

A Simple Game Theoretic Analysis of Peering and Transit Contracting among Internet Access Providers

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Abstract

The paper presents a simple game theoretic model of two Internet access providers who choose between peering and transit agreements. There is no regulation with regard to interconnection policies of providers, though there is a general convention that the providers peer if they perceive equal benefits from peering, and have transit arrangements otherwise. In the literature there is a debate whether the large providers gain and exploit market power through the terms of interconnection that they offer to smaller providers. In this paper we develop a game theoretic model to examine how providers decide who they want to peer with and who has to pay transit. The model discusses a set of conditions, which determine the formation of peering and transit agreements. The model takes into account the costs of carrying traffic by peering partners. Those costs should be roughly equal for the providers to have incentives to peer, otherwise the larger provider believes that the smaller provider might free ride on its infrastructure investments. The analysis suggests that the providers do not necessarily exploit market power when refusing to peer. Moreover, Pareto optimum is achieved under transit arrangements only. The paper argues that the market forces determine the decisions of peering and transit, and there is no need for regulation to encourage peering. Furthermore, to increase efficiency, the regulators might actually need to promote transit arrangements.

Keywords: *Internet, Peering, Transit, Efficiency, Nash Equilibrium*

Introduction

Interconnection of Internet Access Providers (IAPs) has been a concern of regulators since the late 1990s. The providers exchange traffic with each other based on either peering agreements, under which the providers do not charge each other for the exchange of traffic, or transit agreements, under which the downstream provider pays the upstream provider a certain settlement payment for carrying its traffic. There is no regulation with regard to interconnection policies of providers, but there is a general convention that the providers peer if they perceive equal benefits from peering, and have transit arrangements otherwise. There has been a growing concern with regard to the increasing number of transit agreements replacing previously peering agreements. There is a debate whether

the large providers are unwilling to peer with small providers, or that transit arrangements are related to the actual differences in the relative costs incurred by the providers.

This paper presents a simple game theoretic model of two providers who choose between peering and transit agreements. The model discusses a set of conditions, which determine the formation of peering and transit agreements. It is important to recognize that there are costs of carrying traffic by peering partners and those costs should be roughly equal for the providers to have incentives to peer, otherwise the larger provider believes that the smaller provider might free ride on its infrastructure investments.

Norton (2002) generalizes the peering vs. transit tradeoff based on purely average cost analysis. He defines a certain "Peering Breaking Point" based on peering and transit costs, and argues that if the downstream provider exchanges more traffic than indicated by that point, then it should prefer peering with the upstream provider as it saves in transit costs. On the other hand, if the provider exchanges little traffic, then there is a possibility of not realizing sufficient peering traffic volume to offset the cost of peering, and transit is a more cost effective solution for the provider. This partial analysis of interconnection terms is based only on the costs of peering and transit. The author does not take into account the overall effects of peering and transit arrangements on providers' profits.

On the other hand, Laffont et al (2003) develop a model to analyze the impact of an access charge on Internet backbone competition. They distinguish between two types of end users: websites and consumers, and concentrate their analysis on the traffic from websites to consumers. Given the access charge, determined either by regulation or through a bilateral agreement, the backbones set prices to compete for websites and consumers. Their model results in a unique equilibrium, where the prices charged to consumers as well as the prices charged to websites are the same across the backbones. The model does not take into account the additional benefits or costs associated with the asymmetry of traffic flows between the backbones.

In this paper we consider a one stage game, where providers make their transit and peering decisions based on the costs associated with transit and peering as well as the additional benefits and costs associated with the traffic imbalances between the providers. Our analysis suggests that the providers do not necessarily exploit market power when refusing to peer. Our results show that the market forces determine the terms of interconnection. Hence, there is no need for regulation to encourage peering. Moreover, we show that the unique Pareto optimum is achieved under transit arrangements. Thus to increase efficiency, the regulators might actually need to promote transit arrangements.

Preliminaries

Consider two providers, $\{A,B\}$, with established networks and market shares. The providers are connected to each other, and, given their respective networks' as well as customers' characteristics, they have to decide whether to peer with each other, or one has to pay transit to the other. If the providers peer, then they follow so called "hot potato routing" ---each provider passes off net traffic as soon as possible, and the receiving provider bears the cost of transporting the traffic. On the other hand, if one provider pays transit to the other one, then the latter charges for the traffic traveling in both directions. We follow the assumptions of Laffont et al (2003) to capture the traffic imbalances

between the providers. They distinguish between two types of customers: websites and consumers. The traffic between websites, between consumers (emails) and from consumers to websites (the requests for webpage/file downloads) is neglected in our model, as it is much smaller than the traffic from websites to consumers (the actual downloads of webpages/files). We will concentrate our analysis on the traffic from websites to consumers. Consumers receive traffic, while websites send traffic. We assume that each consumer receives one unit of traffic, and each website sends one unit of traffic.

Denote provider i 's market share for consumers by α_i , and its market share for websites by $\tilde{\alpha}_i$, where $i \in \{A, B\}$. Further assume that the providers charge their customers the same prices for the same services, which are given exogenously. Let p be the per unit price charged to consumers, while \tilde{p} be the per unit price charged to websites. Under the peering agreement, when traffic is handed over from one provider to the other, the latter incurs per unit transport cost, c^p (cost per Mega-bits-per second (Mbps)). On the other hand, if one provider charges transit to the other one, then the latter pays per unit price of traffic, c^t (transit price per Mbps), for the traffic in both directions¹. The connection between a larger and a smaller provider is much more valuable to a smaller provider, than it is to the larger provider. We introduce $0 < \theta < 1$ to capture additional benefits providers receive from the connection with each other. It can be interpreted as an additional benefit received by the transit customer, and an additional negative benefit (such as congestion) imposed on the upstream provider under the transit agreement. c^p , c^t and θ are exogenous in our model.

The Game

We consider a simple 2×2 normal form game, where providers decide on peering and transit. The providers are connected to each other and they have the information about market shares, prices charged to consumers and websites, as well as the costs of peering and transit. In the game they simultaneously announce a transfer arrangement for the connection they already have. The transfer choice of a provider shows whether the provider is willing to pay for the traffic exchanged or demand the other party to pay for it. Let t_{ij}^i represent i 's transfer decision on the connection between i and j , where $i, j \in \{A, B\}$,

$$t_{ij}^i = \begin{cases} -1, & \text{if } i \text{ demands } j \text{ to pay for the traffic exchanged} \\ 1, & \text{if } i \text{ offers } j \text{ to pay for the traffic exchanged} \end{cases}$$

If both providers simultaneously seek the same type of transfer arrangement, they end up with a peering agreement. If they choose different transfers, they end up with a transit agreement. Let γ_{ij} , where $i, j \in \{A, B\}$, and $i \neq j$, determine the peering/transit agreement resulting from the transfer arrangement choices of the providers, i.e.,

¹ To simplify our analysis we assume that the per unit cost of transit doesn't vary with the total traffic exchanged. Typically the cost of transit is based on a 95th percentile traffic sampling technique. Prices depend on the total traffic exchanged and are charged on per Megabit-per-second. For further reference refer to W. Norton (2002).

$$\gamma_{ij}^i = \begin{cases} 0, & \text{for transit} \\ 1, & \text{for peering} \end{cases}$$

The outcomes of possible combinations of the decisions are given in the matrix below.

$A \setminus B$	demand ($t_{AB}^B = -1$)	offer ($t_{AB}^B = 1$)
demand ($t_{AB}^A = -1$)	peer	transit (B pays transit to A)
offer ($t_{AB}^A = 1$)	transit (A pays transit to B)	peer

We concentrate our analysis only on the traffic from websites to consumers. Consumers do not know in advance which website they might want to visit and receive traffic. They assume universal connectivity, regardless of which network they are attached to. We assume following Laffont et al (2003) that consumers are interested in all websites independent of the websites' network choices, which is referred to as a "balanced calling pattern" in the aforesaid paper. The total traffic that the consumers of i receive from j 's websites is $\alpha_i \tilde{\alpha}_j$, while the total traffic i 's websites send to j 's consumers is $\tilde{\alpha}_i \alpha_j$. We assume that under the peering agreement i bears the per unit transport cost, $0 < c^p \leq I$, on the traffic coming from j , while j bears the per unit transport cost, c^p , on the traffic coming from i . This is a consequence of so called "hot-potato routing". The providers pass on off-net traffic as soon as possible, and as a result, most of the transporting cost is borne by the receiving provider. On the other hand, when i pays transit to j , then i pays per unit price $0 < c^t \leq I$, for the traffic both to and from j . At the same time, under the transit relationship, if i pays transit to j , then i receives positive benefit for the whole traffic exchanged, while j incurs negative benefit from the whole traffic exchanged.

The profit of i from its connection with j , where, $i \neq j$ and $i, j \in \{A, B\}$, is now given by

$$\pi_i = \alpha_i \tilde{\alpha}_j (p - \gamma_{ij} c^p - t_{ij}^i (1 - \gamma_{ij}) (c^t - \theta)) + \tilde{\alpha}_i \alpha_j (\tilde{p} - t_{ij}^i (1 - \gamma_{ij}) (c^t - \theta)) \quad (1)$$

Equilibrium Analysis

There are three possible outcomes of the game. When both providers demand payments for the traffic exchanged, i.e., $t_{AB}^B = -1$ and $t_{AB}^A = -1$, then $\gamma_{AB} = \gamma_{BA} = 1$, and the providers end up with peering agreement. Similarly, the providers will end up peering, when both of them offer to pay for the traffic exchanged, i.e., $t_{AB}^B = 1$ and $t_{AB}^A = 1$. The profits of the providers is now reduced to

$$\begin{aligned} \pi_A &= \alpha_A \tilde{\alpha}_B (p - c^p) + \tilde{\alpha}_A \alpha_B \tilde{p} \\ \pi_B &= \alpha_B \tilde{\alpha}_A (p - c^p) + \tilde{\alpha}_B \alpha_A \tilde{p} \end{aligned} \quad (2)$$

If the provider A offers to pay, $t_{AB}^A = 1$, and the provider B demands payment, $t_{AB}^B = -1$, for the traffic exchanged, then $\gamma_{AB} = \gamma_{BA} = 0$, a transit agreement will be written and the respective profits are

$$\begin{aligned}
\pi_A &= \alpha_A \tilde{\alpha}_B (p - c^t + \theta) + \tilde{\alpha}_A \alpha_B (\tilde{p} - c^t + \theta) \\
\pi_B &= \alpha_B \tilde{\alpha}_A (p + c^t - \theta) + \tilde{\alpha}_B \alpha_A (\tilde{p} + c^t - \theta)
\end{aligned} \tag{3}$$

On the other hand, if the provider B offers to pay, $t_{AB}^B = 1$, and the provider A demands payment, $t_{AB}^A = -1$, for the traffic exchanged, then $\gamma_{AB} = \gamma_{BA} = 0$, a transit agreement will be written and the respective profits are

$$\begin{aligned}
\pi_A &= \alpha_A \tilde{\alpha}_B (p + c^t - \theta) + \tilde{\alpha}_A \alpha_B (\tilde{p} + c^t - \theta) \\
\pi_B &= \alpha_B \tilde{\alpha}_A (p - c^t + \theta) + \tilde{\alpha}_B \alpha_A (\tilde{p} - c^t + \theta)
\end{aligned} \tag{4}$$

We can represent the game in the payoff matrix given in *Table 1*

$A \setminus B$	-1	1
-1	$ \begin{aligned} \pi_A &= \alpha_A \tilde{\alpha}_B (p - c^p) + \tilde{\alpha}_A \alpha_B \tilde{p} \\ \pi_B &= \alpha_B \tilde{\alpha}_A (p - c^p) + \tilde{\alpha}_B \alpha_A \tilde{p} \end{aligned} $	$ \begin{aligned} \pi_A &= \alpha_A \tilde{\alpha}_B (p + c^t - \theta) + \tilde{\alpha}_A \alpha_B (\tilde{p} + c^t - \theta) \\ \pi_B &= \alpha_B \tilde{\alpha}_A (p - c^t + \theta) + \tilde{\alpha}_B \alpha_A (\tilde{p} - c^t + \theta) \end{aligned} $
1	$ \begin{aligned} \pi_A &= \alpha_A \tilde{\alpha}_B (p - c^t + \theta) + \tilde{\alpha}_A \alpha_B (\tilde{p} - c^t + \theta) \\ \pi_B &= \alpha_B \tilde{\alpha}_A (p + c^t - \theta) + \tilde{\alpha}_B \alpha_A (\tilde{p} + c^t - \theta) \end{aligned} $	$ \begin{aligned} \pi_A &= \alpha_A \tilde{\alpha}_B (p - c^p) + \tilde{\alpha}_A \alpha_B \tilde{p} \\ \pi_B &= \alpha_B \tilde{\alpha}_A (p - c^p) + \tilde{\alpha}_B \alpha_A \tilde{p} \end{aligned} $

Table 1: The Payoff Matrix of the Game

All three outcomes can be equilibrium under certain conditions. We consider two cases:

Case 1: $\theta > c^t$, i.e., the benefit received by the downstream provider generated by the connection between the two providers under the transit agreement is greater than the cost of the transit.

Proposition 1 Suppose $\theta > c^t$

(a) $t_{AB}^B = 1$ and $t_{AB}^A = 1$ is a Nash equilibrium, i.e., the providers will end up with peering agreement,

$$\text{if } \frac{\alpha_B \tilde{\alpha}_A}{\alpha_B \tilde{\alpha}_A + \tilde{\alpha}_B \alpha_A} < \frac{\theta - c^t}{c^p} \text{ and } \frac{\alpha_A \tilde{\alpha}_B}{\alpha_A \tilde{\alpha}_B + \tilde{\alpha}_A \alpha_B} < \frac{\theta - c^t}{c^p} \tag{5}$$

(b) $t_{AB}^A = 1$ and $t_{AB}^B = -1$ is a Nash equilibrium, i.e., the provider A will pay transit to the provider B ,

$$\text{if } \frac{\alpha_B \tilde{\alpha}_A}{\alpha_B \tilde{\alpha}_A + \tilde{\alpha}_B \alpha_A} > \frac{\theta - c^t}{c^p} \text{ and } \frac{\alpha_A \tilde{\alpha}_B}{\alpha_A \tilde{\alpha}_B + \tilde{\alpha}_A \alpha_B} < \frac{\theta - c^t}{c^p} \tag{6}$$

(c) $t_{AB}^A = -1$ and $t_{AB}^B = 1$ is a Nash equilibrium, i.e., the provider B will pay transit to the provider A ,

$$\text{if } \frac{\alpha_B \tilde{\alpha}_A}{\alpha_B \tilde{\alpha}_A + \tilde{\alpha}_B \alpha_A} < \frac{\theta - c^t}{c^p} \text{ and } \frac{\alpha_A \tilde{\alpha}_B}{\alpha_A \tilde{\alpha}_B + \tilde{\alpha}_A \alpha_B} > \frac{\theta - c^t}{c^p} \quad (7)$$

Proof. Let's start with assuming (5) condition. Then A 's best response to the given strategy of B , $t_{AB}^B = 1$, is $t_{AB}^A = 1$, because

$$\alpha_A \tilde{\alpha}_B (p + c^t - \theta) + \tilde{\alpha}_A \alpha_B (\tilde{p} + c^t - \theta) < \alpha_A \tilde{\alpha}_B (p - c^p) + \tilde{\alpha}_A \alpha_B \tilde{p}.$$

On the other hand, A 's best response to the given strategy of B , $t_{AB}^B = -1$, is $t_{AB}^A = 1$, because

$$\alpha_A \tilde{\alpha}_B (p - c^p) + \tilde{\alpha}_A \alpha_B \tilde{p} < \alpha_A \tilde{\alpha}_B (p - c^t + \theta) + \tilde{\alpha}_A \alpha_B (\tilde{p} - c^t + \theta)$$

Similarly, B 's best response to the given strategy of A , $t_{AB}^A = 1$, is $t_{AB}^B = 1$, because

$$\alpha_B \tilde{\alpha}_A (p + c^t - \theta) + \tilde{\alpha}_B \alpha_A (\tilde{p} + c^t - \theta) < \alpha_B \tilde{\alpha}_A (p - c^p) + \tilde{\alpha}_B \alpha_A \tilde{p},$$

and B 's best response to the given strategy of A , $t_{AB}^A = -1$, is $t_{AB}^B = 1$, because

$$\alpha_B \tilde{\alpha}_A (p - c^p) + \tilde{\alpha}_B \alpha_A \tilde{p} < \alpha_B \tilde{\alpha}_A (p - c^t + \theta) + \tilde{\alpha}_B \alpha_A (\tilde{p} - c^t + \theta)$$

The other parts of the proposition follow the same way. ■

Thus, Proposition 1 states that, given that the benefit is greater than the cost of transit, then the providers choose to peer with each other, if the proportion of the traffic traveling in each direction with respect to the total traffic is less than $\frac{\theta - c^t}{c^p}$. On the other hand, the providers will end up with a transit agreement, and i will pay transit to j , if j receives more traffic from i , than it sends, and if the proportion of the traffic received by j with respect to the total traffic is greater than $\frac{\theta - c^t}{c^p}$, while the proportion of the traffic send to i with respect to the total traffic is less than $\frac{\theta - c^t}{c^p}$ where $i, j \in \{A, B\}$, and $i \neq j$.

Corollary 1 If $\theta > c^t + \frac{c^p}{2}$, then only peering occurs in equilibrium.

Denote R_A to be the proportion of the total traffic coming to A from B , and R_B to be the proportion of the total traffic coming to B from A , i.e.,

$$\begin{aligned} R_A &= \frac{\alpha_A \tilde{\alpha}_B}{\alpha_A \tilde{\alpha}_B + \tilde{\alpha}_A \alpha_B} \\ R_B &= \frac{\alpha_B \tilde{\alpha}_A}{\alpha_B \tilde{\alpha}_A + \tilde{\alpha}_B \alpha_A} \end{aligned} \quad (8)$$

Note that $R_A + R_B = 1$. Then, if $\frac{\theta - c^t}{c^p} < 1$, we can summarize Proposition 1 in Figure 1.

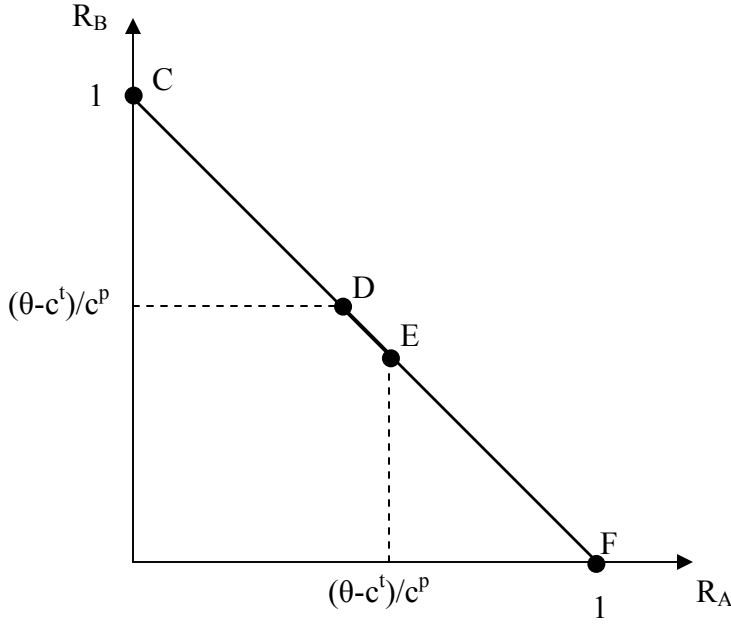


Figure 1: The constraints under Proposition 1

DE shows all the combinations of R_A and R_B , where condition 5 holds. Thus, for all combination of R_A and R_B on DE the providers will end up with a peering agreement. Similarly, CD and EF show, the combinations of R_A and R_B , where conditions 6 and 7 hold, respectively, and the providers end up with a transit agreement.

Case 2: $\theta < c^t$, the benefit received by the downstream provider generated by the connection between the two providers under a transit agreement is less than the cost of the transit.

Proposition 2 Suppose $\theta < c^t$

(a) $t_{AB}^B = -1$ and $t_{AB}^A = -1$ is a Nash equilibrium, i.e., the providers will end up with peering agreement,

$$\text{if } \frac{\alpha_B \tilde{\alpha}_A}{\alpha_B \tilde{\alpha}_A + \tilde{\alpha}_B \alpha_A} < \frac{c^t - \theta}{c^p} \text{ and } \frac{\alpha_A \tilde{\alpha}_B}{\alpha_A \tilde{\alpha}_B + \tilde{\alpha}_A \alpha_B} < \frac{c^t - \theta}{c^p} \quad (9)$$

(b) $t_{AB}^A = 1$ and $t_{AB}^B = -1$ is a Nash equilibrium, i.e., the provider A will pay transit to the provider B,

$$\text{if } \frac{\alpha_B \tilde{\alpha}_A}{\alpha_B \tilde{\alpha}_A + \tilde{\alpha}_B \alpha_A} < \frac{c^t - \theta}{c^p} \text{ and } \frac{\alpha_A \tilde{\alpha}_B}{\alpha_A \tilde{\alpha}_B + \tilde{\alpha}_A \alpha_B} > \frac{c^t - \theta}{c^p} \quad (10)$$

(c) $t_{AB}^A = -1$ and $t_{AB}^B = 1$ is a Nash equilibrium, i.e., the provider B will pay transit to the provider A,

$$\text{if } \frac{\alpha_B \tilde{\alpha}_A}{\alpha_B \tilde{\alpha}_A + \tilde{\alpha}_B \alpha_A} > \frac{c^t - \theta}{c^p} \text{ and } \frac{\alpha_A \tilde{\alpha}_B}{\alpha_A \tilde{\alpha}_B + \tilde{\alpha}_A \alpha_B} < \frac{c^t - \theta}{c^p} \quad (11)$$

Proof. The proof is obvious, and follows from the payoff matrix of the game. ■

Proposition 2 states that, given that the benefit is less than the cost of transit, the providers choose to peer with each other, if the proportion of the traffic traveling in each direction with respect to the total traffic is less than $\frac{c^t - \theta}{c^p}$. On the other hand, the providers end up with a transit agreement, and i will pay transit to j , if j receives less traffic from i , than it sends, and if the proportion of traffic received by j with respect to the total traffic is less than $\frac{c^t - \theta}{c^p}$, while the proportion of traffic send to i with respect to the total traffic is greater than $\frac{c^t - \theta}{c^p}$, where $i, j \in \{A, B\}$, and $i \neq j$.

Corollary 2 *If $\theta < c^t$ and $\theta < c^t - \frac{c^p}{2}$, then only peering occurs in equilibrium.*

If $\frac{c^t - \theta}{c^p} < 1$, then we can summarize the constraints under Proposition 2 in Figure 2. DE shows all the combinations of R_A and R_B , where condition 9 holds. Thus, for all combination of R_A and R_B on DE the providers will end up with a peering agreement. Similarly, CD and EF show, the combinations of R_A and R_B , where conditions 10 and 11 hold, respectively, and the providers end up with a transit agreement.

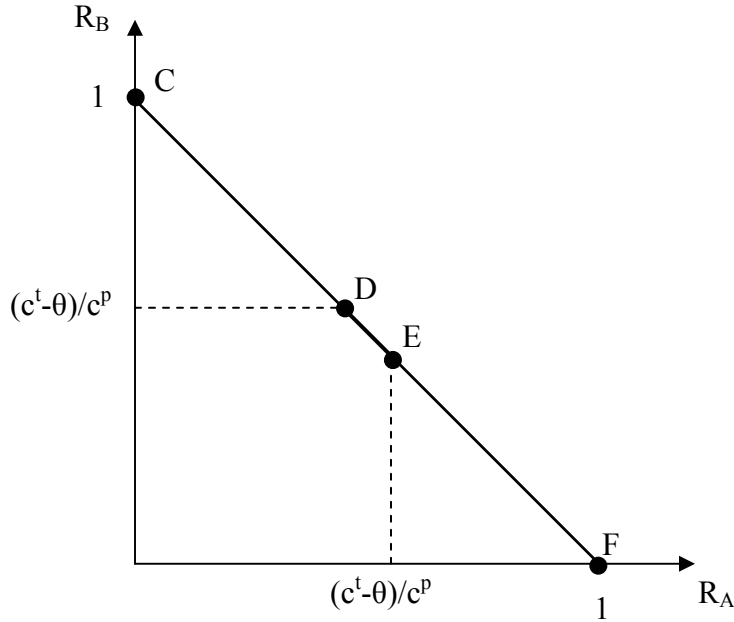


Figure 2: The constraints under Proposition 2

Thus, given the providers network characteristics (which determines θ), customers' characteristics, as well as costs and the prices charged to customers, the model provides conditions that determine the peering/transit decisions of the providers.

Proposition 3 *The joint profits are maximized under a transit agreement.*

Proof. Under the peering arrangements, whether $t_{AB}^B = -1$ and $t_{AB}^A = -1$, or $t_{AB}^B = 1$ and $t_{AB}^A = 1$, the joint profits are $(p + \tilde{p} - c^p)(\alpha_A \tilde{\alpha}_B + \tilde{\alpha}_A \alpha_B)$. On the other hand, the joint profits under transit agreements, i.e., when $t_{AB}^B = 1$ and $t_{AB}^A = -1$, or $t_{AB}^B = -1$ and $t_{AB}^A = 1$, are $(p + \tilde{p})(\alpha_A \tilde{\alpha}_B + \tilde{\alpha}_A \alpha_B)$, which is greater than the joint profits under the peering agreements. ■

Corollary 3 *The Pareto optimum coincides with the Nash equilibrium if any of these conditions hold*

- (a) $\theta > c^t, R_A < \frac{\theta - c^t}{c^p}$ and $R_B > \frac{\theta - c^t}{c^p}$ or
- (b) $\theta > c^t, R_A > \frac{\theta - c^t}{c^p}$ and $R_B < \frac{\theta - c^t}{c^p}$ or
- (c) $\theta < c^t, R_A > \frac{c^t - \theta}{c^p}$ and $R_B < \frac{c^t - \theta}{c^p}$ or
- (d) $\theta < c^t, R_A < \frac{c^t - \theta}{c^p}$ and $R_B > \frac{c^t - \theta}{c^p}$ or

Thus, if there is a large traffic imbalance between two providers, a transit arrangement is a Nash equilibrium, and Pareto optimum is achieved. In this case there is no need for a regulation to increase efficiency.

Conclusion

As there is no regulation with regard to interconnection polices, policymakers are concerned about possible anti-competitive behavior of larger providers. It can be questioned whether larger providers gain and exploit market power through terms of interconnection that they offer to smaller providers. The purpose of this paper was to develop a theoretical framework for modeling the peering/transit decisions of the providers, which examines the basis for the interconnection policies. The model discusses a set of conditions, which determine the formation of peering and transit agreements, which might have some policy implications. The providers weigh the benefits and costs of entering into a particular interconnection agreement. The decisions are based on how one variable weighs against the other. The larger provider may demand a transit arrangement, if it believes that the smaller provider might free ride on its infrastructure investments, because the larger provider might be the one transporting most of the traffic between them. The results suggest that the providers do not necessarily exploit market power when refusing to peer. Moreover, the joint profits are maximized under the transit arrangement. Peering partners do not get any compensations for carrying each other's

traffic, while incurring costs of transporting each other's traffic. Under the transit agreement, on the other hand, the downstream provider pays for the traffic carried by the upstream provider, while getting benefits of dumping most of the traffic on the upstream provider. These two effects cancel out when maximizing the joint profits of the transit partners. The paper argues that the market forces determine the decisions of peering and transit, and, given the current system of peering and transit arrangements, there is no need for a regulation on interconnection policies.

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