Asymmetric access pricing in the Internet backbone market[1]

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Abstract

I study the impact of asymmetric interconnection charges on competition for consumers and websites in the Internet backbone market. For an arbitrary number of networks there exist paid peering agreements for which in equilibrium two network operators foreclose competition or one of them corners one side of the market. Furthermore, if the reciprocal access charge of a pair of networks departs away from a given reciprocal and symmetric access charge in the industry, then in equilibrium the two networks are driven out of one side of the market.

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1 Introduction

To allow customer interaction Internet service providers (ISPs) must connect their customers with customers of other ISPs. There are two ways of interconnection in the Internet market: (1) transit: ISPs buy connectivity from Internet Backbone Providers that have large physical networks and are connected to many other networks; (2) peering agreements: a direct interconnection regime between two networks through which they exchange their own end-customers' traffic with each other, but they do not process traffic from the other network to the remainder of the Internet. Peering is more efficient than transit in terms of avoiding congestion, however under peering arrangements, network operators have incentives to degrade quality when traffic flows are asymmetric. "Paid peering" has recently emerged as a solution to this problem. Under a *paid peering* agreement networks can charge each other for exchanging traffic.[1]

Laffont, Marcus, Rey and Tirole (2003) (LMRT2003) consider a framework in which two network operators engage in a *paid peering* interconnection regime and compete on the two sides of the market: consumers and websites. They show that network operators price consumers and websites as if their connections were entirely off-net. This is the so-called "off-net-cost pricing principle". This pricing principle is robust to generalizations of their model such as mixed traffic patterns, multihoming, quality of service, customer cost heterogeneity and installed bases. Also, it extends to any number of competing networks as long as the access charge is symmetric in the industry −that is, provided that the reciprocal access charge of each pair of networks is the same as the reciprocal access charge of the rest of pairs of networks.

I extend their analysis to asymmetric access pricing in the presence of an arbitrary number of network operators. Networks can use asymmetric access pricing to foreclose competition (even if access charges are reciprocal). For a particular combination of access charges in the industry, I construct an equilibrium in which competition is foreclosed by a pair of networks or one side of the market is cornered by one network. I also show that if the reciprocal access charge of a pair of networks departs away from a given reciprocal and symmetric access charge, then the two networks are driven out of one side of the market.

2 The Model

There are $n \geq 2$ full-coverage networks or backbones, a continuum of consumers of mass 1 and a continuum of websites of mass 1. Networks have the same cost structure: c denotes the total marginal cost of traffic, and c_0 and c_T denote the originating and terminating networks' marginal costs associated with this traffic ($c_0 + c_T = c$).

There is full participation (i.e., all consumers and websites connect to a network), and demand is completely inelastic and equal to one: each consumer demands one unit of traffic from each website. p_i is the retail price charged by network i for receiving traffic and $\widetilde{p}_i$ is the retail price charged by network i for sending traffic.

Let a_{ij} denote the access charge paid by network j to network i for terminating network

[1] Various aspects of *Bill-and-Keep peering* and *paid peering* have been discussed in Badasyan and Chakrabarti (2008), Crémer, Rey and Tirole (2000), Jahn and Prüfer (2008), Laffont, Marcus, Rey and Tirole (2001, 2003), Lippert and Spagnolo (2008), Norton (2001), Shakkottai and Srikant (2006), and Shrimali and Kumar (2008).

j's off-net traffic, then $a_{ij} = a_{ji}$ (reciprocal access pricing)[2]. I depart from the LMRT2003 framework by allowing for asymmetry between the reciprocal interconnection charge of each pair of networks. That is,

$$a_{12} = a_{13} = ... = a_{1n} = a_{23}... = a_{2n} = a_{(n-1)n} = a \quad (1)$$

may fail to hold.

Networks are perfect substitutes and the calling pattern is balanced. Denoting by α_i network i's market share for consumers and by $\widetilde{\alpha}_i$ its market share for websites, network i's profit is (for $i \neq j = 1...n$):

$$\pi_i = \alpha_i \widetilde{\alpha}_i (p_i + \widetilde{p}_i - c) + \alpha_i \sum_{j=1}^{n} \widetilde{\alpha}_j (p_i - (c_T - a_{ij})) + \widetilde{\alpha}_i \sum_{j=1}^{n} \alpha_j (\widetilde{p}_i - (c_0 + a_{ij})).$$

Let me assume that if network operators charge the same price p ($\widetilde{p}$), then for any $i = 1...n$: $\alpha_i > 0$ ($\widetilde{\alpha}_i > 0$). The timing is: (1) the access charge of each pair of networks a_{ij} is determined through a bilateral agreement or by regulation, (2) the network operators compete in prices, and (3) consumers and websites make subscription decisions.

The off-net-cost pricing principle. Suppose that, say, network 1 "steals" a consumer away from network 2. This consumer receives traffic from network 2's websites, from which network 1 incurs the cost c_T and generates revenue a_{12}, obtaining $\widetilde{\alpha}_2(a_{12} - c_T)$. Similarly, the consumer receives traffic from the rest of networks, from which network 1 obtains $\sum_{j=3}^{n} \widetilde{\alpha}_j (a_{1j} - c_T)$. The traffic from network 1's websites to the network 2's consumer, which initially costs $c_0 + a_{12}$, is now internal to network 1, and costs c. Thus, network 1 gains on this traffic $\widetilde{\alpha}_1(c_0 + a_{12} - c) = \widetilde{\alpha}_1(a_{12} - c_T)$. Let C_{ij} be the network i's opportunity cost of stealing a consumer away from network j. Then, (for $i \neq j \neq k = 1...n$)

$$\begin{aligned} C_{ij} &= -[\widetilde{\alpha}_j (a_{ij} - c_T) + \sum_{k \neq i,j}^{n} \widetilde{\alpha}_k (a_{ik} - c_T) + \widetilde{\alpha}_i (a_{ij} - c_T)] \\ &= c_T - a_{ij}(\widetilde{\alpha}_i + \widetilde{\alpha}_j) - \sum_{k \neq i,j}^{n} a_{ik} \widetilde{\alpha}_k. \end{aligned}$$

Similarly, the network $i's$ opportunity cost of stealing a website away from network j is

$$\widetilde{C}_{ij} = c_0 + a_{ij}(\alpha_i + \alpha_j) + \sum_{k \neq i,j}^{n} a_{ik} \alpha_k.$$

LMRT2003 show that if Eq. (1) holds, then in equilibrium networks set prices at the opportunity cost of servicing a customer of the rival network (which is called the off-net cost pricing principle):

$$p = c_T - a \text{ and } \widetilde{p} = c_0 + a.$$

[2] LMRT2003 show that there is no equilibrium in pure strategies when the access charge is non-reciprocal. That is, when a network pays a different amount for having its traffic terminated on a rival network as it receives for terminating traffic originating on a rival network.

I next show that if Eq. (1) fails to hold, then in equilibrium some networks are driven out of the market. But those networks that are present in the market will still charge prices at the off-net cost.

3 The analysis

In this section I exhibit the equilibrium for different combinations of access charges.

3.1 Market foreclosure

To develop the intuition for the result, let me consider first the case of 3 networks with

$$a_{12} > a_{13} > a_{23}. \tag{2}$$

We thus have

$$a_{12} + a_{13} > a_{12} + a_{23} > a_{13} + a_{23}.$$

That is, Eq. (2) implies that: (i) network 1 has a comparative advantage for consumers as the revenue from receiving traffic is higher in network 1 than in 2 and 3; (ii) network 3 has a comparative advantage for websites as its off-net cost is lower than the off-net cost of networks 1 and 2. In view of this result, a first intuition is that in equilibrium network 1 corners the consumers market, network 3 corners the websites market and network 2 is driven out of both markets. A simplifying feature of this outcome is that only one reciprocal access charge is relevant, namely a_{13}. This in turn implies that 1 and 3 will charge prices at the off-net cost[3]:

$$p_1 = p_3 = p = c_T - a_{13},$$

$$\widetilde{p}_1 = \widetilde{p}_3 = \widetilde{p} = c_0 + a_{13}.$$

In this candidate equilibrium, market shares are undetermined. Now, for given α_1 and $\widetilde{\alpha}_1$ −with $\alpha_1 + \alpha_3 = 1$ and $\widetilde{\alpha}_1 + \widetilde{\alpha}_3 = 1$− the network 2's opportunity costs are

$$C_2 \equiv \alpha_1 C_{21} + \alpha_3 C_{23} = c_T - a_{12}\widetilde{\alpha}_1 - a_{23}\widetilde{\alpha}_3,$$

and

$$\widetilde{C}_2 \equiv \widetilde{\alpha}_1 \widetilde{C}_{21} + \widetilde{\alpha}_3 \widetilde{C}_{23} = c_0 + a_{12}\alpha_1 + a_{23}\alpha_3.$$

If $p > C_2$ ($\widetilde{p} > \widetilde{C}_2$), network 2 will attract all consumers (websites) by slightly undercutting the price p ($\widetilde{p}$). Hence to show that in equilibrium network 2 is driven out of the market, it suffices to require that

$$a_{13} > a_{12}\widetilde{\alpha}_1 + a_{23}\widetilde{\alpha}_3, \tag{3}$$

and

$$a_{13} < a_{12}\alpha_1 + a_{23}\alpha_3. \tag{4}$$

[3]Because $C_{13} = C_{31} = c_T - a_{13}$, no network operator $i \neq j = 1, 3$ will charge $p_i > c_T - a_{13}$, otherwise j would corner the consumers segment by charging a slightly lower price. For the same reason, no network $i \neq j = 1, 3$ will charge $\widetilde{p}_i > c_0 + a_{13}$ since $\widetilde{C}_{13} = \widetilde{C}_{31} = c_0 + a_{13}$.

Combining Eqs. (3) and (4), and using $\alpha_1 + \alpha_3 = 1$ and $\widetilde{\alpha}_1 + \widetilde{\alpha}_3 = 1$, we obtain

$$\widetilde{\alpha}_1 < \frac{a_{13} - a_{23}}{a_{12} - a_{23}} < \alpha_1. \tag{5}$$

From this expression, we see that if, for given prices p and $\widetilde{p}$, networks 1 and 3 get half the market, then Eqs. (3) and (4) will imply a contradiction. In equilibrium, Eq. (3) holds if $\widetilde{\alpha}_3$ tends to 1, whereas Eq. (4) holds if α_1 tends to 1. The findings partially confirm the intuition that in equilibrium network 1 would corner the consumers segment and network 3 would corner the websites segment. Notice that asymmetric access pricing is a factor of instability (even if access charges are reciprocal) since Eq. (5) may not hold. More generally, we have

Proposition 1 *Assume that* $a_{ik} > a_{ij} > a_{kj}$ $\forall k \neq i \neq j = 1...n$*; then, there exists an equilibrium in which networks* i *and* j *foreclose competition and charge prices at the off-net cost if*

$$\widetilde{\alpha}_i < \frac{a_{ij} - a_{kj}}{a_{ik} - a_{kj}} < \alpha_i$$

holds. In this equilibrium $\alpha_i > \widetilde{\alpha}_i$, $\widetilde{\alpha}_j > \alpha_j$ *and* $\pi_i = \pi_j = 0$.

Proof. Suppose that only i and j compete for end users, Bertrand-like competition ensures that $p_i = p_j = p = c_T - a_{ij}$ and $\widetilde{p}_i = \widetilde{p}_j = \widetilde{p} = c_0 + a_{ij}$, with $\alpha_i + \alpha_j = 1$ and $\widetilde{\alpha}_i + \widetilde{\alpha}_j = 1$. No network $k \neq i, j$ will find it profitable to attract all end users by charging a slightly lower p and $\widetilde{p}$: $\pi_k = p_k + \widetilde{p}_k - c < 0$ when $p_k < p$ and $\widetilde{p}_k < \widetilde{p}$. Moreover, no network k could attract all end users on at least one side of the market if the conditions

$$C_k = \alpha_i C_{ki} + \alpha_j C_{kj} = c_T - \widetilde{\alpha}_i a_{ik} - \widetilde{\alpha}_j a_{jk} < p,$$

and

$$\widetilde{C}_k = \widetilde{\alpha}_i \widetilde{C}_{ki} + \widetilde{\alpha}_j \widetilde{C}_{kj} = c_0 + \alpha_i a_{ik} + \alpha_j a_{jk} < \widetilde{p}$$

are satisfied. These two conditions boil down to $\widetilde{\alpha}_i < \eta < \alpha_i$, where $\eta \equiv (a_{ij} - a_{kj})/(a_{ik} - a_{kj})$. $\eta < 1$ requires that $a_{ij} < a_{ik}$, whereas $\eta > 0$ requires that $a_{ij} > a_{kj}$ and $a_{ik} > a_{kj}$. Hence, i and j foreclose competition provided that $a_{ik} > a_{ij} > a_{kj}$ $\forall k \neq i, j = 1...n$. ■

Proposition 1 tells us that two networks can foreclose competition if each specializes in one side of the market. To see this, suppose that only 1 and 3 compete for end users. In any Bertrand equilibrium, the two network operators must charge the same prices at the off-net costs of outgoing and incoming traffic, which are functions of the reciprocal access charge a_{13}. By choosing too high access charges a_{1i} (above a_{13}), network 1 raises the opportunity cost of rivals of stealing the websites away from network 3 (if for the same prices consumers favor its own network instead of network 3). Similarly, by choosing too low access charges a_{i3} (below a_{13}), network 3 raises the opportunity cost of rivals of stealing consumers away from network 1 (if for the same prices websites favor its own network instead of network 1). Consider, for example, 5 networks with $a_{12}, a_{14}, a_{15} > a_{13} > a_{23}, a_{43}, a_{53}$: in equilibrium networks 1 and 3 foreclose competition −in particular, the level of a_{24}, a_{25} and a_{45} do not have an impact on the equilibrium.

3.2 Cornered-market equilibria

Without loss of generality, let us assume that, for a given combination of access charges $\{a_{ij}\}_{i\neq j}^{n}$, network 1 charges for terminating the off-net traffic of any rival network i: $a_{1i} = a < \{a_{ij}\}_{j\neq i,1}^{n}$. Then,

$$\sum\nolimits_{j\neq i}^{n} a_{ij} > \sum\nolimits_{k=2}^{n} a_{1k} = (n-1)a.$$

Consequently network 1 has a comparative advantage for websites, whereas the rest of networks are in a better position to compete for consumers. A first intuition is that in equilibrium network 1 corners the websites segment and makes a profit, since there is not Bertrand-like competition on this side of the market. Next proposition confirms partially this result: while network 1 corners the websites segment, it still makes no profit because of the competitive pressure.

Proposition 2 *For any $n > 2$ and any $i \neq j \neq k = 1...n$,*

i) if $a_{ij} > a_{1k} = a_{2k} = ... = a_{nk} = a$, there exists a zero-profit equilibrium in which network k corners the websites segment and all the networks compete for consumers, the equilibrium prices are $p_i = c_T - a$ $\forall i$ with $\sum_i \alpha_i = 1$, and $\widetilde{p}_k = c_0 + a < \widetilde{p}_i$ with $\widetilde{\alpha}_k = 1$.

ii) if $a_{1k} = a_{2k} = ... = a_{nk} = a > a_{ij}$, there exists a zero-profit equilibrium in which network k corners the consumers segment and all the networks compete for websites, the equilibrium prices are $\widetilde{p}_i = c_0 + a$ $\forall i$ with $\sum_i \widetilde{\alpha}_i = 1$, and $p_k = c_T - a < p_i$ with $\alpha_k = 1$.

Proof. Case i: If $\widetilde{\alpha}_k = 1$, then for any network $i \neq j$ we have that $C_{ij} = c_T - a$. Hence, $p_i = c_T - a$ $\forall i$ with $\sum_i \alpha_i = 1$. It remains only to demonstrate that, given this candidate equilibrium, a network does not profit by charging a price $\widetilde{p}$ below the off-net cost. To show this, we must specify and compare the opportunity costs of stealing websites away from competitors. We have that

$$\begin{aligned}\widetilde{C}_{ik} &= c_0 + a(\alpha_i + \alpha_k) + \sum_{j\neq i,k}^{n} a_{ij}\alpha_j \\ &= c_0 + a + \sum_{j\neq i,k}^{n} (a_{ij} - a)\alpha_j,\end{aligned}$$

whereas $\widetilde{C}_{ki} = c_0 + a$ for any $i \neq k$. Hence as $a_{ij} > a$, $\widetilde{C}_{ik} > \widetilde{C}_{ki}$. However, network k does not gain by choosing a price above the off-net cost. To see this, suppose that network k charged a price $\widetilde{p}_k = c_0 + a + x > c_0 + a$, where $x = \min\{\sum_{j\neq i,k}^{n} (a_{ij} - a)\alpha_j\}_{i\neq k}^{n}$. Any network i would corner both sides of the market by choosing $p_i = c_T - a - \varepsilon$ and $\widetilde{p}_i = \widetilde{p}_k - \varepsilon$, where $0 < \varepsilon < x/2$, since $\pi_i = p_i + \widetilde{p}_i - c = x - 2\varepsilon > 0$. Hence, in equilibrium $\widetilde{p}_k = c_0 + a$ and $\widetilde{\alpha}_k = 1$. A similar reasoning proves Case ii. ■

Intuitively, as $a_{ij} > a_{1k} = a_{2k} = ... = a_{nk}$, $\widetilde{C}_{ki} < \widetilde{C}_{ik}$, so network k corners the websites segment. Similarly, as $a_{1k} = a_{2k} = ... = a_{nk} = a > a_{ij}$, $C_{ik} > C_{ki}$, so network k corners the consumers segment. However, in either case, network k cannot make a profit because any rival could then corner the whole market by undercutting network k's prices by lower than the half of the price markup.

3.3 Bilateral deviations from symmetric access pricing

I now study how bilateral deviations from symmetric access pricing affect the market structure. Let us assume that each pair of networks charges the same reciprocal access charge a. If a pair of networks i, j charges $a_{ij} < a$, then it seems that the two networks will have a comparative disadvantage for consumers and a comparative advantage for websites. The following proposition shows that the better position to compete for websites is not enough to allow them to foreclose this side of the market. Moreover, the failure of this strategy raises their opportunity costs of stealing consumers away from the rest of networks. As a result, both networks are driven out of the consumers segment.

Proposition 3 *Suppose that Eq. (1) holds and consider a pair of networks i, j, if*

i) $a_{ij} < a$, then there exists a zero-profit equilibrium in which i, j are driven out from the consumers segment, whereas the rest of networks are present in both segments; equilibrium retail prices are set at the off-net cost,

ii) $a_{ij} > a$, then there exists a zero-profit equilibrium in which i, j are driven out from the websites segment, whereas the rest of networks are present in both segments; equilibrium retail prices are set at the off-net cost.

Proof. Case i: Suppose without loss of generality that $a_{12} < a$. I first show that in equilibrium networks 1 and 2 cannot corner the websites market. If $\widetilde{\alpha}_1 + \widetilde{\alpha}_2 = 1$ (with $\widetilde{\alpha}_1 > 0$ and $\widetilde{\alpha}_2 > 0$), then (for $k \neq 1, 2$): $C_{k1} = C_{k2} = c_T - a$, whereas $C_{1k} = c_T - a\widetilde{\alpha}_1 - a_{12}\widetilde{\alpha}_2$ and $C_{2k} = c_T - a\widetilde{\alpha}_2 - a_{12}\widetilde{\alpha}_1$. Hence as $a_{12} < a$, $C_{k1} = C_{k2} < \min\{C_{1k}, C_{2k}\}$, implying that $p_k = c_T - a$, and $\alpha_1 = \alpha_2 = 0$. Consequently a_{12} does not affect the opportunity cost of any network of stealing websites away from rivals which is then given by $c_0 + a$. This implies that $\widetilde{p}_i = c_0 + a \; \forall i$ with $\sum_i \widetilde{\alpha}_i = 1$, a contradiction. However, we have seen that if $\alpha_1 + \alpha_2 = 0$, then $\widetilde{p}_i = c_0 + a \; \forall i$ with $\sum_i \widetilde{\alpha}_i = 1$. Consequently, $C_{1k} = c_T - a - (a_{12} - a)\widetilde{\alpha}_2$, $C_{2k} = c_T - a - (a_{12} - a)\widetilde{\alpha}_1$ and $C_{k1} = C_{k2} = c_T - a$. As $a_{12} < a$, $C_{ki} < \min\{C_{1k}, C_{2k}\}$. Hence, for any $k \neq 1, 2$: $p_k = c_T - a$ ($< C_{1k}, C_{2k}$) with $\sum_{i=3}^{n} \alpha_i = 1$. A similar reasoning proves Case ii. ■

In view of Proposition 3, when the reciprocal access charge of two networks departs away from a given symmetric access charge in the industry, then both networks are driven out of one side of the market. The case of 3 networks with $a_{12} = a_{13} = a_{23}$ is of interest. For example, if networks 2 and 3 set $a_{23} < a_{12} = a_{13}$, then $a_{12} + a_{13} > a_{12} + a_{23} = a_{13} + a_{23}$. In equilibrium, networks 2 and 3 are driven out from the consumers segment, which is cornered by network 1. Notice that this is a particular case of Proposition 2 (Case ii).

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