COMPETITION, COMPLEMENTARITY AND COMPATIBILITY IN THE INTERNET

by

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Øystein Foros

Introduction[1]

The main topic in this thesis – *Competition, Complementarity and Compatibility in the Internet* - is strategic interaction between competitors and complementors in the Internet industry. When buying Internet connectivity from an ISP[2] the end-users can communicate with other users connected to the Internet and they can access several types of content and applications. I analyze *competition* between firms (ISPs) that are selling Internet connectivity in the retail market. The end-user service may be seen as a system that consists of several components such as local access, regional backbone access and global backbone access. Hence, it is *complementarity* between these components, and the interaction between firms selling complementary components becomes important. Furthermore, since the Internet consists of a number of discrete networks the quality of the interconnection or the degree of *compatibility* between the networks becomes a strategic variable.[3]

The rest of the introduction section is organized as follows. First, I give an overview of the technical structure in the Internet. Second, I discuss the market structure in the Internet. Third, I give an outline of the thesis.

Technical Structure in the Internet

A Brief History of the Internet

In the early 1960s the National Science Foundation (NSF) of the USA initiated the development of the technology and infrastructure behind what we today know as the Internet. As a consequence of this effort, some of the leading academic institutions in the USA became interconnected through an electronic communication network (NSFNET) in 1986. The NSFNET communication technology, invented by the American Ministry of Defence, was based on a so-called Internet Protocol (IP). This

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[1] I am grateful to Lars Sørgard, Hans Jarle Kind and Jan Yngve Sand for useful comments on this chapter.

[2] Internet Service Provider.

[3] Below, I will not distinguish between interconnection quality and compatibility.

has become the standard for distribution of data bits from sender to receiver. At the end of the 1980s commercial firms like IBM and MCI wanted to connect to the Internet, and in 1993 NSF developed a plan for commercialisation and privatisation of the Internet. Two years later NSF withdrew from the NSFNET.

In the early years of the Internet both the users and the services were relatively homogenous. The majority of the users were found at universities and research institutions, and the dominating services were transfers of data files and electronic mail. A common denominator for this kind of users and the applications is that they are relatively "patient" with regard to delays. First, these user groups typically have a relatively low willingness to pay in terms of money compared to time. What I mean by this is that students and researchers in many cases are more likely to accept a delay than to pay a few dollars for an immediate transfer of a data file. Second, services like transfers of data files and e-mail are intrinsically insensitive to delays, since they typically do not require any active real-time cooperation between sender and receiver.

A large fraction of new user groups and new applications are more impatient or sensitive to delays than what was the case earlier. New users in the private business sector often prefer to pay money in order to progress in the queue rather than to wait. Moreover, we have recently observed a large growth in the number of interactive real-time applications. Examples of such applications are interactive video and telephony over the Internet. The required transfer capacity also varies a lot. World Wide Web (www) and real-time video require significantly higher transfer capacity than, for instance, purely text based electronic mails.

The present Internet architecture is based on connectionless packet switching (see below), where data packets are served according to the first come, first served principle. This architecture is not particularly appropriate for serving impatient users or for handling real-time applications. Unless price signals can be used to sort and segment users, it will probably become increasingly difficult to offer real-time applications and to serve impatient users over the open Internet. Impatient users and time sensitive applications may therefore be excluded from the open Internet. This may lead to a process where the Internet becomes segmented into several independent networks instead of further convergence.

A discussion of the development and history of the Internet is offered by Mackie-Mason and Varian (1997) and Werbach (1997), while Cave and Mason (2001) give an overview of the Internet with focus on regulation and the competitive environment.

Layered and Hierarchical Structure

In telecommunication there has traditionally been a close connection between services and the underlying distribution system. Introduction of new services typically requires modifications of the infrastructure, for instance through upgrading of the software in the networks' switches. The situation is completely different within the Internet, since the common protocols between infrastructure and applications/content make it possible to offer new network services independent of the firms that control the infrastructure. Therefore it has become very simple to introduce new applications and services on the Internet, and this has presumably been a central factor behind the success of the Internet.

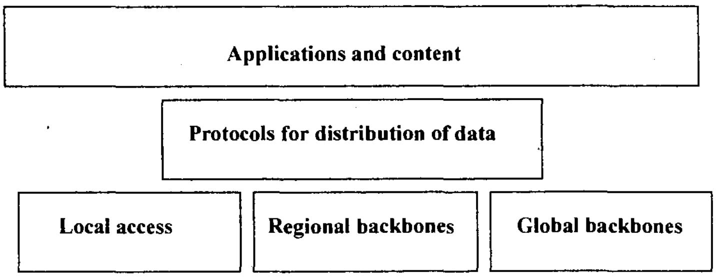

Figure 1: The layered structure of the Internet.

The Internet is often described as having a layered network structure as described in Figure 1. In the bottom layer of the Internet structure we have the physical infrastructure, where local access is an essential component. It should be noted, though, that the total quality of the infrastructure or distribution system does not depend on the quality of local access alone. For instance, there is little reason to upgrade local access to handle broadband applications if the quality of the regional and global backbones implies that the speed of data transfers over the Internet does not increase. A chain is not stronger than its weakest part, and local access is only one of several components of the distribution system that must be upgraded in order to get high-speed Internet. In the higher layers of the Internet structure we find applications and content.

Structure of the Distribution of Data

With regard to the basic physical lines, the Internet by and large uses the same infrastructure as traditional telecommunication. This is true both for local access, where the majority of the consumers uses the traditional telephone line (analogue modem, ISDN, or xDSL), and for the major transmission channels in the regional and global backbones. The local access lines can be considered as short cuts to the Internet, and as such they are not part of the Internet itself. Indeed, local Internet access through the telephone lines uses the same switching technology as traditional telephony – circuit switching. When the user makes a conventional telephone call, or connects the telephone line to the Internet, an end-to-end connection with a given capacity is established (56 kilo bites per second with an analogue modem, and 64-128 kilo bites per second with ISDN).[4] This capacity is dedicated to the user as long as the conversation (connection) lasts, and for traditional phone calls this line switched technology is used independent of distance. Thus, a continuous end-to-end connection is set up whether one calls the neighbor or a person on a different continent. Hence, the circuit switching technology is connection-oriented. On the other hand, the Internet uses packet switched technology, where for instance an e-mail is broken down into several smaller data packets that are sent independently from sender to receiver. Thus, the present Internet standard implies that the packet switched technology is connectionless.

The ex ante advantage of setting up a continuous end-to-end connection with a given capacity is that it is protected from possible third-party interruptions. A disadvantage is that the utilization of the capacity is poor if the capacity requirement varies over time during the connection. This will typically be the case within the Internet world, for instance when a user downloads a web page, and then reads it before a new web page is downloaded. For this kind of use, connectionless packet switching is more effective than an end-to-end connection, since it allows others to use the free capacity.

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[4] Broadband access through the telephone line (xDSL) or cable-TV has capacities of 400 kilobits per second or more.

The disadvantage, of course, is that this may cause interruptions and delays if there is congestion.

The Internet is a network of networks that connects decentralized computers all around the world. Each single computer (host) connected to the Internet has a so-called IP address, which has clear similarities with an ordinary postal address. The IP-address identifies the computer (host id) and which sub network (net id) the computer is connected to. Communication between different computers on the network takes place by sending data packets from one computer to another, and each data packet has an address that identifies the receiver. When the packets have reached the receiver, they are sorted and assembled such that they constitute for instance the e-mail that the receiver sees.

The distribution of data packets from sender to receiver does also takes place by using computers. These computers are termed routers (analogous to switches in the telephone network) and, as indicated by the name, have the overview over the route that the data packets will follow. Each router thus operates a routing table. Most of these tables contain only a limited number of addresses, and data packets with unknown addresses are sent away from the router as unknown (default routing) to routers with a larger routing table higher up in the hierarchy. Standardized rules or Internet protocols (IP), specify how the exchange of data takes place between each single computer and between independent networks.

A hierarchy like the one I have described above needs a top level that does not send away data packets as unknown (default routing). In other words, the core routers at the top of the hierarchy must have complete routing tables with an overview (directly or indirectly) of all the networks further down in the hierarchy. Otherwise, some packets may end up going in indefinite loops. All core routers must be able to communicate with each other, and they must be more or less continuously updated. A small number of such core routers secure complete routing tables, and it is these core routers that define the number of addresses that can be reached over the Internet. A large number of routers with more limited routing tables are in turn connected to the core routers. Thereby the Internet has a vertical or hierarchical address and distribution structure that can be used as inputs for those who operate local and regional networks.[5]

Milgrom et al. (2000) argue that it may be cost efficient that just a few firms control the core backbones and address system in the Internet. Pure cost considerations may therefore indicate that it is optimal to allow the central Internet Backbone Providers (IBPs), who control the core routers, to limit the number of routers that are allowed to enter "the joint venture" of firms that operate core routers.

Market structure in the Internet

In Figure 2 I provide a very simplified illustration of the market structure of the basic distribution system in the Internet. The ISP sells access to the Internet to the end-user, and the function of the ISP is to act as a portal to the global Internet. The end-user either buys Internet connection from the ISP and local access directly from a telecommunication company (Figure 2a) or he buys both services "bundled" from the ISP (Figure 2b). The former model used to be the most common one earlier, but lately it has become more common to buy the bundled variant consisting of both Internet access and local access. This is particularly true for high-speed (broadband) Internet access. Access to the global backbone is in any case an input that local ISPs must buy directly or indirectly from those who control the top level of the Internet (the IBPs), and with the bundled variant the ISP must also buy local access as an input.

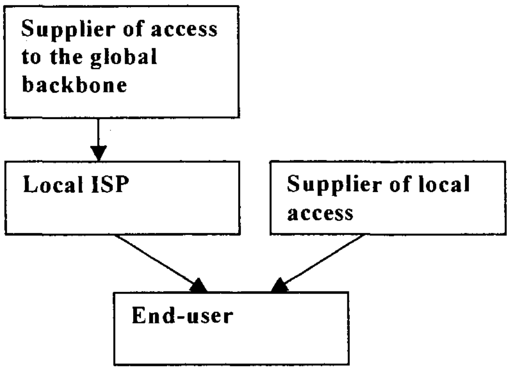

Fig. 2a: Separate supply of local access and Internet access

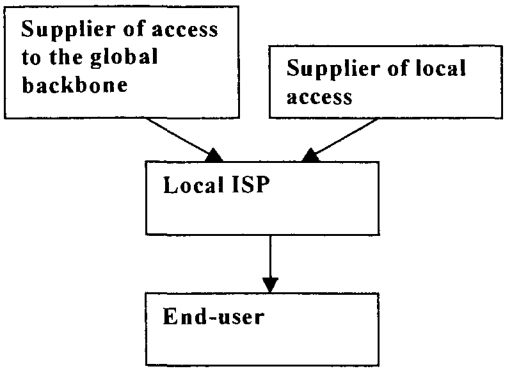

Fig. 2b: Local access and Internet access bundled

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[5] The core routers never send away packets as unknown, as distinct from the routers with more limited routing tables. If the core router receives a packet with an address that it does not recognize, the packet will be deleted.

Today it seems to be dominant firms that control the top level, i.e., the global backbones, of the Internet. We also find dominant firms in the segment for local access (where the dominating telecommunication firms have large market shares). For the ISP segment the situation is different. In this segment there is a large number of firms, and entry barriers are seemingly small compared to the local access segment and the global backbone segment.

Local Internet Service Providers

Usually local ISPs operate their own local data network (regional backbones), but these networks are to a large extent based on leased-lines in a market with relatively tough competition. The profit opportunities for independent ISPs have proven to be relatively small, since there are low entry barriers. Cave and Mason (2001) argue that a main reason for this is the prevailing regulation regimes in telecommunications. However, they maintain that we may observe increased market concentration also in this segment along with increased penetration of broadband technology in the local access.[6]

Internet Backbone Providers

The fact that the addressing within the Internet takes place within a strict hierarchy has immediate implications for the market structure. Those who control the top level of this distribution system and the core routers are in possession of an input that all the other agents down in the system must have access to. In addition, since these firms control much of the basic transmission networks, both in the USA and across the Atlantic Ocean, one may argue that these companies control the global infrastructure in the Internet – denoted the global backbone in Figure 1 and 2. These firms (four to five in number) constitute what has been labelled Tier-1.

Historically, the interconnection agreements between different sub-networks in the Internet were of the form "I bring your traffic if you bring my traffic", with no flow of payments (*peering agreements*). These agreements worked well as long as the public sector financed most of the infrastructure and the Internet was characterized by homogeneity both on the supply and the demand side. Additionally, as discussed above, early applications like e-mail and transfer of data files typically tolerated

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[6] Many ISPs also offer content, but here I will concentrate on access to the infrastructure for the end-user.

delays. The latter implied that neither users nor services were particularly sensitive to small frictions in the interfaces between different networks.[7] The 4-5 dominating IBPs at the top level of the Internet still have "I bring your traffic if you bring my traffic"- agreements with each other. However, since 1997 these firms have charged smaller IBPs and ISPs for access to the global infrastructure and addressing system in the Internet through so-called *transit agreements*.

It is an important question whether the dominating IBPs have incentives to use market power in a manner that directly hurts both smaller IBPs, local ISPs and end-users. On the one hand, there are clearly valid arguments that the top-tier firms should be allowed to cooperate on maintenance of the top level of the Internet. Smaller IBPs may, for instance, be tempted to overload other parts of the network rather than to increase their own capacity (Srinagesh, 1997). Therefore it may be optimal to restrict the number of firms that are allowed to enter into peering agreements. Put differently, it may be socially advantageous that small Internet suppliers have to pay for complete Internet access (Milgrom et al., 2000, Besen et al., 2001). Additionally, Varian (1998) argues that cooperation between the top-tier firms helps to secure high quality on the global backbones in the Internet. However, Varian (1999) also argues: "The problem with such a board would be the temptation to use it as a device for collusion". So even if individual IBPs does not have a sufficiently dominant position to abuse its market power towards either smaller IBPs or retailers further down the hierarchy, the top-tier IBPs as a group may have the ability to come in such a position.

When MCI and WorldCom in 1998 applied for a permission to merge, it was questioned whether the new company, as a dominating IBP, would be able to partly foreclose competitors by increasing their costs (e.g., by setting a high price for interconnection) or by lowering their demand (by reducing the quality of interconnection). The most outspoken concern of the other IBPs was that the merged MCI WorldCom would choose the latter strategy; offer an inferior interconnection quality in order to gain a competitive advantage in the competition of selling inputs (transit) to firms further down in the Internet hierarchy. In order to avoid this scenario,

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[7] See Srinagesh (1997), Kende (2000) and Bailey (1997) for a detailed description of the structure and history behind the interconnection arrangements in the Internet.

both American and European competition authorities set as a precondition for accepting a merger that MCI's IBP activities were sold.[8]

Local Access Providers

The firms that sell Internet access to an end-user must have a physical connection to the outer wall of my house (local access). For private users it is not reasonable to believe that anyone will find it commercially profitable to build new cables into private homes in the near future (Clark, 1999). Thereby private users will at most have two alternatives to choose between, namely the copper cable for telephony and cable-TV. The majority of the households in Europe use the telephone line (through modem or ISDN) to reach the ISP. Thus, the alternatives are limited with regard to local access, and the firms that control the local access network are in possession of a central component. Moreover, the dominating providers of local access are also to a large extent vertically integrated into the ISP segment. In Norway, for instance, the incumbent telecommunication firm (Telenor) controls the most important local access network in the country (through its copper network), and Telenor is also the largest cable-tv provider. At the same time, Telenor is the largest retailer of Internet access.

The market power of the dominant telecommunication companies should not be exaggerated, since they are subject to comprehensive regulation. Noteworthy, it is only the telecommunication companies that are mandated to sell local access as an input to independent retailers. Cable-TV companies do not face the same requirement, and interestingly they have chosen not to sell local access as an input to independent ISPs. Consequently, in this case broadband Internet access has to be bought directly from the network owner. Hausman et al. (2001) analyze the implications of this asymmetric regulation of telecommunication and the cable-TV network with focus on the USA.

Regulation of the Internet Industry

The end-user market for Internet connectivity is currently unregulated in most countries, while the input segment for local access is regulated both with respect to price and quality. If the local bottleneck is eliminated, then head to head competition

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[8] In connection with this case, it should also be mentioned that WorldCom planned to merge with Sprint (a major IBP) in year 2000, but that the EU stopped these plans.

in the retail market may ensure that there is no need for regulation. Consequently, regulation of the local access bottleneck may be sufficient to ensure competition in the retail market. However, the fact that the end-user market is unregulated creates an incentive for a vertically integrated provider of local access to discriminate against rivals in the retail segments (see e.g. Laffont and Tirole, 2000).

The prevailing regulation regime of local access in Europe is cost-oriented, which means that the incumbent is not allowed to charge higher access prices than those reflecting its long-run marginal costs. The incumbent controlling the local telephone network often uses three main arguments against cost-based regulation. The first argument is that it is practically impossible to compute the long run marginal cost in an industry involving large joint costs. The second argument is that the local access network for telephony no longer constitutes a bottleneck, because cable-TV and wireless networks are bypass opportunities for residential users. The third argument is that cost oriented regulation will reduce the incumbent's dynamic incentives to invest in infrastructure and product innovation. The current sector specific cost-based price regulation for local access is often seen as a "hands-on" *ex ante* approach, while the competition rules are seen as an *ex post* regulation approach. This distinction may be misleading, since the current cost-based sector regulation *de facto* will often appear as *ex post* regulation (see e.g. Laffont and Tirole (2000) and Hausman (1997)).

Outline of the Thesis

In this section I briefly summarize the remaining chapters of the thesis.

Chapter 1: Strategic Investments with Spillovers, Vertical Integration and Foreclosure in the Broadband Access Market

by Øystein Foros

In this paper I analyze a market structure where a vertically integrated firm controls an essential input for retail providers of Internet connectivity. The vertically integrated firm may undertake an investment that increases the quality of the input (upgrading to broadband). In the retail market the vertically integrated firm competes with an independent firm that buys access as an input, and I analyse the effect of an access price regulation on investment incentives and welfare. There is only one available instrument for the regulator – the access price – and the regulator has limited commitment ability regarding the access price. Hence, the access price is set after the investment in network quality. Such a regulation may have negative effects on the investment incentives, and I show that the total effect on consumer surplus and welfare critically depends on whether the vertically integrated firm or the rival firm has higher ability to offer value-added services (broadband services) than the rival firm.

When the rival has higher ability to offer value-added services, both firms will be present in the market even without access price regulation. A binding regulation on access price will reduce the cost of the most efficient firm, in this case the rival. For a given level of investment this will obviously increase consumer surplus, since the firm with highest ability to offer value-added services will increase its output. However, the vertically integrated firm's investment incentive is reduced, and a lower investment will hurt both firms. As long as the cost of investment is not too convex, access price regulation lowers consumer surplus.

If the vertically integrated firm's retail subsidiary has the highest ability to offer value-added services when the input quality is improved, the rival will always be foreclosed by a high access price without access price regulation. I analyse two cases. First, I assume that the difference in the two firms' ability to offer value-added services is not too high. Then the rival's quantity increases when the investment increases for a given access price. The conventional trade-off between increasing competition and investment incentives is still present. I show that, similar to above, as long as the cost of investment is not too high, the access regulation lowers consumer surplus. Hence, with not too convex costs the downstream monopoly results in higher consumer surplus than a regulated duopoly.

Second, I assume that the vertically integrated firm's ability to offer value-added services is significantly higher than the rival's ability to use the improved quality of the input. Then, for a given access price, the rival's quantity decreases when the investment increases. In such a case an access price regulation eliminates the vertically integrated firm's ability to use the access price as a foreclosure tool. But now there exists an alternative tool. The vertically integrated firm may use overinvestment as a mechanism to drive the rival out of the market. In this case the regulator's incentives to use an access price regulation may change fundamentally. A restrictive access price regulation gives the rival low input costs, and, hence, the vertically integrated firm must invest more to induce the rival to exit. The regulator can then encourage the firm to increase the investment with a restrictive access price regulation. If the vertically integrated firm's investment in an unregulated monopoly is too low seen from the regulator's point of view, it will also be optimal to do so. Moreover, an access price regulation may be optimal even if it does not result in entry.

Chapter 2: Access Pricing, Quality Degradation and Foreclosure in the Internet (forthcoming in Journal of Regulatory Economics, 2002, 22(1), 59-84)

by Øystein Foros, Hans Jarle Kind and Lars Sørgard

In this chapter we focus on the interplay between providers of the complementary inputs local and global access and on the timing of the interaction between the domestic regulator and the market players. We compare a situation where the domestic regulator credibly commits himself to a given price policy for local access before the input suppliers choose their wholesale prices with a situation where the domestic regulator cannot commit to such a policy. The former we refer to as *ex ante* regulation, while the latter we refer to as *ex post* regulation.

An increasingly larger share of the traffic on the telephone network is associated with Internet traffic, while the share of traditional voice telephony is decreasing. Combined with the fact that most of the Internet traffic goes through the USA this may have some implication for the optimal regulation of local access prices in Europe. In particular, it should be noted that access to the global Internet backbone is an essential input that together with the transatlantic telephone cables is controlled by a few large American companies. Local ISPs that sell Internet connectivity to end-users have to purchase access to the global infrastructure as an input, which is complementary to other essential inputs. Based on this we show that a cost-based regulation of local access possibly is detrimental to national welfare outside the USA, since it may imply excessive profit shifting to American firms. The reason for this is simply that the American firms may increase the price of global access if European regulators reduce the price of local access. A regulation policy that seeks to maximize national welfare may therefore imply that the regulator commits itself to set relatively high prices on local access, even if this should reduce domestic competition.

The distinction between ex post and ex ante regulation is potentially important when we consider the effects of domestic regulation of the local access price. Ex post regulation may actually reduce welfare compared to market equilibrium. The reason for this is that the foreign firms are aware of the fact that the regulator ex post has an incentive to set the price of local access equal to long-run incremental costs. This in turn gives the foreign firms incentives to set relatively high prices on access to the global backbone. If the regulator can commit itself to set a relatively high access price, on the other hand, the foreign firms may have incentives to set relatively low prices. This is due to the fact that local and global access are complements; the higher the price of one of these inputs, the greater the incentives to reduce the price of the other input. This is the opposite of what would be the case between substitutes, where a price increase by one firm typically will be followed by a price increase also by the other firm.

The fact that a strict price regulation may be detrimental to welfare because it leads foreign firms to set higher prices raises the question of whether there is a need for some kind of supranational regulation of global access prices. The problem, however, is that many of these firms are vertically integrated into the end-user market. Thereby they may have incentives to implement quality-reducing actions towards downstream competitors. In the case of IBPs, for instance, it seems difficult to impose quality restrictions. We show that an international regulation may increase welfare, but only if the global access price is set so high that the firms do not have incentives to foreclose the rivals.

Analogous to Crémer, Rey and Tirole (2000) and Dogan (2001) we assume that the IBPs have market power when they offer global backbone access to regional ISPs. In contrast Laffont, Marcus, Rey and Tirole (2001a, 2001b) assume that there exists perfect competition between the IBPs.

Chapter 3: Competition and Compatibility among Internet Service Providers (reprint from Information Economics and Policy, 2001, 13(4), 411-425)

by Øystein Foros and Bjørn Hansen

We analyze the incentives for competing ISPs to become compatible, and in the model we assume that there are two ISPs competing in a Hotelling framework were the services are both vertically and horizontally differentiated. The firms' locations are exogenously given at the extremes of the Hotelling line. A two-stage game is played by the two firms. At stage 1 they choose the degree of compatibility (or the interconnection quality) between their networks. At stage 2 they simultaneously set their prices (subscription fees). There are two effects when increasing the degree of compatibility: First, the price-effect is positive for both firms even if one of the firms have a larger market share due to vertical differentiation. The reason for this is that higher degree of compatibility increases consumers' valuation. Second, the market-share effect, which has opposite sign for a small and a large network. If the degree of compatibility is imperfect, the network size may start to matter when the consumers choose between the two ISPs, and the bigger firm will gain a competitive advantage when the degree of compatibility is less than perfect. In the present model the price effect dominates the market share effect as long as we have market sharing between the two firms. Hence, as long as the cost of compatibility is not to high the ISPs have incentives to set a high interconnection quality, because this reduces the intensity of the price competition.

Our result that vertically differentiated firms do not differ in their incentives with respect to compatibility is in contrast to the result in Crémer, Rey and Tirole (2000).

Crémer et al. extend the model by Katz and Shapiro (1985) in order to analyze compatibility incentives in a context with competition between two IBPs that have each their base of installed customers. They show that if one IBP has a larger base of installed customers than the other, the bigger firm will always have lower incentives to become compatible compared to the smaller rival. Our paper and the paper by Crémer et al. have similar timing structure, but Crémer et al. assume Cournot competition while we assume competition à la Hotelling in stage 2. Roson (2002) compares our paper and the paper by Crémer, Rey and Tirole. He argues that the driving force behind the different results with respect to compatibility incentives is that the market size is fixed in our paper while the market size is variable in Crémer et al. (2000). However, as far as I can see, the fixed market size in our model is not the most important determinant for the result that both firms agree upon the degree of compatibility in our model. The main difference between our model and Crémer et al. in this respect is the following. In our paper the degree of vertical differentiation between the firms is independent of the degree of compatibility. In contrast, in Crémer et al. the degree of vertical differentiation is a function of the degree of compatibility, such that if there is complete compatibility, there will be no vertical differentiation (quality difference) between the firms. If we use the same assumption as Crémer et al., the firm with a quality advantage would have lower incentives to become compatible than the rival in our paper too.[9]

Chapter 4: Price Competition and Interconnection Quality in the Market for Digital Network Services

by Øystein Foros

I combine elements from Ulph and Vulkan (2000) and Foros and Hansen (2001) - the previous article in this thesis. Ulph and Vulkan (2000) show in a one-stage game without network effects that there are two effects of using first-degree price discrimination under Hotelling competition. The first is the effect of the conventional monopoly analysis of first-degree price discrimination – the enhanced surplus extraction effect. The second effect is that the firms will compete consumer by

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[9] Other analysis that focus on the relationship between IBPs include Milgrom et al. (2000), Besen et al. (2001), Laffont et al. (2001a, 2001b), and Little and Wright (2001).

consumer when they use first-degree price discrimination – the intensified competition effect.

In the first part of the paper the pricing mechanisms are exogenously given, and I compare the following three cases; (i) both firms set a linear price, (ii) both firms use first-degree price discrimination, and (iii) one firm sets a linear price and one firm uses first-degree price discrimination. I analyse a two-stage game where the firms choose the degree of compatibility *prior* to the price competition. The timing structure is similar to Foros and Hansen (2001), but I investigate the effects on the compatibility choice of different pricing mechanisms. I show that when the firms use symmetric pricing mechanisms they will agree upon complete compatibility as long as the cost of a compatibility agreement is not too high. In contrast, if the firms use asymmetric price mechanisms both firms will choose low compatibility even if the compatibility agreements are costless.

In contrast to the existing literature, that focuses on the fact that the larger firm has lower incentives to become compatible than the smaller one (e.g. Katz and Shapiro (1985) and Crémer, Rey and Tirole (2000)), low degree of compatibility may be a result of asymmetric pricing mechanisms. Moreover, I show that the network effects will intensify competition such that the price will be set below costs for the consumers that are relatively indifferent between the two suppliers (i.e. consumers located in the middle of the Hotelling line). The observation that network services are sold below costs is usually explained by penetration pricing, where a firm may find it profitable to set the price below costs in one period in order to obtain a critical mass.

In the second part of the paper I endogenize the choice of pricing mechanism – i.e. whether the firms will implement first-degree price discrimination mechanisms or not. When the costs of compatibility are negligible, I find that there will be multiple equilibria. However, as long as the firms are able to coordinate on the *Pareto-superior* outcome, both firms set linear prices and complete compatibility. This will be the case regardless of whether pricing mechanism is set *prior* to compatibility or the two choices are taken simultaneously. When the cost of compatibility is high, such that the firms always choose to be incompatible, the outcome where both firms use price discrimination may be a unique equilibrium.

Chapter 5: The Broadband Access Market: Competition, Uniform Pricing and Geographical Coverage (forthcoming Journal of Regulatory Economics)

by Øystein Foros and Hans Jarle Kind

Broadband access is the last mile of the telecommunication network, and it is an essential component in order to offer broadband Internet connectivity. A key technological feature of this market is that it is considerably more expensive to connect consumers in rural locations than in urban locations. In an unregulated market we should therefore expect that the price of access to broadband would be higher in rural locations than in urban locations. This is true independent of whether the market is served by a monopoly or by several competing firms. There are political concerns that peripheral locations will be harmed unless broadband access providers are required to charge the same price for the same service in all locations that they cover (uniform prices). However, even though there may be implicit or explicit political requirements of uniform prices, the actual price level will hardly be regulated. Instead, as in other industries, governments seek to prevent unduly high prices by inviting several firms to compete. Some implications of this policy mix are discussed in this paper.

First, it should be noted that the socially optimal regional coverage may fall if there is a requirement of uniform pricing. The intuition for this runs as follows: The fact that it is relatively inexpensive to serve consumers in locations with a high population density indicates that also the access price should be low. However, a low price induces too high demand in peripheral locations, where the real costs of providing broadband access are high. In order to reduce the magnitude of the latter effect, it is socially optimal not to serve some of the least populated areas. This clearly indicates that uniform pricing may be a poor regional policy.

Second, increased competition need not improve welfare if there is a requirement of uniform pricing. While a monopolist will still have incentives to set the same regional coverage as the social planner, the coverage level decreases if there is competition. Competition reduces prices, but herein lies, in a sense, also the problem: due to the convexity of the cost function, the lower market price makes it less profitable to serve peripheral locations. Competition therefore implies that the regional coverage falls to a sub-optimal level, and this negative welfare effect is more likely to dominate the larger the number of firms that offer broadband access. Consequently, welfare may be lower with free entry than if the market is served by a monopolist.

The fact that it is relatively more expensive to serve rural areas than urban areas is not unique for the broadband access technology. There is a similar cost structure also for, e.g., postal services and third generation mobile telephone systems (UMTS in Europe). In some countries (like France, Norway and Sweden) the governments have specified a minimum regional coverage by the firms that are granted UMTS licenses, and proposals have been advanced to specify similar requirements for firms providing broadband access. In an extension of the basic model we therefore assume that the government is able to set a binding coverage requirement prior to downstream competition between the firms, and show that this has a positive effect on aggregate consumer surplus. More surprisingly, this policy may also increase the profit level of the firms. The reason for this is that the regulator, by acting as a first-mover, solves a co-ordination problem; the oligopolistic firms would prefer the same regional coverage as the one chosen by a hypothetical monopolist, but this does not constitute an equilibrium in a free market economy. Thus, by requiring the firms to build out to larger areas the government may actually be able to increase both the profitability of the firms and the geographical coverage. This suggests that a requirement of uniform prices alone may be bad policy; it should be combined with a requirement of geographical coverage too.

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Chapter 1

Strategic Investments with Spillovers, Vertical Integration and Foreclosure in the Broadband Access Market[*]

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Abstract
We analyse competition between two firms (ISPs) in the retail market for broadband access. One of the firms is vertically integrated and controls the input market for local access. The vertically integrated firm undertakes an investment that increases the quality of the input (upgrading to broadband). The retailers' ability to offer value-added services when the input quality is improved differs. We analyse the effect of an access price regulation that is set after the investment. The access price regulation may have negative effects on investment incentives, and we show that the total effect on consumer surplus and welfare depends on which firm has the highest ability to offer value-added services.

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1 Introduction

The purpose of this paper is to examine the interplay between a facility-based vertically integrated firm and an independent competitor in the retail market for broadband Internet connectivity. The latter firm buys local access as an input from the former firm. The vertically integrated firm undertakes an investment (broadband upgrades) that increases the quality of the input. We assume that the regulator has only one instrument available, an access price regulation for the input sold to the independent rival.[1] The retail market is assumed to be unregulated.[2] Furthermore, we assume that the access price is set after the investment but prior to retail market competition since the regulator has limited commitment ability. Both the timing structure and the one-sided regulation of the input segment correspond to the dominant regulatory paradigm in the EU and the USA (Laffont and Tirole, 2000, Hausman, 1997, and Cave and Prosperetti, 2001). Installation of fiber in the local access network will be a substantial, lumpy, and irreversible investment, and the economic life of the investment will be longer than the regulation contract used for access prices (Hausman, 1997).[3]

The access price regulation may reduce investment incentives, and the main message of this paper is that the total welfare effect of access price regulation critically depends on which firm has the highest ability to transform input to output. The quality of the input component sold from the integrated firm is the same for both retailers, but the retailers may differ in their ability to offer value-added services (broadband services such as interactive video).[4] Except for the case where the independent firm has the highest ability to use the improved input quality, the integrated firm will foreclose the rival from the market through the access price in an unregulated environment. However, this is not a sufficient condition to ensure that an access price regulation improves consumer surplus and total welfare. If the retailers do not differ too much with respect to their ability to offer value-added services when the input

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[1] See Laffont and Tirole (2000) and Armstrong (2001) for comprehensive overviews of access price theory and practice. Cave and Mason (2001) give an extensive overview of the market structure and regulation in the Internet.

[2] See Laffont and Tirole (2000) for a discussion.

[3] Price cap regulations in telecommunication do not exceed five years, and other types of access price regulation are usually set for a shorter period. In contrast to the present paper, the literature on price caps typically focuses on incentives for cost-reducing activities within the regulatory contract.

[4] The independent firm may be anything from the geeks in the garage to AOL Time Warner. Compared to the facility-based vertically integrated firm, those firms' ability to offer value-added services will obviously vary a lot. The integrated firm's retailer may have an advantage in using the improved input quality due to economies of scope from integration. In contrast, if the independent retailer is a firm like AOL Time Warner, it may have an advantage compared to the integrated firm due to its experience from other markets.

quality is improved, we show that access price regulation reduces the vertically integrated firm's investment incentives. An access price regulation lowers consumer surplus and total welfare as long as the cost of investment is not too convex. If the vertically integrated firm's ability to offer value-added services is much higher than the independent rival, an increase in the investment will reduce the quantity offered by the independent retailer. An access price regulation still eliminates the vertically integrated firm's ability to use the access price as a foreclosure tool, but now the integrated firm may use overinvestment as an alternative tool to drive the rival out of the market.

Today the majority of residential consumers use their telephone lines for the last mile of narrowband Internet connectivity, and by upgrading their local networks the telecommunication providers are able to increase the speed of communication.[5] The high up-front investments of new wire line facilities, and the possibility of increasing the capacity and quality of existing local telephony and cable-tv networks, indicate that telephone companies and the cable-tv-companies that already have installed wires to homes, will control the segment for broadband local access to residential consumers (Mackie-Mason, 1999).[6] In the current regulation only the telephone access provider is mandated to supply local access as an input to non-facility based rivals in the retail market. Therefore, the telephony incumbent has been the only provider of local access as an input to independent ISPs[7]. Hence, given the existing asymmetry in regulation of the telecommunication and the cable-tv technologies (see Hausman et al., 2001), the present model only fits for services offered by the telecommunication incumbents.[8]

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[5] Measured by bits per second (bps). A conventional voice telephone call needs approximately 10 kilo-bps. The bandwidth requirement for broadband services will vary a lot, and it also varies between incoming and outgoing capacity. Compression technologies may reduce the bandwidth requirements considerably, but in order to support e.g. two interactive high-quality tv channels several mega-bps are needed. Current standard modem technology gives access speed of 56 kbps. In Europe, however, the penetration of ISDN is higher. ISDN access speed is no more than 128kbps. The upgrading technologies both for cable-tv and telephone lines should give access speed from a few hundred kbps to 10-20 mbps.

[6] With focus on the US market several analysts have argued that the cable-tv-providers have an advantage over the local telephone providers in supplying broadband Internet access (see e.g. Mackie-Mason, 1999, and Faulhaber and Hogendorn, 2000). The situation seems to be different in Europe (Roche et al., 2001). There may be several reasons for this difference. First, there is high penetration of cable-tv in the US compared to many European countries. Second, and probably more important, the historical separation between local providers and long distance providers of telephony in the US between 1984 and 1996 (the AT&T break-up in 1984).

[7] Internet Service Providers.

[8] However, since the cable-tv providers face an analogous cost structure, the analysis will be relevant for broadband access using cable-tv technology if the cable-tv providers are required to offer broadband access as a wholesale product.

We assume that the investment in higher speed of communication may be seen as an unambiguous improvement of quality.[9] The closer to homes the fiber is installed, the higher is the quality.[10] The trade-off between the distance the existing lines are used and the network quality (speed) implies that the upgrading costs are convex in speed of communication.

In figure 1 we illustrate the Internet as a layered network with the physical network as the bottom layer. Local access is obviously an essential input component for the ISPs. The functions of the retail ISPs are to combine the components' local access, regional backbone capacity and global backbone capacity, and they act as a kind of portal to the applications and content in the Internet.

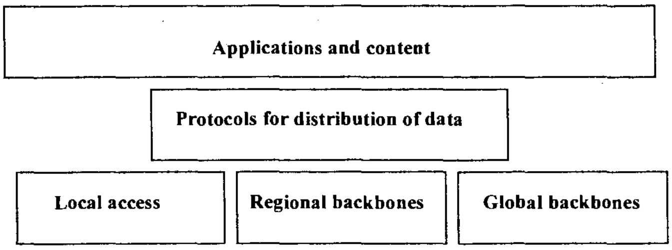

Figure 1: The layered structure of the Internet.

As described by Cave and Mason (2001) and Faulhaber and Hogendorn (2000), the retail ISPs must choose their regional and global backbone capacity before they serve the end users. This implies capacity constraints that limit the number of consumers that can be served.[11] With respect to timing in our model it is reasonable to assume that the investment choice of speed of communication in the access network is taken prior to the ISPs' choice of local and global

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[9] First, an increase in speed of communication gives access to new broadband services (e.g. interactive audio and video). Second, consumers' value from conventional Internet services like web-browsing and e-mail increases when the downloading speed increases. Third, today's dial-up Internet connectivity is only connected when the user makes a phone call to her Internet Service Provider (ISP). The broadband Internet connectivity systems are designed to be available all the time ("always on").

[10] There may be horizontal differentiation in this market (see Foros and Hansen, 2001). However, we make this assumption in order to strengthen the foreclosure incentives of the vertically integrated firm in absence of access price regulation.

[11] Although the total number of retail ISPs is large, the market is quite concentrated since the largest providers are controlling a large part of the market. Cave and Mason (2001) argue that the current narrowband dial-up access limits the economies of scale in the ISP-segment. In the ISPs' local backbones the subscribers' traffic is combined and carried over shared lines, and the ISPs use statistical aggregation in order to reduce the investment in capacity. However, the capacity limits in the narrowband access are constraining the economies of scale from traffic aggregation. The situation will be different with broadband access technologies, and this will probably also increase the concentration in the ISP-segment (Cave and Mason, 2001). The regional ISPs usually have long-term contracts with the providers of transatlantic-lines and access to the core global backbones (Crémer, Rey and Tirole, 2000). To some extent, this will also give capacity constraints in the end-user market.

backbone capacity. The interplay between local retail ISPs and the upstream providers of global access will not be addressed in the present paper.

Our paper is related to the literature on strategic R&D investments with spillovers.[12] In contrast to our model, there is no opportunity for access pricing by the investing firms in this literature. The literature on R&D investments assumes that the investment leads to a reduction in costs, and that there is a spillover that also reduces rivals costs.[13]

Rey and Tirole (1997) analyse the incentives for foreclosure by a vertically integrated firm that controls an input bottleneck in an unregulated market, while Laffont and Tirole (2000) discuss the incentives for non-price discrimination under access price regulation. Several recent papers analyse non-price foreclosure in telecommunications and the Internet. Similar to Economides (1998) we assume an exogeneously given market structure where an integrated firm controls the input-segment, and there is an unregulated Cournot duopol in the retail segment. Economides (1998) shows that the integrated firm will always use non-price foreclosure towards the retail rival. This result contrasts with Weisman (1995, 1998), Sibley and Weisman (1998), Weisman and Kang (2001) and Foros, Kind and Sørgard (2002), who find that that the vertically integrated firm will be less inclined to degrade the quality of the input if the profit margin is high in the input segment. In all these papers the foreclosure activity is assumed to degrade the quality of the input sold to the rivals. In contrast, in our model there is no opportunity to unilaterally reduce the quality of the input sold to the rival. The quality level of the input is the same for both retailers. However, if the vertically integrated firm has significantly higher ability to offer value-added services than the rival, the integrated firm may commit itself to be more aggressive in the retail market by overinvesting in network quality improvement.

Faulhaber and Hogendorn (2000) and Foros and Kind (2002) analyse the broadband access market with focus on the choice of target market (where to upgrade to broadband), while the coverage decision is not analysed in the present paper. Another distinction from the present

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[12] Spence (1984) models spillovers from the investment, but he assumes that the firms are symmetric in their ability to invest. The seminal paper on strategic R&D-investments and spillovers is D'Aspremont and Jacquemin (1988).

[13] Investments that create positive demand side effects are not considered in this literature. Our formulation of the demand side spillover is analogous to Wey (1999), who examines symmetric firms' incentives to invest in compatibility under different degrees of co-operation. Note that the investment in network quality in the present paper may be equivalent to Katz and Shapiro (1985) who see the network quality as the number of expected consumers (see discussion below).

paper is that these two papers develop models of competition among several facility-based broadband access providers, while we analyse the interplay between a facility-based provider and a non-facility-based rival. Hausman, Sidak, and Singer (2001) analyse the asymmetric regulation of telecommunication providers and cable-tv providers regarding broadband access. Rubinfeld and Singer (2001) analyse the merged AOL Time Warner's incentive to engage into two types of non-price foreclosure in the broadband access market.[14]

The article is organised as follows. In section 2 we present the model. In section 3 we give some concluding remarks.

2 The model

In figure 2 we illustrate the stylised market structure analysed in the present paper. In the retail market for Internet connectivity there is competition between a vertically integrated firm's subsidiary and an independent ISP, ISP A and ISP B, respectively. The vertically integrated firm controls the local access component. The broadband Internet connectivity is sold by the two ISPs to end-users at a fixed subscription fee independent of actual usage (the number of packets actually sent and received) and time connected. This also corresponds with what we see in the market place for broadband Internet connectivity.[15] Hence, the ISPs face a downward sloping demand curve. When the subscription fee is reduced (for given quality), more consumers will subscribe. The usage by the infra-marginal consumers is, however, not affected.[16] The access input price charged by the facility-based firm will be a fee for each broadband subscriber served by the rival ISP (ISP B) over the vertical integrated firm's local network facilities.

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[14] Rubinfeld and Singer (2001) show that AOL Time Warner has both the ability and incentive to engage into non-price foreclosure. In contrast to our model, they do not consider investment incentives and access pricing, and they assume that the foreclosure activity will reduce the quality of the component offered to the rival.

[15] This is in contrast to the current narrowband Internet connectivity through modem where the user pays a time-dependent price while he is connected. However, the current billing systems do not charge the users for their actual usage of bandwidth.

[16] Thus, we implicitly assume that the direct network effects are insignificant. In other words, for a given speed of communication in the local loop, the willingness to pay is not affected by the number of consumers subscribing to broadband in the same area. This assumption seems realistic if the user is mostly downloading information from the US. However, if the user's main use of broadband Internet connectivity is to have video-conferences with neighbours this assumption is rarely fulfilled.

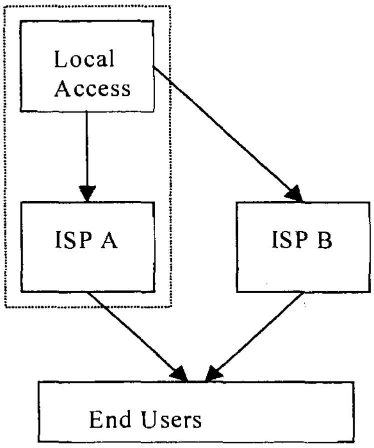

Figure 2: The market structure

When the network quality is improved, the demand curves for both retailers shift outwards, such that the willingness to pay for subscription increases for all potential consumers. If the firms differ in their ability to use the quality improvement of the input, the market shares of the firms will be affected.

We model a three-stage game with the following timing structure:

- Stage 0: The vertically integrated firm chooses the investment level x.
- Stage 1: The vertically integrated firm or the regulator chooses the access price w to the rival.
- Stage 2: The two retail firms compete à la Cournot.

As mentioned above, we focus on how "fat" pipes to homes the vertically integrated firm chooses, and we do not consider the choice of target market (where to upgrade to broadband). Faulhaber and Hogendorn (2000) and Foros and Kind (2002) analyse the choice of target market for a given quality level. The choice of coverage may in fact be set street-by-street, and therefore be taken after the investment choice considered here. However, as long as the integrated firm is obligated to offer broadband access as a wholesale product to the independent ISP in the entire target market, this will not alter the aspects analysed in the present paper.[17]

We assume Cournot competition in the retail market, and the quantity firms dump in the retail market is interpreted as the number of subscriptions they sell. An assumption of Cournot competition seems reasonable, since the retailers face capacity constraints in the regional and the global backbones (see above and the discussion by Faulhaber and Hogendorn (2000) and Crémer et al. (2000)).[18]

Demand side

The investment at stage 0 is given by x. We see this investment as a quality improvement of the local access input that increases the consumers' willingness to pay for broadband Internet connectivity. How much the input quality improvement increases consumers' willingness to pay for Internet connectivity depends on the retail firms' ability to transform input to output. Hence, we have a demand side spillover from the local access provider to the retailers:

$$a_1 = a + \beta_1 x \text{ and } a_2 = a + \beta_2 x$$

Subscript 1 and 2 indicate the facility-based and the non-facility-based firm, respectively. The parameters β_1 and β_2 are the demand side spillover from the facility-based firm to its own subsidiary and the independent ISP, respectively.[19] If $\beta_1 > \beta_2$, the vertically integrated firm has higher ability to offer a value-added service from the investment than the non-facility

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[17] However, an obligation to offer the input in the entire target market combined with an access price regulation will probably reduce the coverage where the integrated firm chooses to upgrade to broadband. The reason for this is that it reduces the revenue, but not the costs from serving a given region.

[18] Faulhaber and Hogendorn (2000) assume that there is a capacity-constrained price game in the retail market for broadband access, and that the conditions for the Kreps-Scheinkman result are fulfilled in their model. They model a three-stage game where the coverage decision is taken in stage 1, stage 2 is the backbone capacity choice, and in stage 3 firms choose prices. Hence, the investment choice analysed in the present paper may be seen as a stage prior to the model analysed by Faulhaber and Hogendorn. The two last stages of their game are shown to be equivalent to a one-stage Cournot game. The result of Kreps and Sheinkman (1983) that a two-stage game of capacity choice and then prices is the same as a one-stage Cournot game rests on very strong assumptions. However, since there are rigid capacity constraints we assume that the Cournot competition assumption seems more realistic than a Bertrand game in the retail market (see the discussion in Tirole, 1988, chapter 5). A necessary condition to ensure the Kreps-Scheinkman conditions in our context is that the ISPs simultaneously set the backbone capacity in a stage 2a, and that they thereafter compete in prices in a stage 2b.

[19] The spillover is analogous to the spillover effect from R&D investment in D'Aspremont and Jacquemin (1988), among others. They assume process innovation, while we assume product innovation.

based firm. In contrast, if $\beta_2 > \beta_1$, the non-facility based firm has the highest ability to increase consumers' willingness to pay. We assume that $\beta_{1,}\beta_2 \in [0,1]$.

The consumers have unit demands. We assume that the consumers are heterogenous in their basic willingness to pay for Internet connectivity, but that they are homogenous in their valuation of the improved network quality. Hence, consumers valuation of ISP *i*'s service is *s* + $\beta_i x$, and *s* is distributed uniformly among the consumers. The consumer with the highest willingness to pay has *s* equal to *a*. The demand structure is analogous to Katz and Shapiro (1985) where the network quality depends on the number of expected consumers connected to firm *i*.[20]

When p_i is the price charged by ISP *i*, a consumer of type *s* buys from ISP *i* if *s* + $\beta_i x - p_i >$ *s* + $\beta_j x - p_j$ (where $i \neq j$). If *s* + $\beta_i x - p_i$<0 for both retailers, the consumer of type *s* will not buy from any of them.

Thus, the inverse demand functions faced by the firms are:

$$p_1 = a_1 - q_1 - q_2$$
$$p_2 = a_2 - q_1 - q_2$$

Note that the parameters $\beta_1 x$ and $\beta_2 x$ do not affect the slope of the inverse demand functions, so that an increase in x implies parallel shifts in the demand functions. If $\beta_2 \neq \beta_1$, there will be different magnitudes in the demand shifts.

Total production is $Q = q_1 + q_2$ and net consumer surplus is:

$$CS = \frac{a_1 - p_1}{2} q_1 + \frac{a_2 - p_2}{2} q_2$$

In absence of the investment we assume that the services offered by the firms are identical. For the existing network quality (absence of the investment), the ISPs offer access to conventional PC-centric services like www and e-mail. For these services there exist known

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[20] In the Katz and Shapiro-model consumers value service i at $s + v(q_i^e)$, where q_i^e is the consumers' expectations of the size of firm *i*'s network.

and accepted standards, but the situation may change when new technology is implemented.[21] When the access network quality is upgraded, the ISPs may offer new TV-centric interactive broadband services that are very different from conventional PC-centric services. Then, there may be differences in their ability to offer such services due to economies of scope from integration and/or different experience. As long as $\beta_1 = \beta_2$ the end user services from the two ISPs will be identical also when the investment is positive (x>0). Then the investment increases the quality level of the retailers' end-user services by the same level. In contrast, if $\beta_i > \beta_j$, then there will be a quality differential between the two retailers' services, and ISP i will offer a higher quality than ISP j (where $i, j=1,2$).

Supply side

Regarding the vertical integrated firm's cost structure in the upstream segment for local access, we assume that cost per user is a constant marginal cost c. This cost is the same irrespective of whether its own downstream subsidiary or the rival is serving the end-user. We assume that the infrastructure quality, i.e. the investment level, does not have any effect on the marginal cost c. The facility-based firm faces a quadratic network investment cost with respect to investment in higher speed (bandwidth) in the local loop, given by $C_1(x) = \varphi x^2 / 2$. The investment cost x is not related to each user; the investment is for every potential user. For simplicity, the marginal costs of buying all other inputs than local access (regional and global backbone capacity) are assumed to be the same for the two retailers, and normalised to zero.

The profit functions for the firms are given by:

$$\pi_1 = (p_1 - c)q_1 + (w - c)q_2 - \varphi x^2 / 2$$

$$\pi_2 = (p_2 - w)q_2$$

The vertically integrated firm is active in both the upstream and the retail segment, while the non-facility based firm earns profit only in the retail segment. The parameter w is the access price charged by the facility-based firm in the upstream segment.

Throughout we make the following assumption

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[21] See e.g. discussion by Shapiro and Varian (1998).

Assumption 1: $\pi_2 \geq 0, \pi_1 \geq 0, w \geq c, x \geq 0$

The first two constraints state that each firm should have a non-negative profit. The third term says that the vertically integrated firm must have a non-negative price cost margin on its sale to the independent firm in the retail segment. The last term states that the investment must be non-negative.

Welfare

The welfare function:

$$W = CS + \pi_1 + \pi_2$$

A benchmark

Let us consider a market context in absence of the investment in quality improvement (*x*=0). In an unregulated market the facility-based firm chooses the access price in the upstream market at stage 1. In a regulated market the regulator chooses the access price at stage 1. At stage 2 the firms compete à la Cournot. In this context the results can be summarised in the following lemma:

Lemma 1: *If the vertically integrated firm does not invest in quality improvement (x=0), the regulator sets the access price equal to marginal cost. If the access price is unregulated, the vertically integrated firm sets an access price that forecloses the rival from the market. The consumer surplus and total welfare level are higher under the access regulation regime compared to the unregulated regime.*

2.1 Retail market competition

We solve the model by backward induction and assume Cournot competition between the two firms (the ISPs) in the retail market for broadband Internet connectivity.

Equilibrium quantities in the competitive segment are:

$$q_1^* = [(a-c) + (w-c) + x(2\beta_1 - \beta_2)]/3$$

$$q_2^* = [(a-c) - 2(w-c) + x(2\beta_2 - \beta_1)]/3$$

Until otherwise stated, we make the following assumption:

Assumption 2: $2\beta_i - \beta_j \geq 0 \, where \, i, j = 1,2, i \neq j$

Assumption 2 ensures that the difference in ability to offer value-added services between the retail firms is not too high. When $2\beta_1 - \beta_2 \geq 0$, the rival's quantity is non-decreasing by the investment in x for given access price w. Hence, the vertically integrated firm cannot use the investment as an alternative foreclosure under access price regulation. In section 2.5 we modify this assumption and assume $2\beta_2 - \beta_1 < 0$. Then the vertically integrated firm may use overinvestment as an alternative foreclosure tool under access price regulation.

2.2 Unregulated access price

The vertically integrated firm sets the access price at stage 1, and stage 2 is as above.

2.2.1 Stage 1:

The objective function for the facility-based firm at stage 1 is:

$$\pi_1 = q_1^2 + (w-c)q_2 - \varphi x^2 / 2$$

The first order condition with respect to w gives the equilibrium access price at stage 1:

$$w^* = (a+c)/2 + x(4\beta_2 + \beta_1)/10$$

If we insert for w^* into the equilibrium quantities, we have the following:

$$q_1^* = [5(a-c) + x(7\beta_1 - 2\beta_2)]/10$$

$$q_2^* = 2x(\beta_2 - \beta_1)]/5$$

$$Q^* = [5(a-c) + x(3\beta_1 + 2\beta_2)]/10$$

Proposition 1: *Let us assume no regulation of the access price. The condition* $\beta_2 > \beta_1$ *is necessary and sufficient to ensure that the downstream rival is active in the market.*

From *Lemma 1* we know that in absence of the investment (x=0) the independent firm is foreclosed from the market. In contrast, we see that under investment in quality improvement (x>0) the independent retail firm will be active in the market if it has higher ability to use the improved input quality such that $\beta_2 > \beta_1$.

2.2.2 Stage 0:

Foreclosure:

From *Proposition 1* it follows that as long as $\beta_1 \geq \beta_2$, the vertically integrated firm will use the access price in the next stage to practice foreclosure towards the rival (firm 2). Hence, in the case where it is optimal to practice foreclosure it chooses the investment level as a downstream monopoly. Downstream monopoly quantity is $q_m^* = 0.5[a - c + \beta_1 x]$, and the objective function for the facility-based firm when it sets x as a downstream monopolist is $\pi_1^m = (q_m)^2 - 0.5\varphi x^2$. Superscript m indicates downstream monopoly.

The first order condition with respect to x gives the following investment level:

$$\frac{\partial \pi_1}{\partial x} = 0 \Rightarrow x_m^* = (a-c)\beta_1 / A_m^* \quad where\ A_m^* = 2\varphi - \beta_1^2$$

The second order condition is fulfilled as long as A_m^*>0.[22] Inserting for x_m^* gives the following equilibrium quantity:

$$q_m^* = \frac{(a-c)\varphi}{2\varphi - \beta_1^2}$$

Market sharing:

From *Proposition 1* we know that both retail firms are active as long as $\beta_2 > \beta_1$. The objective function for the facility-based firm when it sets x is:

$$\max_x \pi_1 = (q_1)^2 + (w-c)q_2 - 0.5\varphi x^2$$

We insert for w^*, q_1^* and q_2^*. Then the first order condition with respect to x gives the following investment level:

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[22] At the investment stage (stage 0) the second order condition ensures that the cost parameter φ is sufficiently high, such that the investing firm will not make an infinite investment in quality improvement.

$$\frac{\partial \pi_1}{\partial x} = 0 \Rightarrow x^* = 5\beta_1(a-c)/A^* \quad where \ A^* = \left[10\varphi - 9\beta_1^2 + 8\beta_1\beta_2 - 4\beta_2^2\right]$$

The second order condition is fulfilled as long as $A^* > 0$. Comparing the investment level under foreclosure (i.e. $\beta_1 \geq \beta_2$) with the market sharing equilibrium ($\beta_2 > \beta_1$), we find the following (see appendix):

Lemma 2: *Let us assume no regulation of the access price. For a given level of* β_1 *the investment will be higher under market sharing (i.e.* $\beta_2 > \beta_1$*) than under foreclosure, (i.e.* $\beta_1 \geq \beta_2$*) as long as the second order conditions are fulfilled. Moreover, the investment and the rival's quantity increase with the rival's ability to use the quality improvement when* $\beta_2 > \beta_1$ *, i.e. that* $dx^* / d\beta_2 > 0$ *and* $dq_2^* / d\beta_2 > 0$.

Without access price regulation, the vertically integrated firm may imitate the strategy in the foreclosure case in the market sharing case as well. Hence, when the vertically integrated firm chooses to serve the rival, this means that the profit by doing so is higher than the monopoly outcome. When the rival is more efficient in using the improved quality of local access, $\beta_2 > \beta_1$, the consumers have higher willingness to pay for the service from ISP 2 than that from ISP 1. Hence, it will be optimal to let the rival be active in the market in order to capture some of the rent from ISP 2. The access price will, however, be set such that the quantity offered by ISP 2 will be low in order to dampen the competition. Inserting for x^* gives the following total quantity:

$$Q^* = \frac{a-c}{A^*}\left[5\varphi - 3\beta_1^2 + 5\beta_1\beta_2 - 2\beta_2^2\right]$$

The reason why the vertically integrated firm does not outsource the retail market to the more efficient rival is the assumption of a linear access price. In contrast, if the vertically integrated firm can use a two-part tariff for access, it will set a unit access price equal to the marginal cost c, and then capture the monopoly profit of the more efficient rival (ISP 2) through the fixed fee. In other words, if the network owner offers the two-part tariff $T(q_2) = \pi_2^m + cq_2$, the retail rival (ISP 2) makes no profit, and the upstream monopolist will achieve the same outcome as if ISP 2 were its own subsidiary (see e.g. Rey and Tirole, 1997). In the present paper we use the linear price assumption since this seems to be the business model the majority of the telecommunications incumbents use in their wholesale service for broadband (see discussion by Petkovic and De Coster, 2000). So why is that the network owners do not outsource their retail activity through non-linear pricing? First, it may be due to economies of scope such that $\beta_1 > \beta_2$. Second, outsourcing the retail market activity may imply that the network owner does not retain the bargaining power needed to offer such a take-it-or-leave-it offer to the retail monopolist (ISP2). Third, if the wholesale segment is regulated, while the retail segment is not (see also footnote 24 below), the network owner may not want to outsource the unregulated activity.

2.3 Access price regulation

The government may regulate w to maximise welfare. In principle, the regulator can act as a first-mover and set w before the facility-based firm sets x. Such a commitment to *ex ante* regulation may, however, not be credible. We assume that the regulator has no ability to regulate the access price *ex ante* of the investment, and, hence, the only difference in the game from the complete unregulated regime is that the regulator decides the access price at stage 1 instead of the vertically integrated firm.

2.3.1 Stage 1:

The welfare function may be written as

$$W = \frac{(q_1 + q_2)^2}{2} + q_2^2 + q_1^2 + (w - c)q_2 - \frac{\varphi x^2}{2}$$

The first term is the consumer surplus. The second term is the profit by the independent firm. The last three terms are the vertically integrated firm's profit.

The regulator sets the access price w after the investment in x has taken place. The first order condition with respect to w gives the regulated access price margin:[23]

$$w - c = -(a - c) + x(4\beta_1 - 5\beta_2)$$

When (w – c) <0, it is a violation of the constraint that $w \geq c$. Then we have the following result (given the assumption that $w \geq c$):

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[23] The second order condition is fulfilled.

Proposition 2: *Let us assume regulation of the access price. A necessary and sufficient condition to ensure that it is optimal for the regulator to set access price equal to marginal cost, ($w^r = c$), is* $-(a-c) + x(4\beta_1 - 5\beta_2) < 0$.

In this section we assume that the necessary and sufficient condition in *Proposition 2* is fulfilled, such that optimal regulated access price will be set to marginal cost ($w^r = c$) at stage 1. Superscript *r* indicates regulated access price.[24]

Inserting for $w=c$ into the equilibrium quantities from stage 2 gives:

$$q_1^r = [(a-c) + x(2\beta_1 - \beta_2)]/3$$

$$q_2^r = [(a-c) + x(2\beta_2 - \beta_1)]/3$$

$$Q^r = [2(a-c) + x(\beta_1 + \beta_2)]/3$$

2.3.2 Stage 0:

Now the facility-based firm has no revenue from the upstream market, and the objective function for the facility-based firm is:

$$\max_x \pi_1 = [(a-c) + x(2\beta_1 - \beta_2)]/3]^2 - 0.5\varphi x^2$$

The first order condition with respect to *x* gives the following investment level:

$$\frac{\partial \pi_1}{\partial x} = 0 \Rightarrow x^r = 2(a-c)(2\beta_1 - \beta_2)/A^r \quad where\ A^r = 9\varphi - 2(2\beta_1 - \beta_2)^2$$

Inserting for x^r into Q^r gives:

$$Q^r = \frac{(a-c)}{A^r}(6\varphi + 2(2\beta_1 - \beta_2)(\beta_2 - \beta_1))$$

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[24] Note that if the regulator were allowed to set the access price below the marginal cost (w<c), it would have done that in order to correct for the imperfect competition in the retail market. If the regulator may use a two-part tariff, it could set $w<c$, and still ensure through the fixed fee that the upstream unit of the integrated firm has non-negative profit. In this case, the regulator could use a unit-price w below marginal cost c in order to correct for the imperfect competition in the retail market.

From *Lemma 2* we know that under market sharing in the unregulated case the investment level increases when β_2 increases. In contrast to the unregulated case, we now see that the investment level decreases in the rival's ability to offer value-added services as the input quality is improved, since $dx^r / d\beta_2 < 0$ (see proof of *Proposition 3* in appendix). Since the facility-based firm has no revenue from its upstream sale, it sees the advantage of the non-facility-based firm from the investment as a pure spillover. The higher the non-facility based firm's ability to use the investment, the higher the spillover from the investment to the rival. Not surprisingly, the higher the spillover, the lower the incentives to make an investment.

Moreover, from *Lemma 2* we know that without regulation the rival's quantity increases with β_2 under market sharing. Under access price regulation we find that:

$$dq_2 / d\beta_2 = \left(2x^r + (dx^r / d\beta_2)(2\beta_2 - \beta_1)\right)/3$$

The first term is positive and indicates that for a given investment level, the rival's quantity increases when β_2 increases. The second term indicates that an increase in β_2 will have an effect on the investment level and that this in turn will affect the quantity offered by the rival. We know that $dx^r / d\beta_2 < 0$ and in this section we assume that $(2\beta_2 - \beta_1) > 0$. Hence, the second term is negative. This is due to the fact that for the vertically integrated firm the parameter β_2 is now seen as a pure spillover, which reduces the investment incentives. And therefore, when the spillover increases, the incentives to invest will be reduced. The total effect on the rival's quantity is then ambiguous.

Related to the quantity offered by the vertically integrated firm's retailer, we have that the higher the spillover, the lower the retail quantity sold from the facility-based firm (such that $dq_1^r / d\beta_2 < 0$). There are two effects leading to this result. First, the higher the spillover is, the lower is the investment. When the investment is reduced, the facility-based firm lowers its retail quantity. Second, since the quantities offered by the two rivals are strategic substitutes, the facility-based firm reacts to an increase in the quantity from the rival by reducing its own quantity (Bulow, Geanakoplos, and Klemperer, 1985). The second effect may be positive or negative (see above), but the total effect on the vertically integrated firm's quantity from an increase in β_2 is negative.

2.4 Comparison of results with and without access price regulation

The motivation behind an access price regulation is to prevent foreclosure and increase competition such that welfare increases. Industry profit will be higher without regulation than with regulation. Hence, a necessary, but not sufficient, condition to intervene with an access price regulation is that the consumer surplus increases compared to the case without regulation. In order to compare the levels of consumer surplus with and without regulation we must make a distinction between the case of foreclosure and the case of market sharing in the unregulated market.

Foreclosure without regulation:

For simplicity we now make the following assumption:

$$\beta_2 \leq \beta_1 \equiv 1$$

In the access price regulation equilibrium, the vertically integrated firm has no profit from the input segment. From assumption 2 we have that $\beta_2 \geq 0.5$. Moreover, we assume that the cost parameter φ is so high that the second order conditions are fulfilled, i.e. $\varphi > \underline{\varphi}^{crit} = 0.5$ in this case.

We have the following results for investment and consumer surplus with and without regulation (see appendix):

Proposition 3: *In the case where $\beta_2 \leq \beta_1 \equiv 1$ we have the following results regarding investment and consumer surplus:*

i. the investment level is lower with than without access price regulation, i.e. that $x^r - x_m^* < 0$.

ii. the consumer surplus is lower with than without regulation as long as the investment cost is not too convex (such that $q_1^r + q_2^r < q_m^*$).

Hence, the parameter φ must be above a critical value to ensure that regulation improves consumer surplus. Similarly, since industry profit is lower with than without regulation, we find that the total welfare is lower with than without regulation when the investment cost is not too convex. The critical value of φ that ensures that access price regulation improves welfare is higher than the critical value of φ that ensures that regulation increases consumer surplus.

In this case the vertically integrated firm has higher ability to transform input into output than the rival. Then, if it is allowed to do so, it will prevent the rival from entering the market through the access price. In order to ensure entry the regulator may then impose an access price regulation that prevents the vertically integrated firm from practising foreclosure. The regulator faces a classic trade-off between triggering competition and dampening investment incentives. Moreover, this trade-off implies that it may be better if the rival has significantly lower ability to offer value-added services than the vertically integrated firm since this will reduce the spillover from the investment. Put differently, the closer β_2 is to β_1, the higher φ has to be to ensure that the consumer surplus is higher with than without regulation. Thus we have:

Corollary 1: *In the case where* $0.5 < \beta_2 \le \beta_1 \equiv 1$, *a lower* β_2 *makes it more likely that consumer surplus is higher with than without access price regulation.*

This gives rise to a paradox. It is more likely that it is optimal for the regulator to ensure entry by access price regulation if firm 2 has low ability to offer value-added services compared to the vertically integrated firm. Usually, we see that the potential entrants are arguing in the opposite direction. They argue that the regulator should encourage entry since they have at least the same ability to offer value-added services as the incumbent. Put differently, in the present model it may be better for the regulator to allow for an inefficient entrant than having an efficient retail monopoly.

Market sharing without regulation:

Both firms are active in the market also in the market equilibrium, and we make the following assumption:

$$\beta_1 < \beta_2 \equiv 1$$

We compare the results with and without regulation when the rival has the highest ability to transform the input to output, and we still assume that $\varphi > \underline{\varphi}^{crit} = 0.5$. Then we have the following results (see appendix):

Proposition 4: *In the case where* $\beta_1 < \beta_2 \equiv 1$ *we have the following results regarding investment and consumer surplus:*

- *i.* *the investment level is lower with than without access price regulation, i.e. that* $x^r - x^* < 0$.
- *ii.* *the consumer surplus is lower with than without regulation as long as the investment cost is not too convex (such that* $q_1^r + q_2^r < q_1^* + q_2^*$*)*.

As in the previous case total welfare is also lower with than without regulation when the investment cost is not too convex.

For $\beta_1$close to 0.5 the welfare loss from dampened competition in the case without access price regulation will be high. The loss from dampened competition, for a given investment level, in the unregulated regime may be separated into two effects. First, there will be a loss due to the fact that total quantity is reduced when the rival pays an access price higher than the marginal cost. This loss is higher the lower β_1 is compared to β_2 (which is equal to one). Second, there will be a loss due to the fact that the less effective firm 1 will serve most of the market. For a given investment level, these two competition effects will imply that the consumer surplus and total welfare may be enhanced by access price regulation. However, access price regulation will reduce the investment incentives of the vertically integrated firm. For β_1 =*0.5* the investment is zero. However, for $\beta_1$close to 0.5 the pro-competitive effects of regulation dominate the negative investment incentives effect even if the cost parameter φ is low. As in the previous case (Corollary 1) it is more likely that the consumer surplus is higher under access price regulation compared to the case without regulation if the difference between the firms' ability to offer value-added services is large.

2.5 Access price regulation and non-price foreclosure

In this section we analyse whether the vertically integrated firm may have incentives to overinvest as an alternative foreclosure tool when assumption 2 is altered. Until now we have assumed that the rival firm's quantity increases when the investment increases for a given access price (assumption 2). In contrast, we now assume that $2\beta_2 - \beta_1 < 0$, such that the rival will reduce its quantity when the investment increases for a given access price (since $dq_2^* / dx < 0$ in stage 2). For simplicity, we make the following assumption:

Assumption 3: $\beta_1 \equiv 1 > 2\beta_2 > 0$

At stage 0 the vertically integrated firm sets *x*, and at stage 1 the vertically integrated firm or the regulator sets the access price. We know that for low values of β_2, it may be optimal for the regulator to set the access price above marginal cost (see above). For the sake of simplicity, we assume that the optimal regulated access price at stage 1 is $\overline{w} \geq c$. At stage 2 the firms compete à la Cournot when both firms are active in the market. The strategic investment game has the timing structure analysed by Dixit (1980).

The stage 2 quantities given that $\overline{w} \geq c$ are $q_1^* = (a - 2c + \overline{w} + x(2 - \beta_2))/3$ and $q_2^* = (a + c - 2\overline{w} + x(2\beta_2 - 1))/3$. We analyse whether the vertically integrated firm (the first-mover) chooses to invest to foreclose the rival (deterrence of entry) or to share the market with the rival (accommodation of entry).

Blockaded entry

The monopoly investment given assumption 3 is $x_m^* = (a - c)/(2\varphi - 1)$. If we insert x_m^* into q_2^* we find that entry is blockaded with the monopoly investment when $\underline{\beta}^c \equiv \beta_2 \leq (a - c)(1 - \varphi) + (\overline{w} - c)(2\varphi - 1)/(a - c)$. The question is whether the vertically integrated firm will overinvest in x when $\underline{\beta}^c < \beta_2 \leq 0.5$.

Entry deterrence through non-price foreclosure:

The effect of the investment *x* on the rival's profit is

$$\frac{d\pi_2}{dx} = \beta_2 q_2 + (-q_2)((2 - \beta_2)/3) = 2q_2(2\beta_2 - 1)/3$$

The first term is the direct effect of *x* on the rival's profit, and it is positive. The second term is the strategic effect, which will be negative. An increase in *x* increases the second stage choice of q_1. Since the quantities offered by the two firms are strategic substitutes, an increase in q_1 will lower the profit margin for ISP 2.

When assumption 3 is met ($2\beta_2 - 1$ <0), the strategic effect dominates the direct effect. To foreclose the rival the vertically integrated firm should overinvest such that $q_2^f = 0$ (superscript *f* indicates foreclosure by overinvestment):

$$q_2^f = 0 \Rightarrow x^f = \frac{-a + 2\overline{w} - c}{2\beta_2 - 1}$$

For $x=0$ we assume that both firms are active in the market, such that $a - 2\overline{w} + c > 0$. Then it follows that for $\beta_2 < 0.5$:

$$\frac{dx^f}{d\overline{w}} = \frac{2}{2\beta_2 - 1} < 0$$

and

$$\frac{dx^f}{d\beta_2} = \frac{-2(-a + 2\overline{w} - c)}{(2\beta_2 - 1)^2} > 0$$

For a lower local access price, the vertically integrated firm's response is to increase the investment if it wants to deter entry. The higher β_2 (but lower than 0.5), the higher the investment must be to enhance a given reduction in the rival's quantity.

When the rival is foreclosed, the vertically integrated firm sets the monopoly quantity in stage 2. Inserting for x^f we find that $q_1^f = [(a-c)(\beta_2 - 1) + (\overline{w} - c)] / (2\beta_2 - 1)$. For $\beta_2 < 0.5$ we see that:

$$\frac{dq_1^f}{d\overline{w}} = \frac{1}{2\beta_2 - 1} < 0$$

Hence, a restrictive access price regulation may be effective even if no inputs are sold to the rival. When the access price increases, the vertically integrated firm must overinvest less compared to the monopoly investment level. If we insert for investment level and quantity offered by the vertically integrated firm, we find the profit and the welfare functions under foreclosure:

$$\pi_1^f = (q_1^f)^2 - 0.5\varphi(x^f)^2$$

$$W^f = \pi_1^f + 0.5(q_1^f)^2$$

Now it can be shown that:

$$\frac{dW^f}{d\overline{w}} = \frac{(a-c)(3\beta_2 - 3 + 2\varphi) + (\overline{w} - c)(3 - 4\varphi)}{(2\beta_2 - 1)^2}$$

When this is negative, we see that an access price regulation may be effective even if the rival is still foreclosed from the market. The reason is that an access price regulation forces the vertically integrated firm to increase the investment if it wants to foreclose the rival. The investment is an investment in quality, and we know that a monopolist may have too high or too low incentives to offer quality seen from the social planner's point of view (Spence, 1975).

We now check that in this particular setting the monopolist offers too low quality (investment) seen from the regulator's point of view. Given entry deterrence, we have non-price foreclosure such that $q_2^f = q_2^* = 0$. The vertically integrated firm chooses the monopoly quantity in stage 2, i.e. $q_1^m = (a - c + x)/2$. As long as $q_2 = 0$, the welfare level will be given by $W = (3q_1^2 - \varphi x^2)/2$. Thus we have $dW/dx = (3q_1(dq_1/dx) - \varphi x)$. We know that without access price regulation $x_m^* = (a-c)/(2\varphi - 1)$. Inserting for x_m^* we find that $dW/dx_{x=x_m^*} = (a-c)\varphi/(2(2\varphi-1)) > 0$.

Even if $q_2^f = q_2^* = 0$, the welfare will increase if the regulator through a binding access price regulation gives the vertically integrated firm an incentive to increase the investment compared to x_m^*.

Proposition 5: *Let us assume that $\beta_1 \equiv 1 > 2\beta_2 > 0$ and that there is a binding access price regulation. Then we have the following results:*

- i. *The vertically integrated firm overinvests compared to the monopoly equilibrium without access price regulation, i.e. $x^f - x_m^* > 0$.*
- ii. *When the unconstrained monopoly underinvests seen from the regulator's point of view, access price regulation increases welfare since it forces the vertically integrated firm to invest more.*
- iii. *If the rival has a low ability to offer value-added services compared to the vertically integrated firm, the rival will be foreclosed from the market both with and without access price regulation, i.e. $q_2^f = q_2^* = 0$.*

If the vertically integrated firm chooses not to foreclose the rival (accommodation of entry) it will set x to maximise its own profit. We interpret $\overline{\beta}^c$ as the critical value for whether foreclosure is optimal or not. Hence we have three intervals analogous to Dixit (1980):

i. Blockaded entry when $\beta_2 \leq \underline{\beta}^c$: The rival is blocked from entry by the monopoly investment level x_m^*.

ii. Deterrence of entry when $\underline{\beta}^c < \beta_2 < \overline{\beta}^c < 0.5$: The vertically integrated firm overinvests to foreclose the rival.

iii. Accommodation of entry when $0.5 > \beta_2 \geq \overline{\beta}^c$: Then it is more profitable for the vertically integrated firm to set x that maximises it's own profit, even if the rival is active in the market.

We see that the outcome may be foreclosure even if the access price is regulated. This is in contrast to the previous sections where both firms were active in the market under access price regulation. Note that the main difference from the previous case is that $\beta_1 > 2\beta_2$. The literature on non-price foreclosure typically focuses on the detrimental impact on welfare when an access price regulation gives incentives to extend the untapped market power by non-price methods. In contrast, in our context, it may increase welfare.

3 Some concluding remarks

In this paper we have analysed a market structure where a vertically integrated firm controls an essential input for retail providers of Internet connectivity. The vertically integrated firm may undertake an investment that increases the quality of the input (upgrading to broadband). In an unregulated retail market the vertically integrated firm competes with an independent firm that buys access as an input. We analyse the effect of an access price regulation that is imposed on the vertically integrated firm. Since an upgrade of the local access network to broadband is an irreversible investment, we assume that the regulator has limited commitment ability with respect to the access price. Hence, the access price is set after the investment, but before retail competition.

We compare the access price regulation regime with the outcome without regulation. The total effect on consumer surplus and welfare critically depends on whether the vertically integrated firm has higher ability to offer value-added services (broadband services) than the rival firm. If the retailers do not differ too much with respect to their ability to offer value-added services, when the input is improved, we show that access price regulation reduces the vertically integrated firm's investment incentives. Furthermore, an access price regulation lowers consumer surplus and total welfare as long as the cost of investment is not too convex. In contrast, if the vertically integrated firm's ability to offer value-added services is much higher than that of the independent rival, an increase in the investment level will reduce the quantity offered by the independent retailer. The vertically integrated firm may then use overinvestment as an alternative tool to drive the rival out of the market.

In our model the regulated access price will be set equal to or close to the marginal cost. Hence, compared to the case without access price regulation the regulator removes most of the vertically integrated firm's cost advantage in the retail market. If the retailers' ability to offer value-added services is quite similar, then the independent firm will have higher profit than the facility-based firm since the latter has to cover the investment costs. Put differently, the access price regulation may imply a second-mover advantage. In the present paper we have not focused on entry, but this feature of the regulation will probably discourage facility-based entry. In particular this will be true if we incorporate uncertainty in the analysis. The non-facility-based firm may enter the market later, and, furthermore, does not need to make the irreversible investment.

The timing structure seems to correspond to the current regulatory paradigm both in the EU and the USA. This paradigm mandates that the access price should be set to the long-run incremental costs (LRIC). At first glance, this may include the investments in e.g. broadband upgrades, while we show that the regulator will set the access price equal to the marginal cost as long as the retailers do not differ too much in their ability to offer value-added services. The main feature is, however, that the determination of the long-run incremental costs is highly discretionary and that the decision is taken after the investment is made. Hence, its impact on incentives to invest before the discretionary decision on the access price will be analogous to the case analysed in the present paper. Hausman (1997) argues that FCC's measure of LRIC ignores the existence of technological progress that is reducing the prices and increasing the quality of the components in a broadband access network. Hence, LRIC implies an access price corresponding to the most efficient components available at the time the access price is set, and this will not cover the investment costs under a rapidly changing technology. Uncertainty is not formerly analysed in the present model, but there is obviously a significant probability of failure when a firm invests in a broadband access network, and this will make the problem of investment incentives even more important. The current LRIC approach does not cover the costs of unsuccessful services.[25] Cave and Prosperetti (2001) focus on the situation in the EU, and they argue that the incumbents do not have sufficient incentives to upgrade to broadband access, since they anticipate that they will be forced to offer access at cost-based prices.

If there was no ability to improve the network quality through the investment, a regulated access price close to or equal to marginal costs will improve welfare compared to the case without an access price regulation. This indicates that the current regulation regime in EU and the USA may be better than no regulation if static efficiency was the only goal for the regulator. In contrast, when there is an investment decision before the access price regulation is decided, the benchmark without access price regulation may imply higher welfare, but the conclusion is ambiguous. Obviously, the regulator may alter the outcome by non-linear wholesale prices, price regulation in the retail market, and line-of business restrictions, but the basic challenge seems to be the choice of rules versus discretion in the governments' policy. When the policymaker has the opportunity to set the access price discretionary after the investment, it will set the access price close to marginal cost (or LRIC). When the decision is taken after the investment, this is the best thing to do for the regulator, given the current situation. It is not a result of non-optimal behaviour from the regulator. If the regulator wishes to realise the outcome in the case without access price regulation, it has to credibly commit to a policy rule before the investment that prevents the regulator from using the discretionary access price regulation.[26]

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[25] See Hausman (1997) for further discussion on these issues.

[26] The classic paper on time inconsistency and rules versus discretion is Kydland and Prescott (1977).

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Appendix

Proof of Lemma 2:

A necessary and sufficient condition for market sharing is now that $\beta_2 > \beta_1$.

$x^* - x_m^* = [4(a-c)\beta_1(\beta_2 - \beta_1)^2]/(A^* A_m^*) > 0$

$dx^* / d\beta_2 = 40(a-c)\beta_1(\beta_2 - \beta_1)/(A^*)^2 > 0 \; if \; \beta_2 > \beta_1$

$dq_2^* / d\beta_2 > 0 \; if \; \beta_2 > \beta_1$.QED.

Proof of Proposition 3:
The higher ability the non-facility-based firm has to use the investment, the lower is the investment level with access price regulation:

$$\frac{dx^r}{d\beta_2} = -\frac{2(a-c)}{(A^r)^2}\left[A^r + 4(2\beta_1 - \beta_2)^2\right] < 0$$

The higher ability the non-facility-based firm has to use the investment, the lower is the consumer surplus with access price regulation:

$dQ^r / d\beta_2 = -2(a-c)\left[3\varphi(2\beta_2 - 1) + 8(1-\beta_2) + 2\beta_2^2\right]/(A^r)^2 < 0$ for $\beta_2 \in [0.5,1]$

i. We have $dx^r / d\beta_2 < 0$. Hence, it is sufficient to ensure $x^r - x_m^* < 0$ for $\beta_2 = 0.5$. For $\beta_2 = 0.5$ we have that $x^r - x_m^* = -(a-c)/3A_m^* < 0$.
ii. We have that $dQ^r / d\beta_2 < 0$ for $\beta_2 \in [0.5,1]$. Hence, let us insert for $\beta_2 = 0.5$. Then we have $Q^r - q_m^* = (a-c)\left[3\varphi^2 - 4.5\varphi + 1.5\right]/ A^r A_m^*$ which is negative for $\underline{\varphi}^{crit} < \varphi < 1$ and positive for $\varphi > 1$.QED

Proof of Proposition 4:

i. $x^r - x^* = (a-c)[2(2\beta_1 - 1)A^* - 5\beta_1 A^r]/ A^r A^*$. Hence to check $x^r - x^* \geq 0$ we see whether $[2(2\beta_1 - 1)A^* - 5\beta_1 A^r] \geq 0$. This requires that $\varphi \leq 2(2\beta_1^2 - 3\beta_1 + 1)/5$ which will never be fulfilled for $\beta_1 \in [0.5,1]$ *and* $\varphi > \underline{\varphi}^{crit} = 0.5$.
ii. $Q^r - Q^* = (a-c)\left[A^*(6\varphi + 2(2\beta_1 - 1)(1-\beta_1)) - A^r(5\varphi - 3\beta_1^2 + 5\beta_1 - 2)\right]/ A^r A^*$. Let us check whether$\left[A^*(6\varphi + 2(2\beta_1 - 1)(1-\beta_1)) - A^r(5\varphi - 3\beta_1^2 + 5\beta_1 - 2)\right] \geq 0$. When solving the inequality with respect to φ we find that: $\varphi \geq \frac{1}{3}(\beta_1(3\beta_1 - 1) + 2)$.

Moreover we see that the restriction on φ to ensure $Q^r - Q^* \geq 0$ is stronger for higher β_1 since $\frac{\partial \varphi}{\partial \beta_1} > 0$ for $\beta_1 \in [0.5,1]$ QED.

Chapter 2

Access Pricing, Quality Degradation, and Foreclosure in the Internet*

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Abstract: Access to both a local and a global network is needed in order to get complete connection to the Internet. The purpose of this article is to examine the interplay between those two networks and how it affects the domestic public policy towards a domestic provider of local access. We find that a cost-oriented regulation is detrimental to domestic welfare, because it shifts profit to the foreign provider of global access. The optimal policy is that the regulator commits itself to set an access price above costs, possibly the same price as in an unregulated market economy. A regulation of the global access price has a non-monotonic effect on domestic welfare, and there is a potential conflict between international and domestic regulation policy.

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1 INTRODUCTION

During the last decade the Internet has become an important industry, for example measured in the number of people using services such as email and web-browsing. Although we can learn a lot about this new industry by applying standard results from economics, there are some idiosyncratic characteristics of the Internet industry that call for a closer examination. For example, Internet connectivity may be seen as a composite good that is produced by the complementary inputs local access and global access. The local access network is typically dominated by a domestic telecommunication company, and the global access network - called the Internet backbone - is dominated by a limited number of US companies. While the providers of local access have historically been regulated both on price and quality in their home country, the providers of global access have so far not been regulated.

The purpose of this paper is to examine the interplay between the firms in the global and the local network concerning price and quality setting, and analyze possible implications of this interplay for the public regulation policy. We show that a strict regulation of the access prices may be detrimental to welfare, and in particular we demonstrate that in our model the price of local access should be set above cost if foreign firms have market power.

Since the Internet is rather new, there are relatively few studies in the literature of this particular industry. Inspired by Mackie-Mason and Varian (1994, 1995a, 1995b), there exist some analyses of the congestion problem in the Internet and price setting to end users without market power. Neither access pricing nor the quality of interconnection between networks are important topics in those studies. More in line with our focus, though, are Cremer *et al.* (2000), Milgrom *et al.* (2000), Economides (1998a, 1998b) and Sibley and Weisman (1998). The two former study the Internet backbone market, while Economides and Sibley and Weisman focus on an upstream monopolist's incentives to foreclose rival downstream firms through quality degradation. An important distinction between our study and theirs is that we are concerned about the interplay between the local and global access network.

In our model a dominant firm provides access to the global network, while the incumbent telecommunication firm provides local access in a particular country. The end-users are served by two Internet service providers, and one of them is owned by the domestic telecommunication firm in charge of the local access network. In the first version of our model we assume that the second end-user provider is an independent firm. We show that in this case the integrated local telecommunication firm would find it profitable to set a high local access price to the independent end-user provider and thereby to monopolize the end-user market (foreclosure). If the global access provider's price setting is exogenously determined, we find that a regulator maximizing domestic welfare should set the local access price equal to long run marginal costs. In such a way it triggers competition in the end-user market. This reproduces the well-known cost-oriented price regulation paradigm, and serves as a benchmark for our analysis.[1]

Results change dramatically if the global access price is endogenous. A restrictive regulation policy, as described above, is now detrimental to domestic welfare. The same is true if the regulator cannot credibly commit itself to a certain access price, and ends up by setting price equal to marginal costs. Such a low local access price would imply that the provider of global access could gain a larger share of the market's profit potential by setting a high access price. Hence, a reduction of the local access price is partly replaced by an increase in the global access price and thereby a profit shift out of the country. If the regulator could commit itself to a public policy, often denoted ex ante regulation, the best it could do would possibly be to not intervene. By doing so, it prevents any profit shift out of the country.

Next, we consider the case where the provider of global access has acquired the independent end-user provider. Now the end-user providers are in a symmetric position, since each of them controls an essential input both of them need. Not surprisingly, we find that foreclosure will not take place in equilibrium. More surprisingly, we find that if the regulator could behave credibly it would set an access price below the one it would prefer if the provider of global access had not acquired the end-user. Hence, an end-user provider owned by the foreign global access provider

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[1] Our main results will not be altered if we allow for a regulated price on local access below marginal costs (see section 3). See also Laffont and Tirole (2000) for a discussion.

should be given more favorable terms than an independent and locally owned end-user provider. The reason is that the global access provider's response to a lower local access price is now distinctly different, because its main response to a lower access price is to act more aggressively in the end-user market. Thereby consumer surplus increases.

We extend the model further by assuming that the provider of global access has the ability to degrade the quality of the input sold to the locally-owned end-user provider. If there is no regulation of access prices, we find that the global access provider decides not to practice quality degradation. The reason is that any quality degradation would harm the global access provider's potential for profit extraction from the end-user provider who is integrated with the provider of local access.

However, there might be a price cap on the global access price, for example due to WTO-agreements that reduce the scope for firms to abuse their international market power. If such a price cap is sufficiently restrictive, the global access provider's profits from serving the locally owned end-user provider are limited. Then the global access provider may have incentives to foreclose it by practicing quality degradation. The domestic regulator, though, would rather have both end-user providers active in the market to ensure rivalry in the output market. The regulator's best choice may then be to set a higher local access price than the provider of local access itself would have done. By doing so it encourages the global access provider not to practice foreclosure. However, for a sufficiently low global access price it is not possible for the regulator to prevent the global access provider from practicing foreclosure.

Finally, note that there is a potential conflict between international and domestic public policy. First, a restrictive price cap on global access would, as noted above, result in foreclosure even if the local access price is regulated. This is detrimental to domestic welfare, and the country would have been better off without any regulation of the global access price. Second, a price cap on the global access price may result in a less restrictive price cap on the local access price, and may even in some cases result in a higher end-user price. Such a response from the domestic regulator would shift profits from the providers of global access to the providers of local access.

2 THE INTERNET

For our purpose, Internet connectivity sold to end-users in Europe can be seen as a composite good that consists of one domestic input (local access into homes) and one global input (access to the Internet backbone in the US). These inputs are supplied by Local Access Providers (LAPs) and Internet Backbone Providers (IBPs), respectively. Internet connectivity is sold to the end-users from a regional Internet Service Provider (ISP), who needs to buy local access to consumers from the LAP and global Internet access from an IBP.[2]

The market structure is dominated by a few firms in both the local and the global access network. Regarding local access, the "last mile into homes", the local telephone lines and the cable-tv lines are the alternatives for private users (Clark, 1999). Obviously, local access has to be offered locally. Due to their dominant position, the LAPs are typically subject to regulation of price and quality for local access as an input component. In the EU, for instance, the evolution of the regulatory regime has led to commitment to a restrictive practice, often denoted ex ante regulation, towards the LAPs.

In contrast, there has so far been no regulation of the global access input supplied by the IBPs. A few US firms provide connection to the global backbone to regional ISPs all over the world.[3] It should be noted that global access is much more essential for Internet connectivity than for conventional telephone services. While only a relatively small portion of world wide telephone calls go to or from the US, the majority of the Internet traffic has to go through the US. For the location of Internet facilities we thus have a clear asymmetry between the US and the rest of the world.

Even if no IBP separately is in position to use market power, a group of co-

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[2] Between the bottleneck components local access and core backbone access there is a chain of intermediates. We do not consider these intermedites segments, since their potential for using market power seems to be limited.

[3] Access to the top-level of global infrastructure is controlled by US firms such as MCI WorldCom, Sprint, Genuity (formerly GTE), and AT&T. The only non-American firm operating a top-level backbone is Cable &Wireless, who bought MCI's backbone operation before the MCI-WorldCom merger. See Cremer *et al.* (2000) and Kende (2000) for an overview.

operating IBPs may be in position to do so (Cremer et al, 2000, Milgrom et al, 2000). In addition to giving access to information located on servers in the US, the input from the IBPs also secures access to the core routing structure and access to all Internet addresses in the world (Milgrom et al, 2000). A limited number of core IBPs co-operate in creation of a consistent routing structure. The full routing tables are a part of the input sold to regional ISPs, and they define the addresses that can be reached. When the IBPs co-operate in coordinating their core routers, it would be a temptation to use it as a collusive device (Varian, 1999). The control over the core routers (with full routing tables) distincts the IBPs from other ISPs that are controlling regional backbones.

Recently, we have witnessed a more active role played by the core IBPs. While they still have cost-free interconnection among themselves, they now charge smaller regional ISPs for access to their global infrastructure and core routing services. In other words, the smaller regional ISPs have become customers (or resellers) of the core IBPs facilities and services.[4] We have also observed that IBPs have integrated vertically into the retail market for Internet connectivity (the ISP segment) in Europe.

3 SOME PRELIMINARIES

Let us consider the stylized market contexts illustrated in figures 1a and 1b. The ISPs buy local access and global access as inputs from the LAP and the IBP, respectively. Throughout the paper we assume that (i) one IBP provides global access and one LAP provides local access, (ii) ISP A and ISP B compete in the market for Internet connectivity sold to end-users, and (iii) the LAP is vertically integrated and operates ISP A as its subsidiary. Since the ISPs have to choose capacity in the regional backbone network as well as in the transatlantic transport network we

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[4] An example of this is UUNET (an MCI WorldCom subsidiary), who ended the cost-free interconnection regime in 1997 and started to charge smaller ISPs for access to their backbone. See Mackie-Mason and Varian (1997) and Werbach (1997) for a summary of the internet's history.

will model downstream competition as a Cournot game.[5] For simplicity, we further assume that there is no horizontal differentiation between the two services offered by the ISPs. However, it should be noted that neither of these assumptions are essential for our main results (see discussion in Section 7).

In section 4 we assume that the non-integrated IBP sells global access as an input to both ISP A and ISP B. This market structure is denoted VS (vertical separation), and it is illustrated by figure 1a. In section 5 we assume that the IBP vertically integrates into the retail market and operates ISP B as its subsidiary, see figure 1b. This market structure is denoted VI (vertical integration). In section 6 we apply the same structure as in section 5, but we allow the IBP to engage in non-price discrimination (quality reduction) towards ISP A.

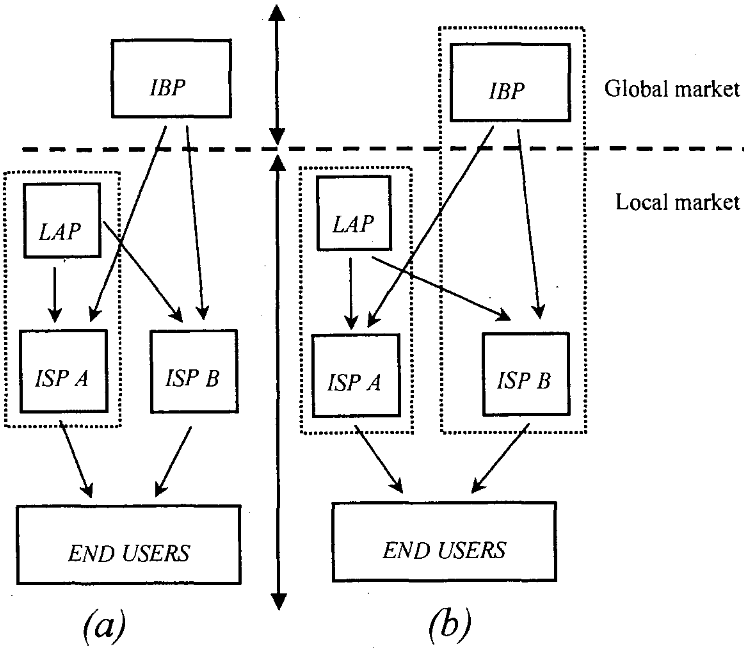

Figure 1: The market structure

Demand side

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[5] Downstream ISPs usually operate their own regional backbones in the territories they serve, while they sign long-term contracts for transatlantic capacity. Hence, it seems appropriate to see the competition between the ISPs as a capacity constrained price game.

Let consumer demand for Internet services be given by

$$p = \alpha - \beta(q_A + q_B), \tag{1}$$

where p is the price, and q_A and q_B denote the quantities from ISP A and ISP B, respectively. The consumer surplus may consequently be written as

$$CS = (\alpha - p)(q_A + q_B)/2. \tag{2}$$

Supply side

The profits for the downstream firms (the ISPs) are

$$\pi_i = (p - w_l - w_g)q_i. \qquad (i = A, B) \tag{3}$$

where w_l and w_g are the prices charged by the LAP and the IBP, respectively. Upstream profits for the LAP and the IBP are given by

$$\pi_{LAP} = (w_l - c_l)(q_A + q_B) \tag{4}$$

and

$$\pi_{IBP} = (w_g - c_g)(q_A + q_B), \tag{5}$$

where c_l and c_g are the respective long run marginal costs.

Since the LAP is vertically integrated, it is useful to express its aggregate profit level as

$$\pi^I_{LAP} = \pi_{LAP} + \pi_A. \tag{6}$$

If the IBP is vertically integrated, the market structure denoted VI, we have

$$\pi^I_{IBP} = \pi_{IBP} + \pi_B. \tag{7}$$

Domestic welfare

Domestic welfare is measured as the sum of consumer surplus and domestic profits (π_D);

$$W = CS + \pi_D. \tag{8}$$

In the case where ISP B is a domestic independent firm we have $\pi_D = \pi^I_{LAP} + \pi_B$, while $\pi_D = \pi^I_{LAP}$ if ISP B is owned by the foreign IBP.

A benchmark: VS with exogenously given global access price

As a benchmark, let us consider the model illustrated in figure 1a (VS). For the moment, we will assume that the IBP charges an exogenously given price w_g. If it is normalized to zero, it can be interpreted as the old regime where the IBPs did not charge the regional ISPs for global access (see Chapter 2).

Rewriting equation (6) we can express the profit level of the integrated LAP as

$$\pi^I_{LAP} = (p - w_g - c_l)q_A + (w_l - c_l)q_B. \tag{9}$$

We assume that the LAP first chooses w_l, and that ISP A and ISP B subsequently compete in quantities. Solving the game by backward induction, we start with the quantity setting by the ISPs. Using equations (1), (3) and (9) we find that the first order conditions $\partial\pi^I_{LAP}/\partial q_A = 0$ and $\partial\pi_B/\partial q_B = 0$ imply

$$q^*_A = (\alpha + w_l - 2c_l - w_g) \,/\, (3\beta) \tag{10}$$

and

$$q^*_B = (\alpha + c_l - 2w_l - w_g) \,/\, (3\beta)\,. \tag{11}$$

At stage 1 the LAP determines the price w_l that it will charge from ISP B. Differentiating (9) with respect to w_l we find that

$$w^*_l = (\alpha + c_l - w_g)\,/2. \tag{12}$$

From equations (11) and (12) it is thus clear that the LAP chooses an access price w_l such that $q^*_B = 0$ (and $\pi^*_B = 0$), and is thereby able to act as a monopolist in the downstream market. Hence, it exploits its control over the local access to deter the rival downstream firm from being active.

The fact that the LAP becomes a monopolist may obviously have negative welfare effects, and indicates that there is a role for public policy. The government maximizes welfare with respect to w_l subject to the constraints

$$\pi^{I*}_{LAP} \geq 0, \pi^*_B \geq 0,\ w_l \geq c_l. \tag{13}$$

The first two constraints state that each domestic firm should have a non-negative profit, and the last inequality says that the LAP must have a non-negative price-cost margin on its sale to ISP B.

Imperfect downstream competition is the only distortion when the global access price is exogenous. Hence, the domestic regulator can achieve a first-best outcome through a restrictive regulation of the local access price (and possibly subsidize the local access provider). The first-best outcome is one where the consumer price for Internet connectivity is equal to long-run marginal costs, $p = c_l + w_g$. Since the ISPs use a positive mark-up, the regulator thus needs to set the local access price below marginal costs ($w_l < c_l$) in order to reach this equilibrium. However, the restriction $w_l \geq c_l$ seems appropriate in our context, since the regulation policy in both the EU and the US typically allows firms to set prices such that their long-run marginal costs are covered. This implies that the local access price should be set equal to marginal cost, since $dW/dw_l < 0$ for $w_l = c_l$. It should be noted that the restriction $w_l \geq c_l$ does not affect any of the results qualitatively. In fact, a central message of this article is that in some cases it may be optimal for the regulator to set the access price strictly above marginal costs ($w_l > c_l$).

By regulating the local access price the regulator prevents the LAP from achieving a monopoly position. It is straight forward to show that the welfare level is now higher than the one without regulation.

Our results so far can be summarized in the following lemma:

Lemma 1: *Let us assume a VS market structure and that w_g is exogenous. If no regulation, then the LAP sets the local access price so high that ISP B is foreclosed. If regulation, a regulator that maximizes domestic welfare sets $w_l = c_l$, and both ISPs are active.*

In the benchmark w_g has been exogenous, which is consistent with the fact that w_g has been equal to zero until recently. Lately, however, the IBPs have begun to charge the ISPs for connectivity to the backbone, and presumably this pricing behaviour will become more widespread along with the increased commercialization of the Internet [see, e.g., Frieden (1999) and Cremer *et al.* (2000)]. In the following sections we analyze the effect of an endogenously determined price w_g from the IBP.

4 VERTICAL SEPARATION

Also in this section we have a market structure as illustrated in figure 1a, where the IBP is vertically separated from the ISPs. The only difference from the benchmark presented in the previous section is that the IBP acts as a monopolist that sets the global access price w_g endogenously. In the benchmark case a lower price w_l of local access reduced the marginal cost of ISP B, and thus led to increased competition and higher output. Therefore it was optimal for the domestic regulator to set a restrictive price cap on local access. Below, we show that this need not be the case when w_g is endogenous. The reason is that in addition to the direct effect on ISP B's costs, a reduction of w_l allows the IBP to charge a higher price w_g of access to the backbone. In this case the regulator therefore faces a trade-off between stimulating to downstream competition and preventing profit shifting from the domestic market to the foreign upstream firm. The problem of the domestic regulator is that there are now two distortions, but only one policy instrument available (the local access price). Not surprisingly, domestic price regulation is therefore possibly less effective than when w_g is exogenous. To show this, we will first analyze the outcome in an unregulated market economy.

Equilibrium

We will assume that prices and quantities are determined in a non-cooperative two-stage game. At stage one the LAP and the foreign IBP simultaneously set the access prices w_l and w_g, respectively, while there is Cournot competition in quantities between ISP A and ISP B at stage 2. The latter assumption implies that q_A^* and q_B^* are still given by equations (10) and (11).

To find the equilibrium value of w_g, we insert q_A^* and q_B^* into (5) and differentiate with respect to w_g. Taking w_l as given, we have

$$w_g(w_l) = (2\alpha + 2c_g - w_l - c_l)/4. \tag{14}$$

In a similar way, we find that

$$w_l(w_g) = (\alpha + c_l - w_g)/2. \tag{15}$$

In the appendix we prove the following Proposition:

Proposition 1: *Let us assume a VS market structure and no regulation. Then the LAP sets* w_l *such that* $q_B^* = 0$.

The LAP thus uses its control over the essential domestic input (access to the local network) to practice foreclosure against the competing downstream firm, ISP B. Thereby the LAP is able to retain its monopoly power over the consumers. Note that this result is identical to the result found when the global access price was exogenous (see Lemma 1). It thus illustrates that strategic behaviour by the global access provider does not change the LAP's strategy of monopolization.

Domestic public policy

In principle, the government can act as a first mover when it regulates the local access price w_l. This means that it sets w_l *before* the IBP sets w_g. However, such a commitment to ex ante regulation may not be credible. If it is not a credible commitment, we can model public policy as if w_l and w_g were set *simultaneously.* In the following we analyze both cases, and we start with the latter.

No credible commitment

In this case we have a two-stage game, where the regulator and the IBP choose w_l and w_g at stage one and the integrated LAP and ISP B choose quantities at stage two. We then have the following results (see the Appendix):

Proposition 2: *Let us assume a VS market structure and that the regulator and the IBP set simultaneously respectively* w_l *and* w_g .

(i)The regulator then sets $w_l = c_l$, *and*

(ii) the welfare level is lower with than without regulation.

Since the regulator and the IBP act simultaneously, the regulator is not able to influence the IBP's choice of w_g. For any given choice of w_g, the regulator's best choice is to set access price equal to marginal costs and thereby eliminate the dead weight loss following from a local access price above marginal costs. The regulated price of local access is thus equal to long-run marginal costs, as is the case when w_g is exogenous (see Lemma 1).

It can be shown that consumers are better off and domestic producers worse off following regulation. Since part (ii) in Proposition 2 states that regulation is detrimental to domestic welfare, then the reduction in domestic profits is only partially passed on to the domestic consumers. The reason is that part of the initial domestic profit is shifted to the IBP. The IBP anticipates that the regulator sets access price equal to marginal costs, and its best choice is then to set a higher access price to the backbone than what is the case without regulation. Put differently, regulation lowers domestic profits and permits the IBP to extract more profits from the domestic market.

Credible commitment

Let us now take for granted that the government succeeds with ex ante regulation. Then we have the following game:

· *Stage 1:* The regulator determines the price w_l

· *Stage 2:* The IBP determines the price w_g

· *Stage 3:* The LAP and ISP B set the quantities q_A and q_B

We have the following result (see the Appendix):

Proposition 3: *Let us assume a VS market structure and that the regulator can set w_l in a credible way. It would then choose not to regulate w_l.*

We see that if the regulator can credibly commit itself, it prefers not to regulate at all. The result in Proposition 3 follows from our result reported in Proposition 2. A binding price cap on w_l would imply that the IBP raises its access price w_g, thereby shifting profits from the domestic producers to the foreign producer. To avoid such a profit shift, the regulator is better off by not intervening in the market and thus by allowing the domestic producers to capture a large portion of the total profit in the domestic market.

5 VERTICAL INTEGRATION

Let us now focus on the market structure illustrated in figure 1b. We assume that both the LAP and the IBP have integrated vertically into the ISP segment, and that ISP B is a subsidiary of the IBP (while ISP A is still owned by the LAP).

In the previous section the domestic regulator faces a trade-off in setting the local access price, since a lower w_l not only reduces the costs of ISP B but also increases w_g. The higher w_g in turn increases the costs of both ISP A and ISP B. So what changes when the IBP integrates into the downstream market? The main difference is that an increase in w_g affects only ISP A's costs. Hence, the problem that a reduction of w_l increases w_g becomes less serious.

If the IBP is vertically integrated, we may write its profit level as [c.f. equation (7)]

$$\pi_{IBP}^{I} = (p - w_l - c_g)q_B + (w_g - c_g)q_A. \tag{16}$$

The profit level of the integrated LAP is still given by (9), and Cournot competition generates the following equilibrium quantities:

$$q_A^* = (\alpha + w_l - 2c_l + c_g - 2w_g)/(3\beta), \tag{17}$$

and

$$q_B^* = (\alpha + w_g - 2c_g + c_l - 2w_l)/(3\beta). \tag{18}$$

Equilibrium

In the first stage of this game the integrated LAP and the integrated IBP set the prices w_l and w_g. Inserting for (17) and (18) into (9) and (16), we find that $d\pi_{LAP}^{I}/dw_l = 0$ and $d\pi_{IBP}^{I}/dw_g = 0$ imply that

$$w_l(w_g) = [5(\alpha + c_l) - w_g - 4c_g]/10 \tag{19}$$

and

$$w_g(w_l) = [5(\alpha + c_g) - w_l - 4c_l]/10. \tag{20}$$

Then we have the following result (see the Appendix):

Proposition 4: *Let us assume a VI market structure and no regulation. Then* w_l *and* w_g *are set such that* $q_i^* > 0$, *where* $i = A, B$.

We see that in this case both ISPs offer positive quantities. This is in contrast to the result stated in Lemma 2, where only the LAP was assumed to be vertically integrated and it foreclosed the ISP B. To understand the distinction between these two outcomes, note that now both the ISPs have access to an essential facility and in that respect they are symmetric. From the LAP's point of view, the ISP B is now a low cost producer. It faces a low marginal cost, since $c_g < w_g$. The LAP then finds it beneficial to serve the low cost producer rather than foreclose it.

Domestic public policy

If regulation is not a credible commitment, it follows from the previous analysis that the regulator would end up with a regulated local access price equal to marginal costs in this case as well. More interestingly, though, is the case where regulation is a credible commitment. In that case the regulator sets w_l at stage 1, the integrated IBP sets w_g at stage 2 and q_A and q_B are set at stage 3.

Proposition 5: *Let us assume a VI market structure and that the regulator can set* w_l *in a credible way. Then it sets* $w_l < w_l^*$, *and domestic welfare increases.*

At first glance, this may come as a surprise. A low local access price is beneficial for the IBP, the foreign owner of the ISP B, and may thus shift profits out of the country. However, the IBP's response to a lower local access price is now distinctly different from what was the case with vertical separation. First, the detrimental effect on the IBP's access price, w_g, is now more limited. The reason is that this access price is now only affecting the ISP A's sale, while under vertical separation it affected both ISPs' sales. Second, the integrated IBP now responds to lower local access price by acting more aggressively in the output market. This is beneficial for the consumers, and explains why the regulator decides to set a lower local access price than what the domestic LAP would have set.

6 QUALITY REDUCTION

Above we have seen that it may not be optimal for the regulator to use cost-based prices on local access, because that may lead to higher prices on global access and increased profit shifting. This raises the question of whether there is a need for a global price regulation.

So far we have assumed that the bottleneck owners' only choice variable is price. However, a price regulation of the access price may induce foreclosure through non-price discrimination (see Laffont and Tirole, 2000). In particular, if the integrated IBP meets a price cap on w_g it may engage in non-price discrimination by reducing the quality of the input sold to the local incumbent's subsidiary ISP A. As shown in Economides (1998a, 1998b), it can be profitable to do so, and thereby put its rival in a disadvantageous position.[6] An LAP who meets a price cap on local access, may also have incentives to practise foreclosure through non-price discrimination.[7] Since the prevailing regulation regime in Europe typically has an ambition to regulate both price and quality on local access, we will, however, not consider this possibility. On the other hand, it seems difficult to implement quality requirements on the backbone providers. For example, it is almost impossible for an international regulatory authority to decide whether an integrated firm such as MCI Worldcom offers new functionality based on technological advantage to its own retail subsidiaries or practices quality degradation on input sold to the rivals.[8]

In line with Economides (1998a, 1998b), we let $f \geq 0$ be a "quality reduction parameter" which is such that one unit increase in f reduces the consumers' willingness to pay by one unit. In this case ISP A faces a parallel downward shift in its demand curve.

By including the quality reduction parameter we can write the profit level of the

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[6] See also Bergman (2000) and Economides (2000) for a note and comment on Economides (1998a).

[7] For further discussions and examples, see Laffont and Tirole (2000) and Economides (1998b).

[8] The Microsoft case gives an illustration of the problems in such a context, see, e.g., Economides (1998b)

LAP as

$$\pi^I_{LAP} = (p - w_g - c_l - f)q_A + (w_l - c_l)q_B. \tag{21}$$

Without any loss of insight we will assume that no costs are incurred for the integrated IBP when it reduces the quality of the input to ISP A. Therefore π^I_{IBP} is still given by (16), and with Cournot competition in quantities at the last stage of the game we have

$$q^*_A = (\alpha + w_l + c_g - 2c_l - 2\,w_g - 2f)\,/(3\beta), \tag{22}$$

and

$$q^*_B = (\alpha + c_l + w_g + f - 2w_l - 2c_g)\,/(3\beta). \tag{23}$$

Differentiating (16) with respect to f we find

$$d\pi^I_{IBP}/df = \frac{2}{9\beta}\left[f + \alpha + c_l + c_g - 2(w_g + w_l)\right], \tag{24}$$

which means that $d^2\pi^I_{IBP}/df^2 > 0$ for any given values of w_l and w_g. Setting $d\pi^I_{IBP}/df = 0$ thus gives us a minimum value of π^I_{IBP}, and therefore we must look at extreme values of f to find the IBP's best choice.

There are two extreme values of f. It cannot be negative, so there is a lower bound at $f^{lb} = 0$. The upper bound is given by

$$f^{ub} = (\alpha + w_l + c_g - 2c_l - 2\,w_g)\,/2, \tag{25}$$

because then $q_A = 0$ from equation (22). There is no reason to set $f > f^{ub}$, because ISP A is deterred from entering the market already at $f = f^{ub}$. Moreover, note that if w_g is unregulated, the IBP does not need the non-price foreclosure instrument f; it can always use w_g as a substitute.

Equilibrium

From the above, it follows that the IBP either sets $f = 0$ and imposes no quality reduction at all, or sets $f = f^{ub}$ and deters ISP A from entering the market. In the former case, we have the vertical integration equilibrium reported in the previous section. In the latter case, the LAP maximizes $\pi^I_{LAP} = (w_l - c_l)q_B$ with respect to

w_l at stage 1 and the integrated IBP maximizes $\pi^I_{IBP} = (p - w_l - c_g)q_B$ with respect to q_B at stage 2. By comparing these two outcomes, we find that the IBP chooses to impose quality reduction if and only if the access price to the backbone is set below some critical value w^c_g.[9] Letting w^*_g denote the access price that the IBP would have chosen in an unregulated market, we have the following result (see the Appendix):

Proposition 6: *Let us assume a VI market structure, that there is no regulation, and the IBP has the option to reduce quality when serving ISP A. Then the IBP will choose*

(i) not to impose quality reduction if $w^c_g \leq w_g \leq w^*_g$,

(ii) to impose quality reduction if $w_g < w^c_g$ *and thereby foreclose ISP A.*

Note that for endogenously determined w_g our result is in contrast to the result found in Economides (1998a, 1998b). He found that quality reduction would always be used to foreclose its downstream rivals. In his model, there is only one provider of an essential facility. Obviously, then, the provider of the essential facility can benefit from putting its downstream rival at a disadvantage by reducing the quality of its input. In our setting, though, quality reduction will not exclude the rival from being partly active in the market, since the rival provides the integrated IBP with local access. Then the integrated IBP is better off by providing the rival with high quality input and extracting profits from the rival through its access price w_g than by foreclosing the LAP's subsidiary ISP A if $w_g > w^c_g$.

As indicated, one important reason why foreclosure through quality reduction would not be profitable is that it would prevent the IBP from extracting profits from the integrated LAP. If so, it could be of interest to examine how any regulation of w_g, for example as a result of international public policy, may affect the IBP's choice of quality reduction. As shown in part (ii) of the Proposition, the IBP will prefer

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[9] Weisman (1995) and Sibley and Weisman (1998), who analyze whether a monopolist subject to price-cap regulation has incentives to increase the costs of rivals to its vertically related affiliate, find a similar result. They argue that these incentives may be weak unless the affiliate makes a sufficiently large share of the firm's total profit. See also Reiffen (1998) and Weisman (1998) for further discussions.

foreclosure if w_g is sufficiently low. A low global access price implies that the IBP earns only a limited price-cost margin on its deliveries to ISP A, and therefore the IBP is better off by foreclosing ISP A. Note that exclusion of ISP A is not a goal *per se*, but only a means to transfer market power from the regulated global bottleneck to the retail segment.

Domestic public policy

In line with the previous sections, we assume that the regulator can credibly commit itself to a certain local access price. Then we have that the regulator sets w_l at stage 1, the IBP sets f at stage 2, and ISP B (and ISP A if no foreclosure) sets quantities at stage 3.

Proposition 7: *Let us assume a VI market structure, the IBP has the option to reduce quality when serving ISP A, and the regulator can set w_l in a credible way. Then*

(i) if $w_g < w_g^l$, the regulator sets $w_l < w_l^*$ and there is foreclosure,

(ii) if $w_g^l < w_g < w_g^h$, the regulator sets $w_l > w_l^*$ and there is no foreclosure, and

(ii) if $w_g^h < w_g \leq w_g^*$, the regulator sets $w_l < w_l^*$ and there is no foreclosure.

Due to the IBP's ability to practice foreclosure the public policy becomes relatively complex. On the one hand, the regulator prefers a low access price w_l in order to increase consumer surplus. On the other hand, a low value of w_l implies that the IBP earns a large price-cost margin on its own sales. This tends to make it more profitable for the IBP to practice foreclosure, and thereby to dampen the rivalry in the end-user market. In figure 2 we have illustrated our results with a numerical example. The dotted lines show how the regulator's choice of w_l is affected by the global access price w_g, while the solid lines show how the choice of the LAP is affected.

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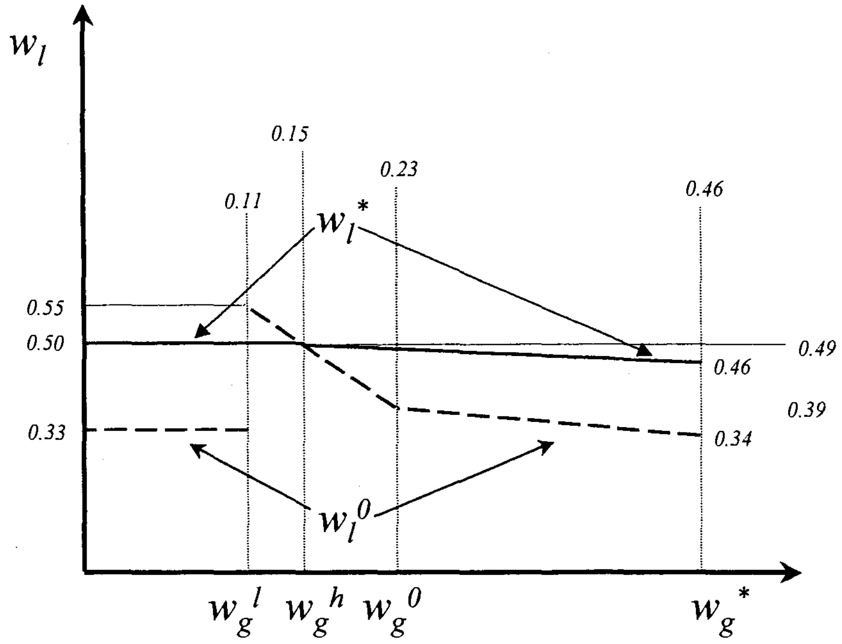

Figure 2: Regulator's or the LAP's choice of w_l (with $\alpha = 1$, $c_l = c_g = 0$)

By setting a high local access price the regulator makes the alternative to foreclosure less attractive for the IBP. If w_g is sufficiently low, the IBP earns such a small profit on its sale to the ISP A that it is not possible for the regulator to prevent the IBP from engaging in foreclosure. However, for an intermediate value of w_g the regulator sets such a high local access price that the IBP decides to switch from foreclosure to no foreclosure. In fact, for some values of w_g the regulator sets a *higher* local access price than the one the LAP would have chosen. Finally, if w_g is high the IBP would have chosen no foreclosure anyway. Then the regulator sets a lower access price than the LAP would have done, as was the case in the previous section where foreclosure was not an option.

It may seem as a surprise that for intermediate values of w_g the regulator sets a higher local access price than the LAP would set, since a high local access price would, all else equal, result in a high price in the output market. However, the welfare gain from a high access price is that it prevents foreclosure of ISP A and thereby ensures rivalry between the ISPs in the output market.

International versus domestic public policy

An exogenously determined w_g can, as argued above, be interpreted as a price cap enforced due to international coordination of public policy. A natural question, then, is how international and domestic public policy interact. Let w_l^o denote the regulator's choice of local access price. We have the following result:

Proposition 8: *Let us assume a VI market structure, the IBP has the option to reduce quality when serving ISP A, and the domestic regulator can set w_l^o in a credible way.*

(i) A price cap on w_g would reduce domestic welfare if $w_g \leq w_g^l$, and otherwise increase domestic welfare.

(ii) $\partial w_l^o / \partial w_g = 0$ if $w_g < w_g^l$, and $\partial w_l^o / \partial w_g < 0$ if $w_g > w_g^l$.

(iii) $\partial p / \partial w_g = 0$ *if* $w_g < w_g^l$, $\partial p / \partial w_g < 0$ *if* $w_g^l < w_g < w_g^o$, *and* $\partial p / \partial w_g > 0$ *if* $w_g > w_g^o$.

A restriction on the global access price would limit the IBP's ability to extract profits from the market in question, and thus be beneficial for the domestic country. We see that this is true if $w_g \geq w_g^l$. However, an even more restrictive price cap than that on global access would result in foreclosure and thereby higher price in the output market. In such a case the domestic country would be worse off than what would have been the case if there was no price cap on global access. Hence, an international regulation of global access price increases domestic welfare only if the global access price is not set below a certain threshold level. See figure 3, where we use a numerical example to illustrate how the global access price affects prices and domestic welfare.

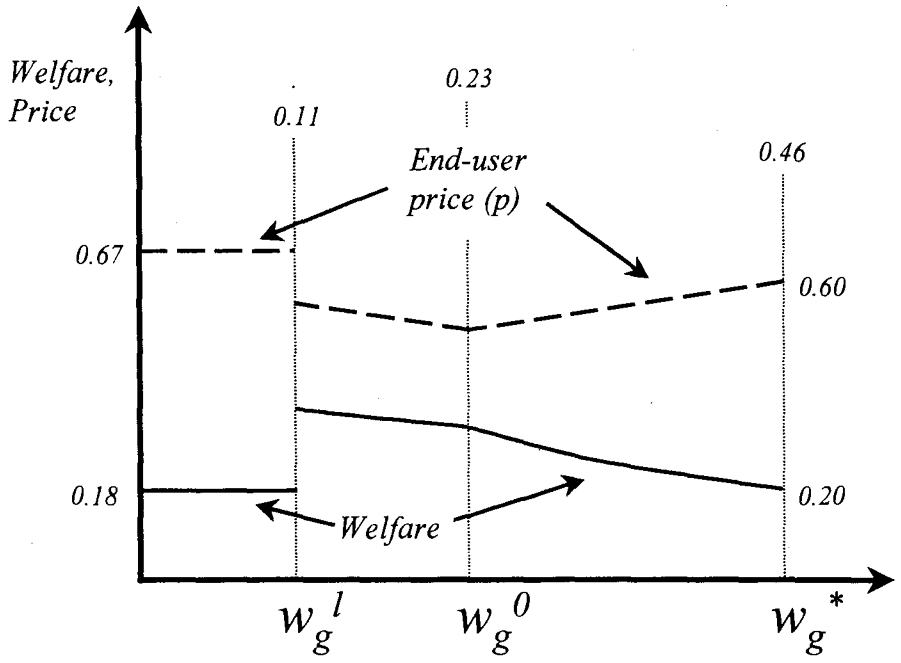

Figure 3: Welfare and end-user price (with $\alpha = 1$, $c_l = c_g = 0$)

Finally, note the potential conflict between international and domestic public policy. First, for high values of w_g a more restrictive price cap on global access results in a less restrictive price cap on local access, but end-user price falls. To understand this, note that a lower global access price shifts profits from the global access providers to the domestic country. The regulator maximizing domestic welfare finds it profitable to let both domestic consumers and domestic producers benefit from the profit shift. It partly offsets the reduction in w_g by increasing w_l. Second, and even more detrimental to the interest of the global access provider, for intermediate levels of w_g a more restrictive global access price increases both the local access price and the end-user price. The reason is that the domestic regulator now responds to a reduction in w_g by increasing w_l substantially, thereby preventing the IBP from practicing foreclosure. This suggests that more restrictive international regulation may be partly offset, and in some cases even more than offset, by less restrictive domestic regulation.

7 DISCUSSION OF RESULTS AND CONCLUSION

Domestic telecommunication firms have historically had a very dominant position in many countries. No surprise, then, that many of these firms have been facing a restrictive regulatory regime in their home country. In particular, some countries have enforced a cost-oriented price regulation for access sold to rivals in the downstream market. In this article we have shown that such a public policy might be misguided in a situation where inputs are provided by both local and foreign firms, which is the case in, for example, the market for Internet. A restrictive policy towards domestic firms may result in a larger profit potential for foreign firms and thereby a profit shift out of the country. The reverse may also be true, where a more restrictive international regulation may trigger a less restrictive domestic public policy and thereby a profit shift to the domestic country.

In this paper we have assumed that there is Cournot competition between the ISPs, and that there is no horizontal product differentiation. We have tested the robustness of our results with respect to these assumptions by analyzing Bertrand competition and differentiated products under vertical separation and vertical integration. The main results are still valid, except for some minor differences in the case of vertical separation. First, with horizontally differentiated products the local access provider will obviously not want a complete foreclosure of the rival, since there are some extra profits that can be extracted from the market by serving the rival. Second, recall that in the case with Cournot competition and identical products the local access provider would prefer to foreclose its downstream rival, and the regulator would choose not to regulate. With Bertrand competition and differentiated products the regulator may interfere. When products are close substitutes the regulator would set a higher access price than the local access provider would prefer. By doing so it would force the backbone provider to reduce its global access price. If the products are very differentiated, on the other hand, the regulator would set a lower local access price than the local access provider would prefer. The reason for this is that the downstream market is less competitive the larger the extent of product differentiation, and therefore a lower local access price is needed to avoid excessively high consumer prices.

We have not analyzed the implications of Bertrand competition and horizontal product differentiation in the context where the integrated backbone provider can use quality reduction as an alternative foreclosure tool, so this may be an interesting extension. However, we would expect that the main results survive also in this case. The reason is that the IBP's trade-off between reducing its upstream profit and increasing its downstream profit when degrading the rival's quality on global backbone access will be the same. Our conjecture is that the key difference is that the rival will be only partly foreclosed if the ISPs supply differentiated services.

In the last section of the paper we assumed that the price of access to the global backbone is regulated, but we did not provide any discussion of how this is done. An interesting extension of the model would thus be to analyze a regulation game between a domestic and a foreign government. On the basis of our linear model we have shown that a too restrictive price cap may be detrimental to welfare, a case that both governments should have incentives to avoid. For a less restrictive price cap, however, there is likely to be a conflict of interests between the governments. In particular, the domestic government may prefer a relatively low global access price and a relatively high local access price, while the preferences of the foreign government are the opposite. It is therefore not obvious what will be the outcome of a regulation game. In fact, it is possible that we end up with a prisoner's dilemma, where both the local access price and the global access price are high.

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9 APPENDIX

Proof of Proposition 1

We can use equations (14) and (15) to find that $w_l^* = (2\alpha + 5c_l - 2c_g)/7$ and $w_g^* = [3(\alpha - c_l) + 4c_g]/7$. Inserting this into equations (10) and (11) it follows that $q_A^* = Q^* = 2(\alpha - c_l - c_g)/(7\beta)$ and $q_B^* = 0$. Q.E.D.

Proof of Proposition 2

(i) The quantities q_A^* and q_B^* are given by equations (10) and (11). Differentiating national welfare W from equation (8) with respect to w_l implies that $w_l = 2c_l + w_g - \alpha$ when $dW/dw_l = 0$. But this value of w_l is a violation of the constraint that $w_l \geq c_l$, c.f. equation (13). The regulator will therefore set $w_l = c_l$.

(ii) Inserting $w_l = c_l$ into equation (14) we have that $w_g^* = (\alpha + c_g - c_l)/2$. From equations (10) and (11) it thus follows that $q_A^* = q_B^* = (\alpha - c_l - c_g)/(6\beta)$ and $Q^* = (\alpha - c_l - c_g)/(3\beta)$. Inserting for the equilibrium values of w_l^*, w_g^* and Q^*

from the proof of Proposition 1 into the welfare function (8) we find that with no regulation welfare is the following:

$$W^* = \frac{6}{49\beta}(\alpha - c_l - c_g)^2. \tag{26}$$

In a similar way, we find that with regulation welfare equals:

$$W^{SO} = \frac{6}{54\beta}(\alpha - c_l - c_g)^2. \tag{27}$$

It is thus evident from equations (26) and (27) that $W^* > W^{SO}$. Q.E.D.

Proof of Proposition 3

The equilibrium quantities q_A^* and q_B^* are still given by (10) and (11). At the second stage of this game the IBP takes w_l as given, and maximizes π_{IBP} with respect to w_g. This generates the same reaction function $w_g(w_l)$ as in equation (14). Inserting this into the welfare function, equation (8), and differentiating with respect to w_l we find that

$$w_l^o = (\alpha + c_l - c_g)/2 \tag{28}$$

when $dW/dw_l = 0$. By comparing equations (15) and (28), and noting that $w_g > c_g$, we see that the regulator prefers a *higher price* than the domestic monopolist. However, $w_l > w_l^*$ is not feasible since it would imply that ISP B sells a negative quantity. Hence, the regulator decides not to regulate w_l. Q.E.D.

Proof of Proposition 4

We can use equations (19) and (20) to find that $w_l^* = \left[45(\alpha - c_g) + 54c_l\right]/99$ and $w_g^* = \left[45(\alpha - c_l) + 54c_g\right]/99$, respectively. Inserting into (17) and (18) we thus find $Q^* = 4(\alpha - c_l - c_g)/\left(11\beta\right)$ and $q_A^* = q_B^* = 0.5Q^*$ if $c_l = c_g$. Q.E.D.

Proof of Proposition 5

The reaction function $w_g(w_l)$ and the equilibrium quantities q_A^* and q_B^* are given from equations (20), (17) and (18), respectively. The regulator maximizes $W = CS + \pi_{LAP}^I$ [c.f. equation (8)] with respect to w_l. Solving this maximization problem we find that

$$w_l^o = \left[35(\alpha - c_g) + 64c_l\right]/99. \tag{29}$$

This price chosen by the regulator is smaller than the one preferred by the LAP (provided that $a - c_l - c_g > 0$, which is the only interesting case). Q.E.D.

Proof of Proposition 6

Let us first examine the case where w_g is endogenous, such that $w_g = w_g^*$. If no foreclosure, we have the equilibrium values reported in the proof of Proposition 4. Inserting those into the IBP's profit function we have that

$$\pi_{IBP}^{f=0} = \frac{14}{121\beta}(\alpha - c_l - c_g)^2. \tag{30}$$

If foreclosure, $q_A = 0$ and w_g is non-existing since there are no deliveries from IBP to ISP A. Then it can be shown that $w_l^* = (\alpha - c_g + c_l)/2$ and $q_B = (\alpha - c_g - c_l)/(4\beta)$. Inserting the equilibrium values into the IBP's profit function, we have that

$$\pi_{IBP}^{f>0} = \frac{1}{16\beta}(\alpha - c_l - c_g)^2. \tag{31}$$

Then it can easily be checked that $\pi_{IBP}^{f=0} > \pi_{IBP}^{f>0}$, which implies that quality reduction is not profitable for the IBP.

Let us now assume that w_g is exogenous, *i.e.*, $w_g < w_g^*$. If foreclosure, w_g plays no role. Hence, $\pi_{IBP}^{f>0}$ is as stated above. If no foreclosure, the IBP's profit for a given w_g is now as follows:

$$\pi_{IBP}^{f=0} = (w_g - c_g)(25(\alpha - c_l) + 2c_g - 27w_g)/(50\beta) \tag{32}$$

Now it can be shown that $\pi_{IBP}^{f=0} > \pi_{IBP}^{f>0}$ if $w_g^c < w_g < w_g^t$. Furthermore, it can be shown that $w_g^t > w_g^*$. Then we have that $\pi_{IBP}^{f=0} > \pi_{IBP}^{f>0}$ if

$$w_g < \left[50(\alpha - c_l) + 58c_g - 5\sqrt{46}(\alpha - c_l - c_g)\right]/108 \equiv w_g^c \tag{33}$$

Foreclosure is then profitable for the IBP if $w_g < w_g^c$. Q.E.D.

Proof of Proposition 7

Suppose that the IBP practices foreclosure ($f > 0$). For a given level of w_l, the IBP's profit is:

$$\pi_{IBP}^{f>0}(w_l) = \frac{1}{4\beta}(\alpha - w_l - c_g)^2. \tag{34}$$

If no foreclosure, for exogenous w_g and w_l the IBP's profit equals:

$$\pi_{IBP}^{f=0} = \frac{1}{9\beta}\left[(\alpha + 5w_g + 2c_l - 7c_g - 4w_l)\alpha - (5w_g - 4c_l + 5c_g - w_l)w_g + Y\right] \tag{35}$$

where $Y = (c_l - 4w_l)c_l + (c_g + 2c_l)c_g + (4w_l - 5c_g)w_l$. Now it can be shown that $\pi_{IBP}^{f=0} > \pi_{IBP}^{f>0}$ if $w_g^0 < w_g < w_g^1$, and that $w_g^1 > w_g^*$. Then the relevant value of w_g, where the IBP is indifferent between foreclosure and no foreclosure for a given level of w_l, is the following:

$$w_g^0 = \left[5(\alpha + c_g) + 2c_l - 7w_l\right]/10 \equiv w_g^c(w_l). \tag{36}$$

Solving with respect to w_l, we have that the IBP is indifferent if the regulator sets the following local access price:

$$w_l = \left[5(\alpha + c_g) + 2c_l - 10w_g\right]/7 \equiv w_l^c(w_g). \tag{37}$$

However, for sufficiently high w_l the IBP decides not to serve its own subsidiary ISP B in the no foreclosure situation (no foreclosure of ISP A). From (18) we find that $q_b \leq 0$ if

$$w_l \geq (\alpha + w_g - 2c_g + c_l)/2 \equiv w_l^0(w_g). \tag{38}$$

Hence, if foreclosure is not possible at $w_l = w_l^0$, then it is not possible at all. By comparison, we find that $w_l^c(w_g) \leq w_l^0(w_g)$ if:

$$w_g \geq (\alpha - c_l + 8c_g)/9 \equiv w_g^l. \tag{39}$$

For $w_g < w_g^l$, it is thus not possible by setting a high w_l to force the IBP not to foreclosure.

Let us now consider the case where $w_g^l < w_g < w_g^c(w_l)$. We know from Proposition 6 that in such a case the IBP would prefer foreclosure. Given foreclosure, the regulator maximizes welfare by setting $w_l^o = (\alpha - c_g + 2c_l)/3$. The welfare is in this case equal to:

$$W^{f>0} = \frac{1}{6\beta}(\alpha - c_l - c_g)^2. \tag{40}$$

Alternatively, the regulator could set w_l so that the IBP prefers no foreclosure rather than foreclosure. If no foreclosure, we have the welfare specified in (8). If we now plug in equilibrium quantities from (17) and (18), as well as the critical value of the local access price to ensure no foreclosure, $w_l^c(w_g)$, we have the following welfare:

$$W^{f=0} = \frac{1}{98\beta}\left[31\alpha^2 - 62\alpha c_l - 12\alpha w_g + 31c_l^2 + 12c_l w_g - 51w_g^2 + X\right] \tag{41}$$

where $X = -50\alpha c_g - 32c_g^2 + 50c_g c_l + 114c_g w_g$. Then we have that $W^{f=0} > W^{f>0}$ if:

$$[22(\alpha - c_l) - 51w_g + 29c_g][2(\alpha - c_l) + 3w_g - 5c_g] > 0, \tag{42}$$

and it can be shown that $W^{f=0} > W^{f>0}$ if :

$$w_g < \left[22(\alpha - c_l) + 29c_g\right]/51 \equiv w_g^u, \tag{43}$$

where w_g^u denotes the value of w_g for which the regulator is indifferent between foreclosure and no foreclosure. Let us compare this critical value with the value where the IBP is indifferent between foreclosure and no foreclosure, given that the regulator sets the optimal w_l for the case of no foreclosure. We plug the regulator's choice of w_l in the case of no foreclosure into $w_g^c(w_l)$. It can be shown that in such a case it is unprofitable for the IBP to engage in foreclosure if

$$w_g > (\alpha - c_l + 2c_g)/3 \equiv w_g^o. \tag{44}$$

By comparison, we have that $w_g^u > w_g^o$. It implies that when w_g is close to w_g^u, the regulator would prefer to set a local access price such that the IBP's best choice is no foreclosure. Then we have shown that the regulator sets w_l so that no foreclosure occurs for $w_g^l < w_g < w_g^o$.

Let us now consider the case when w_g is close to w_g^*. In this case it can be shown that if the regulator sets its optimal access price in the case of no foreclosure, the IBP would choose no foreclosure. Could the regulator then prefer to set w_l so low that the IBP chooses foreclosure? We check for $w_g = w_g^*$. We plug in for the equilibrium values of q_A and q_B, the regulator's choice of w_l and the IBP's choice of w_g. We find that the welfare is the following if no foreclosure:

$$W^{f=0} = \frac{37}{198}(\alpha - c_l - c_g)^2. \tag{45}$$

Alternatively, the regulator could set w_l so that the IBP prefers foreclosure rather than no foreclosure. If foreclosure, we have the welfare specified in (8) for a given w_l. In this case the critical value of the local access price to ensure no foreclosure, w_l^c, is equal to c_l. Then we have the following welfare if foreclosure:

$$W^{f>0} = \frac{1}{8}(\alpha - c_l - c_g)^2. \tag{46}$$

Now it can easily be shown that $W^{f=0} > W^{f>0}$. This implies that the regulator will not prefer foreclosure if no regulation of w_g, and it follows straightforward that it would neither prefer foreclosure for lower w_g.

Finally, let us check how w_g affects the regulator's choice of w_l. First, let us find the value of w_g where the regulator would set w_l identical to the one chosen by the LAP. $w_l^c(w_g)$ denotes the price the regulator has to set to make the IBP indifferent between foreclosure and no foreclosure, while $w_l(w_g)$ shown in (19) is the LAP's choice of access price given no foreclosure. We have that $w_l^c(w_g) = w_l(w_g)$ if

$$w_g = \left[(\alpha - c_l)5 + 26c_g\right]/31 \equiv w_g^{h1} \tag{47}$$

However, the LAP's local access price may increase following a shift from no foreclosure to foreclosure. Comparing (19), the LAP's price for a given w_g and no foreclosure, with the LAP's price if foreclosure ($w_l = (\alpha - c_l - c_g)/2$), we have that the LAP sets a higher price if foreclosure than if no foreclosure if:

$$w_g > 10c_l + c_g \equiv w_g^n \tag{48}$$

It can be shown that $w_g^{h1} \lesseqgtr w_g^n$. If $w_g^{h1} > w_g^n$, then the LAP's price would increase as a result of a shift from no foreclosure to foreclosure. If so, we have to compare $w_l^c(w_g)$ with LAP's price if foreclosure. We have that those two prices are identical when:

$$w_g = (3\alpha + 11c_l + 17c_g)/20 \equiv w_g^{h2}. \tag{49}$$

Then we have the following definition of the critical value where the regulator and the LAP would set identical price:

$$w_g^h = \begin{cases} w_g^{h1} & \text{if} \quad w_g < 10c_l + c_g \\ w_g^{h2} & \text{otherwise} \end{cases} \tag{50}$$

It can easily be checked that $w_l^o < w_l^*$ if $w_g > w_g^h$ and that $w_l^o < w_l^*$ if $w_g^l < w_g < w_g^h$. If $w_g < w_g^l$, the IBP practices foreclosure and the LAP would set $w_l^* = (\alpha - c_g - c_l)/2$ and the regulator would set $w_l^o = (\alpha - c_g + 2c_l)/3$. Then we have that $w_l^* > w_l^o$ if $\alpha - c_g - c_l > 0$, the only interesting case. Q.E.D.

Proof of Proposition 8

From Proposition 7 we know that $W = \frac{1}{6\beta}(\alpha - c_l - c_g)^2$ when $w_g < w_g^l$. If $w_g = w_g^*$, then for $w_l = w_l^o$ it can be shown that $W = \frac{37}{198\beta}(\alpha - c_l - c_g)^2$, which is higher that the welfare when $w_g < w_g^l$.

If $w_g < w_g^l$, then the IBP chooses foreclosure and the regulator's choice of w_l is unaffected by w_g. If $w_g^l < w_g < w_g^o$, then we have that

$$\partial w_l^c(w_g)/\partial w_g = -10/7. \tag{51}$$

If $w_g^o < w_g \leq w_g^*$, then it can be shown that the regulator's choice of w_l for a given w_g is the following:

$$w_l^o(w_g) = \left[135\alpha - 75c_g + 178c_l - 60w_g\right]/313, \tag{52}$$

and it follows straight forward that:

$$\partial w_l^o(w_g)/\partial w_g = -60/313. \tag{53}$$

Finally, let us check how w_g affects end-user price. If $w_g < w_g^l$, then w_g has no effect on end-user price. If $w_g^l < w_g < w_g^o$, then we plug w_l^c into (17) and (18) into (1) and find that

$$\partial p/\partial w_g = -1/7. \tag{54}$$

If $w_g^o < w_g \leq w_g^*$, then we plug w_l^o from the proof of Proposition 5 into (17) and (18) and (17) and (18) into (1) and find that

$$\partial p/\partial w_g = 1/3. \tag{55}$$

Q.E.D.

Chapter 3

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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. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Compatibility; Internet; Competition; Duopoly

JEL Classification: L13; L96; L41

1. Introduction

We consider competition between two ISPs (Internet Service Providers) operating in the same geographical 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.

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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 non-disclosure 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 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

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[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.

[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.

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 et al. (1998a,b), 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 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 telephony 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").

1.1. Related literature

There are to our knowledge few papers explicitly considering ISP competition and compatibility choice, but Crémer et al. (2000) and Mason (1999) are notable examples[3].

We are here following Crémer et al. (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) is 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.

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[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 et al. (2000) and Mason (2000).

This result is in contrast to the results in the present paper 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's. 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 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 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 2 we present a brief overview of the network structure. In Section 3 we present our model. Finally, in Section 4 we conclude.

2. A brief overview of the network structure

In Fig. 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

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[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.

[5] See Laffont et al. (1998a,b), 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.

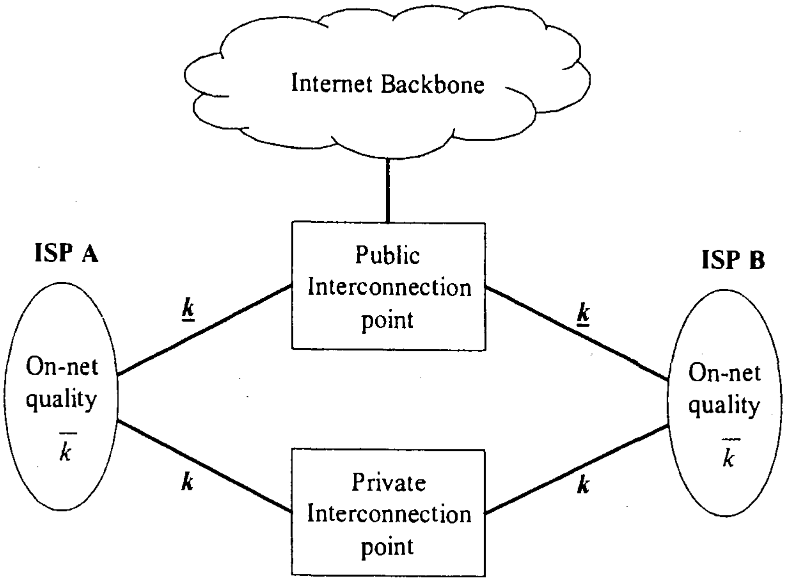

Fig. 1. The interconnection structure.

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 Fig. 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].

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 $\underline{k} \le k \le \bar{k}$ (see Fig. 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.

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

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 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].

3. 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:

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

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

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[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 Crémer et al. (2000) on the interplay between Internet Backbone Providers.

[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.

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 $\beta \cdot (n_i + kn_j)$, where $\beta \geq 0$ and $k\epsilon[\underline{k},1]$. 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 interconnect 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 Fig. 1), whereas $k > \underline{k}$ implies that the two ISPs have agreed upon establishing an interconnect arrangement (the private interconnection point in Fig. 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.

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. Assumptions 1 and 2 are then

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[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).

[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.

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:

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

σ is a function of k where $\sigma(k) > 0$, $\sigma(1) = 1/2t$, $\sigma'(k) < 0$. Notice that Assumption 2 assures that $\sigma > 0$. The market share functions are very similar to the market share functions in a standard Hotelling model and if $k = 1$ and/or $\beta = 0$, 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.

3.1. 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 $\underline{k} \leq k \leq 1$. In the second stage, the two ISP simultaneously set their prices for a given k.

3.1.1. 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:

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

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.

3.1.2. 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:

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

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

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

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 interconnect 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: $\partial p_i/\partial k = \beta$. 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:

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

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.

3.1.2.1. 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.

3.1.2.2. 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 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

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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.

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:

$$k^d = \arg\max(\pi^i(\theta, k) - \tfrac{1}{2} I(k)).$$

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:

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

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.

4. 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.

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Appendix A. 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 $1/2\alpha^2 t$ and $1/2(1-\alpha)^2 t$ for network a and b respectively. In stage 2 of the game the social welfare function is:

$$\begin{aligned} W(k) = \max_{\alpha} [& \alpha\{v_a - \tfrac{1}{2}\alpha t + \beta(\alpha + k(1-\alpha)) - c\} \\ & + (1-\alpha)\{v_b - \tfrac{1}{2}(1-\alpha)t + \beta(1 - \alpha + k\alpha) - c\}] \end{aligned}$$

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: $\alpha^* = 1/2 + \theta_a/2t$ whereas market equilibrium is characterised by: $\alpha^* = 1/2 + \theta_a/6t$. Thus the market share of the firm selling the superior product is to small.

The stage 1 socially optimal investment level is:

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

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

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

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

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: $k^* = \arg\max(W(k) - I(k))$. 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:

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

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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Chapter 4

Price Competition and Interconnection Quality in the Market for Digital Network Services*

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Abstract

We consider competition between two providers of digital network services. The services are horizontally differentiated, and consumers' willingness to pay depends upon the compatibility between the two providers. Asymmetry in size is often used as an explanation of why we see that competing providers do not agree upon compatibility between their networks. In this paper we show that asymmetry in pricing mechanism can reduce the providers' incentives to become compatible. In particular, we show that if one firm uses first-degree price discrimination, while the rival sets a linear price, the degree of compatibility will be lower than if both firms use the same pricing mechanism. When the pricing mechanisms are set endogenously by the firms, we show that both firms prefer the combination of complete compatibility and linear pricing to all other possible outcomes as long as the cost of compatibility is not too high.

Keywords: Compatibility, Network Externalities, Price Discrimination, Internet, Competition

JEL classification: L13; L96; L41

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Introduction

In the Internet and other digital communication networks (e.g. mobile networks) personalisation technologies may give the providers more flexibility with respect to pricing mechanism. The providers may even have the ability to use first-degree price discrimination - or "one-to-one marketing" as the strategy is often called in the marketing literature.[1] In the retail markets for mobile telephony or Internet services the existence of direct and indirect network effects implies that consumers' valuation of the services increases with the degree of compatibility - the interconnection quality between the providers.[2] Several analysts argue that person-to-person communication will be the "killer-application" also in the future networks, such as 3rd generation mobile systems (see e.g. Odlyzco, 2001). A hot topic both in the Internet and in telecommunication is then whether some providers will use a "walled garden strategy" and choose to set higher quality for on-net communication than for off-net communication.[3] We have complete compatibility when on-net quality equals off-net quality, while we have incomplete compatibility if on-net quality is higher than off-net quality of communication.

The quality of communication may be given several interpretations. First, it may be transmission capacity, such that a low capacity in the interconnection point may give a higher degree of delay and congestion for off-net communication than for on-net communication. Second, incompatible proprietary systems may create a quality difference. One example is in the Japanese mobile market where each of the three

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[1] See Shapiro and Varian (1998) and Varian (2001).

[2] Katz and Shapiro (1994), Economides (1996) and Shapiro and Varian (1998), among others, give a classification of direct and indirect network effects. The seminal paper on network externalities is Rohlfs (1974).

[3] On-net communication refers to traffic between computers/consumers connected to the same provider, while off-net communication is between computers/consumers connected to different networks, e.g. communication between consumers subscribing to competing firms.

providers is operating incompatible systems. The largest provider, DoCoMo, has success with its mobile internet service I-Mode (25 million subscribers, August 2001), but the services and content available to I-Mode subscribers are not available to subscribers of the rival providers (see The Economist, October 13th, 2001).[4]

Katz and Shapiro (1985) analyse the choice of compatibility of two competing firms in a static model, and they show that the smaller firm has higher incentives to become compatible than the larger rival. Crémer, Rey and Tirole (2000) are adopting the Katz and Shapiro-model and analyse the competition between Internet backbone providers with asymmetric installed bases. They show that a firm with a large installed base may have incentives to reduce the degree of compatibility towards its smaller rivals.

While both Katz and Shapiro (1985) and Crémer, Rey and Tirole (2000) assume Cournot competition, Foros and Hansen (2001) model competition à la Hotelling and analyse the choice of compatibility between two ISPs[5]. When the two ISPs set a linear price, and compatibility agreements are costless, they show that the ISPs will set complete compatibility since this will dampen the competitive pressure between the rivals.[6] In this paper we show that in a duopoly the choice of compatibility depends on whether one or both of the firms use price discrimination in the retail market. Ulph and Vulkan (2000a) show that in a market without network effects the incentives to use first-degree price discrimination are dampened in competitive markets since it intensifies competition. We also observe that some firms seem to be unwilling to use price discrimination and they are offering a linear price to all even if they have a lot of information about the individual willingness to pay.[7]

We combine elements from Ulph and Vulkan (2000a) and Foros and Hansen (2001). Both these papers are extensions of Hotelling (1929). Similar to Ulph and Vulkan

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[4] Rubinfeld and Singer (2001) analyse whether the merged AOL Time Warner has incentive to use different types of walled garden strategies in the broadband access market.

[5] Internet Service Providers.

[6] Other papers analysing Hotelling-competition between providers of internet access and compatibility are Dogan (2000) and Mason (1999).

(2000a) and Foros and Hansen (2001) the services are assumed to be horizontally differentiated.[8] Analogous to Foros and Hansen (2001), but in contrast to Ulph and Vulkan (2000a), we assume that network effects imply that consumers' willingness to pay depends upon the compatibility between the two firms.[9]

Ulph and Vulkan (2000a) show in a one-stage game without network effects that there are two effects of using first-degree price discrimination under Hotelling competition.[10] The first is the effect of the conventional monopoly analysis of first-degree price discrimination – the enhanced surplus extraction effect. The second, as mentioned above, is that the firms will compete consumer by consumer when they use first-degree price discrimination – the intensified competition effect.[11]

In the first part of our paper the pricing mechanisms are exogenously given, and we compare the following three cases; (i) both firms set a linear price, (ii) both firms use first-degree price discrimination, and (iii) one firm sets a linear price and one firm uses first-degree price discrimination. We analyse a two-stage game where the firms choose the degree of compatibility *prior* to the price competition. The timing structure is similar to Foros and Hansen (2001), but we investigate the effects on the compatibility choice of different pricing mechanisms. We show that:

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[7] See e.g. Shapiro and Varian (1998), Varian (2001), Bakos (2001) and Borenstein and Saloner (2001) for discussions and applications of price discrimination in the Internet.

[8] We assume horizontal differentiation similar to several recent studies of the competition in the telecommunication market, e.g. Laffont, Rey and Tirole (1998a, 1998b). See Foros and Hansen (2001) and Ulph and Vulkan (2000a, 2000b) for a motivation of the assumption of horizontally differentiated goods in our context.

[9] By modelling competition à la Hotelling the market size (the number of consumers) is given. Hence the model is more realistic for mature markets, such as the market for Internet services and mobile telephony in the Scandinavian countries, than for markets where the providers' main focus is to attract new consumers to the industry.

[10] In an extension, Ulph and Vulkan (2000b), they assume that the providers also have the ability to mass customisation of the services.

[11] They show that as long as the transport costs are not too convex, the intensified competition effect dominates the enhanced surplus extraction effect. Hence, in such case the firms prefer to use linear prices rather than first-degree price discrimination. However, the worst case for the firms is to use linear pricing when the rival uses first-degree price discrimination.

i. When the firms use symmetric pricing mechanisms, they will agree upon complete compatibility as long as the cost of a compatibility agreement is not too high.

ii. When the firms use asymmetric price mechanisms, both firms will choose low compatibility even if the compatibility agreements are costless.

When the degree of compatibility increases, the consumers' willingness to pay increases. Furthermore, an increase in the degree of compatibility implies that the advantage from having a large market share decreases. If the firms agree upon complete compatibility, the consumers are indifferent with respect to firms' market shares when they choose between the two firms' services. Hence, in order to dampen the competitive pressure firms that are using symmetric pricing mechanisms choose to set complete compatibility. In contrast, when only one of the firms uses price discrimination, the market share to the firm that uses price discrimination increases when compatibility is reduced. Hence, the firm that uses price discrimination prefers to degrade off-net quality in order to gain an advantage from a larger market share than the rival. The firm that is using a linear price will have zero profit independent of off-net quality when the rival uses price discrimination.

Hence, in contrast to the existing literature, which is focusing on that the larger firm has lower incentives to become compatible than the smaller one (e.g. Katz and Shapiro (1985) and Crémer, Rey and Tirole (2000)), low degree of compatibility may be a result of asymmetric pricing mechanisms. Moreover, we show that the network effects will intensify competition such that the price will be set below costs for the consumers that are relatively indifferent between the two suppliers (i.e. consumers located in the middle of the Hotelling line). The observation of network services sold below costs is usually explained by penetration pricing, where a firm may find it profitable to set the price below costs in one period in order to obtain a critical mass. Thereby, the firm can obtain larger profit in subsequent periods (see Shapiro and Varian (1998) for examples). In contrast, given that the firms choose not to be compatible, we show that price below costs to some consumers may be the result in a simple static model with network effects. When the services offered by the two providers are not completely compatible, the consumers' valuation of the service from one provider increases when one more consumer buys the same service. Hence, to consumers relatively indifferent between the services, the providers may be willing to sell their services even when they do not cover their costs. The reason is that the provider then can extract larger surplus from the other consumers it serves.

In the second part of the paper we endogenize the pricing mechanism choice – i.e. whether the firms will implement first-degree price discrimination mechanisms or not. When the costs of compatibility are negligible, we find that there will be multiple equilibria. However, as long as the firms are able to coordinate on the *Pareto-superior* outcome, both firms set linear prices and complete compatibility. This will be the case regardless of whether pricing mechanism is set *prior* to compatibility or the two choices are taken simultaneously. When the cost of compatibility is high, such that the firms always choose to be incompatible, the outcome where both firms use price discrimination may be a unique equilibrium.

The model

In our basic model we assume that the pricing mechanism is exogenously given, and we analyse the following two-stage game:

Stage 1: The firms set the degree of compatibility between their networks.

Stage 2: The firms compete à la Hotelling. Here we compare three cases: (i) both firms use a linear price, (ii) both firms use first-degree price discrimination, and (iii) only one firm uses first-degree price discrimination.

In the next section we analyse the case where also the pricing mechanism is endogenously set by the firms.

The supply side

We consider a case where two firms (*a* and *b*) offer a service differentiated along the unit interval à la Hotelling. The locations of the firms are fixed at the extremes of this unit line. Firm *a* is located at $x=0$ and firm *b* is located at $x=1$. Each firm offers a single service. At stage 1 the firms choose the degree of compatibility or the quality *k* of off-net communication, such that $0=\underline{k}\leq k\leq\overline{k}=1$. The quality of on-net communication $\overline{k}=1$ is fixed. Furthermore, the quality of off-net communication without any agreement between the firms is $\underline{k}=0$ ("a walled garden strategy")..

We assume that the firms have the ability to employ technologies that allow them to practice first-degree price discrimination (see Ulph and Vulkan, 2000a). If they use first-degree price discrimination, they compete for each individual consumer with the price schedule $p_i(x)$ where $i=a,b$. If they do not use first-degree price discrimination, they set a linear price for all *x* such that $p_i(x)=p_i$. The marginal cost of producing one unit of the service is *c*, and *c* is independent of the degree of compatibility. At stage 1 the cost of compatibility (off-net quality) is *F*. We assume that *F* is independent of the degree of compatibility, such that as long as $k>0$ the investment in interconnection quality is $I(k)=F$, where $F\geq 0$.[12]

The demand side

The preferences of consumers are assumed to be distributed uniformly with density 1 on a line of length 1. The location of preferences on the unit line indicates the most preferred network type for each consumer. Net utility for a consumer located at *x* connected to supplier *a* is (analogous for firm *b*):

$$(1)\quad U_a=v-tx+\beta(n_a+kn_b)-p_a(x)$$

The two first terms are similar to the conventional Hotelling model, where the first term is a fixed advantage *v* of being connected to the network. The second term is the disutility from not consuming the most preferred network type (the transportation cost in the standard Hotelling model). The transportation cost is proportional to the

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[12] For convex investment cost such that $I'(k)>0$ and $I''(k)>0$, see Foros and Hansen (2001). If we introduce costs associated with increasing off-net quality we may have an interior solution with respect to off-net quality. However, this will not change our results qualitatively.

distance from the firms. Hence, for a consumer located in x the transportation cost to firm a is tx and the transportation cost to firm b is $t(1-x)$. When the parameter t is high, then the consumers' tastes differ significantly. In contrast, when t is reduced, the services become closer substitutes.

The third term, $\beta(n_a + kn_b)$, is a utility term that depends on the number of on-net and off-net consumers. Firm a serves the portion n_a of the consumers, while firm b serves the portion n_b of the consumers. The parameter β is indicating how important the quality-adjusted network size is. A high β will be the case if the main attribute of the network is to facilitate people-to-people communication.[13] If β is low, then the consumers do not care so much about how many other people that are connected to the networks. A low β may be realistic if the main attribute of the services offered is to give access to the open Internet.[14] Furthermore, we see that the consumers' net utility is increasing in k. The fourth term is the price, and the consumers' utility functions are accordingly linear in consumption of the network service and money.

We make the following three assumptions:

Assumption 1: *We assume that each of the consumers 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 of being connected to either network is sufficiently large such that* $n_a + n_b = 1$.

Assumption 2: *There exists one consumer in market equilibrium located at x, where 0 < x < 1, who is indifferent between consuming the network service from the two firms.*

Assumption 3: *Equilibrium quality of off-net communication (the level of k) is equal to the level chosen by the firm that values off-net quality the least.*

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[13] As mentioned above, indirect network effects may also have similar effects.

[14] This may also be realistic for services offered by e-commerce providers in competition with bricks and mortar firms. Ulph and Vulkan (2000a) focus on e-commerce, and hence it may be realistic in their context to assume that the consumers' preferences for people-to-people communication are negligible.

Assumption 1 ensures that there will be no uncovered interval in the middle of the Hotelling line, called market coverage. Assumption 2 ensures market sharing so that both firms are active in the market. Assumption 3 means that if firm *a* prefers *k=1* while firm *b* prefers *k=0*, the equilibrium will be k=0.[15] In the first part, where pricing mechanism is exogenously given, the firms always agree on the off-net quality level. Hence, assumption 3 is not binding.

In the appendix we show that in order to ensure Assumption 2, we have to have some restrictions on the parameters *t*, β and *k*. In particular, we show that a sufficient, but not necessary, condition for this assumption is that $t > 2\beta(1-\underline{k})$. Furthermore, we show that the restrictions are stronger when one or both of the firms use price discrimination compared to the situation where both firms use linear pricing.

We define a generalised price for the consumer located in *x* of buying from firm *a* (analogous for firm *b*):

$$\widetilde{p}_a(x) = p_a(x) + tx - \beta(n_a + kn_b)$$

The consumer located in *x* buys from the firm with the lowest generalised price. By denoting this price $\widetilde{p}(x)$ we have the following:

$$\widetilde{p}(x) = \min[\widetilde{p}_a(x), \widetilde{p}_b(x)]$$

Benchmark: Both firms set a linear price

In this section we reproduce the results in Foros and Hansen (2001). Assumptions 1 and 2 imply that $\widetilde{p}_a = \widetilde{p}_b$.[16]

Stage 2:

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[15] This is similar to Crémer, Rey and Tirole (2000) and Foros and Hansen (2001).

[16] The generalised price for firm *a* (analogous for firm *b*) is now $\widetilde{p}_a = p_a + tx - \beta(n_a + kn_b)$.

The demand for firm *a* is given by $n_a = x = 0.5 - (p_a - p_b)/(2(t - \beta(1-k))$ (analogous for firm *b*). Hence, the profit for firm *a*:

$$\pi_a = (p_a - c)\left[0.5 - (p_a - p_b)/(2(t - \beta(1-k))\right]$$

The first order conditions give the following equilibrium price and quantity:

$$p_a^* = p_b^* = c + t - \beta(1-k) \text{ and } n_a^* = n_b^* = 0.5$$

Stage 1:

From the above we note that the equilibrium price increases with *k* ($\partial p / \partial k > 0$). This is due to the fact that an increase in *k* increases the consumers' willingness to pay and dampens the competitive pressure.

By inserting stage 2 equilibrium price into the profit function of firm *a* we have the following:

$$(2) \qquad \pi_a = (t - \beta(1-k))/2$$

We then see that $\partial \pi_a / \partial k > 0$ and $\partial^2 \pi_a / \partial k^2 = 0$, and firm *a* (and analogous for firm *b*) sets *k=1* as long as:

$$\pi_a(k=1) - \pi_a(k=0) = \beta/2 - F \geq 0.$$

We summarise the results where both firms set a linear price in the following lemma:

Lemma 1: *When both firms set a linear price, the price competition is less aggressive the higher the degree of compatibility is between the firms. Hence, as long as the fixed cost of an agreement on compatibility is not too high, the firms will set the same quality for on-net and off-net communication.*

Both firms use first-degree price discrimination

In a context where both firms use first-degree price discrimination we will see a Bertrand game for every consumer. Ulph and Vulkan (2000a) show that without network effects, the price will be set equal to *c* for the marginal consumer. Hence, for the marginal consumer, which in this case is located in the mid-point, the conventional Bertrand solution gives price equal to marginal costs without network effects.

Stage 2:

With network effects, and given that the quality of on-net communication is higher than the quality of off-net communication, the competition will be even harder since the firms will have a gain from the infra-marginal consumers when they capture the marginal consumer. Firm *a* will capture an extra revenue $[\beta(1-k)n_a]$ from its n_a consumers when it captures one more consumer. Hence, to the marginal consumer, firm *a* is willing to set the price $p_a(x) = c - \beta(1-k)n_a$.

Let us focus on the competition for a consumer located at $0 < x < 0.5$, in which case firm *a* has an advantage in serving consumer *x*. The generalised price from firm *b* is $\tilde{p}_b(x) = p_b(x) + t(1-x) - \beta(n_b + kn_a)$. In order to capture the consumer, firm *a* has to ensure that $\tilde{p}_a(x) \leq \tilde{p}_b(x)$. Inserting for $\tilde{p}_a(x)$ and $\tilde{p}_b(x)$ gives:

$$p_a(x) \leq p_b(x) + t(1-2x) + \beta(1-k)(n_a - n_b)$$

Firm *b* is willing to charge a price equal to or higher than $p_b(x) = c - \beta(1-k)n_b$, and if we insert for this we have:

$$p_a(x) \leq c + t(1-2x) + \beta(1-k)(n_a - 2n_b)$$

Hence, in the interval $0 \leq x \leq 0.5$ firm *a* sets the following price schedule:

$$p_a(x) = c + t(1-2x) + \beta(1-k)(n_a - 2n_b) - \varepsilon$$

The parameter ε has a positive arbitrary small value. Both firms are willing to set the price $p_i(x) = c - \beta(1-k)n_i$ to serve the marginal consumer. Hence, by inserting for $n_a = x \ and \ n_b = 1-x$ we find $n_a^* = n_b^* = 0.5$, which means that the marginal consumer is located in the mid-point. The price to the marginal consumer is then $p_a^*(0.5) = c - 0.5\beta(1-k)$.

Proposition 1: *Assume that both firms use first-degree price discrimination, that there are network effects, and that the quality of off-net communication is lower than the quality of on-net communication, i.e.* $k < 1$. *In this case the price to the consumers located in the middle of the unit line will be below marginal cost.*

Hence, we can give an alternative explanation of the observation that some consumers are offered network services below costs. Even in a static game consumers that are relatively indifferent between competing services may be offered a price below costs.

Moreover, Ulph and Vulkan (2000a) show that without network effects, the price to the consumers consuming their most preferred service will be equal to the price in the previous case where both firms use a linear price. This result does not hold with network effects if $k < 1$. Now, we see that as long as $n_a^* = n_b^* = 0.5$, the price to the consumer located at $x=0$ is $p_a^*(0) = c + t - 0.5\beta(1-k)$ while the linear price was $p_a^* = c + t - \beta(1-k)$.

Stage 1:

Using $n_a = n_b = 0.5$, we find the profit for firm *a* (analogous for firm *b*):

$$(3) \qquad \pi_a = (t - \beta(1-k))/4$$

Comparing equations (2) and (3) we see that the profit when both firms use price discrimination is one-half of the profit when both firms set linear prices.[17] Analogous to the previous case we have that $\partial \pi_a / \partial k > 0$ and $\partial^2 \pi_a / \partial k^2 = 0$. Hence, the firms set $k=1$ as long as:

$$\pi_a(k=1) - \pi_a(k=0) = \beta/4 - F \geq 0$$

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[17] This result is similar to the case without network effects analyzed by Ulph and Vulkan (2000a).

Only one of the firms uses first-degree price discrimination

Now the two competing firms use different pricing mechanisms. We assume that firm *a* sets a per-consumer price $p_a(x)$ and firm *b* sets the linear price $p_b \geq c$.

Stage 2:

A consumer located in *x* buys from firm *a* as long as $\tilde{p}_a(x) \leq \tilde{p}_b$, which implies that:

$$p_a(x) + tx - \beta(n_a + kn_b) \leq p_b + t(1-x) - \beta(n_b + kn_a)$$

This can be rearranged to

$$(4) \qquad p_a(x) \leq p_b + t(1-2x) + \beta(1-k)(n_a - n_b)$$

Firm *a* makes a profit as long as $p_a(x) \geq c - \beta(1-k)n_a$. We define $\tilde{x}(p_b)$ as the location of the marginal consumer served by firm *a* (located with the furthest distance from firm *a*) for a given p_b. Firm *a* will serve all consumers between 0 and $\tilde{x}$. We may insert for $n_a = \tilde{x}(p_b)$ and $n_b = 1 - \tilde{x}(p_b)$ into equation (4) to find the price schedule for all consumers located in the interval $0 \leq x < \tilde{x}(p_b)$:

$$(5) \qquad p_a(x) = p_b + t(1-2x) + \beta(1-k)(2\tilde{x}(p_b) - 1)$$

The price to the marginal consumer served by firm *a* is given by:

$$(6) \qquad p_a(\tilde{x}) = c - \beta(1-k)\tilde{x}(p_b).$$

In order to find $\tilde{x}(p_b)$ we insert equation (6) into equation (5):

$$(7) \qquad \tilde{x}(p_b) = \frac{p_b - c + (t - \beta(1-k)}{(2t - 3\beta(1-k))}$$

Hence, $\tilde{x}(p_b)$ is increasing in p_b and decreasing in *k*. As long as $p_b > c$ and/or $k < 1$, we see that $\tilde{x}(p_b) > 0.5$. Analogous to Ulph and Vulkan (2000a) we now show that there exists a unique Nash-equilibrium where:

$$(8) \qquad p_b^* = c$$

$$(9) \qquad p_a^*(x) = \begin{cases} c + t(1-2x) + \beta(1-k)(2\tilde{x}(c)-1) - \varepsilon, & for\, 0 \le x \le \tilde{x}(c) \\ c + t(1-2x) + \beta(1-k)(2\tilde{x}(c)-1) + \varepsilon, & for\, \tilde{x}(c) < x \le 1 \end{cases}$$

The price schedule for firm *a* is then as illustrated in figure 1. In figure 1a we have the situation discussed by Ulph and Vulkan (2000a), where there are no network effects (*k=1* or $\beta = 0$). In figure 1b we have the situation with network effects (*k<1* and $\beta > 0$). The solid lines indicate the price schedule to the consumers served by firm *a*, while the dotted lines indicate the price schedule firm *a* offers to consumers served by firm *b*. In the case without network effects, the price from firm *a* to the consumer located at 0 is $c+t$ (see figure 1a). The profit for firm *a* is then the area *A*, while firm *b* has zero profit. In contrast, if there are network effects the profit for firm *a* is the area (A-B+C).

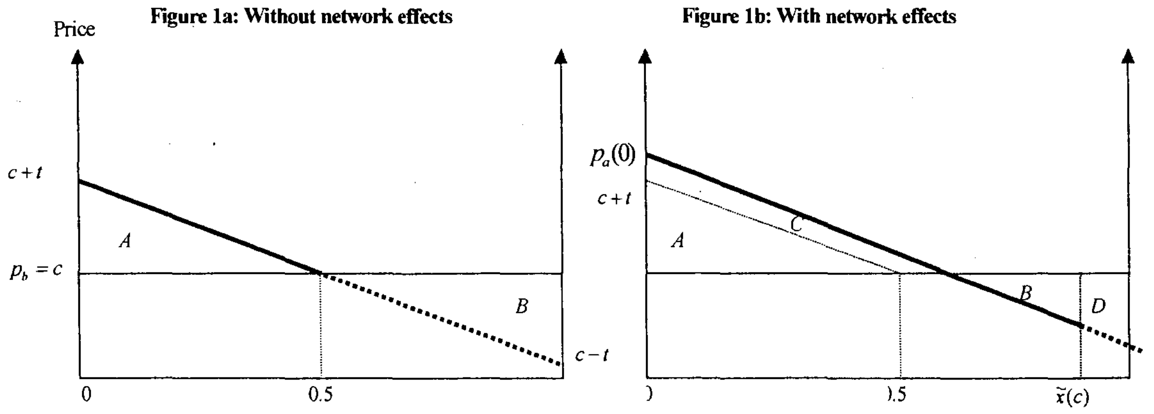
Figure 1a: Without network effects

Figure 1b: With network effects

Figure 1: The price schedule offered by firm A when k=1 (1a) and k<1 (1b).

The proof of this equilibrium is straightforward, and is analogous to the case without network effects given by Ulph and Vulkan (2000a). First, for the price schedule given by equation (9) for firm *a*, firm *b* has no incentives to set p_b>*c*. The profit will be zero in any case. Second, we show by contradiction that no price $\bar{p}_b$>*c* can be part of the equilibrium. If firm *a* sets $p_a(x) = \bar{p}_b + t(1-2x) + \beta(1-k)(2\tilde{x}(\bar{p}_b)-1)$ where $\bar{p}_b$>*c* , firm *b* will always have incentives to set $p_b = \bar{p}_b - \varepsilon > c$ and capture the whole market. Hence p_b>*c* cannot be part of the equilibrium. A more formal proof is given by Ulph and Vulkan (2000a) for the case without network effects.

Without network effects there may obviously be a question of how plausible this outcome will be. Why should firm *a* set the price schedule in (9) in the interval served by firm *b* ($\tilde{x}(c) < x \leq 1$)? From figure 1a we see that any out-of equilibrium moves from firm *b* such that $p_b > c$ implies that the profit to firm *a* will be zero, since *A-B=0*. The same question may be raised with network effects (*k<1*), but now the consequences of an out-of-equilibrium move from firm *B* are less severe. It is now optimal for firm *a* to serve some consumers at a price below marginal cost, and then have a loss equal to area *B*. If firm *b* now sets $p_b > c$, firm *a* has to serve all consumers. This implies a loss equal to area *D* in figure 1b. But when $\tilde{x}(p_b)$ approaches to 1, the willingness to pay increases for all consumers of firm *a*. Hence, the price schedule illustrated in figure 1b will shift upwards, and this will increase the area *C*. Therefore, it seems more plausible that firm *a* will set a price schedule shown by the dotted line (see equation (9)) to the consumers served by firm *b* if we are in figure 1b than in 1a.

We then set $p_b^* = c$ and have the following:

$$(10) \qquad \tilde{x}^*(c) = (t - \beta(1-k))/(2t - 3\beta(1-k))$$

Inserting equation (10) into equation (9) gives:

$$p_a^*(x) = c + t(1-2x) + \beta(1-k)\frac{\beta(1-k)}{2t - 3\beta(1-k)}$$

The price for the consumer located at $\tilde{x}$ *(c)* is:

$$p_a^*(\tilde{x}) = c - \beta(1-k)\frac{t - \beta(1-k)}{2t - 3\beta(1-k)}$$

We find the location of the consumer that buys from firm *a* at a price equal marginal cost:

$$p_a(\hat{x}) = c \Rightarrow \hat{x} = 0.5 + \left[\frac{\beta(1-k)}{2t}\right]\left[\frac{\beta(1-k)}{2t - 3\beta(1-k)}\right]$$

All consumers located in the interval ($\tilde{x}-\hat{x}$) are buying from firm *a* at a price below marginal cost c. We find that

$$\tilde{x}-\hat{x}=\left[\frac{\beta(1-k)}{2t}\right]\left[\frac{t-\beta(1-k)}{2t-3\beta(1-k)}\right]$$

The profit for firm *b* is obviously zero, and the profit for firm *a* is:

$$(11) \qquad \pi_a=[p_a(0)-c]\left[\frac{\hat{x}}{2}\right]+[p_a(\tilde{x}(c))-c]\left[\frac{\tilde{x}(c)-\hat{x}}{2}\right]$$

We illustrate the profit for firm *a* in figure 2. The first term in equation (11) is equal to *(A+B+C)* in figure 2, while the second term in equation (11) is equal to *D* (such that $\pi_a = A+B+C-D$). The first term *A* is equal to the profit level where both firms use first-degree price discrimination and set *k=1*. Hence, we have that *A=t/4* (see equation (3)). The second term *B* is the increased profit from the consumers in the interval [0,0.5] when $\tilde{x}(c) > 0.5$ and $k < 1$. The third term *C* is the profit from the consumers in the interval $0.5 < x < \hat{x}$ that pay a price above marginal costs. The last term *D* is the loss from the consumers in the interval $\hat{x} \le x \le \tilde{x}(c)$ that pay below marginal cost.

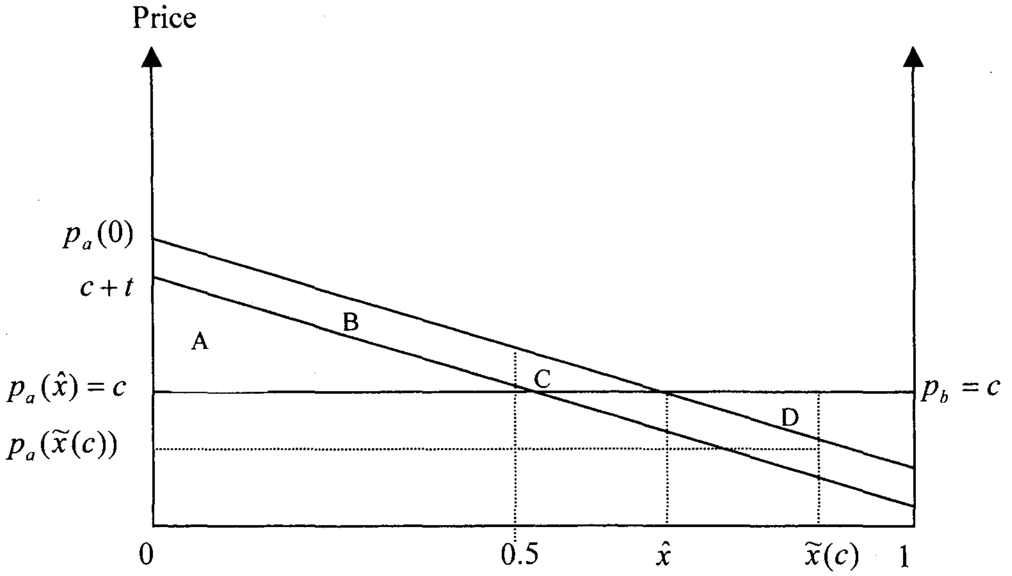

Figure 2: Profit for firm A under asymmetric pricing mechanism.

Stage 1:

If we insert for $p_a(0), p_a(\tilde{x}(c)), \hat{x}$, and $\tilde{x}(c)$ into (11) we have:

$$\pi_a = \frac{t}{4} + \Delta \text{ where } \Delta = \left[\frac{\beta^2(1-k)^2}{4(2t-3\beta(1-k))^2}\right][3t - 4\beta(1-k)]$$

We see that if *k=1*, then Δ=0 since *B=C=D=0*. Then the profit of firm *a* is similar to the case where the rival uses first-degree price discrimination too. In contrast, we show in the appendix that Δ>0 as long as *k<1*. Furthermore we show that $\partial\Delta/\partial k < 0$, such that firm *a* in this case prefers to set *k=0*. When *k=0*, the profit level of firm *a* is:

$$\pi_a(k=0) = \frac{t}{4} + \frac{\beta^2}{4(2t-3\beta)^2}(3t-4\beta) \geq \frac{t}{4}$$

Then we see that the degree of compatibility will be lower when the firms use asymmetric price mechanisms as compared to the case where they use symmetric price mechanisms:

Proposition 2: *If one firm uses first-degree price discrimination and one firm uses a linear price, the firm that uses price discrimination will set k=0 even if compatibility costs are zero. The firm that sets a linear price will in this case always have zero profit and is indifferent to the level of compatibility as long as the cost of compatibility is zero. If there is an* ε *cost of compatibility, the firm that uses a linear price wishes to set k=0.*

Furthermore, when the degree of compatibility is not complete, the firm that uses first-degree price discrimination will prefer that the rival sets a linear price. The reason is that if the rival uses a linear price it will not set its price below costs. In contrast, if the rival is using first-degree price discrimination, it will set price below costs for the consumers in the middle of the line. This is in contrast to the case without network effects shown by Ulph and Vulkan (2000a). They show that without network effects the profit of the firm that chooses to use first-degree price discrimination is independent of the pricing strategy used by its rival.

Proposition 3: *When k=1, the firm that is using price discrimination will obtain the same profit level as in the case where both firms use first-degree price discrimination.*

This reproduces the results in Ulph and Vulkan (2000a). In contrast, if $k<1$, the profit of the firm that is using first-degree price discrimination is higher if the rival uses a linear price compared to the case where the rival uses first-degree price discrimination too.

The choice of pricing mechanism

In stage 2 in the model we have analysed three different cases – both firms set a linear price (LP), both firms use first-degree price discrimination (PD), and only one firm uses first-degree price discrimination. We have assumed that the price mechanism – LP or PD – is exogenously given. In this section we assume that price mechanism (LP or PD) is set endogenously by the firms. From the previous section we know that the firms will set $k=1$ or $k=0$.

Concerning the timing structure we analyse two cases:

i. First, we assume that the choice between LP or PD is taken *prior* to the compatibility choice. Put differently, the price mechanism is determined at stage 0.

ii. Second, we assume that the firms choose price mechanism (LP or PD) and compatibility ($k=1$ or $k=0$) simultaneously at stage 1.

With respect to the cost of off-net quality we also consider two cases:

i. First, we assume that the cost of a compatibility agreement with respect to off-net quality is small, i.e. $F=\varepsilon$.

ii. Second, we assume that the cost of off-net quality, F, is so high that the firms prefer low off-net quality ($k=0$) even in the case where both firms use linear pricing. Then the firms set $k=0$ independent of timing structure and pricing mechanism.

At first glance it may seem reasonable to believe that the choice of compatibility must be made *prior* to the choice of pricing mechanism, i.e. whether the firm should use first-degree price discrimination or a linear price. However, we argue that the opposite is more realistic. The choice of compatibility in our context, or the quality level of off-net communication compared to on-net communication quality, is much more a choice of signing a contract or not with your rival than it is a choice of implementing a new technology. This will certainly be true when you already have implemented the on-net quality such as modeled here (i.e. $k=1$ for on-net communication). For instance, the degree of off-net quality may be to what extent you give your rival's consumers access to all the content located on servers in your network at the same conditions (price and quality) as those given to your own consumers. The choice of implementing first-degree price discrimination is much more a question of adopting personalisation technologies or not. But even if the physical costs of implementing compatibility are low, there may be significant costs of signing a contract (a costly monitoring system may also be needed). Hence, the total cost of compatibility, F, may be high.

Then we have three different cases. First, we assume low cost of off-net quality and the choice of pricing mechanism is taken *prior* to off-net quality. Second, we assume low cost of off-net quality and pricing mechanism and off-net quality are set simultaneously. Third, we assume that F is so high that $k=0$.

Low cost of compatibility

Price mechanism is set *prior* to compatibility

We have shown that given low cost of compatibility firms that are using a symmetric pricing mechanism choose to set the same quality for off-net as for on-net communication ($k=1$). In contrast, they set $k=0$ if they choose asymmetric pricing mechanisms. If the choice between *LP* and *PD* is taken *prior* to the choice of *k=1* or *k=0* we have the following normal-form representation of the game (at stage 0):

Firm B

		LP	PD
Firm A	LP	$\frac{t}{2}-\varepsilon, \frac{t}{2}-\varepsilon$	$0, \frac{t}{4}+\Delta$
	PD	$\frac{t}{4}+\Delta, 0$	$\frac{t}{4}-\varepsilon, \frac{t}{4}-\varepsilon$

Figure 3: Normal-form game when price technology is set prior to the compatibility choice.

In the appendix we show that $t/2 \geq t/4+\Delta$ as long as Assumption 2 is fulfilled (i.e. $t \geq 2\beta$ in this case). Hence, there are two Nash-equilibria in pure strategies, i.e. (*LP, LP*) and (*PD, PD*). Both firms prefer (*LP, LP*) to (*PD, PD*), and we may expect that they will be able to coordinate on (LP, LP).

Price mechanism and compatibility are set simultaneously

Now assumption 3 is binding, and the quality level is equal to the level chosen by the firm that values off-net quality the least. If the choice between *LP* or *PD* and *k=1* or *k=0* are taken simultaneously at stage 1 we have the following normal-form representation of the game:

Firm B

		LP, k=0	LP, k=1	PD, k=0	PD, k=1
	LP, k=0	$\frac{t-\beta}{2}, \frac{t-\beta}{2}$	$\frac{t-\beta}{2}, \frac{t-\beta}{2}-\varepsilon$	$0, \frac{t}{4}+\Delta$	$0, \frac{t}{4}-\varepsilon$
Firm A	LP, k=1	$\frac{t-\beta}{2}-\varepsilon, \frac{t-\beta}{2}$	$\frac{t}{2}-\varepsilon, \frac{t}{2}-\varepsilon$	$0-\varepsilon, \frac{t}{4}+\Delta$	$0-\varepsilon, \frac{t}{4}-\varepsilon$
	PD, k=0	$\frac{t}{4}+\Delta, 0$	$\frac{t}{4}+\Delta, 0-\varepsilon$	$\frac{t-\beta}{4}, \frac{t-\beta}{4}$	$\frac{t-\beta}{4}, \frac{t-\beta}{4}-\varepsilon$
	PD, k=1	$\frac{t}{4}+\Delta-\varepsilon, 0$	$\frac{t}{4}-\varepsilon, 0-\varepsilon$	$\frac{t-\beta}{4}-\varepsilon, \frac{t-\beta}{4}$	$\frac{t}{4}-\varepsilon, \frac{t}{4}-\varepsilon$

Figure 4: Normal-form game when price technology and compatibility are set simultaneously.

In this game there are four Nash-equilibria in pure strategies, i.e. (*LP(k=0), LP(k=0)*), (*LP(k=1), LP(k=1)*), (*PD(k=0), PD(k=0)*) and (*PD(k=1), PD(k=1)*). Analogous to the previous case we see that (*LP(k=1), LP(k=1)*) is *Pareto-superior* to the other outcomes.

We see that (LP(k=0), LP(k=0)) is a Nash-equilibrium only if $\pi_i(LP(k=0), LP(k=0)) \geq \pi_i(PD(k=0), LP(k=0))$. This condition holds if $t/4-\beta/2+\Delta \geq 0$. In the appendix we show that (LP(k=0), LP(k=0)) is a Nash-equilibrium only if $t \geq (2+0.5\sqrt{2})\beta$. Furthermore, note that if $\varepsilon=0$ then the strategy (LP(k=0), LP(k=0)) is (weakly) dominated by the strategy (LP(k=1), LP(k=1)). In equilibrium dominated strategies will never be used. When the costs of compatibility are negligible, we see that the firms prefer that both firms set linear prices and complete compatibility both when pricing mechanism is set *prior* to compatibility, and when these two choices are taken simultaneously.

High costs of compatibility

We now assume that the costs of compatibility, *F*, are so high that *k=0* is chosen independent of pricing mechanism. Then we have the following normal-form representation of the game when the firms choose between LP and PD.

Firm B

		LP	PD
Firm A	LP	$\frac{t-\beta}{2}, \frac{t-\beta}{2}$	$0, \frac{t}{4}+\Delta$
	PD	$\frac{t}{4}+\Delta, 0$	$\frac{t-\beta}{4}, \frac{t-\beta}{4}$

Figure 5: Normal-form game when the costs of compatibility are high.

When $(t-\beta)/2 \ge (t/4+\Delta)$, we see that both (LP, LP) and (PD, PD) are Nash equilibria. Above we have shown that $(t-\beta)/2 \ge (t/4+\Delta)$ if $t \ge (2+0.5\sqrt{2})\beta$. In contrast to the previous cases we now have a unique Nash equilibrium (PD, PD) if $2\beta \le t \le (2+0.5\sqrt{2})\beta$. Hence, in this case we end up in a prisoner's dilemma where (PD, PD) is a unique equilibrium even if both players would have been better off with (LP, LP). The intuition for this can be seen from Proposition 3. When *k=0* the gain from being the only firm that using price discrimination is high. At the same time, as long as *k=0* also when both firms are using linear pricing, there is no loss in interconnection quality when moving from a symmetric case to an asymmetric case.

We can summarise the results regarding the choice of pricing mechanism in the following proposition:

Proposition 4: *When the pricing mechanisms are set endogenously by the firms, we have that:*

i) *Both firms prefer the combination of complete compatibility and linear pricing to all other possible outcomes as long as the cost of compatibility is not too high.*

ii) *If there are significant costs of compatibility, the firms will have lower quality of off-net communication compared to on-net communication. Then there may be a unique equilibrium where both players use price discrimination. This will be a prisoner's dilemma since both players would have been better off if both players used linear pricing.*

Concluding remarks

In the market for digital network services such as Internet services and mobile telephony, consumers' utility does not only depend on the quality of communication in the network they are subscribing to (on-net quality). The consumers' utility and, hence, willingness to pay, also depends on the off-net quality of communication, i.e. the interconnection quality between different networks. When the firms that are controlling different networks compete over the same consumers, the off-net quality of communication becomes an important strategic variable.

In this paper we show that even if the firms do not differ in size, the firms may have incentives to reduce the off-net quality if they use different pricing mechanisms. We show that if one of the firms uses first-degree price discrimination, while the rival uses a linear price, the firms will have lower incentives to be compatible than if they use similar pricing mechanisms, i.e. both use a linear price or both use first-degree price discrimination. When the pricing mechanisms are set endogenously by the firms, we show that both firms prefer the combination of complete compatibility and linear pricing to all other possible outcomes as long as the cost of compatibility is not too high. If there are significant costs of compatibility, the firms will have lower quality of off-net communication compared to on-net communication. In such a context we show that there may be a unique equilibrium where both players use price discrimination. Furthermore, this will be a prisoner's dilemma since both players would have been better off if both players used linear pricing.

We have analysed the possibility to use a personalised price (first-degree price discrimination) in a competitive environment. However, the providers are assumed not to personalise the services, since they offer only one service each. A potential extension will be to analyse whether the ability to offer personalised services to each consumer (mass-customisation) will change the compatibility choice. Ulph and Vulkan (2000b) analyse a case without network effects, but where the firms have the ability to locate in an interval of the Hotelling line.

Another potential extension is to analyse the robustness of the equilibrium where only one of the two firms uses price discrimination. In order to ensure an equilibrium in pure strategies the price schedule offered by the firm that uses price discrimination has to force the rival to set the price equal to marginal cost. This seems counterintuitive since an accommodation strategy implies that the firm would try to soften the competition. However, price equal to marginal cost of the firm that uses a linear price is the only candidate for an equilibrium in pure strategies. We have assumed that the two firms set their prices simultaneously also when they use different price strategies. In this case, it may be interesting to see what happens if the prices are set sequentially. Since the equilibrium in our model implies a price equal to marginal cost for the firm that is using linear pricing, any alternative equilibrium with price above marginal cost would imply higher profit to both firms. Hence, when we consider whether the firms choose to use a linear price or first-degree price discrimination, our results are more robust when the equilibrium strategies imply that the firms use price discrimination compared to the case where they choose linear pricing.

Appendix

A1: Assumption 2

In assumption 2 we have assumed that there exists one consumer in market equilibrium located at x, where $0 < x < 1$, who is indifferent between consuming the network service from the two firms. We now show that the condition ensuring this depends on the pricing schedule set by the firm:

First, if both firms set a linear price, the condition is $t-\beta(1-k)>0$. This can be seen by the following: Assume that almost all consumers along the line buy from B. The consumer with the longest travelling distance to B is located in x=0. He compares the offers from A and B and buys from A if: $v+\beta(0+\underline{k})-p_a \geq v-t+\beta(1+\underline{k}0)-p_b$. For any given $p_b \geq c$, firm A will pick up the consumer located in x=0 by a price $p_a \geq c$ as long as this condition holds. Hence a sufficient condition to ensure market sharing is $t-\beta(1-\underline{k})>0$ when both firms set a linear price

Second, if both firms use first-degree price discrimination, and for some reason almost all consumers are buying from B, firm B is willing to set the price $p_b(0)=c-\beta(1-k)$ in order to capture the consumer located in 0, while firm A is willing to set $p_a(0)=c$. The consumer located at x=0 buys from A if $v+\beta(0+\underline{k})-c \geq v-t+\beta(1+\underline{k}0)-c+\beta(1-\underline{k})$. Hence, now a sufficient condition that ensures market sharing is $t-2\beta(1-\underline{k})>0$.

Third, if only firm A uses first-degree price discrimination, the sufficient condition that ensures that firm A will not monopolize the market is equivalent to the one above where both firms are price discriminating. The condition that ensures market sharing is stronger when at least one of the firms uses first-degree price discrimination compared to the case where both firms use linear pricing. Hence, a sufficient, but not necessary, condition to ensure that both firms are active in the market is that $t-2\beta(1-\underline{k})>0$.

A2: Show that $\Delta > 0$ if k<1

To ensure market sharing we have assumed $t \geq 2\beta$. We now define the following:

$$\Delta_1 = \left[\frac{\beta^2(1-k)^2}{4(2t-3\beta(1-k))^2}\right] \text{and } \Delta_2 = 3t - 4\beta(1-k)$$

Hence, $\Delta = \Delta_1\Delta_2$. We know that Δ=0 if *k=1*, and we see that $\Delta_1 > 0$ if *k<1*. We now show that $\Delta_2 > 0$ since $t \geq 2\beta$. QED.

A3: Show that $\partial\Delta / \partial k < 0$

$$\frac{\partial\Delta}{\partial k} = -\left[\left(\frac{3\beta^2(1-k)}{(2t-3\beta(1-k))^3}\right)\left(t(t-2\beta(1-k)) + \beta^2(1-k)^2\right)\right] < 0$$

This is negative since all terms the bracket are non-negative as long as $k \in [0,1]$. QED.

A4: Show that $t/2 > t/4 + \Delta$ when *k=0*

It is straightforward to show that $\partial\Delta / \partial\beta > 0$. Hence to show that $\frac{t}{2} - \frac{t}{4} + \Delta \geq 0$ we insert the highest possible value for β which is *t=2* β (Assumption 2). Then we have $\frac{t}{2} - \frac{t}{4} + \Delta = 0$. QED.

A5: The condition for $(t-\beta)/2 \geq t/4 + \Delta$ given that *k=0*

From A4 we know that we may have $\frac{(t-\beta)}{2} - \frac{t}{4} - \Delta < 0$. It is straightforward to show that $\frac{(t-\beta)}{2} - \frac{t}{4} - \Delta < 0$ when $2\beta \leq t < (2 + 0.5\sqrt{2})\beta$. Hence, $\frac{(t-\beta)}{2} - \frac{t}{4} - \Delta \geq 0$ as long as $t \geq (2 + 0.5\sqrt{2})\beta$. QED.

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Chapter 5

The Broadband Access Market: Competition, Uniform Pricing and Geographical Coverage *

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Abstract: In this paper we analyze the market for broadband access. A key feature of this market is that it is considerably more expensive to connect consumers in rural locations than in urban locations. We show that while competition increases welfare compared to monopoly when prices are free to differ across locations, the opposite may be true if there is a requirement of uniform pricing across locations. Furthermore, we show that given uniform pricing, the regulator may increase consumer surplus as well as profit by requiring a higher regional coverage than the market outcome.

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1 INTRODUCTION

Broadband access is the last mile of the high-speed information highway, and it is an essential component in order to access bandwidth-demanding services such as interactive video. The costs of providing broadband access are highly convex in the sense that it is considerably more expensive to connect consumers in areas with low population density than in areas with high population density. In a free market economy this cost structure might imply significantly higher access prices in rural areas than in urban areas. We have thus seen a political concern that peripheral locations will be harmed unless broadband access providers are required to charge the same price for the same service in all locations that they cover (uniform prices).[2] However, even though there may be implicit or explicit political requirements of uniform prices, the actual price level will hardly be regulated. Instead, as in other industries, governments seek to prevent unduly high prices by inviting several firms to compete (Laffont and Tirole, 2000). The purpose of the present paper is to investigate how this policy mix affects welfare and geographical coverage of broadband access.

When a firm builds a broadband access network it pushes optical fiber closer to the subscriber. The most common solution has been to build a fiber-optic line that serves a cluster of homes, and use the existing copper lines for "the last mile" (the telephone or cable-TV lines). This solution is called "fiber to the curb", and is much cheaper than building fiber-optic lines all the way to each subscriber (Clark 1999a, 1999b, Speta 2000a). In order to increase the quality (speed of communication) the provider has to employ fiber closer to homes. Hence, the cost of broadband access is increasing in quality. Moreover, within any given geographical radius, there is generally a lower number of homes in rural areas than in urban areas. Hence, it is

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[2] Universal Service Obligations (USO), for instance in the form of a requirement of uniform prices or a requirement of geographical coverage, have been imposed particularly on telecommunications incumbents for a long time (see, e.g., Riordan, 2001, and Valetti, 2000, for overviews).

more costly to provide a given quality in rural areas than in urban areas.

For low-end broadband technologies, such as ADSL and hybrid fiber-coax (HFC) networks, the curbs are used to serve a large number of homes.[3] For these technologies it seems realistic to assume that marginal connection costs are insignificant, but that there are large fixed costs involved in serving any given geographical area. In contrast, for high-end broadband technologies, and in particular for "fiber to the homes" solutions, the real bottleneck is the very last mile. In this case marginal costs are relatively high, especially in rural areas. We focus on high-end broadband technologies in this paper, and thus assume that marginal costs per consumer connected are significant, and higher the lower the population density. Moreover, we abstract from fixed geographical costs. The implications of this are discussed below.

Our model is complementary to those by Faulhaber and Hogendorn (2000) and Valletti, Hoernig and Barros (2002). Faulhaber and Hogendorn (2000) develop a model of competition among facility-based broadband providers, and use engineering data for an HFC network in a metropolitan area in the US. In contrast to ourselves, Faulhaber and Hogendorn do not focus on the issue of uniform pricing. Furthermore, while we assume that marginal connection costs increase when population density decreases, they assume that there is a fixed cost of serving a given area. As argued above, their assumption seems realistic when focusing on an HFC network. For the HFC networks built out by the cable-TV providers in the US in the late 1990's fiber was typically deployed to serve an area (neighborhood) of about 500-2000 homes (Gillett, 1997). When US cable providers (e.g., AT&T) are now migrating their HFC networks to "fiber to the curb", fewer subscribers are allowed to share the access network - typically from 20-200 homes (Gillett and Tseng, 2001). Therefore, when we move from low-end broadband technologies to high-end broadband technologies, the range within which the existing lines can be used is much lower, and it seems

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[3] xDSL are techniques allowing higher speed of access through the existing telephone lines by installing equipments in the homes and before the first switch. ADSL (Asymmetric Digital Subscriber Line) is the DSL-version that can use existing lines the longest distance. VDSL (Very high speed digital subscriber line) requires that the fiber line is much closer to homes, but also gives significantly higher speed of access.

to be more realistic to assume that a significant part of the cost is marginal per consumer connected.

Also Valletti et al. (2002) assume that there is a fixed cost per area and not per consumer connected, and thus focus on the market for low-end broadband technologies. Moreover, in contrast to ourselves, both Valletti et al. (2002) and Faulhaber et al. (2000) assume that the network is already installed in the actual area when the sale of broadband connection takes place. Hence, the investment costs are sunk. At first glance, it seems obvious that this is the most realistic description of the timing of the game. However, if this were true, and marginal costs are insignificant, much of the regulatory authorities' concern that an unregulated monopoly will set a higher price in rural areas than in urban areas will be needless (see Valletti et al. (2002) for a formal proof). But it is far from obvious that geographical coverage is set prior to prices. As long as there is no regulatory constraint on coverage, the coverage may in fact be set street-by-street, as argued by Faulhaber and Hogendorn (2000). In our context the coverage may even be set consumer-by-consumer. In such a context, the providers may try to write a contract with the consumers before they actually build fiber to homes or fiber to a curb near the homes. In the Scandinavian countries, for instance, we have seen that broadband providers advertise their services before they deploy the fiber. Hence, in our basic model we assume that coverage and prices are set simultaneously. Thereafter, we compare the basic model with a game where coverage is set prior to prices.

As a benchmark case we disregard the requirement of uniform pricing, and show that both a monopolist and oligopolistic firms have incentives to serve the socially optimal regional coverage. The reason for this result is that it is profitable to serve new locations until the last (i.e., the most expensive) location exactly breaks even. This is *de facto* the same decision as a hypothetical social planner would make. Abstracting from fixed costs the only effect of higher competition is reduced prices in all locations, and this unambiguously has a positive welfare effect.

Things change fundamentally when we impose a requirement of uniform pricing. First, it should be noted that the socially optimal regional coverage falls in this case. The intuition for this runs as follows: The fact that it is relatively inexpensive to serve consumers in locations with a high population density indicates that also the access price should be low. However, a low price induces too high demand in peripheral locations, where the real costs of providing broadband access are high. In order to reduce the magnitude of the latter effect, it is socially optimal not to serve some of the least populated areas. Thus, it is not certain that uniform pricing is a good regional policy.

Second, and this is our main result, increased competition need not improve welfare when we have a requirement of uniform prices. While a monopolist will still have incentives to set the same regional coverage as the social planner, the coverage level decreases if there is competition. Competition reduces prices, but herein lies, in a sense, also the problem: due to the convexity of the cost function, the lower market price makes it less profitable to serve peripheral locations. Competition therefore implies that the regional coverage falls to a sub-optimal level, and this negative welfare effect is more likely to dominate the larger the number of firms that offer broadband access. Consequently, welfare may be lower with free entry than if the market is served by a monopolist even when we abstract from possible duplication of fixed costs.

The fact that it is relatively more expensive to serve rural areas than urban areas is not unique for the broadband access technology. There is a similar cost structure also for, e.g., postal services and third generation mobile telephone systems (UMTS in Europe). In some countries (like France, Norway and Sweden) the governments have specified a minimum regional coverage by the firms that are granted UMTS licenses, and proposals have been advanced to specify similar requirements for firms providing broadband access.[4]

In an extension of the basic model we thus assume that the government is able to set a binding coverage requirement prior to downstream competition between the firms, and we show that this has a positive effect on aggregate consumer surplus.

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[4] There has not been raised any requirement of uniform pricing for UMTS. This is also not necessary, since uniform pricing will probably be the market outcome. The reason is that in the market for mobile phones arbitrage opportunities strictly reduce the providers' ability to set prices that vary with where people live.

More surprisingly, this policy also increases the profit level of the firms. The reason is that the regulator, by acting as a first-mover, solves a co-ordination problem; the oligopolistic firms would prefer the same regional coverage as the one chosen by a hypothetical monopolist, but this does not constitute an equilibrium in a free market economy.

The regulatory authorities often argue that their goal is a "technologically neutral" regulation. We show that this may not be appropriate in the broadband access market. By comparing our results with Valletti et al. (2002) we show that the policy maker should take into account which technology is employed, since this will have implications for the effects of possible requirements of uniform pricing and coverage.

To bring forward these results we use a highly stylized model where we have a continuum of locations that differ only with respect to their population density. Specifically, the distribution of consumer preferences for broadband access is the same in all locations. This means that the downward-sloping demand curve, adjusted for population size, is the same in each location.

In order to focus on the consequences of higher competition and uniform pricing we make some simplifying assumptions that are not crucial for our conclusions. First, we abstract from fixed costs in order to show that competition may be detrimental to welfare even in the absence of duplication of fixed costs. Including fixed costs at each location, for instance, means that the socially optimal number of locations to serve will in general be higher than the one chosen by the market (see also Valletti et al., 2002). The other results in the paper survive, in particular the one that higher competition tends to reduce regional coverage when prices are uniform.[5]

Second, analogous to fixed cost, the existence of network externalities may favor monopoly to competition (since a monopolist has incentives to internalize the externalities). Hence, we abstract from network externalities, since introducing such effects in the present model would strengthen the result that higher competition may reduce welfare.

Third, we assume that broadband access is a separate market from current narrowband access. Upgrading of the existing telephone and cable-TV networks to

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[5] Since we abstract from fixed costs we do not explicitly consider entry decisions.

broadband seems to be the most promising way of broadband implementation (see e.g. Clark, 1999a, 1999b). Hence, broadband may be seen as a quality improvement of the existing narrowband access. However, even if broadband may be seen as a superior substitute to current narrowband services, narrowband need not be considered as a substitute for potential broadband providers simply because narrowband access cannot deliver bandwidth-demanding services such as real time video, on-demand video, interactive multiplayer gaming and so forth (Hausman et al., 2001).

Fourth, we assume competition between symmetric facility-based firms, and we do not open up for non-facility-based firms that rent capacity from facility-based firms. Similarly to Valletti et al. (2002) we do not consider access pricing problems. Furthermore, we do not consider the implications of one of the firms having a first-mover advantage over the others in the choice of coverage. To analyze the consequences of these kinds of asymmetries seems like an interesting path for future research (see also Hansen, 1999, and Hoernig, 2001).

There are several informal policy analyses of the broadband industry, in particular with focus on the US market (e.g. Speta 2000a, 2000b, MacKie-Mason, 1999, Petkovic and De Coster, 2000). In contrast, there are to our knowledge few papers explicitly modelling competition in the broadband access market, but Valletti et al. (2002), Faulhaber and Hogendorn (2000) and Hoernig (2001) are notable exceptions. Additionally, Hausman, Sidak and Singer (2001) analyze the consequences of asymmetric regulation of telecommunication providers and cable-TV-providers regarding broadband access.

Since the uniform price constraint implies that the markets (locations) are strategically linked, our paper is related to the theory of multimarket oligopoly, where Bulow et al. (1985) is the seminal paper. Our paper is also related to the literature on price discrimination, because uniform pricing in our context *de facto* discriminates against consumers living in urban areas. Hence, it may be seen as spatial price discrimination, see, e.g., Varian (1989) for an overview. The main focus of this literature, however, is to analyze whether an unregulated firm may find it profitable to charge a uniform price throughout a given territory in order to prevent arbitrage or deter entry, since consumers located further away from the firm are more likely to have alternative suppliers.[6] Arbitrage is not relevant for our paper. Obviously, the consumers have to buy broadband access where they live, and they are prevented from buying or reselling their subscription to other areas (locations).

The rest of this paper is organized as follows. The formal model is presented in Section 2, and the benchmark model where prices differ between the locations is analyzed in Section 2.1. In Section 2.2 we assume uniform pricing. We first analyze the case where coverage and quantities are set simultaneously, and we then assume that coverage is set prior to quantities. In section 3 we conclude.

2 THE MODEL

The end-user market consists of a continuum of locations t. In any given location there is a number of consumers that differ in their willingness to pay for broadband access. Denote by $P(t)$ the population size in location t, and let $p(t)$ be the price.[7] We assume that total market demand in location t is given by $x(t) = P(t)y(p(t))$, where

$$y(p(t)) = \frac{\alpha - p(t)}{\beta} \tag{1}$$

is the demand from a representative group of consumers. The parameters α, β are positive constants. Note that this formulation implies that the locations do not differ with respect to the consumers' willingness to pay for broadband access, and that demand will be proportional to population size if there is a uniform price $p(t) = p$ in all locations.

Each location has the same geographical size, and we order it such that location 0 has the largest population and location N the smallest population. The population size of location 0 is, by choice of scale, equal to 1; $P_0 = 1$. We assume that the

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[6] Phlips (1983) gives a comprehensive discussion and examples of spatial price discrimination in Europe.

[7] Note that the consumers usually pay a fixed monthly fee for broadband access, and no usage- or time dependent price as for conventional narrowband access. We assume that the price p may be interpreted as the discounted payment for broadband access.

population size of location t is e^{-t} times the size of location 0. This means that $P(t) = e^{-t}$, or

$$x(t) = e^{-t}y(p(t)). \tag{2}$$

Figure 1, which measures price on the vertical axis and demand in each location on the horizontal axis, provides a graphical illustration of the demand structure. The consumer that values broadband access the most in each location has a willingness to pay equal to α. The intercept with the vertical axis is to thus the same for all locations, but the demand curve is steeper the smaller the population size (i.e., the higher the value of t). Location 0 has the largest population, and thus the largest aggregate demand at any given price, while location N has the smallest population and the smallest aggregate demand.

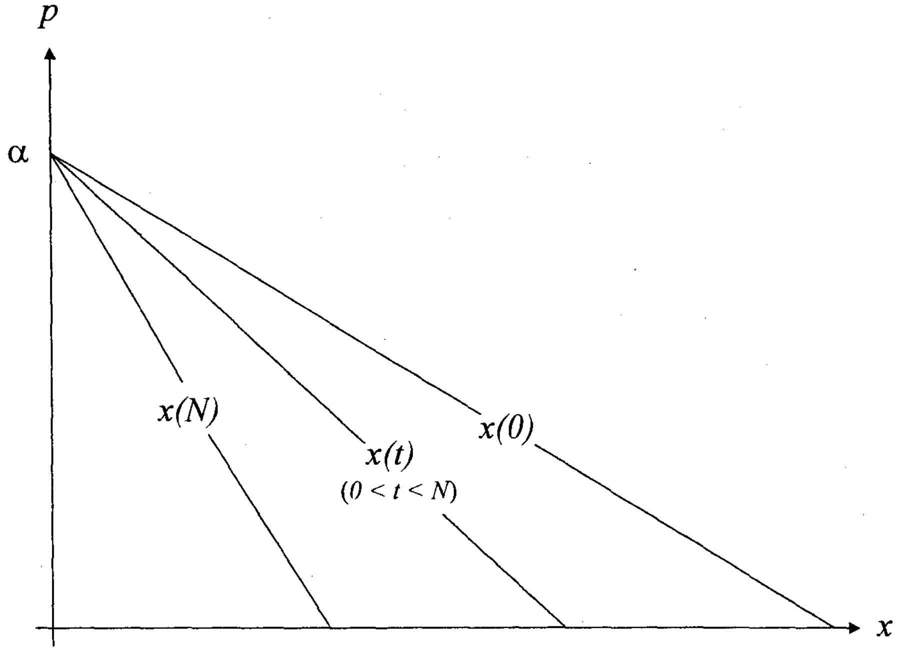

Figure 1: Graphical illustration of the demand structure.

A central feature of providing broadband access is the fact that it is generally significantly more expensive to connect consumers in locations with a low population density than in locations with a high population density. As argued in the introduction, there are two main reasons for this. First, broadband access providers typically have to make some fixed investments in each location that they serve. This gives rise to fixed costs, which only to a limited extent vary with the population size in each location. Second, with a low population density it becomes more expensive to physically connect each single home to the broadband. Thereby the marginal connection costs per consumer will typically be relatively high in locations with a low population density. This is particularly true for high-end broadband technologies like "fiber to the homes", which is our focus. In this paper we will therefore consider a context where the marginal costs of providing broadband access is higher the lower the population density. However, we will abstract from fixed costs and other forms of economies of scale, which have been analyzed by Valletti et al. (2002) and Hoernig (2001).[8]

Let the marginal cost of connecting a consumer in location 0 to the broadband be equal to the constant ϕ. To capture the fact that it is significantly more expensive to connect consumers in locations with low population density than in locations with high population density, we will assume that the cost of providing access to $x(t)$ consumers in location t is $\phi e^{\mu t}x(t)$, with $\mu > 0$. The cost of servicing n locations is consequently

$$C(n) = \phi \int_0^n e^{\mu t}x(t)dt. \tag{3}$$

Throughout we assume that $\alpha > \phi$; otherwise it will not be profitable to serve any location. Since it is prohibitively expensive to serve the least populated locations, it will always be true that $n < N$. This is also true in the model, since $C(t) \to \infty$ as $t \to \infty$.

The exact size of the parameter μ does not matter for the qualitative results, and in the following it proves convenient to choose $\mu = 2$.

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[8] Unless we consider broadband solutions where each home is directly connected with optical fiber, it may seem most realistic to specify a model where fixed costs dominate in urban areas (high population density) and marginal costs dominate in rural areas (low population density). However, in order to make the model tractable we assume that the costs are marginal per connected consumer in all locations. This simplification does not affect the qualitative trade-off between prices and geographical coverage that we focus on below.

2.1 Benchmark: Prices Differ across Locations

As a benchmark case, we will consider the social optimum and the market equilibrium (with monopoly and oligopolistic competition à la Cournot, respectively) when we allow prices to differ across the locations.

The marginal cost of connecting a consumer in location t is $MC = \phi e^{2t}$. In social optimum (denoted with superscript *) the price is equal to the marginal cost:

$$p^*(t) = \phi e^{2t}$$

This implies that

$$y^*(t) = \frac{1}{\beta}\left(\alpha - \phi e^{2t}\right). \tag{4}$$

The social planner will provide broadband access until demand is equal to zero. Solving for $y^*(t) = 0$ in (4) we thus have

$$n^* = \frac{1}{2}\ln\frac{\alpha}{\phi}. \tag{5}$$

But also a monopolist and oligopolistic firms will serve the socially optimal number of locations (see appendix for a formal proof). It is optimal for a monopolist to increase n until the marginal profit of connecting consumers in a new location is equal to zero. This is *de facto* the same decision as the one made by the social planner. Moreover, no matter how small the profit level of a monopolist is in a given location, there will still be some profit left also with oligopolistic competition. Therefore the regional coverage is independent of the number of competing firms in the market. However, the well-known problem that a monopolist charges too high prices remains. With a higher number of firms the competitive pressure increases, and therefore the total quantity offered in each location that is served will also increase.

We may sum up our results so far in the following lemma:

Lemma 1: *Suppose that we allow prices to differ between the locations. Then we have that: (i) both a monopolist and oligopolistic firms will choose the socially* *optimal geographical coverage, and (ii) competition will increase welfare compared to monopoly, since the consumer prices will be lower the larger the number of competing firms.*

2.2 Uniform Pricing

Suppose that the firms are required to charge the same price in all locations. Let p be this common price and let y be the corresponding demand from each representative group of consumers in all the locations that are served. This means that actual demand in location t equals $x(t) = e^{-t}y$. We then find that aggregate market demand equals $Q = \int_0^n P(t)ydt = y\int_0^n e^{-t}dt = y\left(1 - e^{-n}\right)$ and that the costs are equal to $C = \phi\int_0^n e^{2t}ye^{-t}dt = \phi y(e^n - 1)$.

2.2.1 Social Optimum with Uniform Prices

The value for society of the broadband is equal to the consumer surplus (CS) plus revenue (R) minus the costs (C) of providing the service. The regulator's problem can thus be described as

$$W^* = \max_{n,y}\left[\frac{1}{2}\beta y^2(1 - e^{-n}) + (\alpha - \beta y)y(1 - e^{-n}) - \phi y(e^n - 1)\right]$$

From this it follows that

$$y^*(n) = \frac{1}{\beta}\left(\alpha - \phi e^n\right) \tag{6}$$

and

$$n^*(y) = \frac{1}{2}\ln\frac{2\alpha - \beta y}{2\phi}. \tag{7}$$

By combining (6) and (7) we have

$$y^* = \frac{1}{\beta}\left(\alpha - \frac{\phi + \sqrt{\phi^2 + 8\phi\alpha}}{4}\right)$$

and

$$n^* = \ln \frac{1+\sqrt{1+8\alpha/\phi}}{4}. \tag{8}$$

Equations (5) and (8) tell us that:

Proposition 1: *Suppose that the price is uniform across the locations. In this case the socially optimal geographical coverage is lower than when prices are non-uniform.*

The intuition behind the fact that n^* is reduced with uniform prices, runs as follows. The socially optimal uniform price will be somewhere between the marginal costs of serving consumers in the first location and in the last location. A too low price will induce too high consumption, while a too high price will induce too low consumption. If the regional coverage is high, the uniform price must also be high in order to prevent an excessively high demand in high-cost locations. Since a high price harms consumers in all the locations that are served, it is optimal to reduce the regional coverage relative to the case with non-uniform prices.

2.2.2 The Choice of the Monopolist

With uniform prices the optimization problem of the monopolist equals

$$\pi = \max_{y,n} \left[(\alpha - \beta y) y (1 - e^{-n}) - \phi y (e^n - 1) \right]. \tag{9}$$

From this we find the first order conditions (superscript m for monopoly):

$$\begin{aligned} y^m(n) &= \frac{1}{2\beta}\left(\alpha - \phi e^n\right), \text{and} && (10) \\ n^m(y) &= \frac{1}{2} \ln \frac{\alpha - \beta y}{\phi}. && (11) \end{aligned}$$

Combining equations (10) and (11) yields that the equilibrium quantity for each representative group of consumers is equal to

$$y^m = \frac{1}{2\beta}\left(\alpha - \frac{\phi + \sqrt{\phi^2 + 8\phi\alpha}}{4}\right)$$

while the regional coverage is

$$n^m = \ln \frac{1 + \sqrt{1 + 8\alpha/\phi}}{4}. \tag{12}$$

Comparing (5) and (12) we thus see that the monopolist will serve fewer locations when he is forced to charge a uniform price than when prices are non-uniform. The reason is that it is costly to connect locations that have a low population density, requiring a relatively high connection price. With uniform prices the monopolist must therefore charge a higher price from all consumers the larger the regional coverage. By serving a large number of locations the monopolist will therefore loose income from the locations with the highest population density.[9]

Intuitively one may expect that the monopolist will provide a smaller regional coverage than the social planner, since a social planner is not concerned about the profit level *per se.* However, equations (5) and (8) show that we still have $n^m = n^*$:

Proposition 2: *Independent of whether we have uniform or non-uniform prices the monopolist and the social planner will provide the same regional coverage, but the prices charged by the monopolist are too high.*

The fact that the social planner and the monopolist will choose the same coverage with uniform prices can be explained as follows.

In each location t the monopolist obtains a revenue equal to $R(t) = p^m y^m e^{-t}$, or

$$R(t) = (\alpha - \beta y^m)\, y^m e^{-t},$$

while the incurred costs are

$$C^m(t) = \phi y^m e^t.$$

Obviously, the monopolist will not serve locations that are unprofitable. It must thus be true that $R(n) \geq C^m(n)$. Likewise, it cannot be optimal not to serve

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[9] Note that we find a similar argument in the literature of price discrimination; without price discrimination it may well be optimal not to serve some groups of consumers that otherwise have a sufficiently high willingness to pay.

locations that generate pure profit. In equilibrium we thus have $R(n) = C^m(n)$ or $p^m y^m e^{-n} = \phi y^m e^n$;

$$\alpha - \beta y^m = \phi e^{2n}.$$

From a social point of view, however, the benefit from serving location n is higher than $R(n)$, since also the consumer surplus enters the welfare function. Denoting the social benefit (consumer surplus + profit) of serving location t by B, we have $B = \left[\frac{1}{2}(\alpha - p)y + py\right] e^{-t} = \left(\alpha - \frac{1}{2}\beta y\right) y e^{-t}$. Since $y = 2y^m$ we thus have

$$B(t) = 2\left(\alpha - \beta y^m\right) y^m e^{-t}.$$

The social benefit of serving any given location t is thus twice as large as the revenue for the monopolist of serving the same location. However, also the cost of serving location t is twice as large for the social planner;

$$C(t) = \phi y e^t = 2\phi y^m e^t.$$

For the last location it must be true that $B(t) = C(t)$, and we thus see that the monopolist and social planner will choose the same coverage $(n^m(y^m) = n^*(y^*))$. It should be noted, though, that the regional coverage provided by the monopolist is too small from a social point of view, given the quantity chosen by the monopolist. This can be seen from equation (7), which shows that $n^*(y^*) < n^*(y^m)$. The reason why the social planner would choose a higher regional coverage than the monopolist for any given quantity, is simply that the monopolist does not care about consumer surplus. In particular, this means that $B(n^m) > C(n^m)$ for $y = y^m$. Given y^m, the social planner would thus choose a higher regional coverage such that the social benefit is equal to the cost of serving the last location.[10]

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[10] This is analogous to a result found by Spence (1975), who shows that even if a monopolist should have incentives to underprovide product quality, the actual quality level chosen by a social planner and a monopolist may be the same. Given the monopolist's output level, however, the social planner may prefer a higher product quality. We would like to thank Kåre P. Hagen for pointing out this analogy to us.

2.2.3 Oligopolistic Competition

Following Kreps and Scheinkman (1983) a capacity-constrained price game can be solved as a one-stage Cournot-game. In the broadband market the suppliers need to choose the capacity of the transport network prior to the price (see Hansen, 1999, and Faulhaber and Hogendorn, 2000).The capacity choice consists of building own fiber nodes or renting transport facilities both in the national and global backbone. The supplier of access to the Internet typically have long term contracts with suppliers of connectivity to the global backbone. AOL, for instance, have a five year contract with WorldCom (Crémer, Rey and Tirole, 2000). Hence, we assume that there is Cournot competition between m symmetric firms. We further follow Valletti et al. (2002) and assume that each firm i offers broadband connection from location zero up to some endogenously given location n_i (see also later discussion).

Denote by $y_i(t)$ the quantity supplied by firm i to each representative group of consumers, and let $y_{-i}(t)$ denote the analogous quantities from each of the other $(m-1)$ firms. With uniform prices and oligopolistic competition the profit level of firm i equals

$$\pi_i = \max_{n_i, y_i} \left\{ \int_0^{n_i} [\alpha - \beta y]\, x_i(t) dt - \phi \int_0^{n_i} x_i(t) e^{2t} dt \right\}, \tag{13}$$

where $y = y_i + (m-1)\, y_{-i}$. Inserting y_i for x_i and maximizing (13) with respect to y_i and n_i give the first order conditions (see appendix)

$$y_i = \frac{\alpha - 2\beta(m-1)y_{-i} - (e^{-n_i} - 1)^{-1}\beta(m-1) \int_0^{n_i} x_{-i}(t)dt - \phi e^{n_i}}{2\beta} \tag{14}$$

and

$$n_i = \frac{1}{2} \ln \frac{\alpha - \beta y_i - \beta(m-1)y_{-i}}{\phi}. \tag{15}$$

In a symmetric equilibrium we have $x_{-i}(t) = x_i(t) = e^{-t} y_i$, and thus $\int_0^{n_i} x_{-i}(t)dt = y_i(1 - e^{n_i})$. Inserting for this in (14) we find that

$$y^c(n) = \frac{1}{\beta(1+m)} \left(\alpha - \phi e^{n}\right), \tag{16}$$

while equation (15) implies

$$n^c(y) = \frac{1}{2} \ln \frac{\alpha - \beta m y}{\phi}. \tag{17}$$

Combining equations (16) and (17) we can express y^c and n^c in terms of parameters only:

$$n^c = \ln \frac{m + \sqrt{m^2 + (m+1)4\alpha/\phi}}{2(m+1)} \tag{18}$$

$$y^c = \frac{1}{2\beta}\left[\frac{2}{m+1}\alpha - \frac{m\phi + \sqrt{m^2\phi^2 + 4\alpha\phi(m+1)}}{(m+1)^2}\right] \tag{19}$$

It is easily verified that $dn^c/dm < 0$ and $d(my^c)/dm > 0$. Put differently, higher competition reduces both prices and the number of locations that are served. We thus have the following result:

Proposition 3: *Suppose that the telecommunication firms must charge the same price in all the locations that they serve. In this case a higher number of firms implies that prices are reduced, while the regional coverage decreases below the social optimum.*

The welfare implications of Proposition 3 are illustrated in figure 2.[11] The left-hand side panel of the figure measures m on the horizontal axis and the Cournot number of locations served relative to the socially optimal number of locations on the vertical axis $(n^c(m)/n^*)$. This figure illustrates that the regional coverage is decreasing in m. Increased competition will thus clearly harm some peripheral locations, and this is detrimental to national welfare. On the other hand, increased competition reduces consumer prices in those locations that are still served, and this has a positive welfare effect. The right-hand side panel of figure 2, which measures m on the horizontal axis and W on the vertical axis, therefore shows a curve with an inverted U-form. The reason why welfare increases initially is that prices are significantly reduced as we move from monopoly to duopoly. However, as is well known from microeconomic theory, this effect becomes increasingly dampened as the

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[11] The following parameters are used inn all the figures: $\alpha = 5$, $\beta = 1$ and $\phi = 1$. In the left-hand side panel of Figure 2 and in Figure 3 the number of firms (m) is set equal to 8.

number of competitors increases. In the figure this means that the negative effect of a lower regional coverage dominates as the number of firms increases beyond $m = 3$. It should be stressed that this negative effect must dominate for sufficiently high values of m, independent of parameter values. This is most easily understood if we assume that $m \to \infty$, in which case $n \to 0$. If we had also taken into consideration the fact that there are some fixed costs, the negative effects of increasing m would have been even larger.[12]

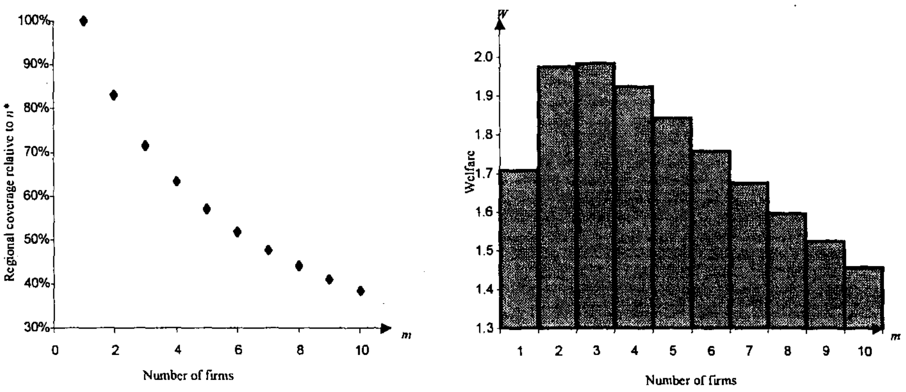

Figure 2: Competition, regional coverage and welfare.

2.2.4 The Regulator Sets Coverage Prior to Competition

In principle, the government can act as a first-mover with respect to regional coverage. In telecommunications we see that governments often have the ambition to do so, and that they mandate the firms to provide access to a minimum geographical coverage. This coverage regulation is typically combined with a requirement of uniform pricing through Universal Service Obligations (USO), see e.g. Laffont and Tirole (2000), Riordan (2001), Valletti et al. (2002), and Valletti (2000). In

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[12] If there are fixed costs of serving each location, and the last location served by the monopolist is relatively large and profitable, it may happen that the same regional coverage will be same also in a duopoly. However, we should still expect that the regional coverage falls as a sufficient number of firms enter. This is particularly true since the marginal locations are, just, marginal.

the mobile telephony market, for instance, we commonly see that the firms that are being granted a license are required to offer access with a minimum coverage.[13]

In this section we assume a two-stage game where the regulator sets the coverage at stage one and where the firms choose quantities at stage two. As usual in this kind of game we start with the second stage:

Stage 2 For a given regional coverage, $\tilde{n}$, the maximization problem of firm i is

$$\pi_i = \max_{y_i} \int_0^{\tilde{n}} [\alpha - \beta y]\, x_i(t) dt - \phi \int_0^{n_i} x_i(t) e^{2t} dt.$$

The response by the telecommunication firms to this requirement is the same as that given by equation (14).

Stage 1 The government sets regional coverage such that welfare is maximized. We use the symmetry of the firms and let $y_i^c = y^c$:

$$\begin{aligned}\tilde{W} &= \max_n \left[\frac{1}{2}\beta m^2 (y^c)^2 (1 - e^{-n}) + (\alpha - \beta m y^c) m y^c (1 - e^{-n}) - \phi m y^c (e^n - 1)\right] \\ &\quad \text{given} \\ y^c(n) &= \frac{1}{\beta(1+m)} (\alpha - \phi e^n)\end{aligned}$$

From the first order condition it follows that the regional coverage chosen by the regulator at stage 1 is identical to the social optimum, such that

$$\tilde{n} = n^* = \ln \frac{1 + \sqrt{1 + 8\alpha/\phi}}{4}. \tag{20}$$

It should be noted that due to the convexity of the cost function, broadband access becomes more expensive when n increases. A binding requirement of regional coverage is thus bad news for consumers in inframarginal locations.

The welfare effects of a regional coverage requirement is illustrated in figure 3. Here we have assumed that $m = 8$, in which case welfare is lower with oligopolistic competition than in the equilibrium with a monopoly if there is no coverage

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[13] Regarding the allocation of licenses for the third generation mobile system (UMTS in Europe), several countries have minimum coverage requirements in their licenses. The governments that allocate the UMTS-licences through "beauty-contests" seem to give more attention to coverage requirements than where the licenses are allocated through auctions.

requirement.[14] First, the figure shows that consumer surplus is increasing in the number of locations that are connected to the broadband for $n \in (n^c, n^*)$. Second, and perhaps more surprisingly, we also see that the same is true for the profit level. What the regulator does when specifying a binding lower bound on n, is to solve a coordination problem. The oligopolistic firms prefer the same price and the same regional coverage as the one chosen by a monopolist (i.e., $n = n^*$), but individually it is profitable for each of the firms to reduce the prices they charge and the number of locations they serve.[15]

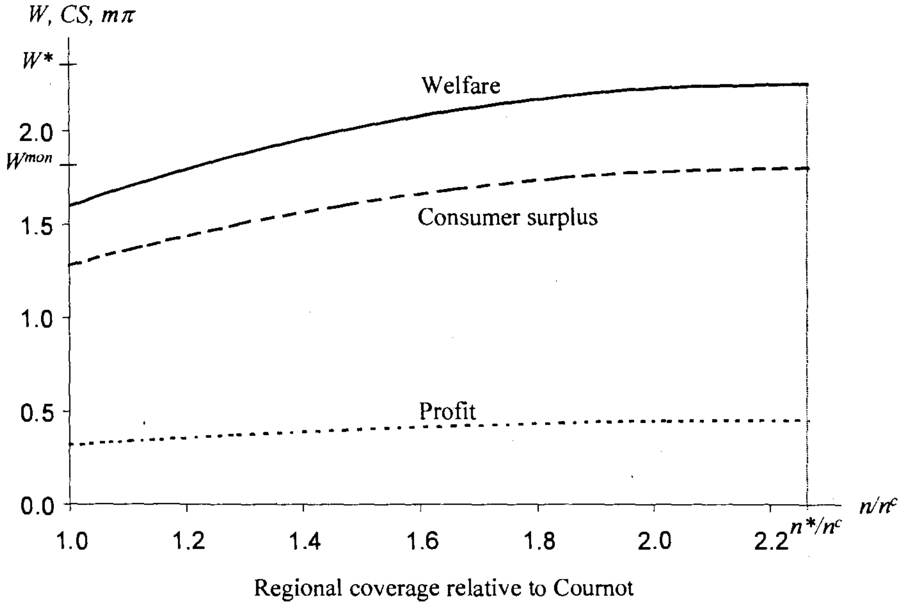

Figure 3: Effects of requirements on regional coverage.

Proposition 4: *By requiring the telecommunication firms to provide a larger regional coverage than the Cournot solution both consumer surplus and the profit level of the firms increase up to the monopoly coverage.*

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[14] See also the right-hand side panel of Figure 2.

[15] By inserting (16) into the expression for π_i it is easily found that profit is maximized when $n = n^*$.

2.2.5 The firms set coverage prior to competition

We have compared a solution where the regulator acts as a first-mover and sets the coverage prior to competition with an unregulated structure where the firms choose coverage and quantities simultaneously. More realistically, the firms will set coverage prior to quantities in the unregulated market too. So in order to check that it is the intervention from the government, and not the timing of the game *per se* that solves the coordination problem, we now assume that the firms set coverage at stage 1 and then compete á la Cournot at stage 2. We assume that the firms are required to set a uniform price and, for simplicity, we let $m = 2$. Using that $x_{-i}(t) = e^{-t}y_{-i}$ it follows from equation (14) that the stage 2 equilibrium is given by

$$\tilde{y}_i^c(n_{i,}^c n_{-i}^c) = \frac{1}{3\beta}(\alpha + \phi e^{n_{-i}} - 2\phi e^{n_i}) \text{ where } i, -i = 1, 2 \text{ and } i \neq -i. \qquad (21)$$

The cross-partial derivative of firm i's profit-function is negative, i.e. $(\partial^2 \pi_i^c / \partial y_i \partial y_{-i}) < 0$. The quantities set by the firms at stage 2 are therefore strategic substitutes as in a conventional Cournot game (Bulow, Geanakoplos, and Klemperer, 1985). We see that $d\tilde{y}_i^c / dn_{-i} > 0$, such that firm i may reduce the quantity offered by firm -i by reducing its own coverage n_i. Since the firms' quantities are strategic substitutes, they will actually do so, and the coverage chosen by the firms would be lower in a two stage game than with simultaneously set coverage and quantity (see also appendix). Hence, it is the intervention from the government that solves the coordination problem. Indeed, by forcing the firms to provide a larger regional coverage than the market equilibrium the regulator solves a prisoners' dilemma for the firms.

3 SOME CONCLUDING REMARKS

Historically, telecommunication incumbents have been required to charge uniform prices throughout the country. At the same time, governments seek to prevent unduly high prices by increasing competition. In this paper we have analyzed the effect of an implicit or explicit requirement of uniform pricing combined with competition in the market for broadband access, which is characterized by the fact that it is considerably more expensive to serve consumers in rural areas than consumers in urban areas. We have shown that welfare may decrease as the number of firms increases, since the regional coverage will be reduced. Furthermore, we have also shown that the government may prevent the negative effect from competition by intervening and setting a coverage requirement prior to competition. Interestingly, this will also benefit the firms. In contrast, if the firms set coverage prior to competition, they will choose an even lower level of coverage than they would have done with simultaneous moves. Hence, it is not the timing of the game *per se*, but the intervention of the government that may increase welfare. Put differently, if the government wants uniform prices, it should set a complete Universal Service Obligation (USO) that requires both a uniform price and a given coverage.

Since our model is very stylized, there may be a need for some comments on our key assumptions. Most importantly, we have assumed that the competing firms are symmetric in several dimensions. First, they are symmetric in their timing of the investment, such that no firm has a first-mover advantage with regard to the investment in coverage. This assumption seems realistic if there is competition between several facility-based firms that already have conventional narrowband networks in the given area. Several analysts argue that this is the most likely scenario in the broadband market for residential users, since it will be controlled by the existing facility-based firms - telephony providers and cable-TV providers. This is due to the high up-front investments of new wireline facilities and the possibility of increasing the capacity of existing networks. The assumption will also be realistic if none of the firms have existing networks or the existing networks cannot be upgraded to broadband. This is possibly the current situation regarding investments in third generation mobile systems (UMTS in Europe). However, in many countries the coverage of the existing telephone network is higher than the coverage of existing cable-TV-networks. Hence, the telephone incumbent may have a first-mover advantage, particularly in many rural locations. Thus, there is need for more research regarding the implications of one firm having a first-mover advantage in the choice of coverage. When firms set coverage sequentially, the result may be altered, and we may expect that firms will be asymmetric with regard to coverage. Some firms may then concentrate their activities in urban areas, while others concentrate in rural areas.

Second, we have assumed that there is competition between vertically integrated facility-based firms that invest in their own broadband access network. With our assumptions on the cost structure the firms will not gain from sharing the infrastructure, since there are only marginal costs per consumer (independent of the number of users). However, there is little doubt that there are also significant fixed costs in broadband provision, and that this may open up for economies of scale. For instance, by including fixed costs per region in addition to marginal costs, we could address the question of access pricing and infrastructure sharing. It is then an open question whether the market will be dominated by competing vertically integrated firms or by vertically separated firms that rent access from the facility-based firm as an input. In the latter case there will be competition between facility-based firms and non-facility based firms renting access from the former type. Today, we see that the telecommunication incumbents are obligated to offer access to non-facility-based rivals, while the cable-TV providers are not.

Third, we have assumed that the firms completely duplicate their network coverage. At the first glance, this may be an unrealistic assumption. But if the convexity of costs is significant, the firms will probably do so. They start with the cheapest and most populated locations (see also Valletti et al., 2002). In the infancy of the broadband access market we now see some evidence of this. The broadband upgrades are concentrated in urban locations. A similar example is the mobile market in several countries where the firms duplicate their coverage almost completely.

Finally, we have assumed that the uniform price is set in a non-cooperative environment. This seems like a natural point of departure, since price competition is in general not allowed in most countries. However, an interesting question is whether tacit price collusion may actually have positive welfare effects in contexts like the one that we have considered. The reason why this may be true is that cooperative price setting will move the price towards the monopoly price and, as shown in the paper this will tend to increase the geographical coverage.

4 APPENDIX

Geographical coverage when prices differ between locations

Monopoly:

The optimization problem of the monopolist equals

$$\pi = \max_{x(t),n} \left[\int_0^n p(x(t))x(t)dt - \phi \int_0^n e^{2t}x(t)dt \right]. \tag{22}$$

Solving (22) we find that $\partial\pi/\partial x(t) = 0$ yields the FOC $p'(x(t))x(t) + p(x(t)) - \phi e^{2t} = 0$. Noting that $p(x(t)) = \alpha - \beta x(t)e^t$ and $p'(x(t)) = -\beta e^t$ we thus have $x(t) = \frac{1}{2\beta}\left(\frac{\alpha}{e^t} - \phi e^t\right)$. This implies that $p(t) = \frac{1}{2}(\alpha + \phi e^{2t})$, or

$$y^m(t) = \frac{1}{2\beta}\left(\alpha - \phi e^{2t}\right), \tag{23}$$

where superscript m indicates monopoly.

The second FOC from (22), $\partial\pi/\partial n = 0$, further implies that $p(x(n))x(n) - \phi e^{2n}x(n) = 0$. By inserting from (23) we thus find that the number of locations served by the monopolist is equal to

$$n^m = \frac{1}{2}\ln\frac{\alpha}{\phi}. \tag{24}$$

Note that consumers in the most populated locations will be most harmed by monopoly pricing, since

$$p(t) - p^*(t) = \frac{1}{2}(\alpha - \phi e^{2t}) \implies \frac{d(p(t) - p^*(t))}{dt} = -\phi e^{2t} < 0 .$$

Oligopolistic competition:

Denote by $y_i(t)$ the quantity supplied by firm i to each representative group of consumers, and let $y_{-i}(t)$ denote the analogous quantities from each of the other $(m-1)$ firms. We thus have $y(t) = y_i(t) + (m-1)\,y_{-i}(t)$, so that firm i faces the inverse demand curve $p(y_i(t), y_{-i}(t)) = \alpha - \beta(y_i(t) + (m-1)y_{-i}(t))$. The profit level of firm i is thus

$$\pi_i = \int_0^{n_i} p(y_i(t), y_{-i}(t))x_i(t)dt - \phi\int_0^{n_i} x_i(t)e^{2t}dt.$$

Defining $x(t) \equiv x_i(t) + (m-1)\,x_{-i}(t) = e^{-t}y(t)$ we can state the maximization problem of firm i as

$$\max_{x_i,n_i}\left[\int_0^{n_i}\left\{\alpha-\beta\left[x_i(t)+(m-1)x_{-i}(t)\right]e^t\right\}x_i(t)dt-\phi\int_0^{n_i}x_i(t)e^{2t}dt\right].$$

The first order condition with respect to $x_i(t)$ gives us $x_i(t) = \left[\alpha - (m-1)x_{-i}(t)e^t - \phi e^t\right]/(2\beta e^t)$. Using that all firms are symmetric in equilibrium, and substituting y_i for x_i, we find that (superscript c for Cournot)

$$y^c(t) = \frac{1}{\beta(m+1)}\left(\alpha - \phi e^{2t}\right) \tag{25}$$

We likewise find that the number of locations served equals

$$n^c = \frac{1}{2}\ln\frac{\alpha}{\phi}. \tag{26}$$

Hence, we have that $n^* = n^m = n^c$ under non-uniform pricing.

Derivations of the FOCs with oligopolistic competition when prices are uniform

Using that $x(t) = e^{-t}y = x_i(t) + (m-1)x_{-i}(t)$ we can write equation (13) as

$$\begin{aligned}\pi_i &= \int_0^{n_i}\left[\alpha-\beta y\right]\left[e^{-t}y-(m-1)x_{-i}(t)\right]dt\\ &\quad -\phi\int_0^{n_i}\left[e^{-t}y-(m-1)x_{-i}(t)\right]e^{2t}dt.\end{aligned}$$

This can further be modified to

$$\begin{aligned}\pi_i &= \left(\alpha y-\beta y^2\right)\int_0^{n_i}e^{-t}dt+\beta y(m-1)\int_0^{n_i}x_{-i}(t)dt\\ &\quad -\int_0^{n_i}\alpha(m-1)x_{-i}(t)dt-\phi\int_0^{n_i}\left[e^{-t}y-(m-1)x_{-i}(t)\right]e^{2t}dt.\end{aligned}$$

We thus find that $\partial\pi_i/\partial y_i = 0$ implies

$$\left[\alpha-2\beta\left(y_i+(m-1)y_{-i}\right)\right]\left(1-e^{-n_i}\right)+\beta(m-1)\int_0^{n_i}x_{-i}(t)dt-\phi(e^{n_i}-1)=0,$$

which can be rewritten to give equation (14).

From equation (13) we further find that $\partial\pi_i/\partial n_i = 0$ implies

$$\left[\alpha-\beta(y_i+(m-1)y_{-i})\right]x_i(n_i)-\phi x_i(n_i)e^{2n_i}=0,$$

which can be written as in equation (15).

Proof that $\tilde{n}^c < n^c$

Suppose that we have a two-stage game where the firms simultaneously choose coverage at stage one and quantities at stage two. The solution to the second stage is given by $\tilde{y}_i^c(n_i^c, n_{-i}^c)$ from equation (21). Inserting for $\tilde{y}_i^c(n_i^c, n_{-i}^c)$ into the profit functions for the firms, we find that the maximization problem at stage one equals

$$\max_{n_i}\left\{\frac{1}{9\beta}(\alpha+\phi e^{n_{-i}}+\phi e^{n_i})(\alpha+\phi e^{n_{-i}}-2\phi e^{n_i})(1-e^{-n_i})-\frac{\phi}{3\beta}(\alpha+\phi e^{n_{-i}}-2\phi e^{n_i})(e^{n_i}-1)\right\}.$$

Solving this, and using that the firms are symmetric, we find that

$$\tilde{n}^c = \ln\frac{3+\sqrt{9+16\alpha/\phi}}{8}.$$

In the game where quantity and coverage were set simultaneously we have $n^c = \ln\frac{2+\sqrt{4+12\alpha/\phi}}{6}$ for $m = 2$ (c.f. equation (18)). Letting $\Delta n = \tilde{n}^c - n^c$ we find that $\Delta n = 0$ if $\alpha/\phi = 1$ and that $d(\Delta n)/d(\alpha/\phi) < 0$ for $\alpha/\phi > 0$. Since $\alpha/\phi > 1$ it follows that $\tilde{n}^c < n^c$. Q.E.D.

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