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**Do Internet Incumbents Choose Low
Interconnection Quality?**

by

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Do Internet Incumbents Choose Low Interconnection Quality?¹

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Abstract: We analyze the interconnection incentives for two networks that differ with respect to the size of their installed bases. In the first part we prove that the smaller firm may be harmed in competition for new customers if the installed base customers pay a high price. In the second part we assume that the interconnection quality to customers in the installed bases is set before the interconnection quality to new customers. We show that both firms prefer perfect interconnection quality to new customers if the installed base interconnection quality is sufficiently high, and we discuss what policy implications this may have.

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1 Introduction

The Internet consists of a number of sub-networks that are not necessarily seamlessly connected. Thus, the customers' willingness to pay for being connected to a particular sub-network depends both on this network's intrinsic quality and on the interconnection quality with other sub-networks. The interconnection quality may therefore become an important strategic variable. The seminal paper by Katz and Shapiro (1985) shows that if rational consumers expect that one network for some reason will be larger than another, then the owner of the larger network will have less incentives to set a high interconnection quality than has the owner of the smaller network. The reason for this is that there will *de facto* be a quality differentiation between the two networks that favors the large network if the interconnection quality is poor.

Firms within the Internet and the telecommunication industry normally have installed bases of customers that they serve at the same time as they compete for new customers. A heavily debated topic, which was raised during the AOL-Time Warner and the MCI-WorldCom mergers, is whether a firm with a large installed base has incentives to degrade the interconnection quality towards its smaller rivals.³ By using a modified version of the Katz and Shapiro (1985) model, Crémer, Rey and Tirole (2000) show that this may indeed be the case. Furthermore, they show that the larger firm's incentive to maintain a high interconnection quality is decreasing in the size difference between the installed bases of the two firms.⁴

Crémer et al. presuppose that the utility of being connected to a network is increasing both in the total network size and in the interconnection quality. Hence, the

³Rubinfeld and Singer (2001) and Crémer et al. (2000) analyze this question for the AOL/Time-Warner merger and the MCI/WorldCom merger, respectively. The Internet backbone market is also analyzed by Besen et al. (2001), Kende (2000), Little and Wright (2000), Milgrom et al. (2000), Malueg and Schwartz (2003), and Laffont et al. (2001, 2003). An overview of the market structure and regulation of the Internet is given by Cave and Mason (2001).

⁴Malueg and Schwartz (2003) extend CRT's analysis to allow for multiple rivals and tipping equilibria with global degradation. An interesting outcome of this extension is that if the firm with the larger installed base faces two or more rivals, then degradation may lead to a unique equilibrium with tipping away from the firm with the larger installed-base.

price charged from new customers is increasing in these variables. However, in analyzing the interconnection incentives they assume that the price paid by customers in the installed bases is fixed. In the present paper we relax on this assumption, and show that the larger firm may then be willing to set a high interconnection quality even if this means that it captures a smaller number of new customers. The intuition for this result hinges on the fact that the firm can offset reduced income from new customers by higher income from customers in the installed base. Interestingly, though, the smaller firm may be harmed if the price charged from customers in the installed bases increases. The reason is that this makes the larger firm more aggressive.

In Crémer et al. (2000) and Katz and Shapiro (1985) the degree of vertical differentiation between the large and the small provider is a function of the interconnection quality. The larger firm has a quality advantage *only* when the interconnection quality is imperfect. In our basic model we have a similar assumption, and analogous to Crémer et al. we assume that the interconnection quality is the same with respect to the installed base segment and the new competitive market. In an extension of our basic model, we relax this assumption and assume that the interconnection quality to the installed base is set before the interconnection quality to the competitive market. Hence, the larger firm needs not reduce the interconnection quality towards the rival's new customers in order to have a quality advantage. We show that in this context we may have an equilibrium with perfect interconnection quality to the new market and imperfect interconnection quality to the installed base segment. Furthermore, we show that if there is high interconnection quality to the installed base customers, the larger firm will always choose to set a perfect interconnection quality in the new market. The policy implications of this are discussed in Section 3 (Concluding remarks).

The existence of an installed base seems realistic for the markets we have in mind. When a firm like AOL Time Warner enters a regional market in Europe, for instance, they compete with a regional ISP. AOL Time Warner's customer base in the USA may be seen as an installed base or clientele. Obviously, AOL Time Warner may gain a competitive advantage by restricting the regional ISP's inter-

connection quality with AOL Time Warner's customers in the USA. However, it is likely that AOL Time Warner's income from American customers also depends on the interconnection quality with European Internet users that are connected to the regional ISPs. Typically, the revenue from the installed base customers will be higher if there are more people with whom they can have high quality communication. This higher revenue may well dominate over the reduced income in the new market, which results from a loss of competitive advantage.

The installed base segment may also be seen as the market for some basic service, and the new competitive segment as the market for emerging services. One example is the development of AOL's instant-messaging service and the rivals' (e.g. Yahoo! and Microsoft) instant-messaging services. When firms like Yahoo! and Microsoft began offering instant-messaging, AOL already had a large installed base and AOL tried to reduce the degree of interconnection towards the new rivals (see Faulhaber, 2002). In this context it seems realistic to assume that there is a separate interconnection variable for existing text-based instant-messaging services. As a precondition for the merger between AOL and Time Warner, FCC imposed the condition that AOL must offer interconnection with other providers of advanced instant-messaging services. However, no condition was imposed on the interconnection agreements for existing text-based instant-messaging services. Faulhaber (2002) argues that even if the interconnection quality to advanced instant-messaging services is perfect, AOL will have an advantage from degrading the interconnection to its large installed base. The reason is that advanced instant-messaging services will probably use the same directory of "buddy lists" (Names and Presence Directory (NPD)). Hence, a low interconnection quality for existing text-based instant-messaging services will give AOL an advantage in the market for advanced instant-messaging services (even if the interconnection quality for new services is perfect).

As another example, consider the market for broadband access to residential users. The two main alternatives are offered by telecommunications incumbents (who upgrade their copper network to handle DSL) and by cable-TV providers. In Europe the coverage of the telecommunications networks is much larger than that of the cable-TV networks. More specifically, there is typically duopolistic competition

in urban areas, while the telecommunications incumbent regularly has monopoly power in rural areas. Suppose that there are strong network effects, such that the reservation price of a customer effectively increases with the interconnection quality between DSL and the cable-TV network. Since existing broadband users in rural areas have no alternative access possibilities, they can be seen as an installed base or a clientele for the telecommunications incumbent. This clientele gives the incumbent a competitive advantage over cable-TV providers in urban areas if the interconnection quality between the competing firms is poor. The incumbent may therefore choose to reduce the data flow capacity between the networks, such that, for instance, interactive videoconferences between people in rural and urban areas are possible only if all parties subscribe to the incumbent's services.⁵

The rest of the paper is organized as follows. First, we present the basic model. Second, we focus on the main features of the market equilibrium for a given interconnection quality. Third, we analyze the incentives of a firm with a large installed base to degrade interconnection quality towards a smaller rival. Fourth, we extend our basic model to examine the case where interconnection is set independently for the installed base and for the new customers. Finally, we make some concluding remarks.

2 The model

Suppose that two firms compete in a Cournot fashion, choosing the quantities q_1 and q_2 simultaneously.⁶ Firm $i = 1, 2$ has an installed base β_i of customers, and

⁵The same feature is found in the mobile networks, where the incumbent controlling a full coverage network may degrade the interconnection quality to smaller entrants. This will most likely become an important topic when new firms enter the mobile market with third generation mobile networks in Europe (UMTS).

⁶Cr mer et al. (2000) argue that an assumption of Cournot competition is realistic in the Internet backbone market. Faulhaber and Hogendorn (2000) show that the conditions in Kreps and Scheinkman (1983) are fulfilled in the broadband access market. Hence, they analyze a capacity constrained price game as a one-stage Cournot game. Foros and Hansen (2001) analyze the incentives to be compatible if the downstream firms compete a la Hotelling. In a model without

without loss of generality we shall assume that firm 1 possibly has a larger installed base than firm 2, i.e., $\beta_1 \geq \beta_2$. The installed base of firm 1 may consist of customers living in an area not covered by the network of firm 2 and vice versa. The total number of installed base (locked-in) customers is fixed, and equal to $\beta \equiv \beta_1 + \beta_2$. We assume that the contracts with the installed base customers are such that the revenue from the installed base increases both with the number of users (the total network size) and with the interconnection (off-net) quality level.

Let s_i denote the perceived quality of network i . The inverse demand curve of firm i is given by:

$$p_i = 1 + s_i - q_i - q_j, \quad (1)$$

where $i, j = 1, 2$ and $i \neq j$. The quality s_i of the service equals:

$$s_i = vN_i$$

The term $N_i \equiv \beta_i + q_i + \theta(\beta_j + q_j)$ is the *quality-adjusted* total network size. Other things equal, N_i is increasing in the total number of (new and locked-in) customers in the two networks and in the interconnection quality, which is measured by the parameter $\theta \in [0, 1]$. There is no interconnection between the networks if $\theta = 0$, while there is perfect interconnection if $\theta = 1$. The parameter v may be interpreted as reflecting the significance of network effects; the higher the value of v the more important is the size of the total network for the customers.

>From the above it follows that we can rewrite equation (1) as:

$$p_i = 1 - q_i - q_j + s_i = 1 + v(\beta_i + \theta\beta_j) - (1 - v)q_i - (1 - \theta v)q_j.$$

This is analogous to Crémer, Rey and Tirole (2000).

The cost of connecting one additional customer is c , where $c \in [0, 1]$. Throughout we assume that the cost of increasing the interconnection quality θ is equal to zero. This means that the profit level of each firm is:

$$\pi_i = (p_i - c)q_i + \pi_i^\beta,$$

installed bases they show that the firms choose to be completely compatible in order to reduce the competitive pressure. Dogan (2002) combines elements from Crémer et al. (2000) and Foros and Hansen (2001).

where the last term is the profit from the installed base β_i . More specifically, we assume that the profit from the installed base is given by:

$$\pi_i^\beta = \beta_i w N_i. \quad (2)$$

The variable w is the price that each customer in the installed base is charged by network owner i .⁷ Since we do not focus on the contracts that the networks have with customers in their installed bases, we treat w as an exogenously given parameter.⁸

Throughout we make the following assumptions:

Assumption 1: *The equilibrium interconnection quality is equal to the level chosen by the firm that values interconnection the least, and there are no interconnection fees.*

Assumption 2: *The firms can price discriminate between new customers and installed base customers, and the installed base customers cannot resign or switch from one provider to the other.*

Assumption 1 is consistent with the framework used by Crémer et al., where the inability to charge interconnection fees between networks in the Internet backbone market is motivated by problems associated with writing complete contracts. We further know that public regulation of incumbents (for instance in the broadband access market and the mobile market) often limits their ability to charge access prices from competitors. See Concluding remarks for a further discussion.

Assumption 2 is realistic for several of the examples discussed in the introduction. In the broadband access market, for instance, customers living in rural areas cannot switch to buy access in other areas in order to take advantage of possible regional price differences. Likewise, it seems reasonable to assume that firms like AOL Time

⁷In the context of broadband access wN_i may be seen as a discounted monthly fee that depends on the quality-adjusted network size.

⁸The exogeneity of w may be justified in our context, since the installed base customers are locked-in to one of the providers prior to the competition for new customers. Renegotiating the contracts with the installed base customers every time they sign up a new customer may prove very costly.

Warner are able to price discriminate between customers in their installed bases at home and those that they capture in new countries.⁹

In the following we consider a two-stage game. In the first stage the firms set the interconnection quality, and in the second stage they choose quantities simultaneously. We first characterize the properties of the second stage, and then proceed to analyze the question of whether the firms may have incentives to set a low interconnection quality.

2.1 Cournot competition

The first-order condition for firm i with respect to quantity gives the following reaction function for firm i :

$$q_i(q_j) = \frac{1 - c + v(\beta_i + \theta\beta_j) + w\beta_i - (1 - \theta v)q_j}{2(1 - v)} \quad (3)$$

Note that neither w nor the sizes of the installed bases affect the slope of the reaction curves. However, an increase in w or β_i will shift the reaction curve $q_i(q_j)$ upwards, and we may end up in a monopoly equilibrium if w or the difference $(\beta_1 - \beta_2)$ is sufficiently large.¹⁰

Throughout the paper we make the following assumption:

Assumption 3: *We assume that $v < 1/2$ and $w \leq v$.*

The first part of Assumption 3 ensures that the equilibrium is stable for all for $\theta \in [0, 1]$; if $v \geq 1/2$, the network effects are so strong that we should expect the market to be served by just one firm. The same may be true if $w > v$. The reason for this is that the value of each customer in the installed base is then so high that the firms' main focus may turn towards the installed base customers, in which case we may end up in a situation where the larger firm is the sole producer.

⁹The assumption that installed base customers cannot resign or switch may be problematic if w becomes very large, but in Assumption 3 below we restrict the magnitude of w to avoid such a problem.

¹⁰Since $\beta = \beta_1 + \beta_2$ is fixed, a larger β_j implies that β_i is smaller. Equation (3) therefore shows that a larger β_j shifts the reaction curve $q_i(q_j)$ downwards.

Solving equation (3) for the two firms we find the equilibrium quantities:

$$q_1^* = \frac{1}{2} \left(\frac{2(1-c) + v(1+\theta)\beta}{2(1-v) + (1-\theta v)} + \frac{v(1-\theta)\Delta_1}{2(1-v) - (1-\theta v)} \right) + \frac{2(1-v)\beta_1 - (1-\theta v)\beta_2}{4(1-v)^2 - (1-\theta v)^2} w \quad (4)$$

$$q_2^* = \frac{1}{2} \left(\frac{2(1-c) + v(1+\theta)\beta}{2(1-v) + (1-\theta v)} - \frac{v(1-\theta)\Delta_1}{2(1-v) - (1-\theta v)} \right) + \frac{2(1-v)\beta_2 - (1-\theta v)\beta_1}{4(1-v)^2 - (1-\theta v)^2} w \quad (5)$$

where $\beta \equiv \beta_1 + \beta_2$ is the total installed base, and $\Delta_i \equiv \beta_i - \beta_j$ is the difference in installed bases of the two firms.

The first term in the bracket of equations (4) and (5) indicates that each firm's output is increasing in β . This simply reflects the fact that larger installed bases make the networks more attractive for unattached customers. However, the firm with the larger base will have a competitive advantage if $\theta < 1$. Therefore, the second term in the bracket is positive for firm 1 and negative for firm 2. The third term in equations (4) and (5) shows how the quantities depend on w and the size of the installed bases, β_1 and β_2 . This term is unambiguously positive for firm 1, but negative for firm 2 if $2(1-v)\beta_2 - (1-\theta v)\beta_1 < 0$.

Adding (4) and (5) we find that total quantity $Q^* \equiv q_1^* + q_2^*$ is:

$$Q^* = \frac{2(1-c) + v(1+\theta)\beta}{2(1-v) + (1-\theta v)} + \frac{2(1-v) - (1-\theta v)}{4(1-v)^2 - (1-\theta v)^2} w\beta. \quad (6)$$

Using equations (4), (5) and (6) we can now state:

Proposition 1 *A larger price w charged to the installed base customers implies that*

- (i) *the total number of new customers served by the two firms increases ($\partial Q^* / \partial w > 0$).*
- (ii) *the number of new customers served by the larger Firm 1 increases ($\partial q_1^* / \partial w > 0$).*
- (iii) *the number of new customers served by the smaller Firm 2 increases if and only if $\beta_2 / \beta_1 > \hat{\beta}$, where $\hat{\beta} \equiv (1 - \theta v) / [2(1 - v)]$.*

The first part of Proposition 1 shows that total network size is increasing in w . The intuition for this is the fact that the larger is w , the more revenue the firms will gain from the installed bases for each new customer they capture. In a certain sense, an increase in w therefore makes both firms more aggressive in the end-user market. However, if the installed base advantage of the larger firm is sufficiently

pronounced, that firm will be so aggressive in competition for new customers that a higher w actually reduces firm 2's output, q_2 . In particular, for β_2 close to 0, the smaller firm's output is monotonically decreasing in w . Indeed, it can be shown that this may imply that the total profit level of firm 2 is decreasing in w .¹¹

>From equation (6) we further see that:

Proposition 2 *For any given level of θ , the aggregate number of new customers, Q^* , depends positively on the total size of the installed base (β) and is independent of the difference in installed bases between the firms ($\beta_i - \beta_j$).*

This result is in line with Bergstrom and Varian (1985), who show that total quantity in a Cournot game under certain conditions is independent of the individual agents' characteristics.

2.1.1 The relationship between the interconnection quality and output

In order to see how improved interconnection quality affects output, we first note from equation (6) that:

$$\frac{dQ^*}{d\theta} = \frac{2(1-c) + (3-(v-w))\beta}{(3-2v-\theta v)^2} v > 0.$$

Improved interconnection quality thus unambiguously increases total quantity. The reason for this is simply that a better interconnection quality enlarges the quality-adjusted network size. Thereby it becomes more attractive for new customers to connect to the networks.

To see how improved interconnection quality affects output of each single firm, we differentiate equations (4) and (5) with respect to θ to find:

$$\begin{aligned} \frac{dq_i^*}{d\theta} = \frac{1}{2}v & \left[-\frac{\Delta_i(1-v)}{(2(1-v)-(1-\theta v))^2} + \frac{2(1-c) + (3-v)\beta}{(2(1-v)+(1-\theta v))^2} \right. \\ & \left. - \frac{w\Delta_i}{(2(1-v)-(1-\theta v))^2} + \frac{w\beta}{(2(1-v)+(1-\theta v))^2} \right] \end{aligned} \quad (7)$$

¹¹This is most easily seen for $\beta_2 = 0$, in which case $\pi_2 = (1-v)q_2^2$. We then have $sign(\partial\pi_2/\partial w) = sign(\partial q_2/\partial w)$.

The two first elements in (7) are identical to Crémer et al. (2000), whereas the latter two elements show how installed base profit influences the solution. More specifically,

- the first term is the so-called *quality differentiation effect*; an improved interconnection quality reduces the competitive advantage of the large firm. This term is negative for firm 1 and positive for firm 2.

- the second term is the *demand expansion effect*; an improved interconnection quality increases all consumers' willingness to pay. This effect is positive for both firms.

- the third and fourth terms are the *installed base effects*, which in essence strengthen the quality differentiation effect and the demand expansion effect, respectively.

We can thus conclude:¹²

Lemma 1 *When the profit from the installed base depends on the quality-adjusted network size we have the following:*

- i) The smaller firm's equilibrium output is increasing in the interconnection quality ($dq_2^*/d\theta \geq 0$).*

- ii) The larger firm's equilibrium output may be increasing or decreasing in the interconnection quality ($dq_1^*/d\theta \leq 0$).*

- iii) Total equilibrium output is increasing in the interconnection quality ($dQ^*/d\theta > 0$).*

2.2 Incentives to set a low interconnection quality?

We will now analyze the firms' incentives to set a low value of θ . The interconnection quality is assumed to be in the interval $\theta \in [0, 1]$, which ensures that all comparative statics are valid for all permissible θ . The equilibrium profit may be written as:

$$\pi_i = (1 - v)(q_i^*)^2 + \beta_i w(\beta_i + q_i^* + \theta(q_j^* + \beta_j)) \quad (8)$$

¹²See Appendix A.1 for a discussion of necessary and sufficient conditions for $dq_1^*/d\theta$ to be negative.

Differentiating the equilibrium profit in (8) with respect to θ we can identify three different effects of improved interconnection quality:

$$\frac{d\pi_i}{d\theta} = \left[2(1-v)(q_i^*) \frac{dq_i^*}{d\theta} \right] + [\beta_i w (q_j^* + \beta_j)] + \left[\beta_i w \left(\frac{dq_i^*}{d\theta} + \theta \frac{dq_j^*}{d\theta} \right) \right] \quad (9)$$

The first term is similar to Crémer et al. (2000), and is the effect on the profit from the new customers when the interconnection quality improves. This term is positive for firm i if and only if the firm captures new customers when θ increases. The second and third terms relate to the installed base effect. The second term is always positive, and measures the increase in profit for firm i from its installed base when θ increases, holding the network size of firm j fixed. The third term reflects the fact that the number of new customers changes when the quality of interconnection improves, which in turn influences the profit captured from the installed base.

All three terms in equation (9) are positive for the smaller firm (see Appendix A.2). Hence, the profit for firm 2 is increasing in θ , implying that a small firm would prefer perfect interconnection quality. In contrast, for firm 1 we may have $d\pi_1/d\theta < 0$ since term 1 and term 3 in equation (9) may be negative (Lemma 1). Consequently, given Assumption 1 it is the larger firm's choice of interconnection quality that determines which interconnection quality will prevail.

In Appendix A.2 we show that the profit function for firm 1 is convex in θ , and that we have the following result:¹³

Lemma 2 *Firm 2 always prefers perfect interconnection quality, while firm 1 chooses $\theta = 0$ or $\theta = 1$.*

>From equation (9) we see that $d\pi_1/d\theta$ is strictly positive if $dq_1^*/d\theta = 0$. By continuity, it then follows that there exists some interval where $d\pi_1/d\theta$ is positive even if $dq_1^*/d\theta < 0$:

Proposition 3 *Assume that the profit from the installed base is affected by the quality-adjusted network size N_i . Then, an improvement in the interconnection*

¹³If we introduce costs associated with increasing interconnection quality, we may have an interior solution with respect to quality if these costs are convex enough. However, this does not change our results qualitatively.

quality may increase the level of profit for the larger firm even if its number of new customers falls (i.e., $d\pi_1^*/d\theta > 0$ even if $dq_1^*/d\theta < 0$).

This is in contrast to the case analyzed by Crémer et al. (2000), where the profit from the installed base is not affected by N_i . Then $dq_1^*/d\theta < 0$ is a sufficient and necessary condition to ensure $d\pi_1^*/d\theta < 0$. The intuition behind the result in Proposition 3 is that a higher interconnection quality increases the effective network size, which in turn raises income from the locked-in customers. Thereby it may be profitable for the larger firm to set a high interconnection quality, despite the fact that this may reduce the number of new customers that the firm captures.¹⁴

In contrast to Crémer et al., we further find that the larger firm will be more aggressive than the smaller firm in competition for new customers even if the interconnection quality is perfect. To see this, set $\theta = 1$ and use equations (4) and (5) to find:

$$q_1 = \frac{1}{3} \left(\frac{1 - c + v\beta}{1 - v} \right) + \frac{2\beta_1 - \beta_2}{3(1 - v)}w \text{ and}$$

$$q_2 = \frac{1}{3} \left(\frac{1 - c + v\beta}{1 - v} \right) + \frac{2\beta_2 - \beta_1}{3(1 - v)}w.$$

We can now state:

Proposition 4 *Suppose that the interconnection quality is perfect ($\theta = 1$). We then have the following:*

(i) *If the profit from the installed base is independent of the quality-adjusted total network size, N_i , the firms will be symmetric in the market for new customers, $q_1^* = q_2^*$, even if $\beta_1 > \beta_2$ (Crémer et al., 2000).*

(ii) *If the profit from the installed base depends on the quality-adjusted total network size, N_i , the firms will be asymmetric in the market for new customers, $q_1^* > q_2^*$.*

¹⁴In addition, it is straightforward to show that the marginal profitability of increasing interconnection quality is affected by the price charged to the installed base customers. A high price w increases the likelihood of high interconnection quality, provided that the product differentiation effect (due to differences in the size of the installed bases) is low relative to the demand expansion effect (due to a large total installed base).

The intuition behind this result is as follows: The competitive advantage a firm gains from having a large installed base falls as the interconnectivity improves, and with perfect interconnection ($\theta = 1$) the networks have the same quality. However, when $w > 0$ the larger firm will always have incentives to be relatively aggressive in the market for new customers. This is due to the fact that the increased profit from the installed base of capturing a new customer is greatest for the larger firm. In this case we therefore observe that $q_1^* > q_2^*$ even if $\theta = 1$.

The result in Proposition 4 is to some extent a consequence of the assumption that firms can price discriminate between new customers and installed base customers (Assumption 2). It should further be noted that both firms will be less aggressive in the market for new customers if they cannot price discriminate, because they will then face a trade-off between the gain from capturing a marginal customer and the loss on the inframarginal customers. Aggressive behavior (i.e., a low price) tends to reduce the income from the installed base.¹⁵

2.3 Installed base interconnection and interconnection for new customers are set sequentially

In contrast to the basic model, we now consider a three-stage game where the firms set the interconnection quality to the installed bases ($\hat{\theta}$) at stage 1, the interconnection quality to new customers (θ) at stage 2, and compete a-la Cournot at stage 3. The *quality-adjusted* total network size can then be written as $N_i \equiv \beta_i + q_i + \hat{\theta}\beta_j + \theta q_j$. To focus on the interconnection quality aspect of this three-stage game, we ignore the installed base profit and set $w = 0$ (this simplification does not affect the qualitative results below). Thereby $\pi_i = (1 - v)(q_i^*)^2$.

The Cournot equilibrium in stage 3 is now given by:

$$q_i^* = \frac{1}{2} \left(\frac{2(1 - c) + v(1 + \hat{\theta})\beta}{2(1 - v) + (1 - \theta v)} + \frac{v(1 - \hat{\theta})\Delta_i}{2(1 - v) - (1 - \theta v)} \right) \quad (10)$$

¹⁵Schmalensee (1983) shows in a setting of advertising and entry deterrence that ruling out price discrimination makes the incumbent less aggressive.

Since q_i^* is convex in θ , firm 1 sets $\theta = 1$ or $\theta = 0$ at stage 2. We define $\theta\hat{\theta}$ as a strategy for firm 1. For instance, $\theta\hat{\theta} = 10$ means that firm 1 sets $\theta = 1$ at stage 2 and $\hat{\theta} = 0$ at stage 1.

The necessary and sufficient condition to ensure that firm 1 sets $\theta = 1$ at stage 2 is given by the following:

$$q_1^{1\hat{\theta}} - q_1^{0\hat{\theta}} = \frac{1}{2}v \left(\frac{2(1-c)}{3(1-v)(3-2v)} + \frac{v(1+\hat{\theta})\beta}{3(1-v)(3-2v)} - \frac{v(1-\hat{\theta})\Delta_1}{(1-v)(1-2v)} \right) \geq 0 \quad (11)$$

From equation (11) we can conclude:

Proposition 5 *If the installed base interconnection is high ($\hat{\theta}$ close to 1), firm 1 will set perfect interconnection quality in the new market ($\theta = 1$).*

Recall from the Introduction that FCC imposed as a condition for allowing the AOL Time Warner merger that AOL should offer perfect interconnection quality for new advanced instant-messaging services ($\theta = 1$ in the present context), while they did not impose a condition on the interconnection quality for existing text-based instant-messaging ($\hat{\theta}$ in the present context). From Proposition 5 we see that a firm will ensure high interconnection quality in the new market if the interconnection quality for the installed base is high. Hence, our result indicates that a high interconnection quality for emerging services may be achieved by ensuring high interconnection quality for mature services. If policymakers prefer a high interconnection quality for new services, it may be easier to obtain this by stimulating (or mandating) high interconnection quality for existing services rather than by imposing obligations on emerging services directly. This may also be simpler from a regulatory point of view, since policymakers obviously have better information about the existing services than the new services.

As discussed in the Introduction, the installed base of a given firm may consist of customers in its home market (e.g. the USA), while it competes for new customers with a local firm in another market (e.g. Europe). Proposition 5 therefore indicates

that there may exist regulatory externalities, such that obligations on interconnection in the USA have implications on the interconnection incentives in European markets.

We define $\Delta_1^{1\hat{\theta}-0\hat{\theta}}$ as the critical value of Δ_1 which ensures that $q_1^{1\hat{\theta}} - q_1^{0\hat{\theta}} = 0$. If $\Delta_1 \leq \Delta_1^{1\hat{\theta}-0\hat{\theta}}$, we have $q_1^{1\hat{\theta}} - q_1^{0\hat{\theta}} \geq 0$, and the stage 2 equilibrium is $\theta^* = 1$. In contrast, if $\Delta_1 > \Delta_1^{1\hat{\theta}-0\hat{\theta}}$, we have $q_1^{1\hat{\theta}} - q_1^{0\hat{\theta}} < 0$, and the stage 2 equilibrium is $\theta^* = 0$.

>From equation (11) we find:

$$\Delta_1^{1\hat{\theta}-0\hat{\theta}} = \left[\frac{1-2v}{3v(1-\hat{\theta})(3-2v)} \right] [2(1-c) + v(1+\hat{\theta})\beta]. \quad (12)$$

Since $d\Delta_1^{1\hat{\theta}-0\hat{\theta}}/d\hat{\theta} > 0$, the term $\Delta_1^{1\hat{\theta}-0\hat{\theta}}$ reaches a minimum at $\hat{\theta} = 0$. Setting $\hat{\theta} = 0$ in equation (12) yields:

$$\Delta_1^{10-00} = \left[\frac{1-2v}{3v(3-2v)} \right] [2(1-c) + v\beta]. \quad (13)$$

If $\Delta_1 \leq \Delta_1^{10-00}$, firm 1 sets $\theta^* = 1$ at stage 2 independent of $\hat{\theta}$ at stage 1. By inserting for $\Delta_1 = \beta$ into equation (13) we find that firm 1 sets $\theta^* = 1$ at stage 2 for all $\hat{\theta} \in [0, 1]$ when $(1-c) \geq \beta$. This result may be summarized in the following Proposition:

Proposition 6 *For low values of β , i.e. $\beta \leq (1-c)$, firm 1 sets $\theta^* = 1$ at stage 2 independent of the degree of vertical differentiation.*

The intuition behind this result is that when the values for β are low, the total installed base $\beta_1 + \beta_2$ is small relative to the new competitive market. Thus, any size differences between the firms will only play a minor role when they compete for new customers, and it will be optimal for firm 1 to set $\theta = 1$ even if $\beta_1 > \beta_2$.

3 Concluding remarks

We have shown that the incentives for an incumbent to set a low interconnection quality towards a smaller rival depend on the price charged to the installed base

customers. The smaller firm may be harmed if the customers in the installed bases are charged a high price, because this makes the larger firm more aggressive in the competition for new customers.

We have also analyzed the situation where the interconnection quality to the installed bases is set before the interconnection quality towards new customers. If the size of the installed bases is small, the larger firm may prefer to set a high interconnection quality to new customers independent of the interconnection quality to the installed bases. Otherwise, the larger firm chooses perfect interconnection towards new customers only if the installed base interconnection quality is sufficiently high. The latter result may have important policy implications. If the regulator wants to ensure high interconnection quality in the market for new customers or new services, this may be achieved by ensuring that the interconnection quality towards the installed base is high. This will in particular be important if the installed base segment is a mature service, while the firms compete for new customers in the market for emerging services. It is reasonable to assume that it will be easier for the regulator to impose obligations on existing services than on emerging services. As a precondition for the AOL/Time-Warner merger, however, the FCC did the opposite: FCC required that AOL should offer perfect interconnectivity for emerging instant messaging services, but did not impose obligations on the existing instant messaging services.

If we interpret the installed base segment and the new competitive market as different geographic markets (e.g., different countries), there may be a regulatory externality. An interconnection obligation imposed on e.g. AOL in the USA may increase AOL's incentives to choose a high level of interconnectivity with local rivals when they enter a European country.

As in the majority of the literature (e.g. Katz and Shapiro (1985) and Crémer et al. (2000)) we have assumed that the firm which values interconnection the least has a veto. Such a veto implies that if one firm has incentives to block or reduce interconnection, it is able to do so. This assumption will not always hold. In several cases, firms may invest in converters or adapters that at least to some extent prevent the rival from blocking interconnection. When Yahoo! and Microsoft entered the

market for competitive instant messaging services in 1999, for instance, the entrants established an adapter that made their customers compatible with AOL's 30 million subscribers.¹⁶ Compared to the outcome in our model, the degree of interconnection will naturally be higher if the smaller firm has the ability to use an adapter.

Moreover, in line with most of the literature we have assumed that the firms decide on a reciprocal interconnection quality. The assumption of reciprocal interconnection does not hold generally, and we can obviously find examples where firms have the ability to practice one-sided degradation of the interconnection quality. In this case each firm may unilaterally decide to what extent the rival shall have access to its customers, and thus be able to establish a "walled garden". Even with respect to transmission capacity one of the providers may have the ability to practice one-sided degradation. For other dimensions, such as content and applications, the toolbox for practicing one-sided degradation is probably even larger, indicating that the degree of interconnection will be smaller than our model predicts. Interconnection incentives should thus be analyzed case by case, taking into account both the ability to use adapters and the ability to practice one-sided degradation.

Finally, we have assumed that there are no access fees for interconnection. If complete and unconstrained contracts can be implemented, we may expect that the firms agree on high interconnection quality as long as this maximizes total profit. However, such contracts can rarely be implemented in the markets that we have discussed (the backbone market, the broadband access market, and other digital communications services), and the fees are often constrained by regulation. It should further be noted that the presence of interconnection fees in some cases actually reduces the larger firm's incentives to provide a high interconnection quality. This may for instance be true if we have a regime where the smaller firm pays the larger firm a compensation that depends on the difference in size between the networks. In that case the firms will compete for interconnection fees, and this tends to make them more aggressive in the end-user market. In isolation, the larger firm will therefore have incentives to reduce the interconnection quality in order to increase

¹⁶AOL tried to block this, but several attempts to break down AOL's "walled garden" were temporarily successful (Faulhaber, 2002).

access revenues. The interplay between access pricing and the incentives for non-price discrimination in such contexts is a topic for further research.

4 Appendix

A.1 Necessary and sufficient conditions for $dq_1^*/d\theta < 0$

Differentiating (7) with respect to θ we find

$$\frac{d^2q_1^*}{d\theta^2} = \left[\frac{(1-v-w)\Delta_1}{(1-(2-\theta)v)^3} + \frac{2(1-c) + (3-v+w)\beta}{(3-(2+\theta)v)^3} \right] v^2 > 0, \quad (\text{A.1.1})$$

which tells us that $dq_1^*/d\theta$ is more likely to be negative at $\theta = 0$ than at $\theta = 1$. This means that a necessary condition for q_1^* to be negatively affected by improved interconnection quality is that $dq_1^*/d\theta|_{\theta=0} < 0$, while a sufficient condition is that $dq_1^*/d\theta|_{\theta=1} < 0$.

For $\theta = 0$ we find

$$\left. \frac{dq_1^*}{d\theta} \right|_{\theta=0} < 0 \text{ if } \Delta_1 > \hat{\Delta}_1 \equiv \frac{2(1-c) + (3-v+w)\beta}{(3-2v)^2(1-v-w)} (1-2v)^2,$$

where $d\hat{\Delta}_1/dw > 0$ and $d\hat{\Delta}_1/d\beta > 0$. Similarly, we find

$$\left. \frac{dq_1^*}{d\theta} \right|_{\theta=1} < 0 \text{ if } \Delta_1 > \check{\Delta}_1 \equiv \frac{2(1-c) + (3-v+w)\beta}{9(1-v-w)},$$

where we also have that $d\check{\Delta}_1/dw > 0$ and $d\check{\Delta}_1/d\beta > 0$.

A.2 Convexity of the profit functions

Differentiating the equilibrium profit, (8), with respect to interconnection quality we obtain the following expression:

$$\frac{d\pi_i}{d\theta} = \left[2(1-v)(q_i^*) \frac{dq_i^*}{d\theta} \right] + [\beta_i w (q_j^* + \beta_j)] + \left[\beta_i w \left(\frac{dq_i^*}{d\theta} + \theta \frac{dq_j^*}{d\theta} \right) \right] \quad (\text{A.2.1})$$

By inspecting equation (7) we see that $dq_2^*/d\theta \geq 0$, whereas the sign on $dq_1^*/d\theta$ is ambiguous (since $v < 1/2$ and $\beta_1 \geq \beta_2$). Furthermore, we can show that:

$$dq_2^*/d\theta - dq_1^*/d\theta = -v\Delta_1(v-w-1)/(1+v(\theta-2))^2 \geq 0$$

Consequently, the profit function for firm 2 is always increasing in θ , and firm 2 prefers perfect interconnection quality.

For firm 1, the first term in (A.2.1) is negative if $dq_1^*/d\theta < 0$. The second term is always positive. The sign on the third term is ambiguous for firm 1. It is obvious that $dq_1^*/d\theta \geq 0$ is a sufficient condition for ensuring that firm 1's profit is increasing in θ for all permissible values of θ .

The second order condition for firm i is given by:

$$\frac{d^2\pi_i}{d\theta^2} = \left[2(1-v) \left[\left(\frac{dq_i^*}{d\theta} \right)^2 + q_i^* \frac{d^2q_i^*}{d\theta^2} \right] \right] + \left[\beta_i w \left(\frac{d^2q_i^*}{d\theta^2} + \theta \frac{d^2q_j^*}{d\theta^2} + 2 \frac{dq_j^*}{d\theta} \right) \right] \quad (\text{A.2.2})$$

To determine the sign on the second-order derivative on firm i 's profit, we need to determine the sign of expression (A.1.1). Examining (A.1.1), we see that $d^2q_1^*/d\theta^2 \geq 0$ since $\Delta_1 \equiv \beta_1 - \beta_2 \geq 0$ and $v < 1/2$, whereas the sign on $d^2q_2^*/d\theta^2$ is ambiguous. Define the difference $\Delta_{socq} \equiv d^2q_1^*/d\theta^2 - d^2q_2^*/d\theta^2$. It can be shown that $\Delta_{socq} = -2v^2(\beta_1 - \beta_2)(v - w - 1) / ((2(1-v)) - (1 - \theta v))^3 \geq 0$. Since (A.1.1) is positive for firm 1, the conditions $\Delta_{socq} \geq 0$ and $\theta \leq 1$ imply that π_1 is convex in θ . Hence, firm 1 will choose $\theta = 0$ if $\partial\pi_1/d\theta < 0$, and $\theta = 1$ if $\partial\pi_1/d\theta \geq 0$.

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