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**Working Paper**

## Cost and Benefits from Infrastructure Competition : Estimating Welfare Effects from Broadband Access Competition

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Max Planck Institute  
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Cost and Benefits from Infrastructure Competition.  
Estimating Welfare Effects from Broadband Access  
Competition

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# **Cost and Benefits from Infrastructure Competition. Estimating Welfare Effects from Broadband Access Competition**

Felix Höfler

January 2005

Cost and Benefits from Infrastructure  
Competition.  
Estimating Welfare Effects from Broadband  
Access Competition

Felix Höfler\*

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**Abstract**

Competition between parallel infrastructures incorporates opposing welfare effects. The gain from reduced deadweight loss might be outweighed by the inefficient duplication of an existing infrastructure. Using data from broadband internet access for Western Europe 2000-2004, this paper investigates which effect prevails empirically. Infrastructure competition between DSL and cable TV had a significant and positive impact on the broadband penetration. Comparing the additional social surplus attributable to cable competition with the cable investments, we conclude that infrastructure competition has not been welfare enhancing. A theoretical model is provided, formalizing why the effect of competition on penetration might be limited.

Keywords: Infrastructure Competition, Service Competition, Broadband, Internet, Cable TV, DSL.

JEL-Classification: L51, L86, L96, L12, K23.

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# 1 Introduction

Infrastructure versus service competition: this is one of the key issues in infrastructure industries. Regulators face the question whether to promote competition on the basis of a single infrastructure with regulated infrastructure access (service competition) or to promote the build-up of competing, parallel infrastructures. Although there is a trade-off between these two objectives, most telecommunications regulators try to provide a framework enabling both forms of competition. The UK regulator OFTEL stated: "By achieving the right level of regulation ..., both network and service competition can develop" (OfTel (2003)).

Furthermore, network competition itself incorporates opposing welfare effects. The gain from reduced deadweight loss due to higher competition might be outweighed by the inefficient duplication of an existing infrastructure. This is theoretically well understood (see e.g. (Laffont and Tirole, 2000, 127-128) for the case of telecommunications, or Mankiw and Whinston (1986) for the general case of inefficient market entry). What is far less clear is which effect prevails empirically. In order to contribute to closing this gap, in this paper we offer an empirical investigation into the increase in the use of broadband Internet access. We find that infrastructure competition has a significant and positive effect on the broadband penetration. In Western Europe<sup>1</sup> - *ceteris paribus* - penetration would have been, at maximum, 20% lower without competition from broadband cable. Using pricing data from the retail market, we estimate the maximum additional social surplus from competition. Viewing this in light of the investment of cable companies into broadband, we conclude that cable competition has not been welfare enhancing.

Broadband access provides a good example of the general question of the pros & cons of infrastructure competition. Technologically, broadband access is usually put into place using one of two underlying infrastructures: DSL (digital subscriber line) or cable modem. DSL uses the PSTN (public switched telephone network), cable modem uses the cable TV infrastructure. A significant upgrade in the network is required in both cases. However, while PSTN covers all households, only a fraction are passed by (i.e. can be hooked up with) cable TV, thus the extent to which infrastructure competition is possible is limited.

A brief comparison of the US and Western Europe suggests a basic intuition about the resulting effects of competition. The percentage of homes passed by cable TV is far higher in the US. Therefore, competition is more intense, and cable has a higher market share in the broadband market. This can lead to higher broadband penetration levels (see Figure 1).

We investigate this intuition, first formalizing it theoretically, then using the heterogeneity within Western Europe with respect to cable competition to focus on the empirical question. We propose two alternative theoretical settings. The

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<sup>1</sup>Western Europe, in the following, comprises the European Union, excluding Greece but including Norway and Switzerland. There are virtually no broadband subscribers in Greece; according to the EU-Commission only 10.000 in January 2004, see EU Commission (2004a).

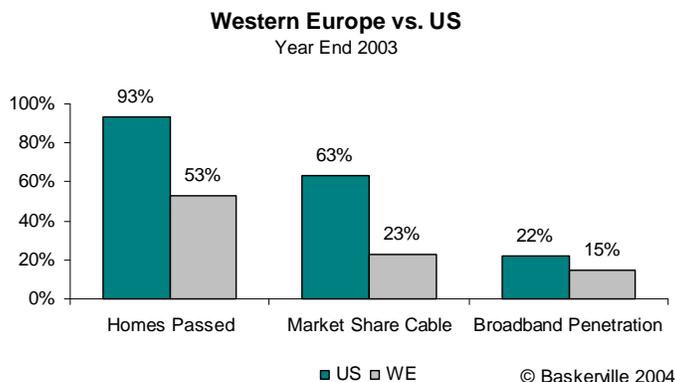


Figure 1: Cable Competition in the US and Western Europe

first is a simple asymmetric entry model where either one or two companies can enter a market with a sunk investment in infrastructure. While the first one faces no capacity constraint (the PSTN operator), the second faces an exogenously given capacity constraint (the percentage of homes passed by cable TV). The higher the capacity constraint, the higher the market share will be and the more intense competition. The model predicts a clear positive correlation between the capacity constraint and the equilibrium quantity (the cable penetration), up to the maximum degree of competition (50% market share for each technology). The entry of the second firm will be socially beneficial (and profitable for the cable company) if the sunk cost of entry is sufficiently small. The second model is slightly more tailored to the broadband industry, taking into account that network build-up costs for both technologies are far lower in cities than in rural areas. Thus, we assume that both firms enter regional markets along a line and compete in Cournot style in the second stage in each market. In line with observations from broadband markets, we assume a uniform price across all regions. This model leads to an ambiguous prediction about the relation between competition and broadband penetration. A new region will be covered only if the second stage profit in this market is sufficiently large. Thus, low competition will lead to more regions being served, while greater competition will result in lower prices and higher quantities in each market but also in less regions being served. The overall effect on the household penetration is not clear.

We confront the theoretical discussions with empirical evidence from Western Europe for the period 2000-2004. We consider a list of additional explanatory variables (GDP, population density and other) and run a pooled regression on the data panel. We find that cable competition has the predicted inverted U-shaped effect on the penetration with broadband access, with a peak for a cable market share of about 50%. We use the - highly significant - coefficients to

estimate the extent to which penetration would have been lower in the absence of cable competition and we evaluate the lower quantity at historic broadband prices. Finally, the estimate for the additional social surplus from cable competition is compared to estimates for the upgrade investments. Though no definite evaluation of the overall welfare effect can be given (as we can give only ranges for the estimates of relevant cable investment with respect to common cost problems and the uncertain lifetime of the equipment), it seems most likely that the welfare effect was, at most, neutral, if not negative.

There is an extensive literature on network and service competition for telecommunications and for the adoption of broadband services. The broadband industry is discussed in Crandall (2003). Most closely related in terms of the theoretical question is the work of Bourreau and Dogan (2005). They investigate the incentives for an incumbent and an entrant a regulator sets by imposing obligations to unbundle the local loop. They allow for flexibility about the timing of entry and the entrants decision to use the unbundled local loop or to build up their own, potentially higher quality, infrastructure. Their theoretical model highlights the fact that an unregulated incumbent has an incentive to delay the adoption of an alternative (i.e. cable) infrastructure. This can be welfare decreasing if the alternative is quality improving. Similar ideas are formulated in Bourreau and Dogan (2004). A theoretical analysis of service competition in the broadband market can be found in Foros (2004). The related question on the geographical coverage of competing network roll-outs has been addressed in Faulhaber and Hogendorn (2000). Foros and Kind (2003) discuss the welfare effects of (mandated) uniform prices and, formalizing an effect similar to our second theoretical model, find that uniform prices will decrease regional coverage.

Related empirical research includes attempts to explain different increases of Internet penetration and the "digital divide", see Chinn and Fairlie (2004). With a focus on broadband access, Aron and Burnstein (2003) have investigated the impact of competition between DSL and cable for the US. In line with our European findings, they report a positive effect, but their work is based on a relatively small data base.<sup>2</sup> In comparison to this literature, the present paper has a broader empirical basis and a focus on the overall welfare effects, including the investments in the alternative infrastructure.

Broadband access is also of high political relevance. In their "eEurope 2005" program the European Union is highly committed to increasing broadband penetration, see EU Commission (2002) and EU Council (2002). Apart from whether this goal makes sense per se, there is a question of the best means for achieving this goal. With the recent introduction of regulated wholesale obligations for DSL, it is clear that the EU actively supports service competition (EU Commission (2003b)). Although not the focus of this paper, the empirical results can also contribute to this discussion. The data suggest that service competition has been less effective than network competition so far. Countries with more

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<sup>2</sup>They perform a cross section analysis for 46 US states, based on data for the year 2000. The estimation, with 10 variables and 46 observations, is not jointly significant at the 5% level.

intense service competition do not exhibit significantly higher penetration rates.

The remainder of the paper is organized as follows. Section 2 explains the broadband industry in more detail. Section 3 discusses some policy issues of the sector. Section 4 proposes the theoretical models. Section 5 is empirical, presenting the data, the model to be estimated, and a discussion of the estimation results. Section 6 concludes by discussing the policy implications.

## 2 Broadband Industry

*Technology* Broadband describes a form of Internet access with a relatively high transmission rate. At a minimum, broadband must exceed the standard ISDN data transmission rate of 128 kbps. We will focus - similarly to the OECD (EU Commission, 2004b, 6) - on products with more than 250 kbps. Since most of the mass market products do not exceed 1,000 kbps (1 mbps), in the following, broadband means roughly transmission rates between 0.5 and 1 mbps.

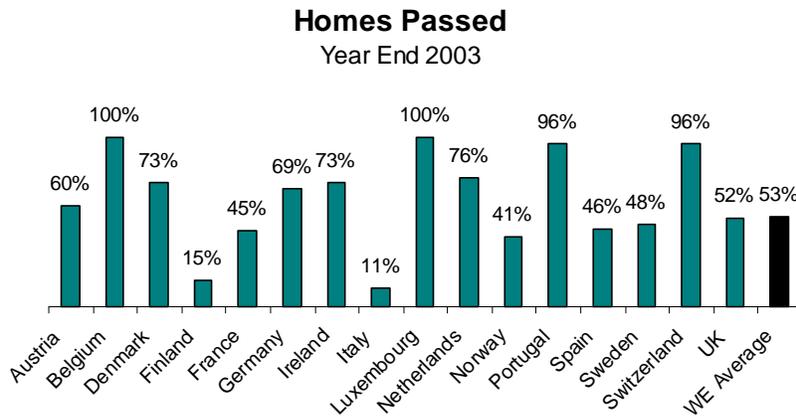
The two main access technologies in Europe and in the US are DSL and cable modem. In both cases the necessary upgrades of the underlying infrastructure exhibit strong economies of scale. Upgrades take place "region by region". It is prohibitively costly to supply only a single household with broadband access. If the network in a region has been upgraded, the cost of providing broadband access to a particular household connected to the network is virtually zero. Although guaranteeing a certain transmission rate requires a backbone capacity (i.e. capacity of the jointly used part of the network) which is increasing in usage, the main cost drivers (see below) are not related to the usage. Having two parallel infrastructures covering the same households, thus constitutes an (inefficient) duplication of assets.

In more detail, DSL is based on the PSTN network, and the upgrades required for broadband are the following: At the customer's premises a splitter (to split the data traffic from the voice traffic) and a DSL modem are needed, and several upgrades in the public network (in particular to reinforce signals depending on the distance to the next local exchange) have to take place. The key cost driver is the maximum distance of a household to the nearest exchange with DSL equipment (which is about 5 Kilometers, but depends also on the quality of the telephone line, see e.g. <http://www.everythingdsl.com>).

Alternatively, the infrastructure of cable TV can be used. Because the cable TV infrastructure was built originally for broadcasting only, it is in a "tree" structure and only "one-way". Upgrading requires cable modems at the customer premise as well as (i) the digitalization of the network (ii) the introduction of a back-channel, which is the main cost driver (iii) the reduction of the homes per segment to ensure bandwidth, and (iv) backbone upgrades (see e.g. Ovum (2003)). There are also other technological solutions, which might play a role in the future, but which have not been of significance yet. These are satellite and wireless broadband access (fixed-wireless access, WiFi, WiMax, UMTS).<sup>3</sup>

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<sup>3</sup>At the end of 2004, all these technologies are still immature. WiFi is a shared bandwidth medium and suffers from the fact that the bandwidth decreases with each customer logged



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Figure 2: Cable Homes Passed in Western Europe

By the beginning of 2004, these technologies accounted for less than 5% of all broadband access in the European Union (EU Commission, 2004a, p.55).

There is a basic asymmetry between both technologies. All households are connected to the PSTN and therefore (after the necessary network upgrade) in principle eligible for DSL; only "cable homes passed" can be supplied with a cable broadband access (again after network upgrades). Homes passed are all homes which can be connected to the existing network without new construction work. The proportion of homes passed, and therefore the potential for competition, varies widely throughout Europe, as depicted in Figure 2.

*Market Structure* In all countries the incumbent telecommunications operator offers DSL and has a dominant retail market position in the DSL segment. Some markets (UK, Netherlands, France) exhibit a significant wholesale DSL market. This has resulted in lower (40-50%) market shares for the incumbents in the DSL retail market. In some countries the telecommunications incumbent used to own the cable infrastructure (Germany, Sweden, in both countries the incumbent sold its cable TV business in 2003). In Portugal and Norway the incumbent's cable TV subsidiary still holds a dominant position in the cable TV market (market share > 80% in 1Q2004).

*Financial Crisis* Nearly all cable companies went through a phase of financial stress in 2002/2003. All companies had invested heavily in the 2000 Internet bubble following a "build and they will come" approach. With financial markets becoming reluctant to support high risk investments, the largest two European

into the same hot spot, thus bandwidth is hard to guarantee. WiMAX is still immature in technological terms. UMTS does typically not offer download capacities in excess of 500 kbps, and like WiFi availability decreases with the number of user in the same radio cell.

cable operators (NTL and UPC), accounting for almost half of all subscribers in Western Europe, had to file for bankruptcy in 2002. Other large operators like Telewest (UK) or ONO (Spain) went through considerable financial restructuring, involving significant debt-for-equity swaps and equity injections by shareholders. Reemerging after Chapter 11 bankruptcy proceedings or financial restructuring, investments were reduced significantly in 2003 and (revenue) growth strategies have been replaced by a focus on short-term cash generation.

### 3 Policy Issues

There is a widespread common understanding in the political arena that broadband Internet access should be politically supported. In its program "eEurope 2005" the EU Commission stated an ambitious goal: by 2005 half of all Internet access lines should be broadband.<sup>4</sup> The EU initiated the development of broadband strategies to achieve this goal in all member countries. Germany's objective, for instance, is to reach more than 20 million broadband subscribers by 2010 (BMWA (2003)) - almost four times the number at the end of 2004.

Views differ significantly about how these targets can be met. The OECD clearly favors competition over subsidization (OECD (2004b)), without specifying whether this means infrastructure or service competition. The EU Commission provides scope for subsidies and for promotion of competition. Most member countries' initiatives focus on subsidization of either demand (e.g. Austria with tax-deductible broadband expenditures (EU Commission, 2004a, p. 29)), or supply (Italy plans to support the incumbent operator by upgrading its network with up to € 270 million, see *Börsenzeitung* (2004)).

The EU has also tried to increase service competition with unbundled local loop access. This has been of limited success EU Commission (2004b). Thus, new initiatives try to reinforce service competition, based on wholesale models requiring lower investments from competitors, compared to solutions realized via unbundled local loop. The EU has identified wholesale DSL as a market which should be ex ante regulated EU Commission (2003a). Bit stream access (a certain technological realization of DSL wholesale products) has been further specified by the European Regulators Group as a regulated wholesale product, see ERG (2004). No overall strategy, however, yet exists, which has quantified and compared the effects from infrastructure competition, service competition and subsidization.

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<sup>4</sup>Reaffirmed by EU Council (2002). However, already by the end of 2002 and in the light of the financial crisis of the industry, Erkki Liikanen, the responsible EU-Commissioner in charge, stated: " The EU recognises the importance of exploiting the broadband potential, although the financial problems of the sector are making the 2005 objectives more difficult to achieve" (Liikanen (2002)).

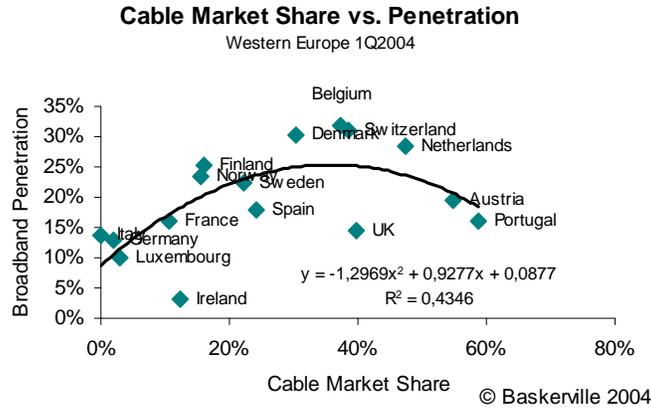


Figure 3: An inverted u-shaped relationship?

## 4 Some simple theoretical ideas

The basic intuition to be investigated, which is very popular among industry experts (see e.g. Neumann (2003)), is depicted in Figure 3, which provides a cross-country comparison of the market share of the cable industry (in terms of subscribers) versus the national household penetration with broadband access lines.

It suggests an inverted U-shaped relationship. If the cable market share is very low, competitive pressure on the incumbent with its DSL product is low, while prices are high. This results in a low penetration. The opposite is true for a dominant cable industry. As striking as this reasoning might be, it is not easily formulated in a theoretical model since market shares and competitive pressure are not exogenous (as suggested in the simple picture) but endogenous. Although our focus is on the empirical side, we formulate simple theoretical models to formalize the reasoning of Figure 3 and in order to highlight potential limits to the positive effects of competition on penetration.

### 4.1 A simple duopoly example with an exogenous capacity constraint for one firm

Two firms can serve a market by choosing a capacity  $q_i$  in the first stage and competing in prices in stage 2. Firm 1 can choose any capacity level. Firm 2 faces an exogenous maximum capacity constraint  $\bar{q}_2$ , which we can interpret as the "homes passed" by the cable TV infrastructure. For simplicity we assume (i) equal and constant marginal cost of capacity  $c_1 = c_2 = c$  for both companies and zero marginal cost for providing the service in stage 2; (ii) linear demand  $D(p) = 1 - p$  and (iii)  $\bar{q}_2 \leq 1/3$ . Given the linear demand specification, the last

assumption rules out the uninteresting case in which the exogenous capacity constraint would not be binding.

**Lemma 1** *A subgame perfect Nash equilibrium of the simple game with capacity constraint  $\bar{q}_2 \leq 1/3$  and linear demand has both firms entering the market, with Firm 2 choosing  $q_2^* = \bar{q}_2$  and Firm 1 choosing  $q_1^* = (1 - \bar{q}_2)/2$ ,  $p_1 = p_2 = p^* = (1 - \bar{q}_2)/2$ , for a capacity cost that is sufficiently low ( $c \leq \frac{1}{2}(1 - \bar{q}_2)$ ). Inefficient market entry can happen.*

**Proof.** See Appendix. ■

This simple example has the following further characteristics which line up with the initial intuition. (i) The market quantity  $Q^* = q_1^* + q_2^*$  is strictly increasing in  $\bar{q}_2$ . (ii) The market share  $s_2$  of firm 2 is strictly increasing from the monopoly situation (with  $\bar{q}_2 = 0$  and  $s_2 = 0$ ) up to the symmetric Cournot outcome (with  $\bar{q}_2 = 1/3$  and  $s_2 = 1/2$ ). (iii) If entry cost  $c$  is very large, only one firm can enter the market. If entry cost  $c$  is very small, both firms enter and the welfare level of the outcome is superior to a monopoly. For intermediate values of  $c$ , entry occurs, but it decreases welfare.

Transferring the simple example into the broadband industry, the prediction is that, with an increasing market share of the competing technology, the broadband penetration should unambiguously increase (up to the maximum competition level of equal market shares).

## 4.2 A simple model with ordered market entry

The costs for upgrading an existing network depend upon geographical parameters, in particular upon the population density. The less densely populated an area is, the more expensive it is to connect a single household. This is true for cable as well as DSL. We want to introduce this important stylized fact in the following model.

There are a large number of regional markets which can be ordered according to a parameter  $d$ , closely related to the cost of covering this region with broadband, i.e. with being able to offer the service to all households in this region (e.g. population density). Each market has the identical demand function for broadband services, which can be represented by the inverse demand function  $p(q)$ . We consider a two stage game in which two firms first decide how many markets to enter (choose  $d_i, i = 1, 2$ , see Assumption 1). In the second stage we assume Cournot competition in each market, where providing Internet access in a region covered has a constant marginal cost of  $c_1 = c_2 = c$ . The number of regions is large and we approximate the setting with a continuum of identical markets along a line of length 1, i.e.  $d_i \in (0, 1)$ . We look for a subgame perfect equilibrium for this game.

We assume ordered market entry, i.e. serving a more "remote" market is possible only if all "more central" markets have been covered already. This ordered market entry might be due to the fact that the network upgrades have

to start from the center (cities) and expand into more remote parts, and this process cannot just "jump".<sup>5</sup>

**Assumption 1 (Ordered market entry):** A firm can serve market  $\hat{d}$  only if it also covers all markets  $d < \hat{d}$ .

Price discrimination between regions is in principle attractive for the companies. In practice, however, regional price differentiation has not yet played a significant role in any of the existing markets, even though no regulatory universal service obligation forces companies to charge the same price throughout a country.<sup>6</sup> One reason might be that communicating different prices in a dynamically growing mass market for a homogenous service is very difficult.

**Assumption 2 (Uniform price):** Market quantity traded and price  $p$  must be the same in all regions.

We are interested in the most simple case in which one firm is more efficient than the other in serving any of the regions. To ensure unique pure strategy equilibria in the Cournot game, we assume  $p'' \leq 0$ .

**Assumption 3 (Entry Cost and Demand):** Entry is costly and convex in  $d$  and asymmetric.  $C_1(0) = C_2(0) = 0$  and  $0 < C'_1 \leq C'_2$  and  $C''_1, C''_2 > 0$ . Demand is concave,  $p'' \leq 0$ .

In what follows we focus on interior solutions,  $d_i < 1$ . This will be ensured if the cost functions  $C_i$  are sufficiently convex. As Firm 1 is more efficient in covering markets, the overall quantity  $Q$  (which, in reference to the broadband example, we will refer to as "penetration") across all regions can be calculated as:

$$Q = q^* * d_1, \quad (1)$$

where  $q^*$  denotes the equilibrium quantity in each of the regions. Figure 4 shows the market situation in which both firms entered.

Penetration  $Q$  is equal to  $0 \overline{d_1} B \hat{q}$ . Firms 1 and 2 compete in all markets between 0 and  $d_2$ , while markets between  $d_1$  and  $d_2$  are served by Firm 1 only (monopoly region). Note that the uniform pricing assumption implies that the quantity  $\hat{q}_1$  offered by Firm 1 in its monopoly region is just the sum of the two Cournot quantities  $q_1 + q_2$  of both firms in the competitive segment. In the second stage, Firm 1 thus maximizes its second stage profit  $\pi_1$ , given  $d_1$  and  $d_2$ :

$$\pi_1 = [d_2 q_1 + (d_1 - d_2)(q_1 + q_2)] (p - c) \rightarrow \max_{q_1}! \quad (2)$$

Firm 1 does not maximize each region independently. In choosing  $q_1$  the following trade-off arises. A higher  $q_1$  might increase profits in the competitive region; but it decreases profits in the monopoly regions, as higher quantities drive the equilibrium price further away from the monopoly price level. No such interdependencies exist for Firm 2, which maximizes in stage two:

<sup>5</sup>Alternatively, we could impose restrictions on the cost of covering a region. If this cost is sufficiently convex in  $d$ , profit maximizing behavior would endogenize the ordered market entry. However, this would only add additional less interesting complexity into the discussion.

<sup>6</sup>At least for the OECD. "In virtually all cases incumbent operators have uniform prices across the country" (OECD, 2004a, p.13).

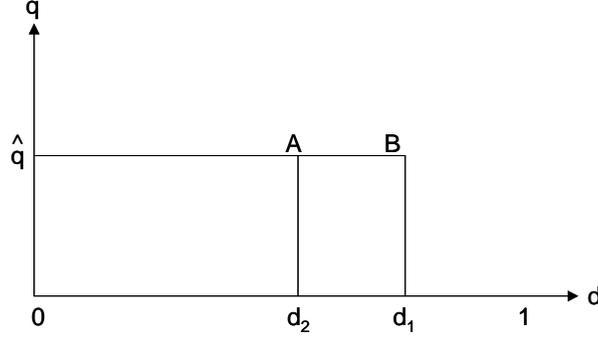


Figure 4: Both firms entered the market

$$\pi_2 = d_2 q_2 (p - c) \rightarrow \max_{q_2}! \quad (3)$$

Overall profits are given by:

$$\Pi_i(d_i, q_i) = \pi_i - C_i(d_i). \quad (4)$$

Thus, each firm covers markets as long as entry costs do not exceed the second stage profit of an additional region.

$$C'_1(d_1) = (q_1 + q_2)(p - c), \quad (5)$$

$$C'_2(d_2) = q_2(p - c). \quad (6)$$

Social welfare (assuming  $d_1 > d_2$ ) is given by:

$$W^D = d_1 \int_0^{q_1+q_2} p(q_1 + q_2) dq - (q_1 + q_2)c - C_1(d_1) - C_2(d_2). \quad (7)$$

In the unconstrained <sup>7</sup> first best only Firm 1 rolls out a network and:

$$\int_0^{q_1} p(q) dq - cq_1 = C'(d_1) \text{ and } p = c. \quad (8)$$

The following Lemma compares the monopoly case (only the more efficient Firm 1 entered,  $d_2 = 0$ ) with the duopoly case ( $d_1 > d_2 > 0$ ).

**Lemma 2** *Compared to the duopoly case, in the monopoly case (i) more regions will be covered, i.e.  $d_1$  will be larger, while (ii) quantity ( $q_1^* + q_2^*$ ) per market will be lower. The overall effect on the penetration  $Q$  is ambiguous. Social welfare will be higher under duopoly only if penetration is higher compared to monopoly and the entry cost  $C_2(d_2)$  is sufficiently small.*

<sup>7</sup> Assuming a lump sum transfer for covering the entry cost.

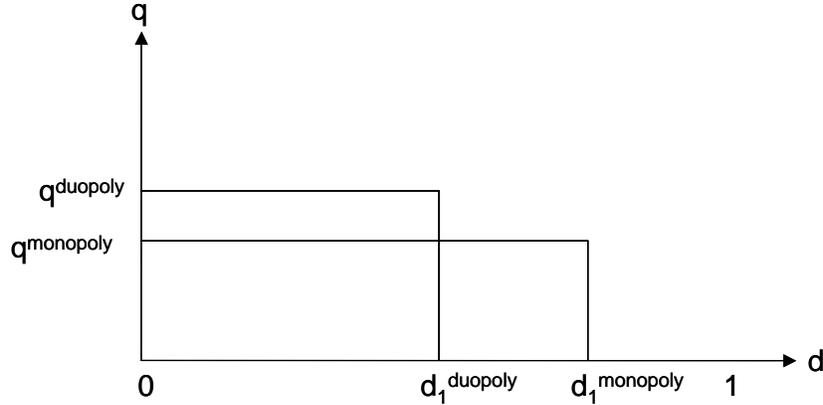


Figure 5: Higher quantities per region vs. lower regional coverage

**Proof.** See Appendix. ■

The duopoly quantities in each market exceed the monopoly quantities, while, at the same time, industry profits are not maximized per region, thus fewer regions are covered.<sup>8</sup> Figure 5 illustrates the two opposing effects. Which of the two effects prevails in terms of penetration as well as in terms of welfare hinges upon the characteristics of the demand and cost functions.

The second firm causes additional entry costs. Entry is only desirable from a social welfare point of view, if a higher quantity ( $q_1 + q_2$ ), provided across all markets, compensates for the network duplication. This will be possible only if entry costs are not too high.

In the case of broadband competition, it is again interesting to discuss the effect of an exogenous maximum value of  $d_2$ , e.g. due to a low number of homes passed. This is addressed in Corollary 1, which provides some sort of "continuity result" between the two extremes addressed in Lemma 2.

**Corollary 1** *Assume that there is a maximum value  $\bar{d}_2$  and that this value is binding, i.e.  $d_2^* > \bar{d}_2$ . A marginal increase in  $\bar{d}_2$  will (i) reduce coverage  $d_1^*$  and (ii) increase quantity per market ( $q_1^* + q_2^*$ ). The overall effect on the penetration  $Q$  is ambiguous.*

**Proof.** See Appendix. ■

Firm 1's quantity in the competitive regions,  $q_1$ , increases in  $d_2$ . This is due to the trade-off the first firm has to consider when choosing  $d_1$ . A higher  $q_1$  tends to increase profits in the competitive markets but reduces profits in the monopolistic region. An increase in  $d_2$  just means that the latter effect is

<sup>8</sup>If firm 1 could engage in price discrimination and choose the monopoly price in the markets it serves alone ( $d_1 - d_2$ ), it would clearly make higher profits in the marginal market, pushing  $d_1$  further out.

endowed with lower importance in Firm 1's considerations as the monopolistic region becomes smaller. Relaxing Firm 2's binding capacity constraint  $\bar{d}_2$  thus implies a higher choice of  $q_1$ . Although quantities are strategic substitutes, our assumptions on the cost and demand functions imply that this will lead to an increase in total quantity,  $q_1 + q_2$ . The welfare effect of an increase in  $\bar{d}_2$  is ambiguous, but (due to the increasing entry cost) it can be positive only if the penetration increased in the first place.

These considerations shed some doubt on whether competition from cable indeed increases broadband penetration (which was the unambiguous prediction of the first model). Neither weaker potential competition (a lower fraction of homes passed) nor weaker actual competition (in the extreme: the absence of cable competition) necessarily imply lower broadband penetration.

## 5 Empirical Analysis

Having in mind the theoretical caveats, we want to test for the effects of competition between DSL and Cable Modem on broadband penetration. We estimate to which extent the social welfare, measured as the sum of consumer and producer surplus, would have been different without cable competition, and compare this with the investment incurred to make this cable competition possible. Our basic hypothesis is that network competition has not been welfare increasing. Therefore we will always tend to take an upper boundary for the benefits and a lower one for the cost.

In order to explain broadband penetration, we try to include all important explanatory variables. Using the estimation results on quantities and combining it with pricing data from the market, we make a *ceteris paribus* statement on the additional consumer surplus that can be attributed to cable competition. We approximate investment into cable upgrade from company filings, so that we are finally able to compare benefits and costs.

### 5.1 Explaining Broadband Penetration

#### 5.1.1 Data and Model

We use data for 16 Western European countries on key explanatory variables for broadband penetration, most of which was provided by the research company, Baskerville, in August 2004. The Appendix provides a more detailed discussion of the data and the sources. We use quarterly data from 4Q2000 until 1Q2004, implying 224 observations. This data set virtually covers the whole industry history, since broadband as a mass market just started in 2000, and there were less than 2 million broadband subscribers in Western Europe at the end of 2000 (implying a household penetration of 1.3%), compared to 27 million subscribers in 1Q2004 (16.7% penetration).

Although broadband use has been increasing in all countries, growth pat-

terns are significantly different with respect to the two underlying technologies.<sup>9</sup> These different dynamics provide valuable heterogeneity across countries and time. Using the panel data set on 14 quarters and 16 countries, we conduct a pooled estimation of the following equation:

$$\begin{aligned}
 pen_{it} = & \beta_0 + \beta_1 cable_{it} + \beta_2 cable_{it}^2 + \beta_3 inctv_{it} + \beta_4 retail_{it} & (9) \\
 & + \beta_5 isdn + \beta_6 \ln gdp_{it} + \beta_7 density_{it} \\
 & + \beta_8 t_1 + \dots + \beta_{20} t_{13} + \varepsilon_{it},
 \end{aligned}$$

where for each period  $t$  and country  $i$ :

<b>Name</b>	<b>Definition</b>
pen	broadband subscribers / all households
cable	cable broadband subscribers / all broadband subscribers
inctv	incumbent cable TV subscribers / all cable TV subscribers
retail	incumbent DSL subscribers / all DSL subscribers
isdn	ISDN subscribers / all households
lngdp	$\ln(\text{gdp/capita})$ , using PPP and annual averages
density	inhabitants / square kilometer
$t_k$	time dummy

Apart from the time dummies, the explanatory variables fall into two classes, three "competition variables" and three "structural variables".<sup>10</sup>

(i) The first competition variable is the market share of cable companies in the broadband market, reflecting the actual infrastructure competition. We use a quadratic specification for the impact of the cable competition for reasons obvious from Figure 3. (ii) The market share of the telecommunication incumbent in the cable TV market influences whether cable indeed is a competitor to DSL. The incumbent's participation might have prevented the upgrading of cable TV to avoid the cannibalization of its PSTN network profits (or vice versa). Still, the effect of this on broadband penetration is not obvious (see the coverage reasoning of the second theoretical model). The absence of competition might provide incentives to the early and complete roll-out of the infrastructure. (iii) In some, but not all, countries there is a strong wholesale market for DSL. The retail market share of the incumbent in the DSL market is included as a proxy for service competition as opposed to network competition. The incumbent's retail market share in the DSL market can be regarded as exogenous, at least as long as market growth is strong. In this phase the incumbent will most likely try to win as much as possible of the market directly, and strong demand makes

<sup>9</sup>At least six patterns can be distinguished: (i) Same quantities of cable and DSL (UK), (ii) Cable still ahead (Portugal, NL), (iii) DSL slowly overtaking (Belgium, CH), (iv) DSL with higher growth rates from the beginning (Denmark, Norway, France, Ireland, Sweden, Spain, Finland), (v) DSL dominant throughout (Germany, Italy, Luxembourg) (vi) Parallel development with DSL ahead (Austria).

<sup>10</sup>Two further obvious candidates are: the fraction of homes passed, and the PC penetration. Both variables exhibit no explanatory value and are therefore omitted. The Appendix shows estimations including these variables and discusses the possible reasons for their insignificance.

wholesale superfluous as an additional sales channel. It is mainly regulatory obligations that drive the DSL wholesale market.

The causal link between broadband penetration and the market share of cable is generally unclear. We want to argue that a high market share of cable implies a high penetration. One could also argue that a high penetration, i.e. a large market size, provides scope for the market entry of a second firm, namely cable companies. We elaborate on the identification problem in the next section when discussing the estimation results.

Clearly, there is country specific heterogeneity in the data which is not covered directly in the pooled estimation employing time dummies. With the remaining three "structural variables", however, we capture significant country specific heterogeneity:<sup>11</sup> (iv) ISDN, supplying customers with more than one channel (typically three) via one access line, serves to some degree as a substitute for DSL. Though allowing only for narrowband Internet access, it provides customers with one key feature similar to DSL, namely the ability to make and receive phone calls while connected to the Internet. (v) GDP per capita shall capture general differences in macroeconomic performance as well as differences in disposable income. (vi) Higher population density makes coverage with broadband services less costly.

Finally, we use period dummies since cable penetration as well as many explanatory variables exhibit a strong positive trend.

### 5.1.2 Estimation Results

Table 1 shows the results for the pooled OLS estimation with robust standard errors.

pen	Coef.	Robust Std. Err.	t	P>t	[95% Conf. Interval]	
cable	.2413668	.0309319	7.80	0.000	.1803778	.3023558
cable2	-.234785	.0310731	-7.56	0.000	-.2960524	-.1735177
inctv	.0551709	.0100692	5.48	0.000	.0353174	.0750245
retail	.0337216	.0241694	1.40	0.164	-.0139336	.0813768
isdn	-.1013194	.0254529	-3.98	0.000	-.1515053	-.0511336
lngdp	.0483591	.017614	2.75	0.007	.0136293	.0830889
density	.0001489	.0000218	6.83	0.000	.0001059	.0001919
cons	-.371725	.1689235	-2.20	0.029	-.7047946	-.0386554

Table 1: Regression Results

The  $R^2$  of the pooled estimation equals 0.72 with  $(prob > F) < .0001$ , and the time dummies are jointly significant, exhibiting a strong positive trend.<sup>12</sup> The results strongly support the assumed inverted U relationship between cable

<sup>11</sup>Fixed effects estimations are not helpful in this case. Important explanatory variables like *density* and *inctv* have little of no variance over time for a single country.

<sup>12</sup>The qualitative results, however, are affected only to a limited extent by the dynamics. See the Appendix for an isolated investigation of the last period and for results for a cross country analysis for a wider sample of countries.

market share and the broadband penetration. Furthermore, we find a peak almost perfectly at a 50% market share of the cable technology. We interpret this as evidence that actual infrastructure competition can explain broadband penetration, and that the effect is strongest where competition is most intense, i.e. at equal market share, in line with the predictions of our first simple theoretical model.

The opposite causality (stronger demand creates space for more than one network) is less likely for at least two reasons. First, the size of the market share of cable is bounded above by the fraction of homes passed by cable TV. Since cable TV was rolled out in the 80s/90s, and therefore clearly predates the internet age, the market share of cable in the broadband market is to some extent exogenous.

Secondly, penetration and prices are negatively correlated. If the opposite causality would dominate, we would not expect a negative correlation between prices and quantities across countries. Higher quantities in a country would stem from a demand function on a higher level, not from lower prices. Unfortunately, we do not have consistent price data for a rigorous test of the relationship between prices and quantities. Based on price data provided by the OECD (2004a) for the 4th quarter of 2003, and abstracting from Finland and Spain with extremely high prices, we find at least weak support for a negative correlation (for  $pen = \beta_0 + \beta_1 price_i + \varepsilon_i$  we get an  $R^2 = 0.14$ ,  $\beta_1 = -.0023$  and  $p > |t| = 0.05$ ). Also the EU Commission report, based on more detailed data for different product qualities for February 2004, states a close negative correlation between prices and penetration (EU Commission, 2004b, p.21).

Apart from the cable market share as an indicator for actual infrastructure competition, the other "competition variables" do not support "pro-competition" arguments. The retail market share is not significant in our estimation. Countries in which competitors to the telecommunications incumbent have gained a significant share in the DSL market (mainly based on wholesale products of the incumbent) do not systematically exhibit a higher broadband penetration. If we again take a high market share of competitors as an indicator for more intense competition, we can conclude that service competition has not been effective in increasing penetration for the period under investigation. The fact that service competition can be effective only with DSL wholesale conditions (or generally: access prices) favorable to competitors, does not weaken this argument. A large market share of competitors is already an indicator that the regulatory regime supports service competition.

The market share of the telecommunications incumbent - being significant - shows an unexpected sign. A strong position of the telecommunications incumbent seems to positively influence the broadband penetration. This result is to be interpreted with care. It is driven strongly by two countries in the sample, Portugal and Norway. In both countries, the incumbent is the dominant player in the cable TV market, and cable was the dominant technology for providing broadband access, at least in the beginning of the period considered here. For Germany and Sweden, the market share of the incumbent dropped from "dominant" to "zero" in the first quarter of 2003 due to the divestment

of the cable assets by Deutsche Telekom and Telia, respectively. One cannot expect an immediate impact from this on the infrastructure competition for the remaining periods. In the light of these considerations, relying on a strong positive relationship between broadband penetration and the incumbents position in the cable TV market might not be justified. It nevertheless seems appropriate to state that the opposite (a clear negative relationship) is definitely not supported by the data. This result fits well to our second theoretical model. A telecommunications incumbent that also controls the rival technology cable does not have to fear competition. Therefore its expected (monopoly) profits provide an incentive for a large network roll-out, albeit, at high prices to the customers. No generally positive or negative effect on the overall penetration can be expected.

The "structural variables" are significant and show the expected sign. ISDN as a partial substitute for DSL negatively influences the broadband penetration. A higher GDP per capita has a positive effect on the broadband penetration. Finally, densely populated countries exhibit higher broadband penetration, because providing broadband is less costly there.

## 5.2 Welfare Effects from Broadband Competition

We use Marshallian social surplus as a welfare measure, abstracting from any externalities from broadband. Crandall (2003) argues for strong externalities of bandwagon effects from broadband along the lines of the literature on network externalities. Critical mass or "chicken-egg" problems might prevent a socially beneficial network size and socially beneficial network choice. Customers will not sign up for broadband as long as attractive applications are lacking. No company will develop applications if there are few potential broadband users. Although this effect might exist, we follow the more sceptical view of Liebowitz and Margolis, claiming "network externalities [are] an uncommon tragedy"(Liebowitz and Margolis (1994)). Typically, network effects can be internalized via the market, e.g. with vertical integration or alliances between network operators and content providers. Virtually none of the large telecommunications operators has diversified significantly into the content industry and the merger between AOL (as an Internet service provider) and Time Warner (a content provider) was unsuccessful. Furthermore, strong empirical support for network effects is not yet available (?).

The last period in our sample, 1Q2004, is taken as our point of reference. We deduce, country by country, in a ceteris paribus approach, how many fewer broadband subscribers there would have been in 1Q2004, if no cable competition had existed (i.e. we set  $cable_{it} = 0 \forall i$  in an ex-post estimation for 1Q2004 and deduct the original values). Without cable competition the number of broadband subscribers would have been approximately 17% lower (22.4 instead of 26.8 million subscriber in 1Q2004). On average this translates into a delta of 2.7% points of penetration. In countries with very strong cable competition this delta goes up to almost 6% points (e.g. Netherlands with 22.6% instead of 28.4%, or Austria with 13.6% instead of 19.4%).

Using market prices as an approximation for the consumers' willingness-to-pay, we evaluate the resulting delta to the actual subscriber base. The inframarginal consumers have a willingness to pay higher than the actual (i.e. 1Q2004 in our case) market price. We try to account for this by first taking the incumbents price (which typically is above the market average) and, second, by taking prices from October 2003 (broadband markets are still expanding quickly, approaching new customer segments with decreasing willingness to pay, implying a continuous decline in prices). Since there is virtually no variable cost for broadband access once a subscriber is connected to the network, this gives a good approximation of the sum of consumer and producer surplus (actually the upper bound). Price data stem from the OECD (2004a).

For investment into broadband cable we produce an estimate of the capital expenditure of all companies in Western Europe whose subscribers are included in the data set for the years 2000-2003: This amounts to at least € 20.5 billion. This probably significantly underestimates the cost of cable competition, since significant investment might well have taken place before that period.

Cable companies did not only invest in upgrading the network for broadband access. There are also maintenance investments, investments in expanding the coverage, and investments in the digitalization of the network. The latter is a common cost for two distinct services, digital TV and broadband access. As a rule of thumb, a split of 10% maintenance, 15% expansion, 15% digital TV, and 60% broadband seems reasonable, but real rates differ widely among companies. The lifetime of the assets is also difficult to estimate. Some assets are extremely long-lived (like the physical infrastructure), other like network intelligence are more short-lived. Because the largest investments took place in 2000 (34% of the whole period 2000-2003), as of 2004 these assets are already at least 3 years old. An average remaining asset lifetime of five years in 2004 might be a good first estimate.

Formally, we want to estimate the welfare impact  $W$ , equal to consumer plus producer surplus, minus the attributed capital expenditures.<sup>13</sup>

$$W = CS + PS - s * Capex/L, \quad (10)$$

where  $L$  denotes the lifetime of the assets, and  $s$  the fraction of total capex attributed to broadband access. We do not discount the positive effects from penetration, although there is an obvious time lag between investment and full network usage. Again, this deliberately biases the results towards the positive welfare effects of competition.

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<sup>13</sup>Since investments provide service over more than one period, the following thought experiment is required: Consider a hypothetical period "2Q2004". In this period, no additional investments take place except for maintaining the 1Q2004 capital stock. No additional customers subscribe to broadband. This hypothetical period 2Q2004 is replicated for all future periods and the welfare of the two cases with and without cable competition compared.

		Percentage broadband of total cable capex										
		0	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Life Time of Assets	1	2.846	832	-1.183	-3.197	-5.211	-7.225	-9.240	-11.254	-13.268	-15.282	-17.297
	2	5.692	3.678	1.663	-3.51	-2.365	-4.379	-6.394	-8.408	-10.422	-12.436	-14.451
	3	8.538	6.524	4.509	2.495	481	-1.533	-3.548	-5.562	-7.576	-9.590	-11.605
	4	11.384	9.370	7.355	5.341	3.327	1.313	-702	-2.716	-4.730	-6.744	-8.759
	5	14.230	12.216	10.201	8.187	6.173	4.159	2.144	130	-1.884	-3.898	-5.913
	6	17.076	15.062	13.047	11.033	9.019	7.005	4.990	2.976	962	-1.053	-3.067
	7	19.922	17.908	15.893	13.879	11.865	9.851	7.836	5.822	3.808	1.793	-221
	8	22.768	20.754	18.739	16.725	14.711	12.696	10.682	8.668	6.654	4.639	2.625
	9	25.614	23.600	21.585	19.571	17.557	15.542	13.528	11.514	9.500	7.485	5.471
	10	28.460	26.445	24.431	22.417	20.403	18.388	16.374	14.360	12.346	10.331	8.317

Table 2: Upper Bound for Welfare Effects (bn.€)

Table 2 shows the results for (10). We cannot provide a point estimate, mainly due to the lack of a precise figure for the lifetime of the assets  $L$  and the percentage of investments attributable to broadband,  $s$ . If the lifetime of the assets is short and nearly all of the investments are attributed to broadband, the welfare effect is clearly negative, and vice versa. We have indicated the parameter region considered most likely in the table ( $4 \leq L \leq 6$ ,  $60\% \leq s \leq 80\%$ ). For this parameter region, the overall welfare effect is just about neutral. However, these numbers reflect only an upper bound for the welfare effect as we considerably biased all estimates in favor of the positive welfare effects from competition. We have (i) not considered pre-2000 investment, (ii) used no discounting although investment predates usage (iii) not taken into account the business stealing effect (i.e. negative effect on producer surplus of DSL-providers), and (iv) used relatively high prices to estimate the marginal willingness to pay. This suggests that the overall welfare effect has probably been negative.

## 6 Conclusion

Actual infrastructure competition from cable TV has had a significant positive effect on broadband penetration in Western Europe. Given a penetration rate of 16.7% in Western Europe at the beginning of 2004, on average 2.7% points can be attributed to cable competition, and a maximum of 6% points per national market. Therefore any policy dedicated a priori to high penetration rates should support infrastructure competition. The effect, based on theoretical reasoning, that infrastructure competition might reduce the "coverage" of regions and therefore can decrease penetration, is not explicitly supported by the data. It could, nevertheless, have limited the positive impact of infrastructure competition on broadband penetration.

The welfare gains from the increase of penetration due to infrastructure competition are not sufficiently large to overcompensate the very high investments into the basically redundant alternative cable infrastructure. The industry history up to 2004 suggests that, overall, the welfare effect - in the absence of any additional welfare enhancing effects from broadband access - of cable competition is likely to have been negative. The critical situation of almost all firms in the industry - high debt burdens, financial stress and restructuring, bankruptcy filings and painful reemergence from chapter 11 - already indicates that producer surplus had been negative. The estimates presented here suggest that the

additional consumer surplus from competition could not compensate for that.

From a purely theoretical point of view this might not be surprising. As is well known from Mankiw and Whinston (1986), for homogeneous goods - and broadband access is very homogeneous - , we can generally expect too much rather than too little entry from the social welfare point of view. Inefficiently low entry can occur only due to an integer problem. Is therefore all discussion about inefficient network overbuild just about the special case of an integer problem, when e.g. 1.8 are optimal and 1.9 firms would enter, but due to an integer problem, only 1 firm actually enters? This might well be the case, but the special case is of high importance in network industries. In these industries we typically consider only a very small number of entrants to be viable. And as numerical examples by Perry (1984)<sup>14</sup> unsurprisingly suggest, the integer problem, causing too little entry, is most common when the socially optimal number of entrants is small. Thus, it could well be the case that two networks are better than one, but this paper suggests that this is not the case for broadband.

Given that the drawback of network duplication is a real threat, one might be tempted to advocate service as opposed to network competition. Yet, the data do not support this simple message either, since service competition has had no significant effect on the broadband penetration so far.

A common regulatory strategy frequently encountered is often described as the "ladder model": When the market is initially opened, the regulator should enable easy market entry, i.e. entry with limited sunk cost, on the basis of service competition. After some time, competitors will try to "go down the ladder", and invest more, enabling them to offer differentiated products; they will then eventually establish sustainable, infrastructure based competition (Cave and Vogelsang (2003)). Thus, the regulator should switch to a strategy more favorable to infrastructure competition only with some time lag after market opening.

The analysis presented here provides stronger support for an opposing recommendation: In newly developing markets in which investments in infrastructure is of high importance, actual network competition is effective from the start. Pure service competition would decrease incentives to invest in (either) network. After the market has stabilized and growth rates are declining, it might be useful (if increasing penetration is still a regulatory and political goal) to enable service competition.

To provide a more solid recommendation in the general discussion of network versus service competition, in particular in newly developing markets, it is important to gain a better understanding of the effects on investment incentives. Further research therefore should focus on the empirical question whether network coverage is indeed adversely affected by competition. Again, broadband Internet access on a more disaggregate level (i.e. to which extent regions within countries have been upgraded for the new service) could serve as a promising empirical test case. Additionally, the question whether demand and supply subsidies (being the most common policy instrument in the EU so far) are more

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<sup>14</sup>See his Table I, p. 320.

effective than (network) competition awaits theoretical and empirical investigation.

## 7 Appendix

### 7.1 Proofs

#### 7.1.1 Proof of Lemma 1:

Given  $q_2 = \bar{q}_2$ , Firm 1 maximizes its profit by choosing

$$\pi_1 = p(1 - p - \bar{q}_2) \rightarrow \max_p \quad (11)$$

which provides  $p^*$ . Firm 2 will not choose  $p < p^*$  due to its capacity constraint. Choosing  $p > p^*$  is also not optimal for Firm 2 as this would imply a lower quantity  $q_2$  and Firm 2's profits decrease with lower quantities. Straightforward calculations for period 2 profits of Firm 2  $\pi_2$  show that

$$\left. \frac{\partial \pi_2}{\partial q_2} \right|_{q_2 = \bar{q}_2} = \frac{1 - 3\bar{q}_2}{2} \quad (12)$$

implying that  $\pi_2$  is increasing in  $q_2$  for  $\bar{q}_2 \leq 1/3$ .

Overall profits are given by

$$\begin{aligned} \Pi_1 &= \pi_1 - \frac{1}{2}(1 - \bar{q}_2)c \\ \Pi_2 &= \pi_2 - \bar{q}_2 c, \end{aligned} \quad (13)$$

implying positive profits in case of market entry of both firms for

$$c < \frac{1}{2}(1 - \bar{q}_2). \quad (14)$$

Straightforward calculations show that social welfare  $W$  is given by

$$\begin{aligned} W^{monopoly} &= \frac{3}{8} - \frac{1}{2}c \\ W^{duopoly} &= \frac{(1 + \bar{q}_2)^2}{8} + \frac{1 - \bar{q}_2}{4} - \frac{1 + \bar{q}_2}{2}c, \end{aligned} \quad (15)$$

implying

$$W^{duopoly} > W^{monopoly} \text{ for } c < \frac{1}{2}\left(1 - \frac{1}{2}\bar{q}_2\right), \quad (16)$$

therefore, comparing the critical values resulting from (14) and (16), it follows that there exist intermediate values of  $c$  s.t. entry occurs and is welfare decreasing. ■

### 7.1.2 Proof of Lemma 2

In case of a monopoly (only Firm 1 serves the market), in stage 2, Firm 1 maximizes  $d_1 q_1 (p(q) - c)$  with respect to  $q_1$ , which yields as first order conditions:

$$p(q_1) + q_1 \frac{\partial p}{\partial q} = c. \quad (17)$$

In the duopoly case, Firm 1's second stage profit function is given by:

$$\pi_1 = [d_2 q_1 + (d_1 - d_2)(q_1 + q_2)](p - c), \quad (18)$$

with the first order condition with respect to  $q_1$ :

$$p(q_1 + q_2) + (q_1 + q_2) \frac{\partial p}{\partial q} = c + \frac{d_2}{d_1} \frac{\partial p}{\partial q} q_2. \quad (19)$$

Comparing (17) with (19) shows that equilibrium quantity in each market is higher in the duopoly case, since even Firm 1 has an excessive (from the industry's point of view) incentive to produce. (The standard Cournot argument, that Cournot duopolists do not account for the "externality" imposed on the competitor from choosing higher quantities, applies fully to Firm 2, but is mitigated in case of Firm 1, which takes into account also the interaction between monopolistic and competitive regions).

In case of monopoly, Firm 1 chooses  $d_1$  to equate

$$C'_1(d_1) = q_1(p^M) \cdot (p^M - c), \quad (20)$$

where  $p^M$  is the monopoly price. Comparing (20) and (5) implies the higher choice of  $d_1$  in case of monopoly. ■

### 7.1.3 Proof of Corollary 1

From the first order conditions for the optimal choice of  $d_1$  we have (with  $\pi_1$  given by (2)):

$$\frac{\partial \Pi_1}{\partial d_1} = \frac{\partial \pi_1}{\partial d_1} d_1 + \pi_1 - C'_1 = 0. \quad (21)$$

Applying the implicit function theorem, we can state:

$$\frac{\partial d_1}{\partial d_2} = -\frac{-(q_1 + q_2)(p - c)}{2(q_1 + q_2)(p - c) - C''_1}. \quad (22)$$

This is negative for any interior solution of Firm 1's first stage optimization problem, as can be easily verified from the second order condition ( $\partial^2 \Pi_1 / \partial d_1^2 < 0$ ). This proves (i).

To show that the total quantity ( $q_1 + q_2$ ) increases in  $d_2$ , we first establish that  $q_1$  is increasing in  $d_2$ . The first order condition for the second stage profit of Firm 1 is given by:

$$d_1 [(p - c) + p' q_1] + p'(d_1 - d_2) q_2 = 0. \quad (23)$$

(23) implicitly defines  $q_1$ , thus we can calculate:

$$\frac{\partial q_1}{\partial d_2} = -\frac{-p'q_2}{d_1[p' + p''q_1 + p'] + p''(d_1 - d_2)q_2} > 0, \quad (24)$$

by our assumptions on  $p(q)$ . It is easy to verify that also in our specific Cournot game, quantities are strategic substitutes. A marginal increase in  $d_2$  will - according to (24) - shift Firm 1's reaction function outwards. Firm 2 will react by decreasing  $q_2$ , but to a lesser extent than  $q_1$  had been increasing, as can be seen from the derivative of Firm 2's reaction function being larger than  $-1$ . Firm 2's reaction function is implicitly defined by:

$$(p - c) + p'q_2 = 0, \quad (25)$$

implying:

$$\frac{\partial q_2}{\partial q_1} = -\frac{p' + p''q_2}{p' + p''q_2 + p'} \in ]-1, 0[, \quad (26)$$

again by our assumptions on  $p(q)$ . Thus, overall quantity ( $q_1 + q_2$ ) increases due to a marginal increase in  $d_2$ , having proven (ii). ■

## 7.2 Regression Data

Most regression data were provided by the specialized broadband market intelligence company "Baskerville" in August 2004. We have cross-checked the data with the latest cross-country analysis of the EU (from May 2004 EU Commission (2004a)) and deviations are very small (e.g. aggregate number of broadband subscribers deviates by less than 2% in both sources). Also, data from "Point Topic", an alternative research company, are quite similar to the data used in this analysis.

Most companies filings state the number of ISDN "channels" as "lines". Thus, we translate the ISDN channels reported by Baskerville on the basis of company information into subscriber figures, by taking 2 ISDN lines = 1 ISDN subscriber, since on average ISDN provides 2 channels per physical access.

GDP data are from Eurostat, using annual averages. Since we want to interpret GDP/capita as a proxy for differences in the level of economic development rather than for short run deviations from the trend, we used annual averages.

Table 3 provides the summary statistics, Table 4 the correlation matrix of the data (excluding the time dummies).

variable	Obs	Mean	Std. Dev	Min	Max
pen	224	.0908269	.0764561	0	.3173083
cable	224	.3973484	.2944095	0	1
retail	224	.7752965	.1526288	.3681922	1
isdn	224	.1568416	.1327081	.0114961	.4857143
gdp	224	25189.29	5.668.857	15300	45900
inctv	224	.2036127	.3090877	0	.8854054
density	224	153.2116	120.3885	11.69321	478.0385

Table 3: Summary Statistics

	pen	cable	retail	isdn	gdp	inctv	density
pen	1						
cable	-0.1121	1					
retail	-0.2751	-0.0100	1				
isdn	-0.1526	-0.2386	0.0563	1			
gdp	-0.0334	-0.3118	0.1149	0.5561	1		
inctv	0.0028	0.0965	0.0466	0.1757	-0.3186	1	
density	0.1766	0.1381	-0.0942	0.0194	0.0884	-0.3297	1

Table 4: Correlation Matrix

### 7.3 Prices

The products (plans) represented in Table 5 have been selected to approximate the inframarginal consumers' willingness to pay in calculating the welfare gain from increased broadband penetration. They are selected as the incumbent's offer for a medium product quality (i.e. average transmission rate) compared to all other plans benchmarked by the OECD. All plans include already significant connectivity on top of the pure access. Prices are therefore an upper bound for the value of the access. (e.g. free 10.000 MB imply already a de facto flat rate for most users with almost 14 hours/month continuous download with 0,5MB/s).

Country	Company	Plan	downstream1	upstream	price in €	connectivity included?
Austria	TA	AonSpeed 500MB	768	128	28,06	500MB
Belgium	Belgacom	ADSL Skynet Go	3000	128	36,06	10.000MB
Denmark	TDC	CableModem	1024	128	44,82	unlimited
Finland	TeliaSonera	ADSL	1024	512	107,69	unlimited
France	FT	eXtense fidelite	1024	128	67,92	unlimited
Germany	DT	T-Online dsl 1000	768	128	27,05	1.000MB
Ireland	eirecom	eircom i-stream starter (residential)	512	128	45,91	4.000MB
Italy	TI	Alice 640	640	128	53,46	unlimited
Luxembourg	p&T	SpeedSurf RUN	512	128	71,67	15.000MB
Netherlands	KPN	ADSL Komfort	1024	160	46,87	unlimited
Norway	Telenor	Online ADSL oppgradert	704	128	42,25	10.000MB
Portugal	SAPO (PT)	SAPO ADSL.PT	512	128	44,47	20.000MB
Spain	Telefonica	Linea ADSL 512	512	128	95,03	unlimited
Sweden	Telia	Telia Broadband 500	500	400	33,28	unlimited
Switzerland	Swisscom	Broadway ADSL600	600	100	35,62	unlimited
UK	BT	BT Yahoo! Broadband Home	512	256	38,71	unlimited

Source: OECD, Benchmarking Broadband Prices in the OECD, 18.6.2004, DSTI/ICCP/TISP (2003)8/final  
all prices as of October 2003  
prices originally in USD, PPP, including VAT, converted into € using average Interbank exchange rate of October 2003

Table 5: Broadband Access Prices

### 7.4 Cable Capex

Investment data have been collected for all cable companies whose broadband subscribers have been considered in the analysis of the broadband penetration. Sources are company reports, except for com hem (national filing with the Swedish Companies' House) and Cablecom (Deutsche Bank High Yield Research estimates). Wherever possible we used "capital expenditures" or "cash used for purchase of tangible assets" to exclude financial investments. Detailed investment data are available for approximately three quarter of the companies

(representing 72% of all subscribers covered). We assume the same investment intensity for the remaining companies and the same investment structure for missing periods (i.e. high investments in 2000, lower in consecutive years). Table 6 shows the details.

Country	Company	BB-cable offering since	Capex in EURO (mn.)					Subscriber
			2000	2001	2002	2003	Sum	
UK	NTL	4Q00	2.129	1.846	722	385	<b>5.082</b>	Subscriber 4Q2003 (tsd.) 1.385
UK	Telewest	4Q00	865,6	881,8	713,1	329,7	<b>2.790,2</b>	408,0
Denmark	Telia Stofa	1Q00	29,1	292,0	104,1	42,9	<b>468,1</b>	104,0
Norway	UPC / chello	1Q00	7,6	67,6	106,0	-	<b>181,3</b>	37,0
Finland	Helsinki Television (HTV)	1Q00	-	-	8,9	8,1	<b>17,0</b>	43,0
Finland	Sonera (small # cable)	4Q01	-	-	-	-	-	24,0
Sweden	Com Hem	1Q00	82,2	61,5	29,3	8,0	<b>180,9</b>	103,0
Sweden	UPC Sverige (chello)	1Q00	9,7	32,1	17,4	-	<b>59,3</b>	68,6
France	NC Numericable	1Q01	-	-	-	-	-	89,0
France	Noos	1Q00	-	-	-	-	-	203,0
France	UPC France (chello)	1Q00	21,4	128,0	240,2	-	<b>389,6</b>	28,0
Ireland	NTL	4Q01	-	-	-	16,4	<b>16,4</b>	6,8
Portugal	TV Cabo (PT subsidiary)	4Q99	-	470,0	34,3	44,4	<b>548,7</b>	224,0
Portugal	Cabovisao	1Q00	-	-	-	-	-	78,6
Spain	ONO	4Q99	428,0	360,0	252,0	199,0	<b>1.239,0</b>	182,0
Spain	Auna	-	-	-	-	-	-	365,0
Germany	iesy (eKabel)	3Q02	-	-	-	-	-	1,0
Germany	PrimaCom	1Q00	99,4	64,7	36,6	32,5	<b>233,2</b>	81,0
Netherlands	UPC (chello)	2Q99	643,7	286,5	112,1	-	<b>1.042,3</b>	322,0
Netherlands	Casema	4Q00	269,6	100,3	71,2	-	<b>441,1</b>	161,0
Netherlands	Essent	2Q99	145,0	176,0	79,8	62,8	<b>463,6</b>	265,0
Netherlands	Multikabel	3Q00	-	-	-	-	-	79,0
Belgium	UPC Belgium	2Q99	3,1	9,3	10,4	-	<b>22,9</b>	25,1
Belgium	Telenet	3Q97	200,0	200,0	67,6	100,4	<b>568,0</b>	300,0
Austria	UPC TeleKabel	1Q00	30,8	103,5	141,5	-	<b>275,8</b>	200,0
Austria	Liwest	4Q97	-	-	-	-	-	18,3
Switzerland	Cablecom	1Q98	-	248,9	141,5	116,6	<b>506,9</b>	190,0
<b>Total</b>	<b>all cable capex</b>						<b>14.526,5</b>	<b>4.991,4</b>
Information on capex for (subscribers)	3.887	-	-	-	-	-	-	-
Total cable subscribers 4Q2003	5.390	-	-	-	-	-	-	-
%-age covered	72,1%	-	-	-	-	-	-	-
<b>estimate of total capex</b>	<b>20.143</b>							

Table 6: Cable Capex

## 7.5 Additional explanatory variables

The number of "homes passed" can be used as an additional explanatory variable. Since cable firms can compete with DSL-offers only for the homes passed, the homes passed and the market share of cable are clearly positively correlated. As the regression results in Figure 11 show, including the homes passed does not improve the estimation results and the number of homes passed are not significant. Thus, we have omitted this variable in the main body of the paper.

The PC penetration is a standard explanatory variable for Internet penetration (see e.g. Chinn and Fairlie (2004)). Not only narrowband applications, but also most broadband applications, require PCs. We nevertheless omitted the PC penetration as an explanatory variable. Table 7 shows that the PC penetration is not significant. This surprising result is only to a very limited extent due to the positive correlation between  $pc$  and  $\ln gdp$ . These variables are not jointly significant at the 5% level ( $Prob > F = .0716$ ). To understand this, it is important to distinguish between the Internet penetration (including narrowband) and the broadband penetration. Broadband subscribers are a subset of Internet subscribers. Internet subscribers might be limited by the PC penetration. But as long as not every Internet subscriber is broadband, the PC

penetration will not limit the broadband penetration. Thus, it seems plausible that a PC penetration in excess of some critical value will not affect the increase in the use of broadband. Given a relatively homogeneous country sample (homogeneous with respect to the level of the countries development towards the "information society"), all countries seem to be beyond the critical value where the PC penetration limits the broadband penetration.

Table 7 shows the estimation results for the following estimation equation:

$$\begin{aligned}
 pen_{it} = & \beta_0 + \beta_1 cable_{it} + \beta_2 cable_{it}^2 + \beta_3 inctv_{it} + \beta_4 retail_{it} + \beta_5 passed_{it} \\
 & + \beta_6 isdn + \beta_7 \ln gdp_{it} + \beta_8 density_{it} + \beta_9 pc_{it} \\
 & + \beta_{10} t_1 + \dots + \beta_{22} t_{13} + \varepsilon_{it},
 \end{aligned}
 \tag{27}$$

where *passed* = homes passed/all households and *pc* = PCs/population. Data are again provided by the market research firm, Baskerville. For some countries, no information on the "homes passed" is available from Baskerville. Missing data have been added, using the research company advanced television Ltd. ([http://www.advanced-television.com/PDF/homes\\_passed\\_projections.pdf](http://www.advanced-television.com/PDF/homes_passed_projections.pdf)). These data focus on digital cable homes passed and therefore underestimate the homes passed for the countries where this source has been used. For this estimation,  $R^2 = 0.72$ , and  $(prob > F) < 0.0001$ . None of the estimation results presented in the main part of the paper are strongly affected, in particular, the coefficients for *cable* and *cable2* are only slightly altered.

pen	Coef.	Robust Std. Err.	t	P>t	[95% Conf. Interval]	
cable	.2305845	.0319657	7.21	0.000	.1675533	.2936157
cable2	-.2279585	.030179	-7.55	0.000	-.2874666	-.1684503
inctv	.0565723	.0130572	4.33	0.000	.0308255	.082319
retail	.0277497	.0276167	1.00	0.316	-.026706	.0822053
passed	.012178	.0158745	0.77	0.444	-.0191239	.0434798
isdn	-.1056511	.0250629	-4.22	0.000	-.155071	-.0562312
lngdp	.0539051	.0343119	1.57	0.118	-.0137524	.1215626
density	.0001403	.0000236	5.96	0.000	.0000938	.0001868
pc	-.0201788	.0578542	-0.35	0.728	-.1342579	.0939002
cons	-.4225143	.3428304	-1.23	0.219	-1.09852	.2534913

Table 7: Regression with additional variables

## 7.6 Cross Country Analysis

In order to investigate, to which extent the results are driven by the dynamics, i.e. the positive trend in *pen*, Table 8 shows the estimation results for the final period, 1Q2004. Although the results in isolation are not very instructive (we have 16 observations and 7 explanatory variables) it is reassuring that the signs of the coefficients are the same as in the panel estimation.

Regression with robust standard errors

Number of obs	=	16
F( 7, 8)	=	4.00
Prob > F	=	0.0353
R-squared	=	0.6631
Root MSE	=	.06572

pen	Coef.	Robust Std. Err.	t	P>t	95% Conf. Interval	
cable	1.011351	.4569909	2.21	0.058	-.0424715	2.065174
cable2	-1.594084	.6484459	-2.46	0.039	-3.089403	-.0987647
inctv	.0828188	.0611909	1.35	0.213	-.0582877	.2239254
retail	.2297705	.1344403	1.71	0.126	-.0802494	.5397903
isdn	-.0997707	.2090355	-0.48	0.646	-.5818074	.382266
lngdp	.071854	.1031128	0.70	0.506	-.1659245	.3096325
density	.0002855	.0001366	2.09	0.070	-.0000295	.0006006
_cons	-.8343984	1.050786	-0.79	0.450	-3.257515	1.588718

Table 8: Estimation Results for 1Q2004

In addition we can perform cross country estimates for a larger set of countries. We have not used this larger set of countries in the main body of the paper as institutional differences are very large and information on the market details is not easily available (like retail market share, stakes of telecommunication incumbents in cable TV companies, and, in particular, investment data for cable companies and broadband prices).

Data are available from the research firm, Baskerville, only for a somewhat arbitrary set of 34 countries and for the third quarter of 2003. And, consistent information on some of the explanatory variables are not available even for this subset of countries. However, Table 9 shows estimation results for the sample of 34 countries with the explanatory variables *cable*, *cable2*,  $\ln gdp$ , and *density*. The sample comprises the 16 Western European Countries of the main body of the paper, plus USA and Canada, three Eastern European countries (Czech Republic, Poland, Hungary), and 13 countries from Asia/Pacific (South Korea, Hong Kong, Taiwan, Singapore, Japan, Australia, New Zealand, China, Malaysia, Philippines, India, Thailand, Indonesia, in decreasing order of broadband penetration). The results of this cross country analysis, however, support again the qualitative results of the main body of the paper: an inverted U-shaped relationship (with a peak at  $\sim 40\%$  market share of cable), a positive correlation with the gdp/capita and the population density. (GDP/Capita in current 2003 prices in USD, source: Worldbank, <http://devdata.worldbank.org/data-query>, population density on the basis of 1999 population, source: CIA World Factbook, [http://www.photius.com/wfb1999/rankings/population\\_density\\_1.html](http://www.photius.com/wfb1999/rankings/population_density_1.html)).

Regression with robust standard errors

Number of obs	=	34
F( 4, 29)	=	19.00
Prob > F	=	0.0000
R-squared	=	0.4084
Root MSE	=	.1434

	Coef.	Robust Std. Err.	t	P>t	95% Conf. Interval	
pen						
cable	.731301	.4263582	1.72	0.097	-.1406995	1.603301
cable2	-.9167432	.5612938	-1.63	0.113	-2.064718	.2312315
lngdp	.0339979	.0150966	2.25	0.032	.003122	.0648739
density	.0000463	.0000113	4.10	0.000	.0000232	.0000694
_cons	-.2763884	.1268264	-2.18	0.038	-.5357776	-.0169992

Table 9: Cross Country Estimates with 34 Countries

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