Competition and Compatibility among Internet Service Providers*

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Abstract

We consider a two-stage game between two competing Internet Service Providers (ISPs). The firms offer access to the Internet. Access is assumed to be vertically and horizontally differentiated. Our model exhibits network externalities. In the first stage the two ISPs choose the level of compatibility (i.e. quality of a direct interconnect link between the two networks). In the second stage the two ISPs compete á-la Hotelling. We find that the ISPs can reduce the stage 2 competitive pressure by increasing compatibility due to the network externality. The firms will thus agree upon a high compatibility at stage 1. When it is costly to invest in compatibility, we find that the firms overinvest, as compared to the welfare maximising investment level.

Keywords: Compatibility, Internet, Competition, Duopoly

JEL classification: L13; L96; L41

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I. Introduction

We consider competition between two ISPs (Internet Service Providers) operating in the same area. The product from these service providers is basically access to the Internet, and the ISPs operate their own local network. Internet access is assumed to be horizontally and vertically differentiated from the customer's point of view. Furthermore we assume that there are positive consumption externalities.

Competition is modelled as a two-stage game. In the first stage the ISPs determine the quality of interconnection. This choice of interconnection quality can be considered as a choice of compatibility between the networks. In the second stage, for given compatibility, the two firms compete à la Hotelling in attracting customers.

The motivation for the paper is the observation that ISPs competing in the same geographic area typically offer higher quality for on-net communication as compared to off-net communication. Roughly, on-net communication refers to traffic between computers/customers connected to the same ISP, while off-net communication is between computers/customers connected to different networks, e.g. communication between customers subscribing to competing ISPs. Some analysts are arguing that competing ISPs have become more willing to establish private interconnection arrangements. It is however hard to verify this observation because ISPs typically have a nondisclosure policy with respect to the agreements.[1]

The majority of the literature on Internet economics focuses on the US-market. In contrast, our paper is motivated by the situation for competing ISPs outside USA. Previously, the attention in the ISP-markets outside USA has been directed to the

[1] The quality in the network is determined by the ratio between capacity and load. The load is varying on a very short time scale. Thus it is hard to observe the quality differential between off and on net traffic from the outside. A customer of a particular ISP will however gain experience over time with particular routes and thus be in a position to assess the quality differential.

quality of the connection to the US.[2] The quality of local communication between competing ISPs was rather unimportant since the majority of the Internet content was in the US. The situation is, however, altered, and the portion of the Internet-traffic where both the sender and the receiver are located in the same area is increasing. This tendency is probably due to new customer-types and new services in the Internet. In non-English speaking countries content intended for the mass-market must be produced locally or translated. Furthermore, for new broadband interactive services, such as telemedicine, tele-education, and video conferencing, a relatively larger portion of the communication is probably between customers in the same geographical area as compared to what is the case for conventional Internet services such as web-browsing. Thus, the importance of local interconnection as a strategic variable has increased.

Utility from network participation depends on the number of potential communication partners and the quality of this communication. For given market shares, the customer's willingness to pay is increasing in interconnection quality. It is not obvious, however, that competing firms will choose a high quality. In the presence of network externalities, customers will *ceteris paribus* consider it more advantageous to choose the larger ISP if the chosen quality of interconnection is reduced. A large ISP may accordingly choose a low interconnection quality in order to increase its market share.

Following several recent studies of the competition in the telecommunication market, e.g. Laffont, Rey and Tirole (1998a, 1998b), we assume that firms offer horizontally differentiated goods. The motivation for this horizontal differentiation is receiving little attention in the literature. In our setting, product differentiation in the horizontal dimension may be given several interpretations. Customers of ISPs are typically

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[2] Baake and Wichmann (1998) are focusing on the German market, Ergas (2000) and Little et al (2000) analyze the Australian market, while Mueller et al. (1997) describe the situation in Hong Kong.

buying some complementary products to the Internet access. Private customers connect to the ISP via the telephone line, the television cable or the mobile phone system. Most ISPs are owned by, or, are in co-operation with a supplier of local access, such as cable-tv or local telephone operators. This is one source of horizontal differentiation, since e.g. cable-tv-access suppliers can offer the best incoming capacity, while local telephony companies have more experience with switching technologies and two-way communications. A customer mainly looking for interactive-tv and secondly internet connectivity, will probably prefer the service from an ISP that is a subsidiary of a cable-tv provider. In contrast, for home-office internet connectivity the customer may prefer a subsidiary of a telephone provider. Customers with preferences for mobility choose mobile wireless access although the capacity is lower than for e.g. cable-tv access.

Another source of horizontal differentiation is the alliances between ISPs and content providers. The ISPs may choose to specialize in offering high quality of some services and thus attracting customers preferring these services. In the AOL-Time Warner merger a hot topic has been whether vertical integration of a content company (Time Warner) and an ISP (AOL) may create incentives to foreclose rivals from accessing some services ("a walled garden strategy").

Related Literature

To our knowledge there are few papers explicitly considering ISP competition and compatibility choice. Crémer, Rey and Tirole (2000), and Mason (1999) are notable examples.[3]

[3] Other papers looking into ISP competition are DangNguyen and Penard (1999) and Baake and Wichmann (1998). Furthermore, there are some papers looking into congestion control for ISPs under competition, see e.g. Gibbons, Mason and Steinberg (2000) and Mason (2000).

We are here following Crèmer, Rey and Tirole (2000) by modelling network externalities such that customers benefit from an increase in network size, and furthermore, the positive network effect is a function of the degree of compatibility. In contrast to the model in the present paper, Crémer et al (2000) are assuming that the firms have installed bases and are engaged in Cournot-type competition where the providers compete in attracting new consumers. They find that the firms may have incentives to degrade interconnection quality under market sharing equilibrium. Their result contrasts our result and is driven by asymmetries in the installed bases. Thus in a market with consumer lock-in as in the Cremer et al model a large firm may choose a low interconnection quality whereas in a market with mobile consumers, as in the present paper, a large firm will choose a high interconnection quality.

Mason (1999) models ISP-competition with both horizontal and vertical differentiation, and, furthermore, with a timing structure similar to our. In line with our results Mason finds that compatibility results in reduced competitive pressure. However, in his paper the firms choose between perfect compatibility and incompatibility at stage 1, and, hence he does not see the positive externality as a continuous function of compatibility.[4] Consequently it is not straightforward to consider questions of over-investment in compatibility in the Mason model.

The strategic effect of interconnection quality does also have many similarities with the strategic effect of interconnect price (for given quality) in telephony networks. In telephony networks, the positive externality effect of having many subscribers on competing networks is reduced when the price of making calls across networks increase. In the limiting case with extremely high price of making off-net calls, the telephony subscriber will be indifferent as to the size of the competing network. A

[4] The Mason (1999) model exhibits both vertical and horizontal heterogeneity in consumer preferences. The relative weight of vertical and horizontal aspects is parameterised. In the extreme case with only horizontal consumer heterogeneity, Mason obtains similar result as in the present paper with respect to compatibility.

high interconnection price will accordingly have similar strategic effects as a low interconnection quality.[5] Both in the telephony interconnection models as well as the present paper, network externalities drives the strategic effect of interconnect quality.[6]

Our paper is organized as follows. In section II we present a brief overview of the network structure. In section III we present our model. Finally, in section IV we conclude.

II. A brief overview of the network structure

In figure 1 we give an illustration of the competition between the ISPs and the choice of compatibility (or interconnection quality). We assume that two ISPs compete in a given market, and we suppose that for communication between own customers (on-net traffic) the ISPs is offering a quality guarantee of $\bar{k}$. If there is no private interconnection agreement between the ISPs, no such quality guarantee is given for off-net traffic. Off-net communication between ISP A and ISP B will be sent through a public interconnection point, and the quality level is equal to off-net communication with other destinations in the global Internet Backbone (see figure 1). Let the quality of off-net traffic through the public interconnection point be $\underline{k}$ (where $\underline{k} < \bar{k}$). We assume that this public interconnection point is administrated and controlled by a non-commercial third party.[7] The quality level at the public interconnection point is assumed to be outside the control of both ISP *A* and ISP *B.*[8]

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[5] See Laffont, Rey and Tirole, (1998a), (1998b) and Armstrong (1998). Furthermore, in Laffont and Tirole (2000) it is provided an extensive overview of interconnection strategy related to telecommunication.

[6] Such externalities were first given a theoretical treatment by Rohlfs (1974). The strategic effect of network externalities on competition was recognized by Katz and Shapiro (1985). As pointed out by Katz and Shapiro, externalities and the choice of compatibility are closely related.

[7] Bailey and McKnight (1997) described four interconnection models where exchange point described here refers to what they called Third-Party Administrator. The other categories are Peer-to Peer Bilateral, Hierarchical Bilateral, and Co-operative Agreement.

[8] The frequently observed bottleneck problems in public interconnection points in both Europe and the US (see e.g. Kende, 2000) are indications that single ISPs not are able to increase the quality of its

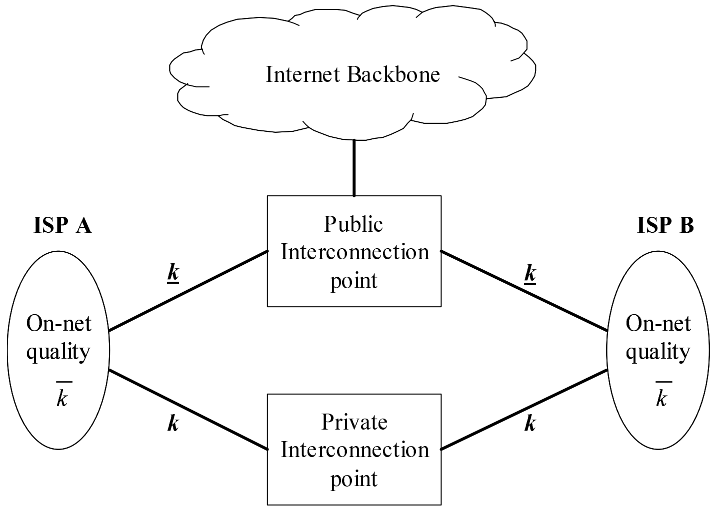

Figure 1

ISP *A* and ISP *B* do, however, have the opportunity to invest in a direct link between their networks, i.e. they can invest in a direct interconnect point. If they do, the quality level related to communication between ISP *A* and ISP *B* is *k*, where $\underline{k} \leq k \leq \overline{k}$ (see figure 1). The aim of this paper is to analyze the incentives competing ISPs have to implement such direct interconnection. The issue will probably be more important when local access networks are upgraded to high-speed internet communication (broadband) and new bandwidth-demanding services that tolerate minor delays (real time services as interactive video) are offered. The quality offered in the open internet (the quality level $\underline{k}$) cannot deliver these services.[9]

In this paper we will not consider the interplay between the regional ISPs we have in mind and the backbone providers controlling the core global infrastructure (the Internet backbone).[10] Furthermore, we do not focus on the interplay between ISPs

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services over the public interconnection points. This is probably due to both coordination and free rider problems.

[9] Interactive services may be among the most profitable services in the Internet. One reason for the profitability of interactive services is that they are less prone to personal arbitrage and reselling than services tolerating some delays (Choi *et al*., 1997). Another reason is that customers have higher willingness to pay for new information. This will be especially true for strategic information such as stock exchange rates (Shapiro and Varian, 1998).

[10] See Cremer, Rey and Tirole (2000) on the interplay between Internet Backbone Providers

selling internet connectivity and the providers of local access (the last mile into homes). However, as mentioned above, the ISPs and the local access providers are often vertically integrated.

The non-disclosure practice related to private interconnection agreements makes it impossible to know exactly the number of such contracts between competing ISPs.[11] In the US private interconnection agreements are common between the core Internet backbone providers. Also the regional ISPs in Europe have private interconnection agreements with backbone providers at a higher level and in other countries. However, until now the competing ISPs seem to have been reluctant to implement direct interconnection links in Europe. The non-disclosure characteristic makes it difficult to say whether this trend is changing, but several analysts argue that private interconnection seem to be more common also outside the US.[12]

III. The model

The preferences of customers are assumed to be distributed uniformly with density 1 on a line of length 1. The two firms (*a* and *b*) are located at the extremes of this unit line, firm *a* is at $x_a = 0$ and firm *b* is at $x_b = 1$. The unit cost for each firm is *c*, and the customers have unit demands. The location of preferences on the unit line indicates the most preferred network type for each customer.

Net utility for a customer located at *x* connected to supplier *i* is accordingly:

$$U_i = v_i - t|x - x_i| + \beta \cdot (n_i + kn_j) - p_i \qquad \text{where} \quad i, j = a, b \quad i \neq j$$

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[11] See Kende (2000) and Gareiss (1999). Kende (2000) gives a comprehensive description of the interconnection agreements between the core backbone providers, and he indicates that as much as 80 % of the internet traffic in the US goes through private interconnection points.

[12] See Chinoy and Solo (1997) and Cawley (1997). In Gareiss (1999) there is an overview of private interconnections agreements.

The first term is a fixed advantage v_i of being connected to network. We define $\theta_i \equiv v_i - v_j$. As long $\theta_i = 0$ there is no vertical differentiation, while the services are vertically differentiated when $\theta_i \neq 0$. The second term is the disutility from not consuming the most preferred network type (the transportation cost in the standard Hotelling model). The third term is a utility term depending upon the number of on-net and off-net customers (n_i and n_j respectively) equal to $\beta \cdot \left(n_i + kn_j\right)$, where $\beta \geq 0$ and $k \in \left[\underline{k},1\right]$. β is measuring the network externality. For $\beta = 0$ consumers are indifferent with the respect to the size of the two networks. The parameter k can be interpreted as a measure of the quality of the interconnect arrangement. When the quality of interconnection equals unity, customers are indifferent as to the distribution of off-net and on-net customers since on- and off-net traffic have identical quality. This is opposed to a situation where $k < 1$. Then, all other things being equal, a customer will prefer a network with many customers. When $k = \underline{k}$ the quality equals the quality available via the Internet (the public interconnection point in figure 1), whereas $k > \underline{k}$ implies that the two ISPs have agreed upon establishing an interconnect arrangement (the private interconnection point in figure 1) with superior quality. The fourth term, p_i is the per period price charged for ISP subscription.[13] The customers' utility functions are accordingly linear in consumption of the network service and money.

[13] Thus, we do not consider any form for usage-based pricing. At first glance, this assumption is more realistic for internet connectivity in the US where flat-rate pricing is the norm for local access. However, we are also observing flat-rate pricing in Europe, in particular for broadband internet connectivity. For a discussion of the usage-based regime in Europe related to Internet access see e.g. Cave and Crowther (1999).

We make the following two assumptions:

Assumption 1:

We assume that each of the customers along the interval $[0,1]$ value the products sufficiently high such that they always prefer to subscribe to one or the other network. Thus, the fixed advantage v_i of being connected to either network is sufficiently large.

Assumption 2:

There exist one customer in market equilibrium located at x, where $0 < x < 1$, who is indifferent between consuming the network service from the two firms. Thus the valuation differential θ_i between products of the two firms is sufficiently low such that: $|\theta_i| \leq 3(t - \beta(1-k))$.

We will later demonstrate that assumption 2 indeed is necessary to obtain a shared market equilibrium. Notice in particular that assumption 2 implies that $t > \beta(1-k)$. If this property is violated equilibrium can be characterized by cornering even in "symmetric" cases with $\theta_i = 0$ and $p_i = p_j$ because the network externality is dominating the transportation cost.[14]

We define α_i as the market share of firm i. Assumption 1 and 2 are then implying that $n_i = \alpha_i$, $n_j = 1-\alpha_i$. For a given price vector, the location of preferences $x \in (0,1)$ for the consumer satisfying $U_a = U_b$ is determining the market shares. By defining $\sigma \equiv 1/(2(t-\beta(1-k)))$ we can write the market shares of firm i:

$$\alpha_i = \frac{1}{2} + \sigma\theta_i - \sigma(p_i - p_j)$$

[14] Assume that almost all customers along the unit line, for some reason, are connected to supplier *a*. The marginal customer with the longest distance to travel to supplier *a,* will compare the offer from the two suppliers and he will choose supplier *a* (and the market will accordingly be characterised by cornering) if: $\beta(1 + \underline{k}0) - t > \beta(0+ \underline{k})$. Thus $t > \beta(1 - \underline{k})$ is ruling out the possibility of market cornering in such symmetric cases.

σ is a function of k where $\sigma(k) > 0$, $\sigma(1) = 1/2t$, $\sigma'(k) < 0$. Notice that assumption 2 assures that σ > 0. The market share functions are very similar to the market share functions in a standard Hotelling model and if k = 1 and/or β =0, the expression for market shares are identical to what we obtain in a standard Hotelling model with unit demand (i. e. a model without network externalities). In the standard Hotelling model, the parameter σ is interpreted as a measure of product substitutability. The products become closer substitutes if the transportation cost, t, between the two products is reduced. From our definition of σ it also follows that the products become closer substitutes, in the eyes of the consumers, if the quality of the link between the two networks is reduced. We can accordingly expect that an increase in the cost of transport and an increase in the quality of the link between the two networks to have similar effects upon prices and profits.

The two-stage game

We are considering a two-stage game. In the first stage the two ISPs set the interconnection quality k such that $\underline{k} \le k \le 1$. In the second stage, the two ISP simultaneously set their prices for a given k.

Stage 2

In stage 2 the firms set their prices simultaneously, and firm i is choosing p_i so as to maximize profits given by:

$$\pi_i = (p_i - c)\alpha_i = (p_i - c)\left(\frac{1}{2} + \sigma\theta_i - \sigma(p_i - p_j)\right)$$

Combining the first order conditions for firm i and j yields:

$$p_i = \frac{1}{2\sigma} + \frac{\theta_i}{3} + c \quad \text{and} \quad \alpha_i = \frac{1}{2} + \frac{\sigma\theta_i}{3}$$

We will have a shared market equilibrium if and only if $\alpha_i \in (0,1)$ which is satisfied under assumption 2.

Inserting equilibrium prices and market shares as well as the definition of σ in the profit function and rearranging yields:

$$\pi_i(\theta,k)=\frac{(t-\beta(1-k))}{2}+\frac{\theta_i}{3}+\frac{\theta_i^{\,2}}{18(t-\beta(1-k))} \qquad (1.)$$

When $k = 1$ and/or $\beta = 0$, this profit function is identical to the one we obtain in a conventional Hotelling model with unit demand.

Stage 1

At stage 1 of the game the two firms decide whether to set up an interconnect arrangement or not. As already stated, stage 2 profit is a function of the quality of interconnection. Direct differentiation of the profit function (1.) with respect to *k* yields:

$$\frac{\partial \pi_i(\theta,k)}{\partial k}=\frac{1}{2}\beta\left(1-\frac{\theta_i^{\,2}}{9(t-\beta(1-k))^2}\right) \qquad (2.)$$

By definition we have $\theta_j = -\theta_i$, and thus we get:

$$\frac{\partial \pi_i}{\partial k}=\frac{\partial \pi_j}{\partial k} \quad \forall k$$

We readily see that the firms do not have conflicting interests with respect to network compatibility, implying that the two firms always agree upon the optimal interconnection quality-level *k*. Consequently, there is no need for an assumption ensuring that the firm with the lowest incentives for quality has a veto in setting *k*. The condition for having a shared market equilibrium is $|\theta_i| \leq 3(t-\beta(1-k))$ (assumption 2). This condition implies that the large bracket above is positive. Thus in any shared market equilibrium profits of both firms increase in interconnect quality.

The effect upon profits from changing interconnection quality can be decomposed into a price and a market share (or volume) effect by differentiating: $\pi_i = \alpha_i (p_i - c)$:

$$\frac{\partial \pi}{\partial k} = \frac{\partial \alpha}{\partial k}(p_i - c) + \alpha_i \frac{\partial p_i}{\partial k}$$

The first term is the market share effect and the second term is the price effect. By inserting the definition of σ in the equilibrium price and differentiating with respect to *k* we obtain: $\frac{\partial p_i}{\partial k} = \beta$. The price effect is accordingly positive for both firms. This is opposed to the market share effect. When $\theta_i \neq 0$, market shares are functions of interconnect quality. By substituting for σ in the equilibrium market shares and differentiating we obtain:

$$\frac{\partial \alpha_i}{\partial k} = \frac{-\theta_i \beta}{6\left(t - \beta(1-k)\right)^2} \qquad (3.)$$

The market share effect is positive for the firm selling the inferior service and thus it is negative for the firm selling the superior service. The negative market share effect for the firm selling the superior product is however dominated by the positive price effect as demonstrated above.

Cost free interconnection quality

Assume it is costless to improve the quality of interconnect. As demonstrated above, the differentiated profit function is everywhere increasing in *k* for both firms. Thus the firms have no incentives to damage the quality of the link between the two networks and furthermore, if possible, they have a mutual interest in improving the quality of this link. Then, both on-net and off-net traffic have the same quality level $k = \bar{k} = 1$.

Prices and profits increasing in the quality of the link between the two networks are due to two effects. First, for given market shares willingness to pay is increasing from all customers as the quality is increased. Second, when the quality of the link is increased the competition between the two suppliers becomes less aggressive.[15] When comparing the conventional Hotelling model with our model featuring network externalities, the argument can be put the other way around: When the networks offer less than perfect connectivity ($k < 1$) then the firms will compete more aggressively than what the conventional Hotelling model predicts.

Convex costs of interconnection quality

The assumption above that firms can increase interconnection quality without incurring costs is clearly an unrealistic assumption since both router and transmission capacity is costly in the market place. Furthermore there will be transaction cost of writing a contract and there will typically be costs of mutual monitoring. We can thus add realism to our model by taking into account that interconnection is costly. Then the shape of the interconnection cost function will affect the optimal solution. A necessary condition for an interior solution ($k \in (\underline{k},1)$) is that the interconnect cost function is convex.

One can argue that it is reasonable to expect the interconnection cost to be convex, since, as interconnect quality increase, the complexity of the contract the two firms can write becomes large. As the quality of interconnect increase, the joint network of the two suppliers become more like a common facility where the firms have ample opportunities of opportunistic behavior. Firms will typically be reluctant to agree upon interconnection unless the contract prohibits opportunistic behavior. In order to

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[15] The best response functions ("reaction functions") in stage 2 of the game is: $p_i = R(p_j) = \frac{1}{2}(t - \beta(1-k) + p_j + \theta_i + c)$. An increase in k will result in parallel shifts outwards for these best response functions and the firms does indeed become less aggressive as the quality of interconnect increase. We can furthermore see R' = 0.5, we are thus considering a stable Nash equilibrium.

observe and verify that the contract indeed is fulfilled, costly mutual monitoring is required.

In the following we will assume the cost of investing in interconnect quality in order to increase the quality of interconnect *k* above $\underline{k}$ is $I = I(k)$, where $I(\underline{k}) = 0$, $I' > 0, I'' > 0$ $\lim_{k \to 1} I(k) = \infty$ and $\lim_{k \to \underline{k}^+} I'(\underline{k}) = 0$. Assume now that the two firms are forming an input joint venture where they equally share the cost of investing in interconnect quality. Each firm will then maximize the stage 2 profit minus the share of the interconnect cost the firm has to pay in stage 1. Thus the two firms will solve identical optimization problems and agree upon a interconnect quality level k^d characterized by:

$$k^d = \arg\max\left(\pi_i(\theta, k) - \tfrac{1}{2} I(k)\right)$$

Thus the investment joint venture investment level is characterized by:

$$I'(k) = \beta - \frac{\beta\theta_i^2}{9(t - \beta(1-k))^2}$$

For $\theta_i \neq 0$ the profit functions are convex in *k*. With our assumptions we have $\pi'(\underline{k}) > I'(\underline{k})$ and $\pi'(1) < I'(1)$. Thus there exist at least one $k \in (\underline{k}, 1)$ satisfying the first order conditions. For $\theta_i = 0$ there is one and only one *k* satisfying the first order condition. The second order conditions are satisfied and this solution is indeed optimal. For $\theta \neq 0$ we cannot rule out the possibility that there is more than one *k* satisfying the first order condition. A sufficient condition for a single unique solution is that the marginal profit curve and the marginal investment curve cross only once. We will in the following assume that the marginal curves cross only once.

We can compare this equilibrium quality level with the socially optimal quality. The first best interconnect quality, *k**, is defined as the quality level that is maximizing customer gross surplus minus total production cost. Consider, for simplicity, the model in the absence of vertical differentiation (i.e. $\theta_i = 0$). First best is then evidently characterized by sharing customers evenly among the two firms since the unit cost of serving customers in the two firms are identical and customers are distributed uniformly on the interval, Then average distance from the most preferred brand is 0.25. Inserting this average distance as well as the optimal market shares in the utility function yields the following welfare function:

$$k^* = \arg\max\left[v_i - 0.25t + 0.5\beta \cdot (1+k) - c - I(k)\right]$$

The first best investment level is then characterized by:

$$0.5\beta = I'(k)$$

This is in contrast to the investment level in the input joint venture. In the absence of vertical differentiation the optimal investment level for the input joint venture is: $\beta = I'(k)$. An input joint venture will thus choose a quality level of the interconnect arrangement exceeding the socially optimal level. In the appendix we demonstrate that we obtain a similar over investment result in the model under vertical differentiation as well. The intuition behind the over investment result is the following: There are two effects leading to the firms' stage 2 profits increasing in interconnect quality: The first effect is that for given market shares willingness to pay is increasing from all customers as the quality is increased. The second effect is that when the quality of the link is increased, the competition between the two suppliers becomes less aggressive. Only the first effect is a social gain. Thus the input joint venture is over-investing in interconnect quality in order to reduce the stage 2 competitive pressure.

V. Conclusion

In this paper we have considered the incentives for an Internet Service Provider (ISP) to strategically degrade the interconnection quality with the competitors. We have modeled this in a game where two firms choose the quality of interconnection before they compete over market shares á la Hotelling. In the case where there is no vertical differentiation, the firms split the market equally, and they have no incentives to degrade interconnection quality. Moreover, when interconnection is costly the firms will over-invest in interconnection quality as compared to the first best quality level.

We have also demonstrated that if the products from the two firms also are vertically differentiated, then the firm providing the superior product will have the larger market share. When the necessary conditions for a shared market equilibrium is fulfilled, the firms will agree upon the optimal interconnection quality. Furthermore, if interconnection quality is costly, the firms will agree upon a quality of interconnect exceeding the welfare maximizing quality level.

Finally it is not straightforward to compare the model results with the interconnection policy in the market place due to the non-disclosure policy. Representatives in the industry do however make statements indicating that competing ISPs do interconnect in cases where the two firms in question are sufficiently symmetric. Such observations are lending support to the results of the present paper.

Appendix Welfare maximizing interconnect investments

Consumers with preferences to the left of some point α join network *a.* Since the individual transport cost is *tx,* and the distribution of consumers is uniform along the line, the sum of travelling costs for all consumers joining the networks are $\frac{1}{2}\alpha^2 t$ and $\frac{1}{2}(1-\alpha)^2 t$ for network *a* and *b* respectively. In stage 2 of the game the social welfare function is:

$$W(k) = \max_{\alpha}\left[\alpha\left\{v_a - \tfrac{1}{2}\alpha t + \beta(\alpha + k(1-\alpha)) - c\right\} + (1-\alpha)\left\{v_b - \tfrac{1}{2}(1-\alpha)t + \beta(1-\alpha+k\alpha) - c\right\}\right]$$

The welfare maximizing market share α^* is thus:

$$\alpha^* = \frac{1}{2} + \frac{\theta_a}{2(t - 2\beta(1-k))}$$

It can be shown that the market share of the firm selling the superior product will be to small in market equilibrium as compared to the welfare maximising market share. In special cases, the welfare maximising solution is to let the firm selling the superior product serve the entire market whereas both firms are active in the market equilibrium Notice that this results not is specific to our model featuring network externalities. With the parameter value $\beta = 0$, the model does not exhibit network externalities (and thus there is no effect upon utility by improving interconnect quality). Then the welfare maximising market share is: $\alpha^* = \frac{1}{2} + \frac{\theta_a}{2t}$ whereas market equilibrium is characterised by: $\alpha^* = \frac{1}{2} + \frac{\theta_a}{6t}$, Thus the market share of the firm selling the superior product is to small.

The stage 1 socially optimal investment level is:

$$k^* = \arg\max\left(W(k) - I(k)\right)$$

$$\text{FoC:} \quad W' = I'$$

By applying the envelope theorem on *W*(*k*):

$$\frac{\partial W}{\partial k} = 2\beta\alpha^*\left(1-\alpha^*\right) = 2\beta\alpha_a^*\alpha_b^* = \frac{\beta}{2} - \frac{\beta\theta_a^{\,2}}{2(t - 2\beta(1-k))^2}$$

In cases where the welfare maximizing network is characterized by market sharing, the following condition is fulfilled: $t - 2\beta(1-k) > |\theta_a|$. Both the numerator and denominator are then positive and in such cases welfare is everywhere increasing in interconnect quality. The welfare maximizing interconnect quality is found by solving: $k^* = \arg\max\left(W(k) - I(k)\right)$. The first order condition is accordingly:

$$\frac{\partial W}{\partial k} - I'(k) = 0 \Leftrightarrow \frac{\beta}{2} - \frac{\beta\theta_a^{\,2}}{2(t - 2\beta(1-k))^2} = I'(k)$$

The input joint venture will accordingly over-invest in interconnect quality when:

$$\beta - \frac{\beta\theta_i^2}{9(t-\beta(1-k))^2} > \frac{\beta}{2} - \frac{\beta\theta_a^{\ 2}}{2(t-2\beta(1-k))^2} \Leftrightarrow \frac{\beta}{2} + \beta\theta_i^2\left(\frac{1}{2(t-2\beta(1-k))^2} - \frac{1}{9(t-\beta(1-k))^2}\right) > 0$$

A sufficient condition is then that the large bracket is positive. This is the case since:

$$\begin{aligned}
&2(t-2\beta(1-k))^2 < 9(t-\beta(1-k))^2 \\
&0 < 7t^2 - 10\beta t(1-k) + \beta^2(1-k)^2 = 7t^2 - 10\beta t(1-k) - 8\beta^2(1-k)^2 + 9\beta^2(1-k)^2 \\
&0 < (t-2\beta(1-k))\underbrace{(7t+4\beta(1-k))}_{+} + \underbrace{9\beta^2(1-k)^2}_{+}
\end{aligned}$$

It is only socially optimal to set up a direct link between the two networks if both networks have a positive market share, this is the case when $(t-2\beta(1-k)) > |\theta_a|$. Thus the first bracket has to be positive. An input joint venture will accordingly over invest in interconnect quality under product differentiation as well as in the absence of vertical differentiation.

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