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Interconnection Between Asymmetric Internet Backbone Providers

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Abstract: The interconnection between Internet backbone providers plays the key role during the development of the Internet. However, the asymmetries between backbones affect the backbones' choices in interconnection. This paper presents a game model of the interconnection agreement between backbones in case of network congestion. We prove the validity that the larger network charges the smaller one during interconnection. We also attempt to demonstrate how the asymmetric network capacity and the percentage of ICP affect the interconnection between backbones.
Keywords: Internet backbone providers; interconnection; asymmetry; congestion

1 INTRODUCTION

The Internet is a network of networks, owned and operated by different companies. Networks' connectivity significantly affects the development of Internet. Because the Internet is structured hierarchically, each network has its unique position in the entire network system. IBPs (Internet Backbone Providers) are at the top of hierarchy. Most ISPs (Internet Service Providers) connect with each other through IBP. And end users and ICPs (Internet Content Providers) access Internet via ISP or some IBP. In general, IBPs own or lease national or international high-speed fiber optic networks. ISPs only own regional Internet networks.

compete for customers. IBPs differentiate themselves by hosting different ICPs. The value of differentiation for maintaining profits in a competitive marketplace is reduced by high capacity interconnections. Intuitionally the IBP with the larger proportion of ICPs generally will choose the lower peering capacity.

The combination of congestion effects and differentiation strategies determine the value of interconnection to each of the IBPs in the agreement. The IBP that prefers lower peering capacity will have the more bargaining power during the interconnection negotiation.

The factors that affect the IBPs' peering agreement mainly include network geographic coverage, network capacity, network size and scope, traffic exchange ratio and consumer distribution. We present a two-stage model of two IBPs that operate in the same area and compete for customers. Their network capacities are given constant. They host different proportion of ICPs. Both the networks and the interconnection point are sources of congestion. Customers incur delay costs when accessing content on the two networks. There are four kinds of traffic in the Internet: customer to ICP, ICP to ICP, customer to customer and ICP to customer. But as the total of the first three kinds of traffic are far less than the last one, we will only consider the last one in the model.

3 THE MODEL

3.1 Demand for access and social surplus

To simply the analysis, we only consider two IBPs in this model. We assume that they host α and 1-α proportions of ICPs, respectively. Let p1 and p2 is the per unit time price charged by IBP1 and IBP2 for Internet access price.

Let the utility of joining the Internet through IBPs enjoyed by consumer indexed by r be

$$U = r - p - d \qquad (1)$$

where r > 0 is a positive benefit of joining the Internet which is uniformly distributed in[0,A](A>0). p is the per unit time price charged by IBPs and d is the disutility (or dis-benefit) of delay incurred by customers. While r is independent from which IBP is providing access, the disutility of delay depends on the degree of congestion on network.

The customer chooses whether or not to get Internet services and he picks the IBP that offers him the highest positive surplus. At the equilibrium, consumers must be indifferent between joining IBP1 and IBP2; from the indifferent condition:

$$p_1 + d_1 = p_2 + d_2$$

Let us call δ this "hedonic" price (Fabio M. Manenti,2003). Only customers with r⩾δ buy the connection, therefore at the equilibrium there is a total amount of consumers xt=A-δ connecting to the Internet. Hence, using (1), the demand function

3.3 Network costs and network profit

Network industry has one important character: fixed cost is high but marginal cost low; Within certain range, with the traffic increasing, marginal cost decreases gradually and approach zero. Therefore we only consider the fixed cost of the network in this model. For the sake of simplicity, given that cost per unit of IBP_1, IBP_2 and interconnection point are all θ, which means $\theta_1=\theta_2=\theta_p=\theta$. Then when IBP1 peers with IBP2, we assume the cost is equally shared between the interconnecting parties and IBP_i's profit is

$$\pi_i = p_i x_i - \theta\left(k_i + \frac{k_p}{2}\right) \qquad i=1，2 \tag{11}$$

3.4 Two-stage model

To simulate the interconnection between IBPs better, we present a two-stage model in this paper. Because investment in network capacity is a long run decision, we assume that IBPs choose their capacities at the beginning of the game and compete afterwards. At first stage, IBPs choose interconnection capacities, and IBPs compete ´a la Cournot to choose the amount of consumers that can maximize its profit at the second stage.

Using the congestion function as (8), (9)and the delay function as (10)into , we can get IBP1 and IBP2's profit is therefore :

$$\pi_1 = \left(A - \left(\frac{1}{k_1} + \frac{(1-\alpha)^2}{k_2} + \frac{(1-\alpha)^2}{k_p} + 1 \right) x_1 - \left(\frac{\alpha}{k_1} + \frac{\alpha(1-\alpha)}{k_p} + \frac{(1-\alpha)}{k_2} + 1 \right) x_2 \right) x_1 - \theta(k_1 + \frac{k_p}{2})$$

$$\pi_2 = \left(A - \left(\frac{\alpha}{k_1} + \frac{(1-\alpha)}{k_2} + \frac{\alpha(1-\alpha)}{k_p} + 1 \right) x_1 - \left(\frac{\alpha^2}{k_1} + \frac{\alpha^2}{k_p} + \frac{1}{k_2} + 1 \right) x_2 \right) x_2 - \theta(k_2 + \frac{k_p}{2})$$

We solve the model by backward induction. In the second stage, competition occurs given capacities and in the first stage; backbones anticipate second stage equilibrium and choose capacities.

4 SOLUTION AND RESULTS ANALYSIS

4.1 Solution

IBPs' equilibrium outputs given capacities $x_1^*\left(k_p\right)$ and $x_2^*\left(k_p\right)$ are obtained by solving the profit function of first order conditions. Using $x_1^*\left(k_p\right)$ and $x_2^*\left(k_p\right)$ in the profit functions of IBP_1 and IBP_2, we can get $\pi_1 = \pi_1\left(k_p\right)$ and $\pi_2 = \pi_2\left(k_p\right)$,

IBP_1,which indicates that IBP_2 benefits more from interconnection .

The total social welfare curve are all unimodal. Because of the existence of the cost of interconnection , the interconnection is not the larger the better to the society. We will reach two proposition:

Proposition 1. In a bilateral peering relationship, IBP1 with larger network capacity and market share trends to lower peering capacity, and IBP2 trends to higher peering capacity.

This proposition means that network capacity and relative number of ICPs will affect the two IBPs' choice of peering capacity. As network capacity and relative number of ICPs of IBP1 are all more than those of IBP2, when the peering capacity increases, the shorten of difference between two IBP affects IBP1's profit more than IBP2's, so the best peering capacity of IBP1 is lower than that of IBP2.

Proposition 2. The best peering capacity to total social welfare is between the best capacity of IBP1 and that of IBP2.

(2) Possible choice for peering capacity

In business negotiation, as the capacity it chooses is less than IBP2, IBP1 has more advantages. But the choice of IBP1 is obviously not the best one of IBP2, and it is not the best choice to total social welfare. How can we change IBP1's choice?

The first solution is that the government forces IBP1 to add capacity on peering point. Certainly, this peering capacity cannot be fully satisfied with IBP2, because the best peering capacity to total social welfare is between the best capacity of IBP1 and that of IBP2. This solution makes total social welfare and IBP2's profit better, but it harms IBP1, so this is not a Pareto superior outcome and IBP1 will resist it.

We can get the other solution from the figure below. In some conditions, the increase of IBP2's profit is much more than the decrease of IBP1's profit as the increase of the peering capacity. IBP2 can pay for the increase of peering capacity to IBP1; it will benefit both of them. And the increase of peering capacity make the capacity is much close to the best capacity for total social welfare, so it is a Pareto superior outcome.

Proposition 3. In interconnection between different IBPs, IBP2 can pay for the increase of peering capacity to IBP1; IBP2 can get more profit than it pays to IBP1 from this increase of capacity. It will benefit not only the two IBPs, but also the increase of total social welfare.

This proposition is accord with the fact that the smaller IBP pay to the larger IBP in interconnection, and give a certain explanation to this fact. Certainly, the fee pay for interconnection must be reasonable, too much payment will do harm to IBP2's profit.

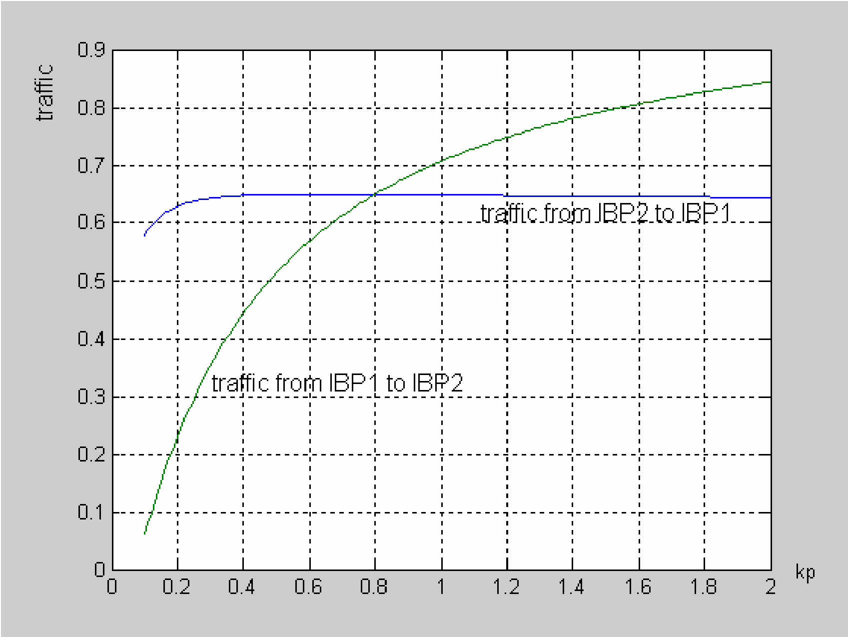

Figure 4.Traffic between the two IBPs

Furthermore, when k_p=0.8, we can find that IBP1's off-net traffic equals to IBP2's off-net traffic. This k_p is higher than IBP1's best interconnection capacity (0.22) and lower than IBP2's best interconnection capacity (1.57).

Proposition 4. When IBP1 have more network capacity and host more ICPs than IBP2, IBP2's consumers benefit from the increase on peering capacity more than IBP1's. And when k_p equals IBP1's best interconnection capacity, D_{12} (the difference between IBP1's off-net traffic and IBP2's off-net traffic) is negative and increases with the adding investment on peering capacity. It becomes zero when k_p between IBP1's best interconnection capacity and IBP2's.

This proposition shows that why settlement according to the difference between IBP1's off-net traffic and IBP2's off-net traffic can not be used widely in interconnection settlement between IBPs of Internet.

(4) The influence of asymmetric market structure to the choice of peering capacity

The relative network capacity and ICP proportion is one of the factors that influence the peering capacity. Now we'll analyze how they influence the choice of peering capacity.

First we change the value of α. that is we change the ICP proportion of IBP1 and IBP2. we get the result in table 1.

First we give some definition:

BPC: best peering capacity;

BPCS: best peering capacity for society.

investment on peering capacity directly makes its network become more congested, so it obviously trends to lower peering capacity. The best peering capacity of the network holds less content is inverse proportion to its relative network capacity. This is due to that major traffics of its consumer are originated in the other network, so the larger IBP's congestion can affect its consumer in some conditions. As there are few consumers will change network, reducing investment on the best peering capacity a little can alleviate its costs. The best peering capacity for society is always between the two IBPs' best capacities of peering point.

Table 2
The influence of network capacity to peering capacity

$\alpha=0.8$			
$k_p/x_1/x_2$	$k_1=4, k_2=1$	$k_1=2, k_2=1$	$k_1=1, k_2=1$
IBP1's BPC / IBP1's ICP proportion / IBP2's ICP proportion	0.21/ 3.1543/ 0.3054	0.17/ 2.6119/ 0.2747	0.12/ 1.9531/ 0.2188
IBP2's BPC / IBP1's ICP proportion / IBP2's ICP proportion	1.57/ 3.2282/ 1.0032	1.53/ 2.6473/ 1.002	1.42/ 1.9279/ 0.9589
BPCS / IBP1's ICP proportion / IBP2's ICP proportion	1.25/ 3.2353/ 0.9462	1.07/ 2.6622/ 0.9154	0.86/ 1.9528/ 0.8468

Proposition 7. IBPs' network capacity can also affect the choice on peering capacity, when the ICP proportion keeps fixed and the network capacity of larger IBP decreases, the best peering capacity for the two IBP will decrease all.

5 CONCLUSIONS

During the development of Internet industry, there appears an asymmetry in backbone market. It affects the interconnection between IBPs. The congestion effect and the differentiation strategies determine backbones' behaviors of interconnection together. We draw some conclusions by analyzing the game theory model of the interconnection of two asymmetric networks: the network capacity and the ICP proportion of each IBP can all affect the choice of peering capacity. The larger IBP (IBP which holds more network capacity and more ICP proportion) prefers to lower peering capacity, and the smaller IBP prefers to higher capacity. The second one can pay certain to the first so that the peering capacity can become larger. This solution not only benefits the two IBPs, but also can improve total social welfare. It is a Pareto superior outcome.

In China, the two dominant IBPs are China telecom and China Netcom. The main settlement between different IBPs is the smaller IBP pay to the larger IBP (China telecom and China Netcom) and there is No-settlement between different