using the framework of Laffont *et al*. (1998), we analyze the structure of access pricing rules that induce collusive market prices, and identify the structure of pro-competitive access pricing rules in a two-way access problem. We find that the access charge may be used as a collusive device if high access charges inflate retail prices. Thus, an efficient access pricing rule must not inflate retail prices. We show that the Generalized Efficient Component Pricing Rule (GECPR) exhibits such a property, and induces a highly pro-competitive outcome for a wide range of parameters. The GECPR dominates the Efficient Component Pricing Rule (ECPR), marginal cost pricing (MCP), and any non-negative fixed access charges in terms of efficiency.

The ECPR, which determines access charges based on the incumbent's opportunity cost of providing access to a competitor, was originally developed in the context of a one-way access model. While the ECPR in general ensures efficient entry, it does not necessarily result in efficiency in the retail market unless the retail price is also regulated.[1] Economides and White (1995) recommend caution in using the ECPR, since, if the incumbent is more efficient than entrants, no entry occurs with the ECPR, even though such entry might provide beneficial competition. Laffont *et al*. (1998) show that the ECPR is not efficient in a two-way access problem either. The ECPR yields perfect collusion, as each network sets the access price to induce the monopoly price.

The GECPR resembles the ECPR in that it also determines access charges based on the incumbent's opportunity cost. But the GECPR measures the opportunity cost in terms of the entrants' retail price instead of the incumbent's retail price. The GECPR was also initially developed in the context of the one-way access problem. Sibley *et al.* (2004) introduce the GECPR and compare it with MCP in terms of efficiency. They find that, if entrants are more efficient than the incumbent, the GECPR dominates MCP regardless of whether the competition is à la Bertrand, Cournot, or monopolistic. In all cases, in equilibrium under the GECPR, an efficient entrant produces at the price equal to the incumbent's marginal cost of production. In Bertrand and Cournot equilibrium, the incumbent exits the market and simply earns access revenue. However, if the entrant is less efficient than the incumbent, the GECPR cannot induce potentially beneficial entry without a government subsidy. Moreover, if the entrant is inefficient, in quantity competition, MCP may lead to lower production costs than the GECPR does.

[1] There is abundant literature on the efficiency of the ECPR in the one-way access case. A detailed discussion of the efficiency of the ECPR can be found in Economides and White (1995), Armstrong et al (1996), and Larson (1998), for example.

In this paper, we introduce the GECPR into the two-way access problem. This paper makes a unique contribution to the literature for two reasons. First, we provide a general condition for an anti-competitive access rule in the two-way access problem. Second, we provide an explanation for why the GECPR is more efficient than most access pricing rules in the two-way access problem. Our analysis may help policymakers set optimal two-way interconnection fees.

The reason the GECPR is highly efficient in the two-way access case is two-pronged. First, under the GECPR, networks cannot use the access charge as an instrument of collusion. Networks cannot directly control the access charge because it depends on the rival network's price. Second, and more importantly, under the GECPR, it is costly for networks to increase their retail price, since they must make higher access *payments* if they do so. This intensifies competition as networks competitively lower their prices in order to increase their market share and lower their access payments. The GECPR generates a lower equilibrium price than does MCP, the ECPR, and any non-negative fixed access charges, under which networks' access *revenue* is proportional to their own retail price.

We find that some below-cost access charges, including bill-and-keep (zero access charges), are also effective in promoting competition.[2] However, a considerably high marginal cost of termination and a low degree of substitution between network services are required for such access charges to be more efficient than the GECPR. In a competitive market, if the marginal cost is negligible, the GECPR is more likely to dominate below-cost access charges.

This paper proceeds as follows. Section II describes the network competition model and the Ramsey benchmark case. Section III explains the structure of the GECPR and specifies the symmetric equilibrium. Section IV compares the GECPR with the ECPR, MCP, and negotiated fixed access charges in terms of efficiency. The last section concludes.

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[2] Bill-and-keep is a commonly observed practice owing to the savings in transaction costs. Several authors have studied whether bill-and-keep is anti-competitive. See Gans and King (2001), Cambini and Valletti (2003), and Berger (2005), for example.

II. THE MODEL AND THE RAMSEY BENCHMARK

We use the same framework as Laffont *et al*. (1998). Consider two full-coverage networks, 1 and 2, with the same cost structure. To serve customers, networks must incur a fixed cost f. The marginal cost of originating or terminating a call is c_0, and the marginal trunk cost of a call is c_1. Thus, the total marginal cost of a call is $c \equiv 2c_0 + c_1$.

The networks are differentiated à la Hotelling. Consumers are uniformly located on an interval $[0,1]$ and the two networks are located at the end of the interval, i.e. $x_1 = 0$ and $x_2 = 1$. Given income y, a consumer located at *x* and joining network *i* has utility of $y + v_0 - t\,|\,x - x_i\,| + u(q)$ from consuming q calls, where v_0 represents reservation utility from being connected to either network, $t\,|\,x - x_i\,|$ denotes the cost of being connected to network *i*, and the variable gross surplus *u(q)* is given by $u(q) = \frac{q^{1-(1/\eta)}}{1-1/\eta}$, which yields $u'(q) = p, q = p^{-\eta}$. We assume that $\eta > 1$. For a given p (price per call), the consumer's indirect utility from calling is $v(p) = \max_q\{u(q) - pq\} = \frac{p^{-(\eta-1)}}{\eta - 1}$. We also assume that v_0 is large enough that all consumers choose to be connected to a network.

For given p_1 and p_2 charged by the two networks, a consumer located at $x = \alpha$ is indifferent between the two networks if and only if $v(p_1) - t\alpha = v(p_2) - t(1-\alpha)$. This determines the market share of each network. Let $\alpha_1 = \alpha$ and $\alpha_2 = 1 - \alpha$ be the two networks' market shares. Then $\alpha \equiv \alpha(p_1, p_2)$ $= \frac{1}{2} + \sigma[v(p_1) - v(p_2)]$, where $\sigma \equiv \frac{1}{2t}$ is the degree of substitution between the two networks.

The Ramsey price maximizes consumer welfare under the constraint that the industry breaks even. A symmetric Ramsey solution $p_1 = p_2 = p^R$ is the lowest price satisfying the budget constraint $(p^R - c)q(p^R) = f$. On the other hand, a monopoly price p^M solves $Max_p\,(p - c)q(p)$, which yields $p^M \equiv \frac{\eta c}{\eta - 1}$. By assumption, the Ramsey price is lower than the monopoly price.

III. EQUILIBRIUM UNDER GECPR

The GECPR is not a fixed price, but a rule that determines the access price from the opportunity cost to the access provider in terms of the *entrant's* retail price instead of the *incumbent's* retail price. That is, network *i*'s access charge to network *j* is

$$a_i = p_j - (c_0 + c_1), \quad i, j = 1, 2, i \neq j. \qquad (1)^{3,4}$$

Under the GECPR, the game consists of the following three stages. In stage 1, the regulator announces the access rule. In stage 2, the networks simultaneously choose their prices. At the end of stage 2, the retail prices are realized. In stage 3, the regulator enforces the access payments according to the rule.

With the symmetry in cost structure,[5] network *i*'s profit function is

$$\pi_i(p_1, p_2) = \underbrace{\alpha_i(p_1, p_2)\{(p_i - c)q_i - f\}}_{A} + \underbrace{\alpha_i(p_1, p_2)\alpha_j(p_1, p_2)\{(a_i - c_0)q_j - (a_j - c_0)q_i\}}_{B}. \qquad (2)$$

Under the assumption of balanced calls, the amount of calls made across networks, i.e. off-net calls, is proportional to the size of the networks. Hence, a fraction α_i of consumers subscribe to network *i* and make $\alpha_i\alpha_j$ calls to the consumers in network *j*. Part A is network *i'*s retail revenue, $\alpha_i^2[(p_i - c)q_i - f]$, from on-net calls and $\alpha_i\alpha_j[(p_i - c)q_i - f]$ from originating off-net calls. Part *B* is the access revenue/deficit, which varies as the access pricing rule changes. Plugging $a_i = p_j - (c_0 + c_1)$ into the profit function, we obtain

$$\begin{aligned}\pi_i(p_1, p_2) &= \alpha_i(p_1, p_2)\{(p_i - c)q_i - f\} + \alpha_i(p_1, p_2)\alpha_j(p_1, p_2)\{(p_j - c)q_j - (p_i - c)q_i\} \\ &= \alpha_i^2\{R(p_i) - f\} + \alpha_i(1 - \alpha_i)\{R(p_j) - f\}\end{aligned} \qquad (3)$$

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[3] Originally, in Sibley *et al.* (2004), the GECPR takes the form of $a_i = Max[p_j - (c_0 + c_1), c_0], \quad i, j = 1, 2, i \neq j$, with a lower bound at c_0 to guarantee that the incumbent does not incur losses from providing access to the entrant. In this paper, the lower bound of the access price is dropped, first because a below-cost access charge is not a problem in the two-way access model as it is in the one-way access model, and second because it is interesting to see whether networks would charge access below cost in the two-way access case.

[4] While this rule does not exactly "generalize" the ECPR, we call it by the name it is given in Sibley *et al.* (2004).

[5] For simplicity, we consider only the symmetric cost structure. The major results under the symmetric cost structure continue to hold under the asymmetric cost structure.

where $R(p_i) \equiv (p_i - c)q_i$ and $R(p_j) \equiv (p_j - c)q_j$. When networks are substitutable, $\sigma \neq 0$, the first-order condition at the symmetric solution for each network is

$$-\sigma q_i \left[R(p_i) - f\right] + \alpha_i^2 \left[\frac{\partial R_i}{\partial p_i}\right] = 0. \tag{4}$$

Since $-\sigma q_i \left[R(p_i) - f\right]$ is negative for $p > p^R$ and $\alpha_i^2 \left[\partial R_i / \partial p_i\right]$ is positive (negative) for $p < p^M$ ($p > p^M$), the left-hand side of (4) is always positive if $p < p^R$, but negative if $p > p^M$. Thus, the symmetric equilibrium $p*$ must satisfy $p^R \leq p* \leq p^M$. Solving (4), we get the symmetric equilibrium.

PROPOSITION 1. *For any σ, there exists a unique, symmetric equilibrium characterized by $p_1 = p_2 = p*$, $p^R \leq p* \leq p^M$, and $p*$ satisfies $\frac{(p^* - c)}{p^*} = \frac{1}{\eta}\left[1 - 4\sigma\pi(p^*)\right]$, where $\pi(p*) = (p* - c)q(p*) - f$ is per-customer profits.*[6]

PROOF: See the Appendix.

Since $p^R \leq p* \leq p^M$, $\pi(p*)$ is nonnegative. As $\sigma \to 0$, $p*$ converges to p^M. As $\sigma \to \infty$, $p*$ converges to p^R.

IV. PRO-COMPETITIVE EFFECT OF GECPR

The GECPR was designed in the context of the one-way access problem. Although Sibley *et al.* (2004) prove that the GECPR can be more efficient than MCP in the one-way access case, it is uncertain how efficient the GECPR would be in a two-way access framework, since the nature of competition and the role of access rule in the two-way access case fundamentally differ from those in the one-way access case.

In the one-way access case, an integrated monopolist alone owns the essential facility and any entrant must acquire access to it in order to compete with the monopolist. In the two-way access case, however, interconnection of networks is mandatory. All the networks must negotiate to gain access to rivals' network to compete for market share. In this case, the danger is not so much one of foreclosure as

[6] The non-existence of equilibrium in a market with a large σ is a non-trivial problem in the case of negotiated fixed access charges or the ECPR as shown by Laffont *et al.* (1998). Under the GECPR, however, the non-existence problem disappears and equilibrium exists for *any* σ. The proof of the existence of equilibrium is available in the appendix.

in the one-way access case, but of collusion between networks. Laffont *et al*. (1998) find that negotiated fixed access charges and the ECPR soften competition. Under these rules, a high access charge is a commitment to charge a high retail price, and thus, networks use the access charge as an instrument of tacit collusion. Equilibrium features high prices inflated by high access charges.

In contrast, under the GECPR, a network cannot directly control its access charge, since the access charge depends on the rival network's price.[7] Obviously, in this case, the access charge cannot be used as a device to promote tacit collusion.[8]

PROPOSITION 2. *Under the GECPR, networks are unable to use their access charge as a collusive device to induce higher retail prices.*

According to the GECPR, networks have to make high access payments to their rival network if they set a high retail price. Given this effect, networks are inclined to lower their price. The following proposition states that the GECPR dominates the ECPR, MCP, and any non-negative fixed access charges in terms of efficiency. Moreover, the GECPR is more efficient than below-cost fixed access charges when c_0 is small and/or σ is large.

PROPOSITION 3. The *GECPR induces a lower equilibrium price than does MCP, the ECPR, and any non-negative fixed access charges. The GECPR also dominates below-cost fixed access charges if* $\frac{(\eta-1)}{\eta}\left(p^M - p_{GECPR}\right) > (c_0 - a)$.

PROOF: Assume that there exists a symmetric equilibrium under each pricing rule and that, in equilibrium, the second-order condition is satisfied. Under the GECPR, the symmetric equilibrium satisfies

$$\phi_{GECPR}(p_i) = \mathrm{Z}(p_i) - (\tfrac{1}{4})[R'(p_i)] = 0, \qquad (5)$$

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[7] In the one-way access case, the fact that the entrant's price determines the access charge implies that the incumbent has no ability to foreclose entry, other things being equal. The foreclosure of entry occurs only if there is intense competition, such as Bertrand competition, in the final goods market, and the entrant is not efficient enough to survive. To avoid the problem that the GECPR may deter entry that enhances competition when the entrant is inefficient, Sibley *et al.* (2004) consider a government subsidy to guarantee entry.

[8] This incentive structure is similar to the one generated by the yardstick mechanism by Schleifer (1985) in that both the GECPR and the yardstick mechanism specify that the monopolist's decision variable depends on its competitor's cost.

where $Z(p_i) \equiv -\sigma q_i[R(p_i)-f]+(1/2)[R'(p_i)]$. Under MCP, $a_i = c_0$, and thus, $\pi_i(p_{1,}p_2)=\alpha_i[(p_i-c)q_i-f]$.

The symmetric equilibrium satisfies

$$\phi_{MCP}(p_i)=Z(p_i)=0. \tag{6}$$

Under the ECPR, $a_i = p_i-(c_0+c_1)$, and thus, $\pi_i(p_{1,}p_2)=\alpha_i[(p_i-c)q_i-f]+\alpha_i\alpha_j[(p_i-c)q_j-(p_j-c)q_i]$.

The symmetric equilibrium satisfies

$$\phi_{ECPR}(p_i)=Z(p_i)+1/4\left(q_j-(p_j-c)(\tfrac{\partial q_i}{\partial p_i})\right)=0. \tag{7}$$

Under reciprocal fixed access charges, $a \gtreqless c_0$, $\pi_i(p_{1,}p_2)=\alpha_i\left[(p_i-c)q_i-f\right]+\alpha_i\alpha_j\left[(a-c_0)q_j-(a-c_0)q_i\right]$. The symmetric equilibrium satisfies

$$\phi_{FA}(p_i)=Z(p_i)+\frac{1}{4}[\eta(a-c_0)(\frac{q_i}{p_i})]=0. \tag{8}$$

Let p_{GECPR}, p_{MCP}, p_{ECPR}, and p_{FA} be the prices satisfying (5), (6), (7), and (8), respectively. Since $p^R \le p_{GECPR} \le p^M$ from Proposition 1, $R(p_{GECPR})-f \ge 0$ and $R'(p_{GECPR}) \ge 0$. (i) Plugging p_{GECPR} into (6) we have, $\phi_{MCP}(p_{GECPR})=1/4 R'(p_{GECPR})>0$. Since $\phi_{MCP}(p_{MCP})=0$ and $\phi_{MCP}'(p_i)<0$, the condition that $\phi_{MCP}(p_{GECPR})>0$ implies $p_{GECPR}<p_{MCP}$. (ii) Plugging p_{MCP} into (7), we get $\phi_{ECPR}(p_{MCP})$ $=1/4[q_{MCP}+\eta(p_{MCP}-c)(q_{MCP}/p_{MCP})]>0$. Since $\phi_{ECPR}(p_{ECPR})=0$ and $\phi_{ECPR}'(p_i)<0$, the condition that $\phi_{ECPR}(p_{MCP})>0$ implies $p_{MCP}<p_{ECPR}$. Since $p_{GECPR}<p_{MCP}$, $p_{GECPR}<p_{ECPR}$. (iii) For $a \ge c_0$, plugging p_{GECPR} into (8), we have $\phi_{FA}(p_{GECPR})$ $=1/4[R'(p_{GECPR})]+1/4[\eta(a_j-c_0)(q_{GECPR}/p_{GECPR})]>0$. Since $\phi_{FA}(p_{FA})=0$ and $\phi_{FA}'(p_i)<0$, the condition that $\phi_{FA}(p_{GECPR})>0$ implies $p_{GECPR}<p_{FA}$. (iv) For $a<c_0$, plugging p_{GECPR} into (8), we have $\phi_{FA}(p_{GECPR})$ $=1/4\{R'(p_{GECPR})-\eta(c_0-a_j)(q_{GECPR}/p_{GECPR})\}$. If $\phi_{FA}(p_{GECPR})>0$, it implies $p_{GECPR}<p_{FA}$. $\phi_{FA}(p_{GECPR})$ is positive if and only if

$$\eta c-(\eta-1)p_{GECPR}>\eta(c_0-a)>0 \Leftrightarrow \frac{(\eta-1)}{\eta}\left(p^M-p_{GECPR}\right)>(c_0-a).$$

This condition is likely to hold if c_0 is small and/or σ is large since $p_{GECPR} \to p^R$ as $\sigma \to \infty$. *Q.E.D.*

For any given access pricing rule, network i's profit function is characterized by $\pi_i(p_1, p_2) = \alpha_i(p_1, p_2)\{R(p_i) - f\} + \text{net access revenue}$. At the symmetric equilibrium,

$$\phi(p_i) = -\sigma q_i[R(p_i) - f] + \tfrac{1}{2}R'(p_i) + \left(\partial[\text{net access revenue}]/\partial p_i\right) = 0 .$$

Under MCP, a change in a network's retail price does not affect the network's net access revenue, i.e. $\left(\partial[\text{net access revenue}]/\partial p_i\right) = 0.$ This implies that, under an access rule with the property that $\left(\partial[\text{net access revenue}]/\partial p_i\right) > 0$, the equilibrium price is higher than that of MCP. That is because networks are encouraged to set a higher retail price under such an access rule, as they can earn higher net access revenue from doing so. Therefore, such a pricing rule inflates the retail price. In contrast, under the GECPR, $\left(\partial[\text{net access revenue}]/\partial p_i\right) < 0$. That is, networks have to pay more for access to the rival's facility if they set a higher retail price. This effect makes networks less prone to set a high retail price. Table 1 summarizes how each access pricing rule interacts with networks' pricing strategy.

Table 1: Pricing Strategy and Access Rules

	ACCESS CHARGES	$\left(\partial[\text{net access revenue}]/\partial p_i\right)$
GECPR	$a_i = p_j - (c_0 + c_1),$	$-\frac{1}{4}\left(\frac{\partial R_i}{\partial p_i}\right) < 0$
MCP	$a_i = c_0$	0
ECPR	$a_i = p_i - (c_0 + c_1)$	$\frac{1}{4}\left(q_j - (p_j - c)(\frac{\partial q_i}{\partial p_i})\right) > 0$
$a \geq c_0$	a	$\frac{1}{4}\left(-(a - c_0)(\frac{\partial q_i}{\partial p_i})\right) > 0$
$a < c_0$	a	$\frac{1}{4}\left(-(a - c_0)(\frac{\partial q_i}{\partial p_i})\right) < 0$

While positive fixed access charges $a > c_0$ inflate the retail price, below-cost fixed access charges $a < c_0$ can be pro-competitive. Laffont *et al*. (1998) find that market price can be reduced to the level of the Ramsey price if the fixed access charge is mandated at $a^R = c_0 - 2\frac{(\eta - 1)}{\eta}\left(p^M - p^R\right) < c_0$. The socially optimal *fixed* access charge lies strictly below marginal cost c_0.[9] However, a^R may not be feasible in many cases.

[9] Several earlier works document the idea of setting access price below marginal cost to offset market power. See Panzar and Sibley (1989), Armstrong *et al.* (1996), Armstrong and Vickers (1998), and Vickers (1995), for example.

Given that a is bounded below by zero in practice, for $\eta > 2$, c_0 has to be greater than $\left(p^M - p^R\right)$ in order for the optimal access charge to exist. That is, for $\eta > 2$, a^R exists only for a large enough c_0.[10]

Networks' widespread bill-and-keep arrangement corresponds to the zero access charge (the lowest below-cost fixed access charge). Proposition 3 implies that bill-and-keep can be more efficient, than the GECPR if $\frac{(\eta-1)}{\eta}\left(p^M - p_{GECPR}\right) \leq c_0$. In this case, bill-and-keep is the most efficient as it induces at least as low a price as does the GECPR at no transaction costs.[11] However, if the market is highly competitive and/or the marginal cost of terminating calls is negligible, the GECPR is likely to dominate bill-and-keep in terms of efficiency, since ${(\eta-1)}/{\eta}\left(p^M - p_{MECPR}\right)$ grows as $\sigma \to \infty$, and thus, it is more likely that $\frac{(\eta-1)}{\eta}\left(p^M - p_{GECPR}\right) > c_0$.

V. CONCLUSION

This paper examines the efficiency of the GECPR in the two-way access problem. The analysis concludes that the GECPR prevents access charges from being used as an instrument for collusion, enhances competition, and creates an incentive for networks to lower their retail prices through access charges. If the marginal cost of termination is not so high, the GECPR is likely to dominate below-cost fixed access charges, including bill-and-keep, especially in a highly competitive market.

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10 Implementing a^R is informationally demanding, since it requires information about σ, η, f, c_0, c, and p^R. Clearly, an access rule that requires a lot of information costs also requires a lot of transaction costs because, in order to enforce such a rule, administrators need to take much administrative action to verify appropriate access payments. For this reason, the transaction costs of the GECPR can never be greater than those of the ECPR, MCP, or any non-zero fixed access charges, at the least. Under the GECPR, a network's access payment is proportional to the size of the network's market share and profit. That is, network i's access payment to network j is $\alpha_i \alpha_j (p_i - c) q_i$. In order to enforce the payments, administrators simply need to look at whether appropriate amounts of access payments were made based on the reported profits of networks and their market shares, both of which are easily observable and *verifiable*. Given that all the other transaction costs are common to the GECPR, the ECPR, MCP, and non-zero fixed charges, the GECPR is more attractive than the ECPR, MCP, and non-zero fixed access charges, as it requires no costs of monitoring networks to verify detailed components of their profits.

11 Cambini and Valletti (2003) show that bill-and-keep may be beneficial because of its positive impact on investments in quality prior to the competition stage. In Gans and King (2001), in contrast, bill-and-keep may be used to soften competition.

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APPENDIX

PROOF OF PROPOSITION 1

A few preliminary lemmas are useful for the subsequent proofs of the existence and uniqueness of equilibrium.

LEMMA 1. *There exists no "cornered-market" equilibrium.*

PROOF: Suppose $\alpha_1=1$ and thus $p_1<p_2$ and $\pi_2=0$. p_1 has to be greater or equal to p^R. Otherwise, network 1 earns negative profits. For $p_1 \geq p^R$, network 2 can always find a price $p_1+\varepsilon$, $\varepsilon \geq 0$ earning positive market share and positive profits. Therefore, there is no cornered market equilibrium. *Q.E.D.*

LEMMA 2. *If (p_1,p_2) is an asymmetric equilibrium with $p_1<p_2$, then $p_2 > p^M$.*

PROOF: Given (p_1,p_2), the equilibrium profit for each network is

$$\pi_i(p_1, p_2) = \alpha_i[\, R(p_i) - f] + \alpha_i\, \alpha_j\, [(p_j-c)\, q_j - (p_i-c)\, q_i\,].$$

This equilibrium profit must be greater than what network i can earn when it matches its price to the rival's price. That is,

$$\pi_i(p_1, p_2) \geq 1/2[\, R(p_j) - f] \qquad i = 1,2,\ i \neq j.$$

Adding the two equations and plugging the definition of $\pi_i(p_1, p_2)$ yield

$$(1/2- \alpha_2)\ [\, R(p_1) - R(p_2)\,] \geq 0.$$

Since $p_1<p_2$, $\alpha_2 < ½$, and $R(\cdot)$ is strictly quasi-concave, $p_2 > p^M$. *Q.E.D.*

LEMMA 3. *If (p_1, p_2) is an equilibrium, then p_i cannot be lower than the Ramsey price or higher than the monopoly price. That is, $p^R \leq p_i \leq p^M$, $i=1,2$.*

PROOF: From Lemma 1, in equilibrium, each network earns a positive market share, i.e. $\alpha_i > 0$, i=1,2.

(1) Equilibrium prices cannot be lower than the Ramsey price.

Suppose $p_1 < p^R$. It must be the case that $p_1 < p^R < p_2$ where network 1 earns positive access revenue. Otherwise, network 1 earns negative profits. Then, $\alpha_1 > ½$ and $R_2 > R_1$. Network 1's profits at (p_1, p_2) should be greater than the profits that it could have earned by matching the rival's price. That is,

$$\pi_1(p_1, p_2) = \alpha_1[R(p_1) - f] + \alpha_1 \alpha_2 [(p_2 - c)q_2 - (p_1 - c)q_1] \geq ½[R(p_2) - f]$$

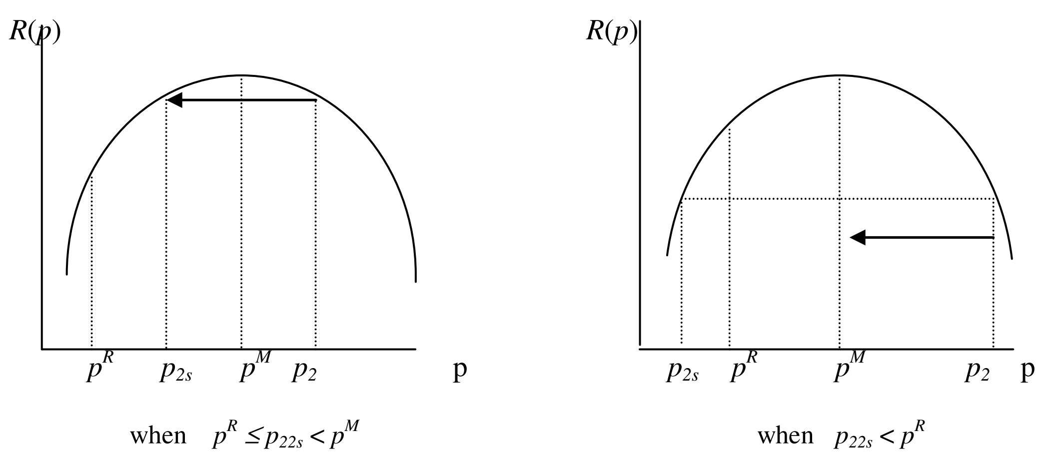
$$\Leftrightarrow \pi_1(p_1, p_2) = \alpha_1[R(p_1) - f] + \alpha_1 \alpha_2 [R(p_2) - f - \{R(p_1) - f\}] \geq ½[R(p_2) - f]$$

$$\Leftrightarrow \alpha_1^2[R(p_1) - f] + (\alpha_1 \alpha_2 - ½)[R(p_2) - f] \geq 0$$

The inequality contradicts since $R_1 - f < 0 < R_2 - f$ and $\alpha_1 \alpha_2 < ½$.

(2) Equilibrium prices cannot be higher than the monopoly price.

(i) In equilibrium, at least one network charges its price below or equal to the monopoly price. Suppose that $p_1 > p^M$, $p_2 > p^M$ and that network 2 gets α_2 of market share at (p_1, p_2). Network 2 earns $\pi_2(p_1, p_2) = \alpha_2[(1-\alpha_1)R(p_2) - f] + \alpha_1 \alpha_2 [(p_1 - c)q_1]$. Since $R(p) - f$ is symmetric around p^M, there exists a price $p_{2s} < p^M$ that yields the level of revenue $R(p_{2s}) - f = R(p_2) - f$, but with a higher market share $\alpha_{2s} > \alpha_2$. If $p^R \leq p_{2s} < p^M$, network 2 can always do better by deviating to p_{2s}. If $p_{2s} < p^R$, network 2 can always do better by lowering its price to p^M since $R'(p) = (\eta - 1)p^{-\eta-1}[\frac{\eta c}{\eta - 1} - p] < 0$ for $p > p^M$. The following graphs illustrate the profitable deviations by network 2.



(ii) In equilibrium, $p_1 > p^M \geq p_2$ cannot be true. From (i), $p^R \leq p_2 \leq p^M$ if $p_1 > p^M$. For network 1 to set $p_1 > p^M$ in equilibrium, it must be true that the profit at p^M is lower than the profit at p_1. That is,

$$\pi_1(p_1, p_2) = \alpha_1[\, R(p_1) - f] + \alpha_1\, \alpha_2\, [(p_2\text{-}c)\, q_2 - (p_1\text{-}c)\, q_1\,]$$

$$\geq\; \pi_1(p_1^M, p_2) = \alpha_1^M[\, R(p_1^M) - f] + \alpha_1^M\, \alpha_2^M[(p_2\text{-}c)\, q_2 - (p_1^M\text{-}c)\, q_1^M\,]$$

$$\Leftrightarrow \alpha_1^2\,[R(p_1) - f\,] - (\alpha_1^M)^2\;[R(p_1^M) - f\,] + (\alpha_1\,\alpha_2 - \alpha_1^M\,\alpha_2^M)\;[\,R(p_2) - f]\;\geq\; 0,$$

where α_i^M is the market share of network i when the prices are (p^M, p_2). The inequality contradicts since $\alpha_1 < \alpha_1^M$, $R(p_1) - f < R(p_1^M) - f$, and

$$\alpha_1\alpha_2 - \alpha_1^M\alpha_2^M = \left\{\frac{1}{4} - \sigma^2\left(v(p_2) - v(p_1)\right)^2\right\} - \left\{\frac{1}{4} - \sigma^2\left(v(p_2) - v(p^M)\right)^2\right\}$$
$$= -\sigma^2\left[v(p_2) - v(p_1) + v(p_2) - v(p^M)\right]\left[v(p^M) - v(p_1)\right] \;<\; 0.$$

From (i) and (ii), equilibrium prices fall into the range $p^R \leq p_i^* \leq p^M$, i=1,2. *Q.E.D.*

LEMMA 4. *There is no asymmetric equilibrium.*

PROOF: From Lemma 1, $\alpha_i > 0$, i=1,2, in equilibrium. From Lemma 2, if there is an asymmetric equilibrium, at least one of the two networks has a price above p^M. From Lemma 3, equilibrium prices cannot be greater than p^M. Therefore, there is no asymmetric equilibrium. *Q.E.D.*

Existence of a unique symmetric equilibrium for any σ.

For the proof of the existence and the uniqueness of the symmetric equilibrium, let us redefine the best response function of each network in terms of consumer welfare v. The equilibrium satisfies

$$v_i = \gamma(v_j) \equiv arg\ max_{\,vi}\ \pi_i(v_i, v_j) \text{ for i, j= 1,2,}$$

where $\pi_i(v_i, v_j) = \alpha_i(v_i, v_j)[\, R(v_i) - f] + \alpha_i(v_i, v_j)\, \alpha_j(v_i, v_j)[\, R(v_j) - R(v_i)\,]$

$$= \alpha_i^2\,[\, R(v_i) - f] + \alpha_i\,(1 - \alpha_i\,)[\, R(v_j) - f]$$

where $\alpha_i(v_i, v_j) \equiv ½ + \sigma[v_i - v_j]$, $p(v) = [(\eta\text{-}1)v]^{-1/(\eta\text{-}1)}$, $q(v) \equiv [(\eta\text{-}1)v]^{\eta/(\eta\text{-}1)}$, $R(v) = (\eta\text{-}1)v - c\,[(\eta\text{-}1)v]^{\eta/(\eta\text{-}1)}$.

Note that $R'(v) = (\eta - 1) - \eta c[(\eta - 1)v]^{1/(\eta - 1)} \leq 0$ for $p \leq p^M$, but $R'(v) > 0$ for $p > p^M$. $R(\cdot)$ is strictly concave: $R''(v) = -\,\eta c\,[(\eta\text{-}1)v]^{(2\text{-}\eta)/(\eta\text{-}1)} < 0$.

A.1. Concavity of profit function

Each network's best response function is given by

$$v_i = \gamma(v_j) \Leftrightarrow \alpha_i^{\,2}[\,R'(v_i)\,] + \sigma[\,R(v_j) - f] + 2\alpha_i\,\sigma[\,R(v_i) - R(v_j)] = 0,\ \text{i,j} = 1,2,\ \text{or}$$

$$\Leftrightarrow \alpha_i^{\,2}[\,R'(v_i)\,] + 2\alpha_i\,\sigma[\,R(v_i) - f] + (1-2\alpha_i)\sigma[\,R(v_j) - f] = 0 \qquad \text{(A-1)}$$

from the first-order condition. The revenue function $R(\cdot)$ is continuous in p and strictly concave.

To prove that the second-order condition is satisfied, let us first show that $p_i > p^M$ is never a best response to network i. If $p_j > p_i > p^M$, then $R'(v_i) > 0$, $R(v_j) - f > 0$, $R(v_i) - R(v_j) > 0$, and thus (A-1) is not satisfied. If $p_i > p_j > p^M$, $0 < \alpha_i < ½$, $R'(v_i) > 0$, $R(v_i) - f > 0$, $R(v_j) - f > 0$, and thus (A-1) is not satisfied. Similarly, setting $p_i > p^M$ when $p^M > p_j$ is never a best response to network i. If $p_i > p^M > p_j > p^R$, $0 < \alpha_i < ½$, $R'(v_i) > 0$, $R(v_i) - f > 0$, and $R(v_j) - f > 0$, and thus (A-1) is not satisfied. If $p_i > p^M > p^R > p_j$, lowering p_i to p^M increases α_i and $R(v_i)$, and thus network i can always improve profits by doing so. Therefore, $p_i > p^M$ is never a best response to network i regardless of network j's strategy choice.

Similarly, $p_i < p^R$ is never a best response, either. From the profit function, $\pi_i(v_i, v_j) = \alpha_i^2\,[\,R(v_i) - f] + \alpha_i(1 - \alpha_i)[\,R(v_j) - f]$. If $p_i < p^R$, it must be the case that $p^R < p_j$. Then $\alpha_i > ½$ and (A-1) is negative for all $p_i < p^R$.

Now, for the relevant prices on the best response, $p^R \le p_i \le p^M$,

(i) $R'(v_i) < 0$, and $R''(v_i) < 0$.

(ii) If $p_i = p_j$, $R(v_i) - R(v_j) = 0$, and therefore, $SOC_i\,|_{p_i = p_j} = 4\sigma\alpha_i R'(v_i) + \alpha_i^2 R''(v_i) < 0$ from (i).

(iii) If $p_i < p_j$, $R(v_i) - R(v_j) < 0$, and therefore,

$$SOC_i\,|_{p_i < p_j} = 4\sigma\alpha_i R'(v_i) + \alpha_i^2 R''(v_i) + 2\sigma^2[R(v_i) - R(v_j)] < 0\,.$$

(iv) If $p_i > p_j$, $R(v_i) - R(v_j) > 0$. Since $\sigma[R(v_i) - R(v_j)] = -\frac{\alpha_i}{2}R'(v_i) - \frac{\sigma[R(v_j) - f]}{2\alpha_i}$, from (A-1), we get $\sigma[R(v_i) - R(v_j)] \le -\frac{\alpha_i}{2}R'(v_i) < -\alpha_i R'(v_i)$. That is, $\alpha_i R'(v_i) + \sigma[R(v_i) - R(v_j)] < 0$. Under this condition, the second-order condition is satisfied.

$$SOC_i\,|_{p_i>p_j} = 4\sigma\alpha_i R'(v_i) + 2\sigma^2(R(v_i) - R(v_j)) + \alpha_i^2 R''(v_i)$$
$$= 2\sigma\alpha_i R'(v_i) + 2\sigma\left\{\alpha_i R'(v_i) + \sigma(R(v_i) - R(v_j))\right\} + \alpha_i^2 R''(v_i) < 0$$

Therefore, the second-order condition is satisfied at every price on the best response function, and the program is strictly concave. Since the profit function is strictly concave, the symmetric equilibrium is unique.

A.2. Existence of equilibrium: Deviation from shared-market equilibrium is unprofitable.

Since the profit function is strictly concave, there is no local deviation. However, the non-existence problem may arise because networks may be tempted to deviate non-locally. Networks may find that deviation to a cornering strategy may be more profitable than sharing the market with a rival network. If the cornering strategy yields a higher profit than the equilibrium profits, there is no equilibrium from Lemma 1. Therefore, we need to prove that such a non-local deviation from the equilibrium is not profitable. It is sufficient to show that the cornering price is always lower than the Ramsey price for *any* σ. That is, we prove that the *highest* cornering price under the GECPR is the Ramsey price when $\sigma \to \infty$.

For a given σ and p^*, a network can corner the market by charging a price p_σ that satisfies $v(p_\sigma) = v(p^*) + 1/(2\sigma)$. That is,

$$\underbrace{p_\sigma q_\sigma}_{A} = \underbrace{p^* q^*}_{B} + \underbrace{(\eta - 1)/(2\sigma)}_{C}. \qquad \text{(A-2)}$$

As σ changes, the equilibrium price p^* changes, and so does the cornering price p_σ. Suppose that a higher σ decreases the value of the right-hand side, $(B+C)$, in (A-2). Then the left-hand side (A) also has to decrease for a higher σ to maintain the equality. Since the net variable surplus at the cornering price, $p_\sigma q_\sigma$, is a decreasing function of p, it implies that the cornering price increase as σ increases. That is, we can determine how the cornering price changes under the GECPR as σ changes by looking at the changes in the right-hand side $(B+C)$ of (A-3). If $\Delta(B+C)/\Delta\sigma < 0$, the cornering price p_σ increases as σ increases. The highest cornering price, in this case, will be the cornering price when $\sigma \to \infty$, or when p^* and p_σ

converge to p^R. Therefore, in order to prove that the cornering price is always lower than the Ramsey price, we just need to prove that the following condition is true:

$$\frac{\Delta\{p^*q^*+(\eta-1)/(2\sigma)\}}{\Delta\sigma}=(1-\eta)p^{*-\eta}\left(\frac{-q^*\pi^*}{-SOC}\right)-\frac{(\eta-1)}{2\sigma^2}$$
$$=(\eta-1)\left(\frac{q^{*2}\pi^*}{-SOC}-\frac{1}{2\sigma^2}\right)\quad<\quad 0.$$

Plugging the second-order condition, $\sigma\eta\left(q\pi/p\right)-\sigma q(1+2\alpha)\left(\partial R/\partial p\right)+\alpha^2\left(\partial^2 R/\partial p^2\right)$, into above equation, and evaluating terms at equilibrium, we obtain the following condition to prove

$$2\sigma q^*\left(\frac{\partial R}{\partial p}-\sigma q^*\pi^*\right)-\sigma\eta\frac{q^*\pi^*}{p^*}-\frac{1}{4}\frac{\partial^2 R}{\partial p^2}\quad>\quad 0.$$

Since p* satisfies $\left(-\sigma q^*\pi^*\right)+(1/4)\partial R/\partial p=0$, the above condition can be rewritten as follows.

$$2\sigma q^*\left(\frac{1}{4}*\frac{\partial R}{\partial p}-\sigma q^*\pi^*\right)+\frac{3}{2}\sigma q^*\frac{\partial R}{\partial p}-\sigma\eta\frac{q^*\pi^*}{p^*}-\frac{1}{4}\frac{\partial^2 R}{\partial p^2}\quad>\quad 0 \qquad \text{(A-3)}$$
$$\Leftrightarrow\qquad \frac{3}{2}\sigma q^*\frac{\partial R}{\partial p}-\sigma\eta\frac{q^*\pi^*}{p^*}-\frac{1}{4}\frac{\partial^2 R}{\partial p^2}\quad>\quad 0.$$

Recall that, according to the second-order condition, $\sigma\eta\left(q\pi/p\right)-\sigma q(1+2\alpha)\left(\partial R/\partial p\right)+\alpha^2\left(\partial^2 R/\partial p^2\right)$ is negative for all $\alpha\in(0,1)$ from A.1. Thus, when $\alpha=1/4$,

$$-SOC\,|_{\alpha=1/4}=\frac{3}{2}\sigma q^*\frac{\partial R}{\partial p}-\sigma\eta\frac{q^*\pi^*}{p^*}-\frac{1}{16}\frac{\partial^2 R}{\partial p^2}\quad>0.$$

Comparing this result with (A-3), we confirm that the inequality in (A-3) holds.

$$\frac{3}{2}\sigma q^*\frac{\partial R}{\partial p}-\sigma\eta\frac{q^*\pi^*}{p^*}-\frac{1}{4}\frac{\partial^2 R}{\partial p^2}\quad>\quad\frac{3}{2}\sigma q^*\frac{\partial R}{\partial p}-\sigma\eta\frac{q^*\pi^*}{p^*}-\frac{1}{16}\frac{\partial^2 R}{\partial p^2}\quad=-SOC\,|_{\alpha=1/4}>0$$

Therefore, the cornering price p_σ increases as σ increases. When $\sigma\to\infty$, or $p^*\to p^R$, the cornering price converges to p^R, which is the highest cornering price under the GECPR. Since the cornering price is always lower than the Ramsey price, any deviation from the equilibrium is not profitable. *Q.E.D.*