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Abstract

We examine the interrelation between interconnection and competition in the internet backbone market. Networks asymmetric in size choose among different interconnection regimes and compete for end-users. We show that a direct interconnection regime, Peering, softens competition compared to indirect interconnection since asymmetries become less influential when networks peer. If interconnection fees are paid, the smaller network pays the larger one. Sufficiently symmetric networks enter a Peering agreement while others use an intermediary network for exchanging traffic. This is in line with considerations of a non-US policy maker. In contrast, US policy makers prefer Peerings among relatively asymmetric networks.

Keywords: Internet Backbone, Endogenous Network Interconnection, Asymmetric Networks, Two-Way Access Pricing

JEL Classification: *L10, L96, D43*

1 Introduction

The rapid development of e-commerce industries and the emergence of Voice over IP and Video-on-Demand services, which all rely on the Internet Protocol (IP) standard, have increased the importance of the internet as a global medium of data exchange. Being a communications industry, the internet is subject to network externalities. These externalities have forced Internet Backbone Providers (IBPs) to interconnect with each other in order to provide their customers with "world-wide connectivity", hence increasing consumers' benefits and willingness-to-pay for internet access. From an economic perspective there are several ways to interconnect with other networks. The specific type of interconnection influences competition for end-users, and vice versa.

This paper aims to provide a general analysis of the industrial organization of an unregulated internet backbone market, i.e. the market for interconnection among IP-networks, which are also selling internet access to end-users. We endogenize both networks' interconnection and competition decisions while explicitly accounting for asymmetric network sizes, which are widely observed in practice. We will study the following questions: What determines networks' choice of interconnection? How do different types of interconnection affect competition for end-users? Who pays whom for interconnecting networks? Are networks' decisions in line with welfare considerations?

We will suggest to consider a new interconnection regime, Paid Peering, and find that networks which are sufficiently symmetric in size prefer it (together with better known Bill-and-Keep Peering) over using an intermediary network to exchange data. For medium ranges of network asymmetry, Paid Peering even dominates both alternative interconnection regimes: networks can raise profits in comparison to a situation where they were restricted to the choice of Bill-and-Keep Peering versus IP-Transit. Only for large asymmetries, they buy IP-Transit from an intermediary network in equilibrium. Our model will suggest that this interconnection behavior is not always desirable from a welfare point of view. Finally, taking into account that the market for IP-Transit is dominated by US carriers, a non-US trade policy oriented regulator would find that there is too much Peering and would seek to restrict Peering of networks which are sufficiently asymmetric in size.

Our model has the following timing: first, two networks, which are ex ante connected via an intermediary backbone, negotiate their interconnection regime. In case of Paid Peering, they bargain for a settlement-fee (interconnection fee or access price) that could flow either direction on stage two of the game. Third, they compete in prices for consumers with heterogeneous preferences in a Hotelling model. Finally, consumers choose the network maximizing their net benefits.

Our results show that the initial level of asymmetry in network sizes affects equilibrium outcomes: the larger the ex ante asymmetry is, the larger the profit differences between the networks when using an intermediary backbone, which in turn serve as threat points in the Nash bargaining game. As a consequence, both the settlement-fee resulting from the bargaining process and the interconnection decision reached in equilibrium depend on the degree of network asymmetry.

We obtain these results without assuming direct network externalities in the utility function of consumers. If internet-users valued direct connection to a large network over a small network, our results would be even more pronounced.

There is a large body of literature on interconnection and two-way access pricing in telecommunications, which one might think of being related to the internet backbone market. Armstrong (1998) and Laffont et al. (1998) constitute two fundamental works, while Vogelsang (2003) provides a comprehensive survey on this literature. However, there are two crucial differences which make an adoption of the analysis on the telecommunications market to the internet backbone highly problematic: First, interconnection in the internet backbone is not subject to regulation. Cash flows associated with interconnection on the internet do not depend on the direction of traffic but may be negotiated freely in the market.[1] Second, destination based price discrimination is usual in telecommunications, while it is practically impossible on the internet.[2]

There is also a more recent theoretical literature on telecommunications relaxing these industry specific restrictions: Carter and Wright (2003), Armstrong (2004), Gilo and Spiegel (2004) and Peitz (2005) study competitively chosen asymmetric access prices, asymmetric networks or IP-Transit as an outside option when negotiating the terms of interconnection. Yet our paper is the first to unify all three issues in one model.

Focusing on the internet, Laffont et al. (2003) study the strategic behavior of backbone operators in an environment of reciprocal access pricing in two-sided markets. Mendelson and Shneorson (2003) extend this framework to consumer delay costs and capacity decisions. Contrarily, because of already existing world-wide connectivity we abstract from network externalities in consumers' utility functions.

[1] In the telecommunications industry there exist various regulatory schemes around the globe, which rule network interconnection. Moreover, policy makers often require termination charges or "access charges" to be set reciprocally.

[2] It is standard for consumers to pay more for long-distance or international phone calls than for local ones. To imitate such price discrimination on the internet, a consumer would have to be asked before each click on a Web link whether she would be willing to pay a specific price depending on the network distance to a specific target Web site's location.

Because of the unregulated nature of the internet backbone, we let networks negotiate access prices freely.

Using a model of price competition, Giovannetti (2002) shows that the introduction of competition for Transit services may lead to fiercer competition in original areas of the Internet and thereby lower access and retail prices. Crémer et al. (2000) analyze in a Cournot model (thus endogenizing capacity) whether dominant network operators have incentives to lower the interconnection quality to rival networks. By extending the Katz and Shapiro (1985) network competition model they show that a network with a large installed base of customers is likely to degrade its interconnection quality with smaller networks.[3] However, nowadays there is excess capacity all over the backbone market,[4] and the marginal costs of data transmission are virtually zero.[5] Therefore, instead of modelling competition based on capacities/quantities we focus on price competition with differentiated products in the retail market against the background of (exogenous) competition in the Transit market. Instead of competition based on quality of interconnection we assume perfect transmission quality, which is due to existing world-wide connectivity and the absence or bottlenecks, and

[3]Foros and Hansen (2001) also study interconnection quality and competition between IBPs but derive opposing results concerning the development of market shares. Roson (2002) provides a more thorough discussion of Crémer et al. (2000) and that article. Foros et al. (2005) analyze interconnection in a two-stage game where networks first decide about interconnection quality and compete in quantities thereafter.

[4]Telegeography, a consultancy, notes: "Despite significant and consistent growth in data traffic flows across the world's communications networks, a huge portion of potential network capacity remains unused. [...] only three percent of the maximum possible intercity bandwidth in Europe and the U.S. has been 'lit' for service provision." (http://www.telegeography.com/press/releases/2005-04-20.php)

[5]See Atkinson and Barnekov (2004) or Nuechterlein and Weiser (2005, p.38).

let networks choose among several interconnection regimes.[6]

The papers connected most closely to our's are Baake and Wichmann (1999) and Besen et al. (2001) in the sense that they also endogenize the choice of IBPs' interconnection regime. The former studies the Transit vs. Peering decision in the context of quality differentials though, while the latter provides a bargaining process of Peering partners (implicitly introducing the option for Paid Peering). Both do not consider effects on competition for end-users. To the best of our knowledge, our paper is the first attempt to endogenize both networks' interconnection and competition decisions among asymmetric networks while taking into account the economic differences between the internet backbone and telecommunications markets.

The paper is organized as follows. Section 2 describes the most widely used interconnection regimes in more detail. Section 3 sets the stage for the model and derives networks' equilibrium prices, market shares and profits under Intermediary and Bill-and-Keep Peering regimes, respectively. Section 4 introduces the Nash bargaining game used under the Paid Peering regime. Section 5 examines incentives to peer and defines parameter ranges of interconnection equilibria. Section 6 takes a welfare perspective. Section 7 discusses the robustness of some central model assumptions, while section 8 concludes.

2 Interconnection Practice in the Internet Backbone Market

The United Nations Conference on Trade and Development (UNCTAD) mentions in its Information Economy Report 2005 (p.93) that over 300 operators were providing

[6] In the internet backbone, excess capacity leads to virtually perfect quality of interconnection.

commercial backbone services at the end of 2004 and that the "broader network services industry sales are estimated at about $1.3 trillion worldwide. [...] Of the 300 backbone networks mentioned before, the top 50 carry nearly 95 per cent of all IP traffic, and only five of them can be considered to have a truly global presence." These numbers suggest that IP-networks are heterogenous in size, i.e. in traffic volume or subscribers, which could have an impact on interconnection practice.

How does traffic get from consumer 1 to consumer 2? Suppose 1 and 2 are communicating via the internet and consumer 1 (2) is connected to network A (B). The networks have two main options to exchange traffic, Transit and Peering.

IP-Transit/Intermediary: If a direct connection is not feasible or desirable, two networks can buy so-called Transit services from a third network. Under such an arrangement both networks pay a variable charge per unit of traffic to the intermediary network which obligates to deliver the traffic to any specified destination and from a certain origination. For being able to fulfil this obligation, networks offering Transit mostly have a large physical network and are connected to many other networks via Peering or further Transit sales. The IP-Transit market is dominated by so-called Tier-1 networks which are mainly US based.[7]

Peering:[8] *Bill-and-Keep Peering*, also called settlement-free Peering, has evolved as the regular type of direct interconnection regime between two networks since pri-

[7]A network is regarded to have Tier-1 status if it is connected to the whole internet while never paying for interconnection itself.

[8]In the industry, there is a difference between "Private Peering", where exactly two networks build or lease lines to interconnect, and "Public Peering" where several networks interconnect their lines in a node, a so-called Internet Exchange Point. As economic differences are not very significant and more and more networks use Private Peering, we only consider this type in our model. See Kende (2000) for more details.

vatization of the internet. Networks exchange traffic without charging any fees to each other. However, under such a Peering agreement no participating network has the obligation to terminate traffic to or from a third party. Each network must only process traffic from the Peering partner to its own customers (and the customers of their customers and so on), but not to the remainder of the internet. This constitutes a major difference between IP-Transit and Peering. In our example, consumers 1 and 2 can exchange traffic without causing any interconnection costs to the networks they have subscribed to if those are peering.

A *Paid Peering* regime between two networks implies the same rights concerning their exchange of traffic. In contrast to Bill-and-Keep, one network charges the other for exchanging traffic. We may emphasize that Paid Peering is a relatively new type of interconnection regime and has only recently begun to be employed.[9] In our example, suppose network A agreed to pay for traffic exchange with network B, thereby forming a Paid Peering interconnection regime. In this environment it has no impact on the stream of money whether 1 sends an e-mail to 2, or vice versa: in both cases network A will pay B. However, since Paid Peering is no Transit contract, network B will not proceed traffic from A to a third party that is not a customer of B.[10]

[9] A Paid Peering settlement could appear in several different forms of payment, either fixed amount payments or a variable charge per unit of traffic (or a combination of both). The previous type of payment could involve asymmetric cost sharing regarding the technological fixed costs of installing traffic exchange points between Peering partners.

[10] For more details on internet traffic, see Giovanetti and Ristuccia (2005) or Kende (2000).

3 The Model

3.1 Key Assumptions

There are two networks $i \in \{A, B\}$ each having a fixed installed base of customers α_i that is not subject to competition.[11] Without loss of generality we assume $\alpha_A \geq \alpha_B$. On top, $\bar{\alpha}$ consumers are situated in a *battlezone*, where networks A and B compete in prices.[12] We assume excess capacity on the part of the networks so they could serve battlezone consumers without extra investments. This reflects the current infrastructure environment. Ex ante both networks are connected to the remainder of the internet by using an intermediary, thereby offering their customers world-wide connectivity.[13] As there is Bertrand price competition in the market for IP-Transit, we assume the intermediary to be the cheapest Tier-1 network available, by definition offering access to all remaining consumers connected to the internet,

[11] Internet Service Providers selling internet access to those consumers are integrated into the networks.

[12] The most intuitive explanation is of a geographic nature: the locked customers of network i can only be connected directly to network j for prohibitively high costs, e.g. because they live in a rural area. The battlezone, however, consists of consumers living in large cities where both networks have a point of presence (POP). Another interpretation is that A and B compete in new services, e.g. Voice over IP, in the battlezone but also have legacy customers who are not interested in such services.

[13] In line with this, we model no quality differentials among Peering and Transit, unlike as in Crémer et al. (2000) or Baake and Wichmann (1998), since, according to industry representatives, there is no clear relationship between interconnection quality and regimes. Consequently, demand-side network effects do not play a role in the model since customers enjoy world-wide connectivity on a constant quality level regardless of the networks' interconnection decision or competition.

κ.[14] It is not important whether the intermediary directly serves the κ consumers as ISP or connects other networks' consumers via its backbone to networks A and B. There is a continuum of consumers, of mass 1, so $\alpha_A + \alpha_B + \bar{\alpha} + \kappa = 1$. Figure 1 charts the competition set-up.

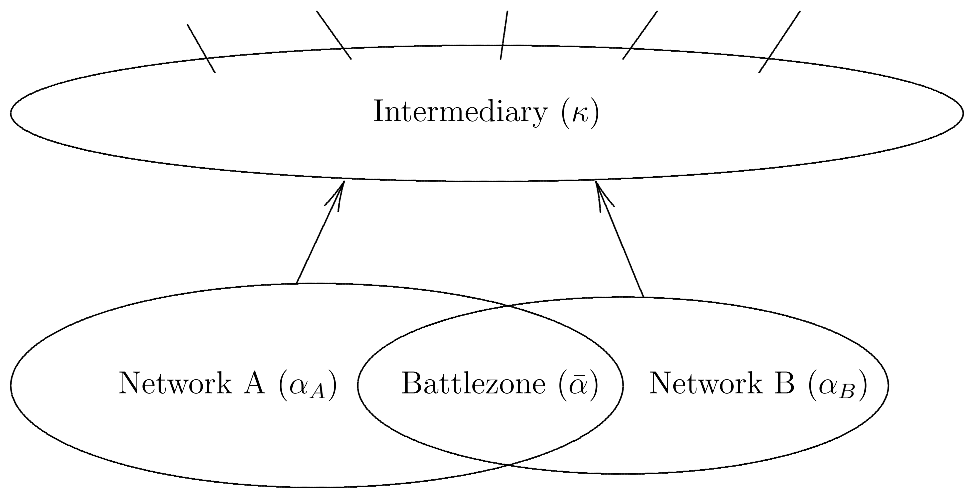

Figure 1: Network interconnection via an intermediary

Networks' cost structure:

- Networks face an exogenous market price for upstream Transit, t_u, per unit of data.

- Technical marginal cost of sending data are zero.[15] We discuss this assumption in section 7.

[14] In our model we do not cover competition where one of the two networks has Tier-1 status. Therefore, we do not endogenize the intermediary's price of IP-Transit. See Prüfer and Jahn (2007) for a discussion of the influence of Bertrand competition on the internet backbone industry's outlook and market structure.

[15] Refer to the literature mentioned in footnote 5.

- Costs of connecting customers to a network within the battlezone are symmetric and, for simplicity, normalized to zero.

- In case of a Peering arrangement, each network has to bear a fixed cost F, where $0 < F \leq t_u\bar{\alpha}(\alpha_A + \alpha_B + \frac{\bar{\alpha}}{2}) + 2\alpha_A\alpha_B t_u \equiv t_u w$.[16]

Since top-level backbones do not charge different fees for upstream or downstream traffic, we merely assume that each consumer sends one unit of data to each other consumer and receives one unit of data from each other consumer, thereby not taking into account which network the other consumer is connected to (*balanced calling pattern*). This yields every consumer a gross benefit, v. Finally, we assume that prices p_i^L in the locked areas are not affected by competition in the battlezone, where both networks charge every customer a price p_i.

3.2 The Game

The timing of the game is as follows:

1. Networks A and B decide non-cooperatively about the interconnection regime between them, *Intermediary*, *Bill-and-Keep Peering* or *Paid Peering*. If networks cannot agree on a specific Peering regime, both are forced to use the intermediary.

2. In case of Paid Peering, networks bargain for a fixed settlement which could flow either direction.

[16] F encompasses all fixed-step costs for setting up a physical interconnection, buying routers, etc. and organizational costs for managing a Peering agreement. Without an upper boundary for F, namely $t_u w$, Peering can never be an equilibrium, which makes the analysis less interesting.

3. Networks A and B set prices p_i for consumers in the battlezone. Consumers have heterogeneous preferences, so networks compete in a Hotelling-like environment.[17]

4. Consumers in the battlezone choose the network maximizing their net benefits.

We will derive equilibrium profits of both networks under Bill-and Keep Peering (BK) and Intermediary regimes at the third stage of the game first, derive Paid Peering (PP) profits at the second stage and compare them at the first stage afterwards to yield incentives for choosing the regimes. Then we derive parameter constellations where choosing Bill-and-Keep Peering, Paid Peering or Intermediary constitute equilibrium strategies for both networks.

3.3 Price Competition under the Intermediary Regime

Consider a standard Hotelling (1929) model. Consumers are indexed by x and uniformly distributed on the interval $[0, 1]$ with increasing preference for network B. The network differentiation parameter (transportation cost parameter) is $\tau > 0$, so that a consumer's utility function is given by

$$U = \begin{cases} v - \tau x - p_A & \text{if buying from network A} \\ v - \tau(1-x) - p_B & \text{if buying from network B} \\ 0 & \text{otherwise.} \end{cases} \tag{1}$$

[17] Heterogeneity could depend on different complementary services offered by the networks, e.g. specific Web content or software applications certain consumers are already used to. Note that heterogeneity refers to the retail market of internet access, while data exchange between networks is a homogenous good.

We assume v sufficiently large such that the market is covered. It is simple to calculate the standard marginal consumer who is indifferent between A and B and denoted by

$$\hat{x} = \frac{1}{2} + \frac{p_B - p_A}{2\tau}. \tag{2}$$

Note that $\hat{x}$ also specifies A's market share within the battlezone, while $(1 - \hat{x})$ is B's battlezone market share. Profit functions[18] under the Intermediary regime are given by

$$\Pi_A^I = \hat{x}\bar{\alpha}(p_A - 2\kappa t_u) + \alpha_A(p_A^L - 2\kappa t_u) - 2t_u(\hat{x}\bar{\alpha} + \alpha_A)((1 - \hat{x})\bar{\alpha} + \alpha_B) \tag{3}$$

$$\Pi_B^I = (1 - \hat{x})\bar{\alpha}(p_B - 2\kappa t_u) + \alpha_B(p_B^L - 2\kappa t_u) - 2t_u(\hat{x}\bar{\alpha} + \alpha_A)((1 - \hat{x})\bar{\alpha} + \alpha_B). \tag{4}$$

The first term of each function describes a network's direct profits from customers in the battlezone net of Transit costs which stem from sending data to or receiving data from customers of the other network. The second term denotes the same for its locked customers, while the third term adjusts for the traffic that is exchanged between A and B. This term has to be paid to the intermediary by each network, is of equal size for both firms and will become a main formal driver of the model. Note that traffic has to be paid twice for each consumer since we have assumed that all consumers both send data to and receive data from all other consumers. The first-order-condition of network A is given by

$$\frac{\partial \Pi_A^I}{\partial p_A} = \frac{\bar{\alpha}}{2\tau^2}(\tau(p_B - 2p_A + \kappa 2t_u - \alpha_A 2t_u + \alpha_B 2t_u + \tau) + p_A 2t_u\bar{\alpha} - p_B 2t_u\bar{\alpha}) = 0, \tag{5}$$

[18]We assume that networks are able to discriminate prices between locked consumers and the battlezone. If that was not possible, as $\alpha_A \geq \alpha_B$, there would be no price Nash equilibrium in pure strategies. Therefore, and because we believe in the feasibility of price discrimination based on the sender's—not the receiver's—location in the internet, we restrict our analysis to this case.

while B's is analogous. We derive reaction functions as

$$p_A(p_B) = \frac{2t_u\bar{\alpha}-\tau}{2(t_u\bar{\alpha}-\tau)}p_B + \frac{2\tau t_u(\alpha_A-\alpha_B-\kappa)-\tau^2}{2(t_u\bar{\alpha}-\tau)} \tag{6}$$

$$p_B(p_A) = \frac{2t_u\bar{\alpha}-\tau}{2(t_u\bar{\alpha}-\tau)}p_A + \frac{2\tau t_u(\alpha_B-\alpha_A-\kappa)-\tau^2}{2(t_u\bar{\alpha}-\tau)}. \tag{7}$$

Second-order-conditions are satisfied and the slope of the reaction functions is between zero and one for $\tau > 2\bar{\alpha}t_u$, which we assume henceforth. This yields the following equilibrium prices

$$p_A^* = \tau + \frac{2t_u(\kappa(3\tau-4t_u\bar{\alpha})-\Delta\tau)}{3\tau-4t_u\bar{\alpha}} = \tau(1-z\Delta)+2\kappa t_u \tag{8}$$

$$p_B^* = \tau + \frac{2t_u(\kappa(3\tau-4t_u\bar{\alpha})+\Delta\tau)}{3\tau-4t_u\bar{\alpha}} = \tau(1+z\Delta)+2\kappa t_u, \tag{9}$$

where $\Delta = \alpha_A - \alpha_B \geq 0$ and $z = \frac{2t_u}{(3\tau-4t_u\bar{\alpha})} > 0$. Hence, A's equilibrium market share is

$$\hat{x} = \frac{1}{2} + \frac{2t_u\Delta}{(3\tau-4t_u\bar{\alpha})} = \frac{1}{2} + z\Delta. \tag{10}$$

Equilibrium profits under the Intermediary regime are given by

$$\Pi_A^I = \frac{1}{2}\tau\bar{\alpha}(1+z\Delta-2z^2\Delta^2) + z^2\Delta^2\bar{\alpha}(3\tau-2t_u\bar{\alpha}) - t_uw + \alpha_A(p_A^L-2\kappa t_u) \tag{11}$$

$$\Pi_B^I = \frac{1}{2}\tau\bar{\alpha}(1-z\Delta-2z^2\Delta^2) + z^2\Delta^2\bar{\alpha}(3\tau-2t_u\bar{\alpha}) - t_uw + \alpha_B(p_B^L-2\kappa t_u). \tag{12}$$

It is obvious that A's direct profits from the battlezone, $\frac{1}{2}\tau\bar{\alpha}(1+z\Delta-2z^2\Delta^2)$, increase while B's direct profits decrease with growing asymmetry Δ. Furthermore, total Transit costs of each network, $t_uw+\alpha_i 2\kappa t_u - z^2\Delta^2\bar{\alpha}(3\tau-2t_u\bar{\alpha})$, are maximized for symmetry ($\Delta = 0$). We find:

Lemma 1 *Under the Intermediary regime of interconnection, network A prices more aggressively than B leading to a higher market share and larger profits of A in the battlezone.*

The key to understanding this Lemma is that Transit payments of A and B to the intermediary decrease with growing network asymmetry. Thus, the larger network A has higher incentives to increase its market share than the smaller one: if A could sell to a marginal consumer, its income would increase and its Transit costs would decrease. B faces an extra trade-off: if acquiring a marginal customer within the battlezone, its income would increase, but corresponding Transit costs would increase in line. Therefore, A's marginal profit from acquiring another customer is larger than B's making A more aggressive. Similarly, A's ex post profits increase with growing ex ante asymmetry, which also minimizes both networks' Transit payments since more traffic is exchanged "on-net", i.e., if sender and receiver are customers of the same network.

3.4 Price Competition under Bill-and-Keep Peering

If networks peer with each other, their profit functions show two differences in relation to the case without Peering: Peering's upside is that networks do not have to pay the intermediary for traffic that is exchanged solely between the two networks involved, anymore. Its downside is that the Peering partners have to set up direct lines, buy new equipment such as routers and have to bear Peering management costs. All these types of costs are compiled in the variable F, which is not, according to various industry talks, correlated with network size or the amount of traffic transmitted.

This leads to the following profit functions under Peering:

$$\Pi_A^P = \hat{x}\bar{\alpha}(p_A - 2\kappa t_u) + \alpha_A(p_A^L - 2\kappa t_u) - F, \tag{13}$$

$$\Pi_B^P = (1-\hat{x})\bar{\alpha}(p_B - 2\kappa t_u) + \alpha_B(p_B^L - 2\kappa t_u) - F. \tag{14}$$

Equilibrium prices can be derived as

$$p_A^* = \tau + 2\kappa t_u \tag{15}$$

$$p_B^* = \tau + 2\kappa t_u, \tag{16}$$

leading to an equilibrium market share for A (and for B, respectively) of

$$\hat{x} = \frac{1}{2}. \tag{17}$$

Equilibrium profits under the Peering regime are given by

$$\Pi_A^P = \frac{1}{2}\tau\bar{\alpha} + \alpha_A(p_A^L - 2\kappa t_u) - F \tag{18}$$

$$\Pi_B^P = \frac{1}{2}\tau\bar{\alpha} + \alpha_B(p_B^L - 2\kappa t_u) - F. \tag{19}$$

These equations yield:

Lemma 2 *Under the Peering regime of interconnection, (i) regardless of asymmetries in installed bases networks' pricing behavior is symmetric. (ii) Market shares in the battlezone are symmetric. (iii) Leaving out profits from the installed bases, profits from competition in the battlezone are symmetric. (iv) If installed bases were symmetric ($\Delta = 0$), equilibrium prices and battlezone market shares would be the same under Intermediary and Peering regimes.*

The intuition for (i) through (iii) is that, since under a Peering regime Transit costs for traffic between the two parties are waived, the larger network has no extra incentives to undercut the smaller one, anymore. Therefore, incentive structures, behavior and profits are symmetric. This intuition is confirmed by (iv) stating that symmetric networks always behave in the same way regardless of the interconnection regime.

4 Bargaining under Paid Peering

Given networks decided to interconnect under the Paid Peering regime, on the second stage of the game we should calculate the settlement-fee, S, one network has to pay the other to make the latter agree to Peering.[19] If they opted for Intermediary or BK, this stage would be waived.

It facilitates further analysis, if we first derive the networks' relative individual incentives to accept Bill-and-Keep Peering.

Lemma 3 *The smaller network always has higher incentives to reach a Bill-and-Keep Peering relative to Intermediary than the larger network.*

Proof: Network A's incentives to BK—the gains from Peering—are smaller than B's, if $\Pi_A^P - \Pi_A^I < \Pi_B^P - \Pi_B^I$, or $(18) - (11) < (19) - (12)$, which is true for all defined parameter realizations. $\square$

Because of Lemma 3, it is clear that network B always has to pay network A under Paid Peering, not vice versa. It is noteworthy that we obtain this finding even without assuming network externalities in the utility functions of consumers. If we did so, consumers would ex ante prefer network A over network B, which would increase A's bargaining power and the settlement-fee even more. Let

$$S \equiv \frac{1}{2}(\Pi_B^P - \Pi_B^I - (\Pi_A^P - \Pi_A^I)) = \frac{\bar{\alpha}\tau z \Delta}{2} \tag{20}$$

be this settlement B has to pay A, meaning that we assume equal bargaining power and use the respective equilibrium profits under the Intermediary regime as threat

[19] Here, the transfer payment or *access charge* between networks, unlike in most papers on interconnection in telecommunications, is of a lump-sum type, not a per unit of data fee. See section 7 and appendix A.5 for a comparative analysis of the per-unit case. For now, we follow Besen et al. (2001) in assuming a lump-sum payment.

points.[20] At a non-cooperative bargaining outcome, the networks share equally any gains relative to their threat points. This formulation ensures that each player obtains (or keeps) profits from the Intermediary case, at least, while only "excess" profits are shared. Therefore, the assumption of equal bargaining power—which is expressed by the factor 1/2 in (20)—is not crucial here since it does not affect absolute incentives to agree to Paid Peering relative to Intermediary.

In general, A's equilibrium profits under Paid Peering are $\Pi_A^{PP} = \Pi_A^P + S$ while B's are $\Pi_B^{PP} = \Pi_B^P - S$. Using (20) yields

$$\Pi_A^{PP} = \frac{1}{2}\tau\bar{\alpha} + \alpha_A(p_A^L - 2\kappa t_u) - F + \frac{\bar{\alpha}\tau z\Delta}{2} \tag{21}$$

$$\Pi_B^{PP} = \frac{1}{2}\tau\bar{\alpha} + \alpha_B(p_B^L - 2\kappa t_u) - F - \frac{\bar{\alpha}\tau z\Delta}{2}. \tag{22}$$

5 Regime Equilibria

Being aware of Nash equilibria in prices given the respective regimes, we now proceed to analyze incentives on the first stage: When do networks wish to peer with a specific competitor? What form of Peering would prevail if side payments were feasible?

Before analyzing equilibria, we are to specify the support of Δ in general. (10) implies that, to receive interior solutions for $\hat{x}$ such that $\hat{x} \in [0, 1]$, it is necessary that

[20] This formulation is analogous to Besen et al. (2001) whose approach is based on the Nash bargaining model of Binmore et al. (1986). It can be applied if we assume that the lack of Peering is sustained only temporarily during bargaining until an agreement is reached, since this resembles the bargaining result according to the non-cooperative bargaining theory with short times between offers. Hence, we can use the formulation of the cooperative bargaining theory, as done in (20), and obtain the same result that the (more detailed and complicated) non-cooperative bargaining theory would provide.

$\Delta \in [-\frac{1}{2z}, \frac{1}{2z}]$. Thus, as $\Delta \geq 0$ by definition, we have $\Delta_{max} \equiv \frac{1}{2z}$, where $t_u \geq \frac{3\tau}{4(1+\bar{\alpha})}$ which is always true for defined values. If Δ lies outside of these boundaries, the larger network's aggressiveness in the price competition is so strong that the smaller network will be driven out of the (battlezone) market. Henceforth, we restrict our analysis to $\Delta \in [0, \Delta_{max}]$.

Now, recall that each network can force the other one to play the Intermediary strategy. If and only if both parties either agree on BK or on PP, that regime will be a Nash equilibrium. Therefore, following our assumption that the Intermediary regime is the status-quo when playing the first stage of the game, Intermediary is a Nash equilibrium for all levels of asymmetry. This might explain why we observe usage of IP-Transit among both symmetric and asymmetric networks in practice, given the cost of alternative Peering regimes, F, are not too low.

When is Bill-and-Keep Peering a candidate for equilibrium outcomes? It is an equilibrium strategy for both A and B if no player has an incentive to deviate from it and to obtain the Intermediary outcome. We find

Proposition 1 *Bill-and-Keep Peering is an equilibrium outcome for small network asymmetries (where $\Delta \in [0, \Delta_{BK}]$).*

Proof: refer to the appendix.

When is Paid Peering a candidate for equilibrium outcomes? Because of our assumption that under Paid Peering "excessive" joint profits can be perfectly exchanged, no player will prefer the Intermediary strategy over PP as long as $\sum \Pi_i^{PP} > \sum \Pi_i^I$. Rearranging this relation based on equations (11), (12), (21) and (22) yields that Paid Peering is an equilibrium outcome if

$$\Delta < \sqrt{\frac{t_u w - F}{2z^2\bar{\alpha}(\tau - t_u\bar{\alpha})}} \equiv \Delta_P. \tag{23}$$

According to our assumptions, we always have $\Delta_P \geq 0$. Via resubstitution of z we find that $\Delta_P < \Delta_{max}$ for $t_u w - F < \frac{\bar{\alpha}}{2}(\tau - t_u\bar{\alpha})$. Summarizing, if F is sufficiently low ($F \leq t_u w$), networks' interconnection decision is largely dependent on their ex ante size asymmetry: Paid Peering dominates Intermediary for low Δ, and vice versa for large Δ. But if F is too low, Intermediary can never be an equilibrium as (23) emphasizes that networks will interconnect via an Intermediary if the difference in size of two networks is relatively large.

Proposition 2 *Assume $t_u w - \frac{\bar{\alpha}}{2}(\tau - t_u\bar{\alpha}) < F < t_u w$. (i) Intermediary constitutes a Nash equilibrium for any level of network asymmetry. (ii) However, for low asymmetry networks prefer Peerings: (a) For all $\Delta \in [0, \Delta_{BK}]$, both Bill-and-Keep and Paid Peering form equilibrium outcomes. (b) For all $\Delta \in (\Delta_{BK}, \Delta_P]$, Paid Peering is an equilibrium outcome. (iii) For all $\Delta \in [\Delta_P, \Delta_{max}]$, Intermediary is an equilibrium outcome (for $\Delta > \Delta_P$ even uniquely).*

Proof: refer to the appendix.

Figure 2 provides a graphical intuition of Proposition 2: It plots where *(a)* Bill-and-Keep Peering, *(b)* Paid Peering and *(c)* Intermediary constitute Nash equilibria. Left of Δ_P, at least one Peering regime is preferred by the networks over buying IP-Transit—and they can deviate from playing an Intermediary strategy without risk.[21] We have used a dashed line to indicate this.

Amongst others, this proposition suggests an intuition why, according to anecdotal evidence, Bill-and-Keep Peering has been the dominant Peering regime in

[21] This implies that we could use a stronger equilibrium concept, *equilibrium in weakly dominant strategies*, to rule out (Intermediary, Intermediary) as an equilibrium strategy for all $\Delta < \Delta_P$. For the sake of consistency with stages 2 and 3 of the game, however, we stay with (subgame-perfect) Nash equilibrium as our solution concept.

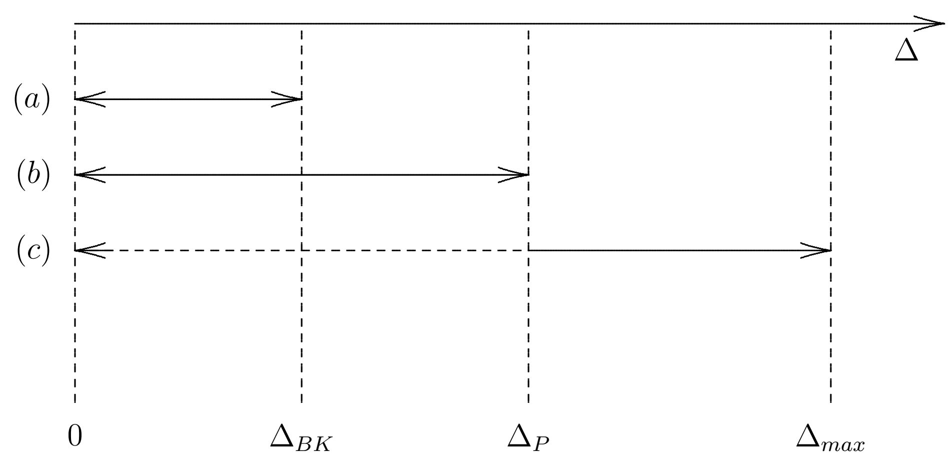

Figure 2: First stage Nash equilibria

practice. If networks are sufficiently symmetric and the smaller network can credibly announce that it will not bargain over a settlement-fee, the larger network is better off by accepting BK instead of being tough, too, and ending up paying the Intermediary.[22] If networks' asymmetry is small but not very small, the smaller network knows that the larger one would never accept BK because the Intermediary outside option is more attractive. Then, the smaller network is better off by paying some of its gains from Peering via a settlement-fee thereby compensating the larger one for its losses. Reflecting on these two arguments indicates that in practice—and outside of our model—the sequence of moves is crucial.

[22]One reason for the smaller network's resistance to bargain at all could be explained by the fact that the bargaining process associated with Paid Peering may involve extra transaction costs in comparison to BK. Another explanation could be *legacy* which is, however, questionable from a purely economic point of view. The argument claims that, at the beginning of the commercial internet era, networks did not focus on the strategic aspects of interconnection but strived for reaching world-wide connectivity fast. Nowadays, they found themselves in the resource consuming process of reviewing their existing Peering policies.

6 Welfare

Now we know which interconnection regime networks will choose given exogenous parameter realizations. But are market outcomes beneficial for consumers and total welfare, as well?

6.1 Consumer Surplus

We restrict the analysis to the $\bar{\alpha}$ consumers residing in the battlezone since consumer surplus within the locked regions is neither a function of the networks' interconnection regime nor of their battlezone prices. Hence aggregate consumer surplus is the integral over individual net benefit (according to (1)) using the marginal consumer as boundary. As under (Paid) Peering, equilibrium prices of networks A and B are equal and each one gets a market share of 0.5, we can calculate consumer surplus as

$$CS^P = 2\bar{\alpha}\int_0^{0.5}(v - \tau x - p_A)dx = \bar{\alpha}(v - \frac{5}{4}\tau - 2\kappa t_u). \quad (24)$$

In contrast, consumer surplus under Intermediary is denoted by

$$CS^I = \bar{\alpha}\left(\int_0^{\hat{x}}(v - \tau x - p_A)dx + \int_{\hat{x}}^1 (v - \tau(1-x) - p_B)dx\right)$$
$$= \bar{\alpha}(v - \frac{5}{4}\tau - 2\kappa t_u) + \bar{\alpha}\tau z^2\Delta^2 = CS^P + \bar{\alpha}\tau z^2\Delta^2. \quad (25)$$

Analogously to section 3, $CS^P = CS^I$ if networks are symmetric ($\Delta = 0$). But for all $\Delta > 0$ consumer surplus is larger under the Intermediary regime. This is intuitive since in the Intermediary case the larger network competes more aggressively in prices than in the Peering case, but it also obtains a higher market share within the battlezone. Hence a majority of consumers enjoys extra surplus which is not offset completely by higher prices that are paid by the fewer customers of the smaller network. It is straightforward to observe from (25) that consumer surplus under Intermediary relative to Peering increases even further with growing network asymmetry.

6.2 Total Welfare

Up to which asymmetry should networks peer from a social perspective? Clearly, we can find this point, Δ_P^{Soc}, where a social planner including both consumer surplus and producer surplus (i.e. profits of networks A and B and the intermediary network) in his calculation would be indifferent between Peering and Intermediary. As $\sum \Pi_i^P = \sum \Pi_i^{PP}$, we can find this level via setting

$$CS^P + \Pi_A^P + \Pi_B^P + \Pi_{Int}^P = CS^I + \Pi_A^I + \Pi_B^I + \Pi_{Int}^I \tag{26}$$

where profits of the intermediary are denoted by $\Pi_{Int}^P = 2\kappa t_u(\alpha_A + \alpha_B + \bar{\alpha})$ and $\Pi_{Int}^I = \Pi_{Int}^P + 2t_u w - 2z^2\Delta^2\bar{\alpha}(3\tau - 2t_u\bar{\alpha})$ respectively. Employing equations (24), (18) and (19) as well as (25), (11) and (12) yields that from a social perspective networks should peer if

$$\Delta > \sqrt{\frac{2F}{z^2\tau\bar{\alpha}}} \equiv \Delta_P^{Soc}. \tag{27}$$

However, since currently all major intermediary backbones are US based firms,[23] one might also be interested in the ranges of asymmetry where a non-US policy maker would like networks to peer, i.e. without taking into account the profits of the intermediary network. Therefore, we set

$$CS^P + \Pi_A^P + \Pi_B^P = CS^I + \Pi_A^I + \Pi_B^I \tag{28}$$

[23]See http://www.fixedorbit.com/stats.htm.

and find that in this “trade policy” case, a regulator would want networks to peer as long as

$$\Delta < \sqrt{\frac{2(t_u w - F)}{z^2 \bar{\alpha}(5\tau - 4t_u\bar{\alpha})}} \equiv \Delta_P^{TP}. \tag{29}$$

It might be startling that both a trade policy regulator and the profit maximizing networks prefer Peering for a lesser degree of asymmetry, while a social planner prefers Peering for larger asymmetry. To understand the intuition of the three Δ-thresholds recall that the respective optimizers include different parameters in their calculi.

Networks trade-off Peering costs F versus Transit costs depending on t_u. If Δ increases, F remains constant while joint Transit costs decrease. Therefore, above a certain level of asymmetry, Δ_P, networks prefer the Intermediary regime.

A *“trade policy” regulator* faces the same trade-off and hence prefers Peering for low levels of asymmetry. But in addition he regards consumer surplus, which grows with Δ under Intermediary due to fiercer network competition but remains constant under Peering. Therefore, trade policy makers wish to have the Intermediary regime implemented even for lower levels of asymmetry than networks themselves.

A *social planner*, in contrast, does not observe the effect of decreasing Transit costs for larger asymmetry as this money flows to the intermediary backbone, which is included in his optimization calculus. Therefore, for low levels for asymmetry he only takes into account Peering costs F and prefers Intermediary regimes. With rising Δ, under Intermediary the social planner observes distortions due to networks' fiercer competition, which depend on the transportation cost τ in the model. As a consequence, above a threshold, Δ_P^{Soc}, he prefers interconnection via Peering regimes.

Proposition 3 *(i) Excess Peering: The level of asymmetry of network sizes up to which a “trade policy” regulator would prefer Peering, Δ_P^{TP}, is smaller than the* *asymmetry up to which networks peer without regarding consumer welfare, Δ_P. (ii) Within the range where networks peer but where it is suboptimal from a "trade policy" viewpoint, the loss increases with growing asymmetry.*

Proof: see appendix.

Now we know that always $\Delta_P^{TP} < \Delta_P$. However, Δ_P^{Soc} is not fixed within this range. What happens for low, medium and large realizations of Δ_P^{Soc}, and when do those cases occur? We distinguish among three possible realizations. Please, recall that the minimum level of F is $wt_u - \frac{\bar{\alpha}}{2}(\tau - t_u\bar{\alpha})$ and its maximum level is wt_u:

- Case I: $\Delta_P^{Soc} \leq \Delta_P^{TP} \quad \forall \quad F \in (wt_u - \frac{\bar{\alpha}}{2}(\tau - t_u\bar{\alpha}), \frac{\tau}{6\tau - 4t_u\bar{\alpha}}wt_u]$
- Case II: $\Delta_P^{TP} < \Delta_P^{Soc} \leq \Delta_P \quad \forall \quad F \in (\frac{\tau}{6\tau - 4t_u\bar{\alpha}}wt_u, \frac{\tau}{5\tau - 4t_u\bar{\alpha}}wt_u]$
- Case III: $\Delta_P < \Delta_P^{Soc} \quad \forall \quad F \in (\frac{\tau}{5\tau - 4t_u\bar{\alpha}}wt_u, wt_u)$

By checking these cases with the respective definitions of Δ_P, Δ_P^{Soc} and Δ_P^{TP}, we easily observe

Proposition 4 *(i) Within cases I and III but not in case II, there exist ranges where the equilibrium interconnection regime is in line with the views of both a social planner and a "trade policy" regulator. In case I (III) Peering (Intermediary) is optimal from these three perspectives as long as $\Delta_P^{Soc} < \Delta < \Delta_P^{TP}$ ($\Delta_P < \Delta < \Delta_P^{SOC}$). (ii) If Peering costs are sufficiently large, Peering never occurs where it is socially efficient ($\Delta_P < \Delta_P^{SOC}$). (iii) If Peering costs are sufficiently large, "trade policy regulators" only support Peering where it is socially inefficient ($\Delta_P^{TP} < \Delta_P^{SOC}$).*

Proof: see appendix.

Figure 3 provides a graphical intuition for Propositions 3 and 4. Peering is preferred by (a) the networks themselves (b) a "trade policy" regulator (c) a total welfare maximizer.

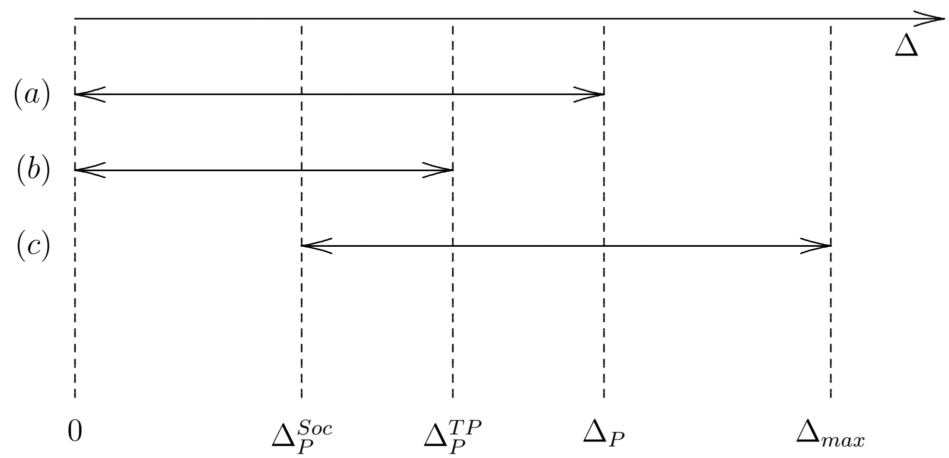

Figure 3: Welfare considerations for $\Delta_P^{Soc} \leq \Delta_P^{TP}$ (Case I)

Therefore, it is possible that both types of regulators are content with networks' actions, but it is also feasible that they would like to intervene in the market. We can characterize as a general rule that networks always peer excessively from a "trade policy" regulator's point of view.

7 Discussion

Paid Peering using a per-unit access charge: Hitherto we assumed the transfer payment or *access charge* between networks to be of a lump-sum type, not a per-unit of data fee (henceforth: *variable fee*). The two are structurally similar as long as the variable fee does not influence pricing behavior in the retail market. Given that, S could be interpreted as the sum of all per-unit fees in a given period. In contrast, a variable fee does indeed have an influence on the third stage of our game: networks tacitly collude even more than under lump-sum Paid Peering by splitting the battlezone 50:50 and symmetrically increasing retail prices. Thus, some consumer surplus is shifted to the networks. The quality of our results, namely Propositions 1 to 4, remain unchanged, though. For a more detailed analysis of variable Paid Peering refer to appendix A.5.

Positive marginal costs of sending data: In our analysis, building on established institutional literature and interviews with industry representatives, we assumed the marginal costs of sending data to be zero.[24] If those costs were positive, they would influence retail prices as a mark-up in all interconnection regimes symmetrically[25] as long as there would be no differences in costs for sending on-net or off-net traffic, which we see no technical reason for. Atkinson and Barnekov (2004, p.3) support our view by pointing out that the operating costs of a telecommunications network can be estimated well by the number of end-users connected to that network. They reject the idea that traffic volume is a major determinant for networks' operating costs.

Non-covered market: Let s_i be the market share of network i in the battlezone. If we lift our restriction, that the market be covered, we have $s_A + s_B \leq 1$. Under the intermediary regime, the costs that a marginal consumer residing in the battlezone creates when buying from network A by exchanging data with consumers connected to network B are $\bar{\alpha}(\alpha_B + \bar{\alpha}s_B)2t_u$. If he buys from network B, these marginal costs are $\bar{\alpha}(\alpha_A + \bar{\alpha}s_A)2t_u$. Assuming that both networks start with an equal market share, say $s_A = s_B = 0$, and using $\alpha_A > \alpha_B$, it is obvious that the marginal costs of connecting an additional consumer are lower for network A than for network B.

[24] Refer to the literature mentioned in footnote 5.

[25] This is a standard effect in Hotelling models.

Because of the uniform distribution of consumers along the $[0, 1]$-interval, marginal revenues are equal for both networks. Consequently, network A's marginal profit for connecting another consumer in the battlezone is larger than B's. This makes A more aggressive and leads to $p_A < p_B$, just as in Lemma 1. Under the Peering regime, when assuming equal battlezone market shares $s_A = s_B$ as a starting point, ceteris paribus the marginal incentives to attract another consumer are equal for both networks, just as in Lemma 2.

Non-linear and asymmetric Transit charges: We assumed that the Intermediary charges for Transit via a linear pricing scheme. If we allowed for non-linear tariffs, e.g. quantity discounts, that could make the marginal t_u asymmetric for networks A and B. However, the amount of traffic/capacity already bought from the Intermediary by network A could be larger or smaller than the amount of B (independent of α_A or α_B). Hence, it is unclear which of the two networks would perceive the lower marginal price. Therefore, we abstract from a more detailed discussion of the impact of non-linear Transit charges.

8 Conclusion

In this paper we have suggested a model of the internet backbone market, which explicitly takes into account differences in the size of networks. We have analyzed the consequences of those asymmetries for the optimal interconnection decisions of IBPs, which are strategically linked to retail competition for end-users. In line with that, we have studied the role of unregulated access charges as a means of tacit collusion when networks choose a Paid Peering regime. The main practical implications of our model both for networks, consumers, and policy makers inside and outside the US are the following:

1. If, besides Intermediary and Bill-and-Keep, networks also consider Paid Peering as a possible type of interconnection, we expect to observe more Paid Peering in the future. This would translate to more Peering agreements in general which, in turn, would lead to higher profits of IBPs.

2. This development would harm consumer surplus.

3. Since the emergence of Paid Peering also lowers demand for IP-Transit, top level backbones can be expected to lose revenues.

4. As all top level backbones are US-based, non-US policy makers do not include profits from IP-Transit in their calculus. Instead of considering to punish large networks who refuse (Bill-and-Keep) Peering to smaller ones, these policy makers should consider to restrict Peering because networks do not care about the fact that fiercer competition under Intermediary benefits consumers, and peer excessively instead. In contrast, since US-based policy makers do account for profits from IP-Transit, they should favor Peerings among networks sufficiently asymmetric in size. Hence, they should seek to discourage large networks from refusing to peer with smaller ones.

These implications could also be applied to a telecommunications market which was both unregulated in terms of inter-carrier compensation fees and not subject to price discrimination regarding destinations of calls.

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A Appendix

A.1 Proof of Proposition 1

If the larger network A prefers BK over Intermediary, according to Lemma 3 the smaller network B will do so as well. Hence we can prove Proposition 1 by proving existence of a defined parameter range where $\pi_A^P > \pi_A^I$. As we assumed $F \leq t_u w$, $\pi_A^P > \pi_A^I$ holds for $\Delta = 0$, which forms the lower boundary of this range. Define Δ_{BK} as the upper boundary. As long as $t_u w - F \geq \frac{1}{4}\bar{\alpha}(3\tau - 2t_u\bar{\alpha})$ we have $\Delta_{BK} = \Delta_{max}$ as a corner solution. As a consequence, $\pi_A^P > \pi_A^I$ holds for all defined values of Δ. For $t_u w - F < \frac{1}{4}\bar{\alpha}(3\tau - 2t_u\bar{\alpha})$, $\Delta_{BK} < \Delta_{max}$. Then, $\pi_A^P < \pi_A^I$ at Δ_{max}. According to equation (18), $\pi_A^P(\Delta)$ is constant. According to (11), $\pi_A^I(\Delta)$ is a continuous, strictly increasing function on $[0, \Delta_{max}]$. Therefore, Δ_{BK} exists and is unique. Thus, for $\Delta \in [0, \Delta_{BK}]$ both networks will not deviate from a BK strategy, given the other party does not deviate. $\square$

A.2 Proof of Proposition 2

Proof: Ad *(i)*: This follows from our assumption that the agreement of both networks is needed to deviate from the Intermediary regime.
Ad *(ii.a)*: For $\Delta = \Delta_{BK}$, by definition we have

$$\pi_A^P = \pi_A^I, \tag{A.1}$$

and, by Lemma 3, there we have

$$\pi_B^P > \pi_B^I. \tag{A.2}$$

We shall distinguish among three cases:

1. Assume $\Delta_{BK} = \Delta_P$. Then, Δ_P requires $\pi_A^P + \pi_B^P = \pi_A^I + \pi_B^I$. Substituting (A.1) in this condition yields $\pi_B^P = \pi_B^I$, which is in contradiction to (A.2).

2. Assume $\Delta_{BK} > \Delta_P$. Then, Δ_P requires $\pi_A^P + \pi_B^P < \pi_A^I + \pi_B^I$. Substituting (A.1) in this condition yields $\pi_B^P < \pi_B^I$, which is in contradiction to (A.2).

3. Assume $\Delta_{BK} < \Delta_P$. Then, Δ_P requires $\pi_A^P + \pi_B^P > \pi_A^I + \pi_B^I$. Substituting (A.1) in this condition yields $\pi_B^P > \pi_B^I$, which is in line with (A.2).

Therefore, for $\Delta \in [0, \Delta_{BK}]$ both BK and PP are equilibria, while for $\Delta \in (\Delta_{BK}, \Delta_P)$ PP is a unique equilibrium. *(ii.b)* and *(iii)* follow from our above argumentation. $\square$

A.3 Proof of Proposition 3

Ad (i): Δ_P and Δ_P^{TP} both have the same denominator. Therefore $\Delta_P^{TP} < \Delta_P$ if $2\bar{\alpha}t_u^2(5\tau - 4t_u\bar{\alpha}) > 8\bar{\alpha}t_u^2(\tau - t_u\bar{\alpha})$, which is true for all defined parameter realisations.
Ad (ii): The loss (L) accumulates to

$$L = \{CS^I(\Delta^2) + \sum \Pi_i^I(\Delta^2) - (CS^P + \sum \Pi_i^P)|\Delta_P^{TP} \leq \Delta \leq \Delta_P\}. \tag{A.3}$$

By using (25) and the fact that $\frac{\partial}{\partial \Delta^2}\left(\bar{\alpha}\tau z^2 \Delta^2\right) > 0$ and $\frac{\partial}{\partial \Delta^2}\left(\sum \Pi_i^I(\Delta^2)\right) > 0$, it follows that

$$\frac{\partial L}{\partial \Delta^2} > 0. \quad \square \tag{A.4}$$

A.4 Proof of Proposition 4

Ad (i): This follows directly from the respective definitions.
Ad (ii): Peering occurs if $\Delta < \Delta_P$. It is efficient if $\Delta > \Delta_P^{Soc}$. It never occurs when it is efficient if $\Delta_P < \Delta_P^{Soc}$. This is true for all $F \in (\frac{\tau}{5\tau - 4t_u\alpha_c}wt_u, wt_u)$.
Ad (iii): A "trade policy" regulator supports Peering if $\Delta < \Delta_P^{TP}$. Peering is efficient if $\Delta > \Delta_P^{Soc}$. It is never supported by a "trade policy" regulator when it is efficient if $\Delta_P^{TP} < \Delta_P^{Soc}$. This is true for all $F \in (\frac{\tau}{6\tau - 4t_u\alpha_c}wt_u, wt_u)$. $\square$

A.5 Analysis of Per-Unit Access Fees/Variable Paid Peering

Assume that $a \in \mathbb{R}$ is a fee that network B has to pay network A for every unit of data exchanged between the two networks under a Paid Peering regime. The profit functions in the retail market on the third stage change to:

$$\begin{aligned}
\Pi_A^{vPP} &= \hat{x}\bar{\alpha}(p_A - 2\kappa t_u) + \alpha_A(p_A^L - 2\kappa t_u) + 2a(\hat{x}\bar{\alpha} + \alpha_A)((1-\hat{x})\bar{\alpha} + \alpha_B) - F \\
\Pi_B^{vPP} &= (1-\hat{x})\bar{\alpha}(p_B - 2\kappa t_u) + \alpha_B(p_B^L - 2\kappa t_u) - 2a(\hat{x}\bar{\alpha} + \alpha_A)((1-\hat{x})\bar{\alpha} + \alpha_B) - F
\end{aligned}$$

Equilibrium prices are derived as $p_A^{vPP} = \tau + 2\kappa t_u + 2a\Delta = p_B^{vPP}$, leading to an equilibrium market share for A (and for B, respectively) of $\hat{x} = \frac{1}{2}$. Consequently, equilibrium retail profits under variable Paid Peering are

$$\begin{aligned}
\Pi_A^{vPP} &= \frac{1}{2}\bar{\alpha}(\tau + 2a\Delta) + \alpha_A(p_A^L - 2\kappa t_u) + aw - F \\
\Pi_B^{vPP} &= \frac{1}{2}\bar{\alpha}(\tau + 2a\Delta) + \alpha_B(p_B^L - 2\kappa t_u) - aw - F
\end{aligned}$$

Next, assume that after bargaining, in line with the economic logic used in section 4 to find the lump-sum payment, the networks agree on a variable fee $a(\Delta) = a^*$, which incorporates the difference in threat points but also makes sure that extra profits from Paid Peering are equally split. Then, a^* has to satisfy:

$$\pi_A^{vPP}(a(\Delta)) - \pi_A^{Int}(a(\Delta)) = \pi_B^{vPP}(a(\Delta)) - \pi_B^{Int}(a(\Delta))$$

The unique solution to this problem provides:

$$a^* = \frac{\bar{\alpha}\tau z\Delta}{2w}$$

If, on the first stage of the game, we look for ranges of Δ where A and B prefer Paid Peering over the Intermediary regime, we find that, in contrast to the lump-sum case, those ranges *completely* overlap: Paid Peering is a Nash equilibrium iff:

$$0 \leq \Delta \leq \sqrt{\frac{2w(t_u w - F)}{4wz^2\bar{\alpha}(\tau - t_u\bar{\alpha}) - \bar{\alpha}^2 z\tau}} \equiv \Delta_P^{vPP}$$

Interpretation: Using a variable Paid Peering fee lets networks not only tacitly collude in the battlezone (and share that market 50 : 50) but it lets them increase prices even more than under lump-sum Paid Peering ($p_i^{vPP} = p_i^{PP} + 2a\Delta$.) A variable access charge is used to increase the other network's perceived marginal cost (even if the access charge is received, not paid!).[26] Consequently, joint profits are larger and consumer surplus is smaller when a variable fee is used. Additionally, recall that:

$$\begin{aligned} w &\equiv \bar{\alpha}(\alpha_A + \alpha_B + \frac{\bar{\alpha}}{2}) + 2\alpha_A\alpha_B \\ &= 2(\alpha_A + \frac{\bar{\alpha}}{2})(\alpha_B + \frac{\bar{\alpha}}{2}) \end{aligned}$$

Thus, by definition, w is the amount of data A and B exchange if they split the battlezone equally. We find that $a^*w = S$ (cf. equation (20)). Therefore, the total amount of fees paid from B to A under variable and lump-sum Paid Peering is equal (as they indeed split the battlezone equally). Because of the construction of a^*, which leads to the same *additional* profits that the networks gain from Paid Peering compared to the Intermediary regime, the upper bound on the Δ-range, where networks prefer Paid Peering, is the same for both A and B. In contrast to lump-sum Paid Peering, the threshold of A is not reached for lower Δ-values than the threshold of B. Taking this together with the increasing effect of the variable fee on profits leads to:

$$\Delta_P^{vPP} > \Delta_P^{PP}$$

However, since the other firm-level results remain unchanged, Propositions 1 and 2 do not change. Due to the fact that, under variable Paid Peering, the reduction of consumer surplus is completely redistributed to networks, Δ_P^{SOC} and Δ_P^{TP} are not altered, too. Consequently, Propositions 3 and 4 hold.

[26]There exists a large body of literature studying the potential usage of two-way access charges as an instrument of tacit collusion in telecommunications. See Armstrong (1998) or Laffont et al. (1998) for more details.