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 the 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 welfare as well as profit by requiring a higher regional coverage than the market outcome.

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 like interactive video. The costs of providing broadband access are highly convex in the sense that it is considerable 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 would 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). 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.

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 to reduce prices in all locations, and this unambiguously has a positive welfare effect.

Things changes 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 peripher 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 of the firms that are granted UMTS licenses, and proposals have been advanced to specify similar requirements of 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 we show that this has a positive effect on aggregate consumer surplus. 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.

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 absent 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 monopolist. The other results in the paper survive, in particular that higher competition tends to reduce regional coverage when prices are uniform.[1]

Second, analogous to fixed cost, the existence of network externalities may favour 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 broadband seems to be the most promising way for 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 to be considered as a substitute for potential broadband providers simply because narrowband access cannot deliver bandwidth-demanding services (videoconferencing and so forth).

Forth, 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. Furthermore, we do not consider the implications of one of the firm having a first-mover advantage over the others in the choice of coverage. To analyze the consequences of these kinds of asymmetries seem like an interesting path for future research (see also Hansen, 1999).

There are several informal policy analysis 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

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

explicitly modelling competition in the broadband access market, but Faulhaber and Hogendorn (2000) is a notable exception. They develop a model of competition among several broadband access providers based on engineering data, and find that oligopolistic competition is likely to emerge in the US. Our paper is also related to the literature of 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.[2] 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). Hence, the suppliers need not worry about arbitrage.

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 3. In Section 4 we assume uniform pricing. We first analyze the case were coverage and quantities are set simultaneously, and then we assume that coverage is set prior to quantities. In section 5 we conclude.

2 The model

The end-user market consists of a continuum of locations. In a given location there is a number of consumers that differ in their willingness to pay for broadband access. The demand from a representative group of consumers in location t equals

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

where y is quantity, p is the price and α, β are some positive constants.[3]

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

[3] 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

With uniform pricing $p(t) = p$ in all t. We will assume that equation (1) applies for all locations, which means that the locations do not differ with respect to the consumers' willingness to pay for broadband access. However, the absolute market size differs between the locations. Let $P(t)$ be the population size in location t, such that total market demand in location t is $x(t) = P(t)y(t)$. Each location has the same geographical size, and we order such that location 0 has the largest population and location N the smallest population.[4] The population size of location 0 is, by choice of scale, equal to 1; $P_0 = 1$. We assume that the population size of location t is e^{-t} times the size of location 0. This means that $P(t) = e^{-t}$, or

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

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

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

Throughout we assume that $\alpha > \phi$; otherwise it will be 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 $\mu = 2$.

be interpreted as the discounted payment for broadband access.

[4] Technically, this means that the intercept of the inverse demand curve with the vertical axis is the same for all locations, but that the curve is steeper the higher the value of t (reflecting a smaller population size).

3 Benchmark: Prices differ across locations

As a benchmark case, we will consider the social optimum and the market equilibrium (with monopoly and oligopolistic competition a 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 chose 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.*

4 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 $C = \phi \int_0^n e^{2t}ye^{-t}dt = \phi y(e^n - 1)$.

4.1 Social optimum with uniform prices

The value for the society of providing broadband access 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 to serve 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 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 excessive high demand. This harms consumers in all the locations that are served. By reducing the regional coverage below the one that is optimal with non-uniform prices, the price can be reduced in all remaining locations.

4.2 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):

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

Combining equations (10) and (11) yields that the equilibrium quantity is equal

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

while the number of locations that is served 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.[5]

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 monopolist charges too high prices.*

The fact that the social planner and the monopolist will choose the same coverage also 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

[5]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 form 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 $B = \left[\frac{1}{2}(\alpha - p)y + py\right] e^{-t} = \left(\alpha - \frac{1}{2}\beta y\right) ye^{-t}$. 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.[6]

[6] 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.

4.3 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).[7] Hence, we assume that there are m symmetric firms in this market, competing á-la Cournot. Denote by $y_i(t)$ the quantity supplied by firm i, and let $y_{-i}(t)$ denote the quantities from each of the other $(m-1)$ firms. With uniform prices and oligopolistic competition the profit level of firm i equals

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

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 gives 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

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

while equation (15) implies

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

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

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

[7]The capacity choice consists of building own fiber nodes or renting transport facilities both in the national and global backbone.

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

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 1.[8] The left-hand side panel of the Figure measures m on the horizontal axis and the Cournot number of locations served relative to 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 1, 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 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

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

that there are some fixed costs, the negative effects of increasing m would have been even larger.[9]

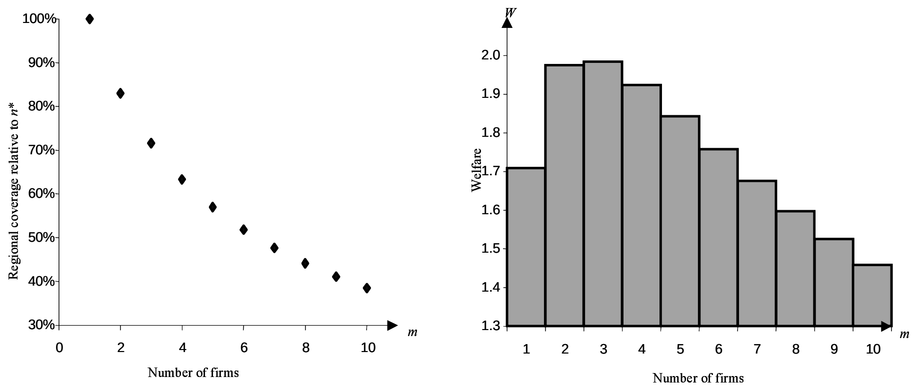

Figure 1: Competition, regional coverage and welfare.

4.4 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) and Valletti (2000). In 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.[10]

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

[9]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 served also by a duopoly. However, we should still expect that the regional coverage falls as sufficiently many firms enter. This is particularly true since the marginal locations are, just, marginal.

[10]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.

Stage 2 For a given number of locations to serve, $\tilde{n}$, 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 the number of locations to be served such that welfare is maximized. We use the symmetry of the firms and let $y_i^c = y^c$:

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

From the first order condition it follows that the optimal number of locations set 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 2. 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 are no coverage requirement.[11] First, the Figure shows that consumer surplus is increasing in the number of locations that is 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 it specifies 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

[11]See also the right-hand side panel of Figure 1.

it is profitable for each of the firms to reduce the prices they charge and the number of locations they serve.[12]

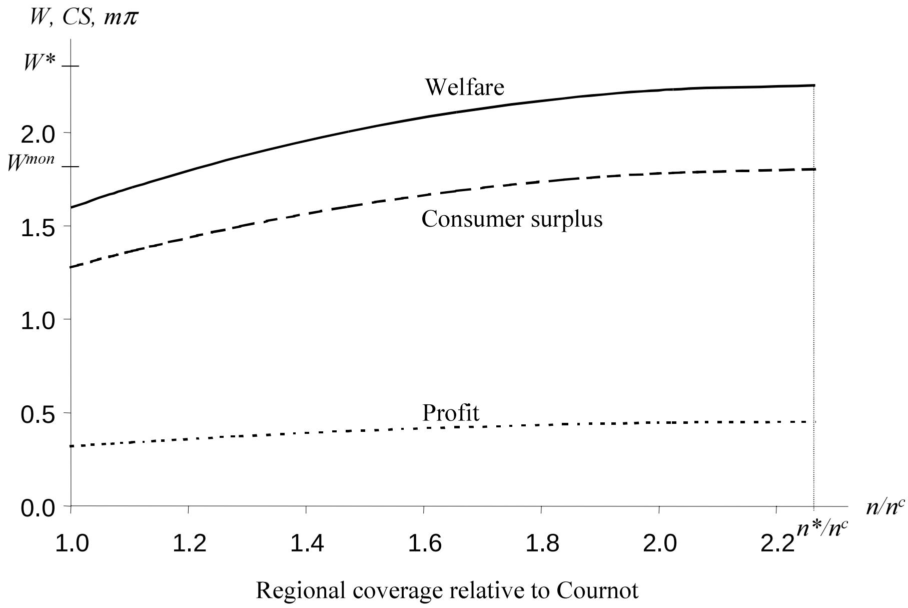

Figure 2: Effects of requirements on regional coverage.

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.*

4.4.1 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

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

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

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

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 in stage 2 is 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 it's 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.

5 Some concluding remarks

Telecommunication incumbents have historically 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 considerable 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 a lower number of locations will be served. 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 simultaneously moves. Hence, it is not the timing of the game *per se*, but the intervention of the government that may increases 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 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 regarding 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 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 firms 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 some firms concentrate their activities in urban areas.

Second, we have assumed that there is competition between vertically integrated facility-based firms that invest in their own broadband access network. It is an open question whether the market will be dominated of 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 firms renting access from the former type. This will result in a more asymmetric market structure. 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 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. In the infancy of the broadband access market we now see some evidence for 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.

6 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, and let $y_{-i}(t)$ denote the 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

$$\begin{aligned} \pi_i &= \int_0^{n_i} [\alpha - \beta y] \left[e^{-t}y - (m-1)x_{-i}(t) \right] dt \\ &\quad - \phi \int_0^{n_i} \left[e^{-t}y - (m-1)x_{-i}(t) \right] e^{2t}dt. \end{aligned}$$

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

$$[\alpha - 2\beta\left(y_i + (m-1)y_{-i}\right)]\left(1 - e^{-n_i}\right) + \beta(m-1)\int_0^{n_i} x_{-i}(t)dt - \phi(e^{n_i} - 1) = 0,$$

which can be rewritten to give equation (14).

From equation (13) we further find that $\partial\pi_i/\partial n_i = 0$ implies

$$[\alpha - \beta(y_i + (m-1)y_{-i})]\, x_i(n_i) - \phi x_i(n_i)e^{2n_i} = 0,$$

which can be written as in equation (15).

Proof that $\tilde{n}^c < n^c$

Suppose we have a two-stage game where the firms simultaneously choose coverage in stage one and quantities in 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 in 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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