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# The effects of asymmetric regulation on the quality of broadband networks

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SEO Economic Research

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## Abstract

Network operators of competing infrastructures in European electronic communications markets face asymmetric regulation: incumbent telecommunications firms are required to open their networks for retail broadband competition, while cable companies have no such obligation. Furthermore, for historical reasons, cable companies have better quality networks thanks to the DOCSIS 3.0 technology than DSL-based telecom firms. How would the market structure of electronic communications markets and the quality of networks develop in the presence of asymmetric regulation and original quality differences? Based on a location model for product differentiation, I find that access revenues can compensate incumbent telecom firms for the loss due to having a lower quality network than cable companies. Therefore, access obligation reduces the incentives of telecom firms to compete with cable companies by upgrading network quality. In the absence of retail competitors without networks, however, telecom firms need to upgrade network quality to be able to remain competitive with cable companies. Furthermore and in line with the existing literature, the exclusion of retail competitors is more likely in the presence of higher access prices and stronger substitution between firms' products. Finally, if the original difference between network quality is large and high returns on investments are unlikely, telecom firms may not be able to invest sufficiently and lose substantially from their market shares.

**JEL classification:** L51, L96, L10, K23

**Keywords:** Telecommunications, Investments, Quality, Access regulation, Asymmetric regulation

## 1. Introduction

According to the objective of the European Commission, by 2020 all European household should have access to Next Generation Networks (NGN; that has a speed of 30 Mbps or more) and at least 50% of households should have a connection of 100 Mbps or higher.<sup>2</sup> Accomplishing this objective requires more maturity in broadband markets in terms of internet penetration and more importantly, investments in NGNs.

In this paper, I focus on the development of the quality of fixed broadband networks in relation to the market structure of telecommunications and access regulation. The starting point of the analysis

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<sup>2</sup> <https://ec.europa.eu/digital-agenda/en/high-speed-broadband>

is a situation in which two networks exist: a former telecommunications network and a cable network. Both operators of these networks provide broadband internet services. These network operators face, however, an asymmetric situation with respect to regulation. Based on the European telecommunications framework, the operator of the incumbent telephony network is subject to access regulation. Consequently, it needs to open its network for competing service providers and can charge only regulated access fees. The operator of the cable network does not face such access obligation. This situation reflects for instance the broadband internet market in the Netherlands.

Another characteristic of European broadband markets that plays a role in the future developments towards the EC objectives is that broadband services provided on cable networks by DOCSIS 3.0 technology have a (potentially) higher quality than DSL services provided by telecom firms. Even though (mainly) telecom firms have already started to deploy fiberglass networks, the coverage of this technology lacks behind the other two dominant technologies. Furthermore, the future return on investments in fiberglass is highly uncertain.

In the above-described market, three questions are of particular interest for this paper:

- What is the role of infrastructure-based competition in the development of broadband quality?
- How does asymmetric regulation influence future investments in NGNs, in particular in the presence of uncertainty?
- What is the effect of asymmetric regulation on network quality and the broadband market structure?

In several empirical studies, the effects of different types of competition on broadband penetration are analyzed (e.g., Bouckaert et al. 2010). These studies show that infrastructure-based competition is the main driver of fixed broadband penetration in the OECD countries. More closely related to my paper, Crandall et al. (2002) test empirically the effects of asymmetric regulation in the US broadband market. They find that DSL and cable modems compete on the same market but DSL providers do not have market power in contrary to cable companies. Consequently, they recommend a more equal consideration of firms providing products that compete in the same market. What is lacking in the most papers assessing the effect of infrastructure-based competition on broadband penetration is that these studies do not take into consideration that competing networks often provide broadband access of different quality. One could expect that by such vertical differentiation, network operators can avoid the commodity trap of broadband internet and competition will be reduced. An exception is the paper of Nardotto et al. (2013). The authors argue in their empirical study on the UK broadband market that infrastructure-based competition has a positive impact on network quality even if firms offer packages of differentiated quality. This result holds in the presence of asymmetric regulation.

A very extensive literature analyzes the effects of access regulation on investment incentives. As empirical and theoretical studies show, access regulation reduces investment incentives (e.g., Grajek & Röller 2012, Brito et al. 2012, and Cambini & Ying 2009). Furthermore, upgrading networks to better quality requires large investments with uncertain returns. By comparing several regulatory regimes in the case of a monopoly infrastructure, Nitsche & Wiethaus (2011) find that the current

regulatory regime based on long run incremental costs incentivizes investments to the least extent and achieves the lowest level of consumer welfare. With respect to incentives, fully distributed costs and regulatory holiday perform the best and risk sharing provides the highest level of consumer welfare. These results suggest that the current access regulation provides too low investment incentives for the telecom firm in comparison to cable firms that are not subject to regulation. Consequently, under insufficient funding for investments in NGNs, the incumbent fixed telephony network may become a smaller infrastructure provider and once again the market may be dominated by a natural monopoly, in this case, the cable company. De Bijl (2011) and Noam (2010) consider already the emergence of natural monopolies as a feasible future scenario in electronic communications markets.

In the paper, I intend to analyze whether the above-mentioned intuition are plausible. For the analysis, a spatial location model is used that considers competing upstream companies and a downstream entrant. The used Spokes model is based on Chen & Riordan (2007). Jeanjean (2012) uses a similar model to analyze investments in broadband quality. However, his model considers an upstream monopoly and does not take uncertainty into consideration. I extend the Spokes model with ex ante asymmetries between firms à la Carter & Wright (2003; called brand loyalty) and quality differentiation à la Cambini & Valletti (2004), both models developed for mobile telephony thus network competition. In my model, the cable company has initially higher quality and the telecom company can invest in network upgrades. The return on these investments is uncertain.

In the model, I find first of all that network operators can differentiate themselves by providing access of different quality. The firm that has a better quality can set higher prices and still achieve a higher market share. Consequently, quality differentiation reduces competition and by doing so, network operators can avoid the commodity trap of homogenous products. Second, an access fee that is closer to the marginal cost of providing access erodes investment incentives, also in the presence of uncertainty. The incumbent telecommunications firm will invest less than it would be socially optimal. This result is in line with the literature on one-way access pricing. However, if the access price increases, the entrant faces higher wholesale costs and may need to leave the market. This is a general result in the literature on exclusion by unregulated firms. In this case only two network operators compete in the retail market. In this duopoly situation, the telecom firm has incentives to overinvest in order to be able to compete with the cable company. As the results also show, the cable company, which is not subject to regulation, benefits from a higher access fee as a higher access fee reduces competition between the incumbent and entrant and therefore the cable company also does not need to compete so fiercely any more.

Finally, the original difference between network quality and consumer loyalty also influence the equilibrium market structure. The firm that provides internet access with higher quality and has higher brand loyalty attracts more consumers and achieves larger market shares. In extreme situations, this firm can become a monopoly infrastructure in the market. This result also depends on the success of investments. If the probability of low return by the telecom firm is high, the cable company has an advantage with respect to quality and achieves a potentially exclusive market share. If, however, upgrading the telecom network has a high return with a large probability, monopolization by the cable company is less likely.

## 2. The Dutch broadband market

The Netherlands has the highest broadband penetration per 100 inhabitants in the EU and the second highest within the OECD countries.<sup>3</sup> Infrastructure competition contributed substantially to this performance. In the Netherlands, both cable networks and the network of the incumbent telecommunications company, KPN, have full coverage with market shares of approximately 35% and 65% per region, respectively. However, the market shares of these network operators differ between network quality (see Table 1).

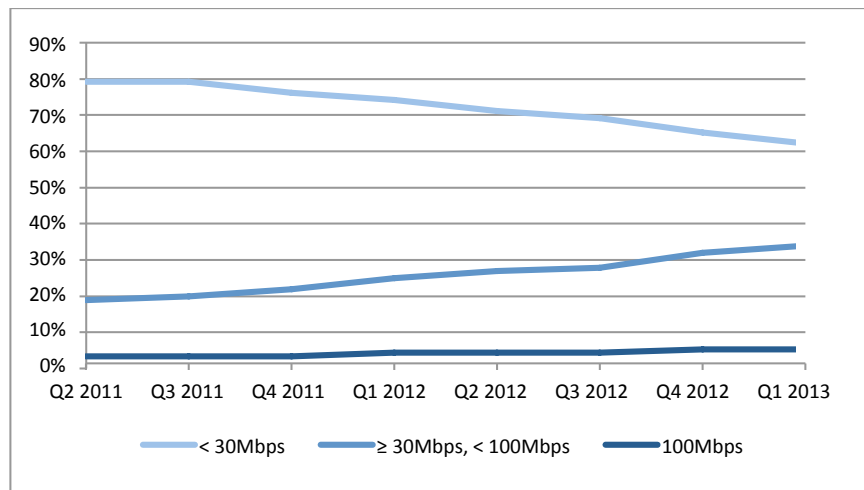
**Table 1** High speed internet is dominated by the cable technology and very high speed is shared between cable and fiberglass

	Share in number of connections	Share per speed category		
		DSL	Cable	Fiber
< 2Mbps	1%	99%	1%	0%
≥ 2 Mbps, < 10 Mbps	31%	63%	37%	0%
≥ 10 Mbps, < 30 Mbps	30%	68%	31%	1%
≥ 30 Mbps, < 100 Mbps	33%	18%	69%	13%
≥ 100 Mbps	4%	0%	55%	45%

Source: ACM, data from Q1 2013 (<https://www.acm.nl/en/publications/publication/11674/Telecom-Monitor-2013-Q1-Speeds-of-broadband-subscriptions-increase/>)

Due to technological development, KPN is the market leader in the old copper-based (DSL) infrastructure. The ADSL technology provides access in the speed range of 10 to 30 Mbps and KPN has 68% market share in that quality range. Cable companies are the dominant providers of better quality network services: 69% in the quality range of 30 to 100 Mbps by DOCSIS 3.0 technology. In the same range, KPN also achieves 31% due to its VDSL, pair bonding, and fiber technology.

**Figure 1** The share of high-speed internet penetration increases rapidly but it is still below 40%



Source: ACM (<https://www.acm.nl/en/publications/publication/11674/Telecom-Monitor-2013-Q1-Speeds-of-broadband-subscriptions-increase/>)

<sup>3</sup> 39.7 per 100 inhabitants in December 2012. Only Switzerland has a higher broadband penetration in the OECD countries; <http://www.oecd.org/sti/broadband/oecdbroadbandportal.htm>.

The coverage and so the penetration of very fast (100+ Mbps) internet is increasing (Figure 1) but it is at the moment still only 4%. DOCSIS 3.0 technology is capable of providing 150 Mbps speed, yet it is incomparable with the speed of fiberglass that can theoretically achieve 500 Mbps. These two technologies share the high-speed range almost equally.

The future development of broadband quality depends on several factors, among others the regulatory regime. According to the current regulation, cable network operators are not subject to access regulation, while KPN falls under the European regulatory framework and has access obligation. The following model is motivated by these market characteristics and regulatory setup to assess potential developments in broadband markets.

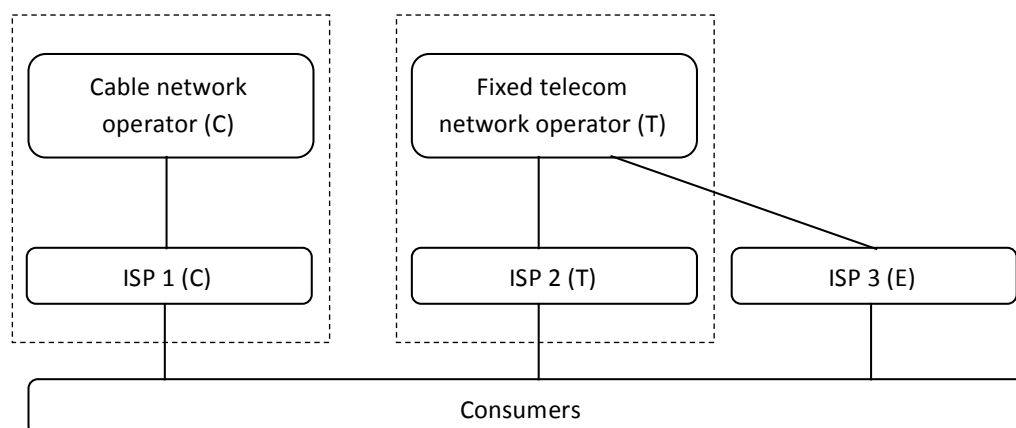
### 3. The model

#### 3.1 Environment

I consider a vertically related broadband internet market, in which regionally two firms own fixed infrastructures, a cable and a fixed telecom company (see Figure 2). These firms provide network services as an input for internet service providers on the retail market. Electronic communications networks have different quality and the telecom firm can invest in network upgrade. Only investments provide the telecom network higher quality. The outcome of these investments is, however, uncertain.

The network operator cable and telecom firms are vertically integrated to their downstream affiliates and active in the retail market. In line with the EU telecommunications regulation, the fixed telephony company has access obligation and charges a regulated access price for retail competitors. For simplicity, in the baseline model I assume one entrant in the retail market. The sector specific regulator determines the access fee ex ante. The cable company is not subject to access regulation. The retail market is considered by a location model of horizontal product differentiation with three competing firms.

Figure 2 Market structure



The timing of decisions is as follows:

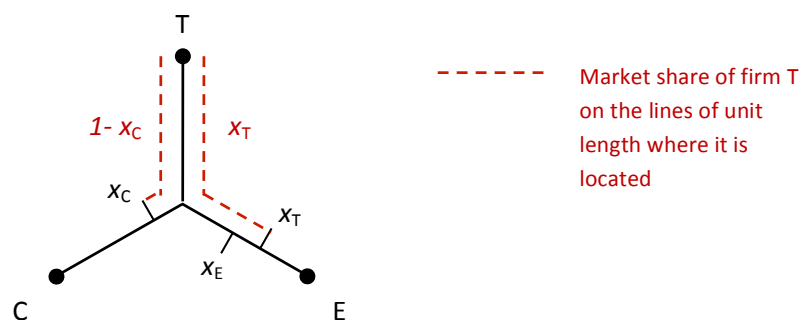
- *Stage 0*: The sector specific regulator determines the wholesale access fee. The tariff is assumed to be exogenous in the baseline model.<sup>4</sup>
- *Stage 1*: The telecommunications network operator invests in network upgrade without knowing the future success of investments.
- *Stage 2*: Consumers' willingness to pay for the upgraded network quality is revealed. Knowing that, firms compete in prices on the retail market.

### 3.2 Spokes model

The market is represented by a Spokes location model on the basis of Chen & Riordan (2007).<sup>5</sup> Starting at the midpoint of a line of unit length, each spoke has a length of one-half. Spokes together form a radial network. In this model, there are three distinct products each delivered by one of the retail firms and located at the origin of spokes (see Figure 3). Let  $i$  be the index for the retail firms (and their products), where  $i = T, E, C$  are the indices for the incumbent telecom firm, the entrant, and the cable firm, respectively. The spoke on which product and firm  $i$  is located is denoted by  $l_i$ . In the model, I do not take market entry into consideration. Therefore, the firms' locations are fixed. The products are physically identical – internet access – but are differentiated by their location. Different location can mean differences in client service or switching costs.

There are a large number of consumers that are normalized to 1. They are uniformly distributed on the radial network. A consumer needs to travel to buy a product, which incurs travelling costs. Travelling costs also mean disutility because a consumer's choice deviates from her most preferred choice (imperfect preference match). For instance, a consumer that is located in spoke  $l_i$ , product  $i$  is her most preferred choice and any other product is equally likely to be her second preferred choice. Therefore, the probability that she buys from another firm than  $i$  is  $\frac{1}{2}$ .

Figure 3 Retail firms are located in an even distance from the center at the origin of spokes



<sup>4</sup> In the extension of this paper, different modes of determining the access fee will be considered (based e.g. on Nitsche & Wiethaus 2011).

<sup>5</sup> The advantage of a Spokes model – in comparison to a Salop model – is that firms' locations do not change as a result of competition. Furthermore, firms stay in competition with every other firm. A similar model is used in Jeanjean (2012).

A consumer located at  $x_i$  on spoke  $l_i$  needs to travel distance  $x_i$  to buy product  $i$  and  $\frac{1}{2} - x_i + \frac{1}{2} = 1 - x_i$  to buy any other product. Travelling unit distance costs  $\tau > 0$ . The larger  $\tau$ , the more differentiated the products are, that is, the less strong the substitutability is between products. A consumer gains gross utility  $v_0$  by buying internet access from any firm.  $v_0$  is assumed to be high enough to provide full consumer participation in the market.

In addition, a consumers receives extra utility  $\beta_i$  when she buys a product from firm  $i$ . The utility function of consumers is additive in brand loyalty.  $\beta_i$  can be translated as brand loyalty (Carter & Wright 2003). Assume that  $\beta_T > \beta_C > \beta_E = 0$ , that is, the incumbent has the strongest and the cable company the second strongest reputation on the market. Brand loyalty justifies differences in original market shares: if firms set the same price and demand is also symmetrical in any other parameters, firm  $T$  achieves the largest and firm  $C$  the second largest market share.

Electronic communications network  $i$  has quality  $k_i$ . In the status quo, the quality of telecoms network  $k_0$  is lower than the quality of the cable network  $k_C$ :  $k_0 < k_C$ . However, the telecom firm can invest in quality upgrade  $k$ , by which  $k_0 + k > k_C$  can occur. This situation corresponds the quality differences between DSL, DOCSIS 3.0, and fiberglass technologies. In the model, I assume that only the telecom firm invests in network upgrade. The entrant operating in the telecom network also provides internet access with quality  $k_T$  and has a preference for higher quality. Consumers also value those services higher that are provided in a better quality network. I assume that a consumer's utility function is additive in quality. This way of exposition is in line with Cambini & Valletti (2004).

However, as mentioned earlier, at the moment of investments, it is not known if consumers will value quality upgrades positively. Therefore, consumers' willingness to pay cannot be observed when investments are made. It is only known that two states of the world can appear:  $j = S$  success or  $j = F$  failure. In the case of success, each consumer's utility increases by  $\tau k$ , that is, the additional value of quality in the utility function is  $\tau k_T^S = \tau(k_0 + k)$ . In the case of failure, a consumer's utility does not change even in the presence of investments; hence, the added value in each consumer's utility function is  $\tau k_T^F = \tau k_0$ . Let  $\mu \in [0,1]$  denote the probability of success, and consequently,  $1 - \mu$  the probability of failure.<sup>6</sup>

Firms set prices simultaneously. I assume that each consumer buys a unit of product  $i$ , which can be translated to an internet package that consists of a certain amount of data flow. Firms offer the same amount of data flow in a package for internet access. Let  $p_i^j \geq 0$  denote the retail price of product  $i$  in state  $j$ , that is, a flat fee.

Based on the above description, the total utility of a consumer located at  $x_i^j$  in state  $j$  is

$$v_0 - \tau|x - x_i^j| + \tau\beta_i + \tau k_i^j - p_i^j,$$

where  $x$  is the location of the firm, from which the consumer buys internet access.

In state  $j$ , a consumer located on spoke  $l_i$  is indifferent between variety  $i$  and  $i' \neq i$  if

$$v_0 - \tau x_i^j + \tau\beta_i + \tau k_i^j - p_i^j = v_0 - \tau(1 - x_i^j) + \tau\beta_{i'} + \tau k_{i'}^j - p_{i'}^j.$$

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<sup>6</sup> This modeling assumption is in line for instance with Nitsche & Wiethaus (2011) and Cambini & Silvestri (2012).



In this case,  $x_i^j$  also means the share of firm  $i$  on spoke  $l_i$  in state  $j$ . The comparisons for indifferent consumers are made in pairs between all firms. If there are  $N$  firms, there are  $\frac{N(N-1)}{2}$  comparisons in each state, namely three in this model:

$$v_0 - \tau x_T^j + \tau \beta_T + \tau k_T^j - p_T^j = v_0 - \tau(1 - x_T^j) + \tau k_T^j - p_E^j,$$

$$v_0 - \tau x_E^j + \tau k_T^j - p_E^j = v_0 - \tau(1 - x_E^j) + \tau \beta_C + \tau k_C - p_C^j,$$

$$v_0 - \tau x_C^j + \tau \beta_C + \tau k_C - p_C^j = v_0 - \tau(1 - x_C^j) + \tau \beta_T + \tau k_T^j - p_T^j,$$

out of which the market shares of firms on each line of unit length are

$$x_T^j = \frac{1}{2} + \frac{\beta_T}{2} + \sigma(p_E^j - p_T^j),$$

$$x_E^j = \frac{1}{2} + \frac{k_T^j - k_C - \beta_C}{2} + \sigma(p_C^j - p_E^j),$$

$$x_C^j = \frac{1}{2} + \frac{k_C - k_T^j + \beta_C - \beta_T}{2} + \sigma(p_T^j - p_C^j),$$

where  $\sigma = \frac{1}{2\tau}$  is the measure of product differentiation. The smaller the  $\sigma$ , the weaker substitutes products are.

As noted earlier, buying from any other firm than  $i$  has the conditional probability of  $\frac{1}{2}$ . Furthermore, the density of consumers in any line of a unit length is  $\frac{2}{3}$ . Consequently, the probability that firm  $i$  achieves a market share on each line of unit length where it is connected to is  $\frac{1}{2} * \frac{2}{3} = \frac{1}{3}$ . By using this probability and from the above expressions, the market share  $s_i^j$  of firm  $i$  in state  $j$  is

$$s_T^j(p_T^j, p_E^j, p_C^j) = \frac{1}{3}(x_T^j + 1 - x_C^j) = \frac{1}{3} + \frac{2\beta_T - \beta_C}{6} + \frac{k_T^j - k_C}{6} + \frac{\sigma}{3}(p_E^j + p_C^j - 2p_T^j),$$

$$s_E^j(p_T^j, p_E^j, p_C^j) = \frac{1}{3}(x_E^j + 1 - x_T^j) = \frac{1}{3} - \frac{\beta_T + \beta_C}{6} + \frac{k_T^j - k_C}{6} + \frac{\sigma}{3}(p_T^j + p_C^j - 2p_E^j),$$

$$s_C^j(p_T^j, p_E^j, p_C^j) = \frac{1}{3}(x_C^j + 1 - x_E^j) = \frac{1}{3} + \frac{2\beta_C - \beta_T}{6} - \frac{k_T^j - k_C}{3} + \frac{\sigma}{3}(p_T^j + p_E^j - 2p_C^j).$$

As the formulas suggest, the market shares are increasing (decreasing) in own (rivals') quality and brand loyalty and decreasing (increasing) in own (rivals') price. In addition, the more clearly products are differentiated (weaker substitution, i.e., small  $\sigma$ ), the smaller role prices play in determining market shares and the less fierce price competition becomes.

For simplicity, I assume that firms are evenly efficient in providing wholesale and retail products, and the marginal costs are zero. The entrant, however, needs to pay an access fee  $w$  to the incumbent telecom firm. The access fee is regulated ex ante and is exogenous for the baseline model. The incumbent firm also incurs investment costs in case network upgrades are made. Similarly to Nitsche & Wiethaus (2011) and Cambini & Silvestri (2012), investment costs are assumed to be convex in  $k$ . More specifically, investment costs take the form of  $\frac{\gamma k^2}{2}$ , where  $\gamma > 0$  is a parameter. The convex

form is justified as marginal investments cost are increasing when fiber networks are deployed in less and less populated areas or further towards customers' locations. Other fixed costs are also zero for a simple exposition.

Based on these assumptions on costs and for prices  $(p_T^j, p_E^j, p_C^j)$ , the firms' objective functions in state  $j$  are as follow:

$$\pi_T^j(p_T^j, p_E^j, p_C^j) = s_T^j(p_T^j, p_E^j, p_C^j)p_T^j + s_E^j(p_T^j, p_E^j, p_C^j)w - \frac{\gamma k^2}{2},$$

$$\pi_E^j(p_T^j, p_E^j, p_C^j) = s_E^j(p_T^j, p_E^j, p_C^j)(p_E^j - w),$$

$$\pi_C^j(p_T^j, p_E^j, p_C^j) = s_C^j(p_T^j, p_E^j, p_C^j)p_C^j.$$

In state 2, each firm maximizes its profit with respect to its own price. In stage 1, the incumbent telecom firm maximizes its expected profit with respect to quality upgrade.

#### 4. Individual equilibrium

The model represents a two-stage game, which is solved by backward induction.

##### 4.1 Second stage equilibrium: retail competition

Firms maximize simultaneously their profit functions with respect to own prices, given the quality of networks. At the moment of retail competition, firms can observe consumers' willingness to pay, that is, the state of the world. Therefore, there is equilibrium for each state of the world. The equilibrium prices are calculated from the first order conditions and are the following in state  $j$ :<sup>7</sup>

$$p_T^{j*} = \frac{1}{2\sigma} + \frac{w}{2} + \frac{2\beta_T - \beta_C}{10\sigma} + \frac{k_T^j - k_C}{10\sigma},$$

$$p_E^{j*} = \frac{1}{2\sigma} + \frac{7w}{10} - \frac{\beta_T + \beta_C}{10\sigma} + \frac{k_T^j - k_C}{10\sigma},$$

$$p_C^{j*} = \frac{1}{2\sigma} + \frac{3w}{10} + \frac{2\beta_C - \beta_T}{10\sigma} - \frac{k_T^j - k_C}{5\sigma}.$$

By substituting the equilibrium prices to the original expressions for market shares, I receive the equilibrium market shares:

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<sup>7</sup> The first order conditions are  $\frac{\partial \pi_i^j}{\partial p_i^j} = 0$  for each firm  $i$  in state  $j$ . As the profit functions are concave, the second order conditions satisfy for all profit functions:  $\frac{\partial^2 \pi_i^j}{\partial (p_i^j)^2} = -\frac{4\sigma}{3} < 0$ .

$$s_T^{j*} = \frac{1}{3} + \frac{2\beta_T - \beta_C}{15} + \frac{k_T^j - k_C}{15},$$

$$s_E^{j*} = \frac{1}{3} - \frac{3\sigma w}{5} - \frac{\beta_T + \beta_C}{15} + \frac{k_T^j - k_C}{15},$$

$$s_C^{j*} = \frac{1}{3} + \frac{3\sigma w}{5} + \frac{2\beta_C - \beta_T}{15} - \frac{2(k_T^j - k_C)}{15}.$$

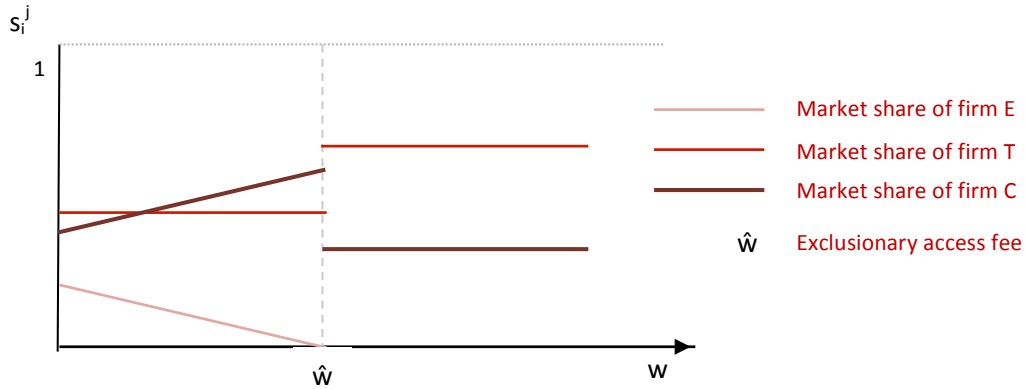
As the formulas for equilibrium prices and market shares indicate, the equilibrium is not symmetric. Both brand loyalty, quality, and the access fee influence the equilibrium outcome. In addition, the relationship between firms' prices and market shares is not straightforward. What follows clearly from the above formulas is that those firms can set higher prices that have more loyal customers and provide internet access with higher quality. Furthermore, firms win market shares because of their own brand loyalty and quality and lose due to the brand loyalty and quality of competitors. With respect to *brand loyalty*, the entrant has the least favorable position. In the case of strong brand loyalty to the telecom and cable companies – for instance due to high switching costs –, the entrant can be excluded from the market. Exclusion may occur in equilibrium, if a firm's market share becomes zero.

With respect to *quality* given that other parameters remain unchanged, if the investments of the telecom firm are not successful ( $k_T^F = k_0$ ) or successful but too low ( $k_T^S = k_0 + k < k_C$ ), the cable company can set a higher price and win a larger market share than the other firms. If the original quality difference is very high and investments are less likely to be successful, the entrant and the telecom company can be excluded from the market (see Figure 5). If investments are successful and extensive ( $k_T^S = k_0 + k > k_C$ ), the telecom company and the entrant benefit from providing higher quality, can set higher prices and achieve larger market shares. In this case, the likelihood of exclusion reduces. In the other extreme situation, when the telecom firm's return on investment is excessively high with a large probability, the cable company can be excluded from the market.

The *level of product differentiation* has its expected effect: the more a firm can differentiate its product from its competitors, the higher prices it can set without losing market shares. The stronger the product differentiation (the lower the  $\sigma$ ), the less likely that exclusion occurs. Or vice versa, the stronger the substitution between products, the fiercer the price competition and the more likely that the entrant will be excluded from the market (see Figure 5).

Finally, all prices are increasing in the *access price*. Because the access fee is a cost element for the entrant, its retail price is the most sensitive to regulation. Interestingly, the cable company can also benefit from a higher access fee: as a high access fee softens competition between the telecom firm and the entrant, the cable company also does not need to compete intensively.

Figure 4 Market shares of firms as a function of the access fee\*



\* This situation reflects stronger brand loyalty and higher quality for the telecom firm than for the cable firm.

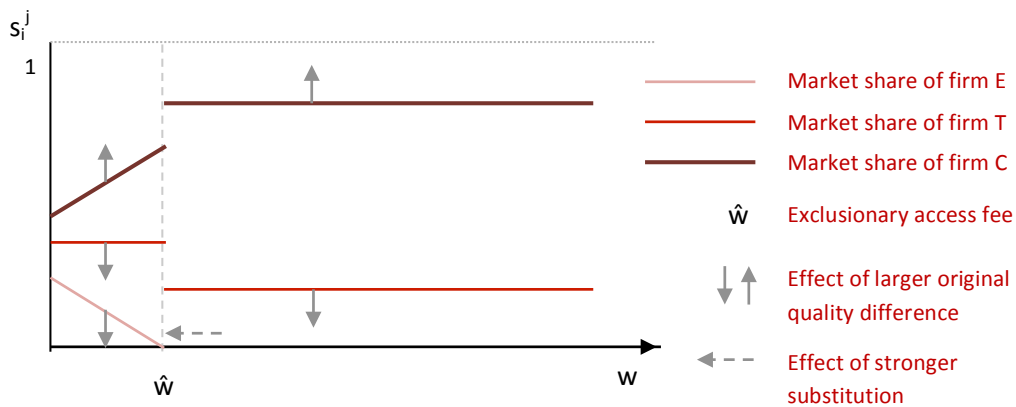
In line with the literature on one-way access pricing, I conclude that the higher the access fee, the more likely that a downstream competitor, i.e. the entrant, will be excluded from the market (see Figure 4, left hand side of the graph). The exclusionary level of access fee  $\hat{w} = \frac{5 - (\beta_T + \beta_C) + k_T^j - k_C}{9\sigma}$  is decreasing in product differentiation and the brand loyalty of competitors and increasing in relative quality advantage ( $k_T^j - k_C$ ; see Figure 5). Once the entrant exited the market (i.e.,  $w > \hat{w}$ ), the network operators compete in a duopoly fashion and share the potential market for the entrant equally. In this duopoly equilibrium, the access price does not influence prices and market shares any more (see Figure 4, right hand side of the graph):

$$p_{iD}^j = \frac{1}{\sigma} + \frac{\beta_i - \beta_{-i}}{6\sigma} + \frac{k_i^j - k_{-i}^j}{6\sigma}, i = T, C,$$

$$s_{iD}^j = \frac{1}{2} + \frac{\beta_i - \beta_{-i}}{12} + \frac{k_i^j - k_{-i}^j}{12}, i = T, C,$$

where  $D$  denotes the duopoly outcome with two vertically integrated firm.

Figure 5 Higher access fees, stronger substitution, and larger quality difference can lead to exclusion



\* This situation reflects stronger brand loyalty and higher quality for the cable firm than for the telecom firm.

The following proposition concludes the results on exclusion. The proof of the proposition follows directly from the formulas.

**Proposition 1** *The chance of excluding a firm from the market is increasing with the level of substitution and its disadvantage with respect to brand loyalty and quality. Furthermore, the entrant exits the market in the case of a sufficiently high access fee.*

#### 4.2 First stage equilibrium: investments

As mentioned earlier, at the moment of investments, consumers' willingness to pay cannot be observed. Therefore, the incumbent telecom firm invests under uncertainty. When deciding on quality upgrade, the telecom firm maximizes its expected profit with respect to  $k$ :

$$E\pi_T = \mu(s_T^S(p_T^S, p_E^S, p_C^S)p_T^S + s_E^S(p_T^S, p_E^S, p_C^S)w) + (1 - \mu)(s_T^F(p_T^F, p_E^F, p_C^F)p_T^F + s_E^F(p_T^F, p_E^F, p_C^F)w) - \frac{\gamma k^2}{2},$$

where  $s_i^j$  and  $p_i^j$  are the equilibrium market shares and prices from the second-stage game, for all  $i = T, C, E$  and  $j = S, F$ . As the expected profit function is concave in  $k$ ,<sup>8</sup> the optimization yields a maximum at:

$$k^* = \frac{5 + \frac{15\sigma w}{2} + 2\beta_T - \beta_C + k_0 - k_C}{\frac{75\sigma\gamma}{\mu} - 1}.$$

Some characteristics of the equilibrium level of investment can easily be seen from the formula. First of all, the more likely the *success of investment*, the more the telecom company will invest. Second, and in line with the literature, as the nominator of  $k^*$  increases in  $w$ , higher *access fees* provide larger investment incentives. However, at a high access fee ( $w > \hat{w}$ ), the entrant exists the market and, consequently, the network operators compete in a duopoly fashion. Given the duopoly equilibrium prices ( $p_{iD}^j$ ) and market shares ( $s_{iD}^j$ ), the optimal level of investment is:

$$k_D^* = \frac{6 + \beta_T - \beta_C + k_0 - k_C}{\frac{72\sigma\gamma}{\mu} - 1}.$$

The difference between investments in the presence of an entrant and in a duopoly is not straightforward and depends on the relative ratio between brand loyalty, original difference, and the access fee (see dashed lines in Figure 6).

Third, for a given probability of success, the *original difference between network quality* has a minor effect on optimal investment level in the presence of an entrant. In this case, obtaining access revenues compensates the incumbent for the loss due to lower quality. However, once the entrant is excluded from the market, the incumbent telecom firm loses access revenues and needs to upgrade network quality to remain sufficiently competitive with the cable firm (see dashed lines in Figure 6).

<sup>8</sup> If  $\frac{\partial^2 E\pi_T}{\partial k^2} = 1 - \frac{75\sigma\gamma}{\mu} < 0$ , the second order condition holds and the denominator of the equilibrium investment is positive.

**Proposition 2** *The presence of an entrant and access revenues compensates the incumbent telecom firm sufficiently for the original quality disadvantage. If the entrant exits, the incumbent needs to remain competitive with the cable company, which can only be achieved by upgrading its network quality.*

Fifth, stronger *substitution* between firms lowers the equilibrium level of additional broadband quality. Stronger substitution increases the level of price competition, which reduces investment incentives. Similarly, due to larger *investment costs*, the telecom firm will invest less. Finally, the more *loyal* the customers of the telecom firm are, the more the firm will invest.

## 5. Socially optimal investment

For the social optimum, it is expected that the telecom firm install the welfare-maximizing quality level. Calculating the social optimum is relevant for two reasons. First of all, one can observe to what extent an individual firm would deviate from the welfare-maximizing level of investment. Second, if there were any deviation, regulation needs to be adjusted to get closer to the social optimum.<sup>9</sup>

When determining the socially optimal level of investment, the regulator faces the same uncertainty as the telecom firm: the regulator cannot observe the actual willingness to pay of consumers at the moment of investment.<sup>10</sup> Although, it can be verified that the firm is serving all demand at its prices.

To find the social optimum, I assume that the regulator operates the telecom firm, chooses quality upgrades, and sets prices conditional on the success of investments. To calculate the social optimum, the regulator maximizes the weighted sum of the expected consumer surplus and the expected profit of firms:<sup>11</sup>

$$EW = ECS + \sum_{i,j} E\pi_i^j,$$

where  $EW$  denotes the expected welfare and  $ECS$  the expected consumer surplus.

The expected consumer surplus is the sum of consumers' net utility in any state of the world:

$$ECS = \mu \sum_i (s_i^S v(p_i^S) - T_i^S) + (1 - \mu) \sum_i (s_i^F v(p_i^F) - T_i^F),$$

where  $v(p_i^j) = v_0 + \frac{1}{2\sigma}(\beta_i + k_i^j) - p_i^j$  denotes the net utility from buying internet access from firm  $i$  in state  $j$  and  $T_i^j$  is the total travelling cost of consumers buying internet access from firm  $i$  in state  $j$ . In state  $j$ , the travelling cost of a consumer who buys from firm  $i$  and whose most preferred product is of firm  $i$ , is  $x_i^j$ . The travelling cost of a consumer, who buys from firm  $i$  and whose second most preferred product is of firm  $-i$ , is  $(1 - x_{-i}^j)$ . The total travelling cost for consumers travelling to firm  $i$  in state  $j$  is then:

<sup>9</sup> Optimal regulation will be analyzed in the extension of this paper. This version of the paper focuses on the first question.

<sup>10</sup> This assumption can be translated as follows: the regulator has to face high costs in order to observe the actual willingness to pay in the whole population.

<sup>11</sup> With this formulation, it is implicitly assumed that the regulator equally weighs consumers and firms, as if consumers fully owned the firms.

$$T_i^j = \frac{1}{6\sigma} \left( \int_0^{x_i^j} y \, dy + \int_{x_{-i}^j}^1 (1-y) \, dy \right) = \frac{1}{6\sigma} \left( \frac{(x_i^j)^2}{2} + \frac{(1-x_{-i}^j)^2}{2} \right).$$

Consequently, the total travelling cost in the market in state  $j$  is:

$$\sum_i T_i^j = \frac{1}{6\sigma} \left( \frac{1}{2} + \sum_i (x_i^j)^2 \right),$$

where  $x_i^j$  is the market share of firm  $i$  on each line of unit length.

Because access payments are transfers between the incumbent telecom firm and the entrant, and retail payments are transfers between firms and consumers, these transfers cancel out in the welfare function. As a consequence, the total expected welfare remains the sum of consumer surplus net of retail payments ( $ECS_+$ ) minus the investment costs:

$$EW = ECS_+ - \frac{\gamma k^2}{2}.$$

I assume that the telecom firm has limited liability,<sup>12</sup> implying that its profit should be non-negative in any state of the world. The reason for using this assumption is as follows. Even though the firm invests before knowing whether investments will be successful, it sets prices after learning the realized willingness to pay. In formulas, limited liability means that in the social optimum, the following participation constraints should satisfy:

$$\pi_T^j(p_T^j, p_E^j, p_C^j) \geq 0 \text{ for any } j.$$

To find the social optimum, the regulator maximizes the expected welfare subject to the participation constraints and given the equilibrium prices and market shares from stage 2. In the social optimum, the telecom firm receives zero profit if investments fail (that participation constraint is binding) and positive profits if investments succeed.<sup>13</sup> From the conditional optimization, I obtain that:<sup>14</sup>

$$\hat{k} = \frac{50 - 9\sigma w \left(5 + \frac{1}{\sigma}\right) + (\beta_T - 2\beta_C + 2(k_0 - k_C)) \left(10 + \frac{3}{\sigma}\right)}{\frac{150\sigma\gamma}{\mu} - 20 - \frac{6}{\sigma}}.$$

*Ceteris paribus changes of parameters*, except of the access fee, affect the socially optimal level of investment in the same direction as they affect the individual optimum. The impact of the *access fee* on the socially optimal investment level is, however, negative: the lower the access fee, the higher the optimal level of investment. Similarly to the individual optimum, for large access fee ( $w > \hat{w}$ ), the entrant exits the market and a duopoly situation emerges. Given the duopoly equilibrium prices ( $p_{iD}^{j*}$ ) and market shares ( $s_{iD}^{j*}$ ), the socially optimal level of investment is:

<sup>12</sup> Limited liability is extensively discussed for instance in Laffont and Martimort (2002).

<sup>13</sup> The proof is available on request from the author.

<sup>14</sup> If  $\frac{\partial^2 EW}{\partial k^2} = 10 + \frac{3}{\sigma} - \frac{75\sigma\gamma}{\mu} < 0$ , the second order condition holds and the denominator of the socially optimal investment is positive. If this condition holds, the second order condition for the individual optimum also satisfies.

$$\hat{k}_D = \frac{72 + 23(\beta_T - \beta_C + k_0 - k_C)}{\frac{288\sigma\gamma}{\mu} - 23}$$

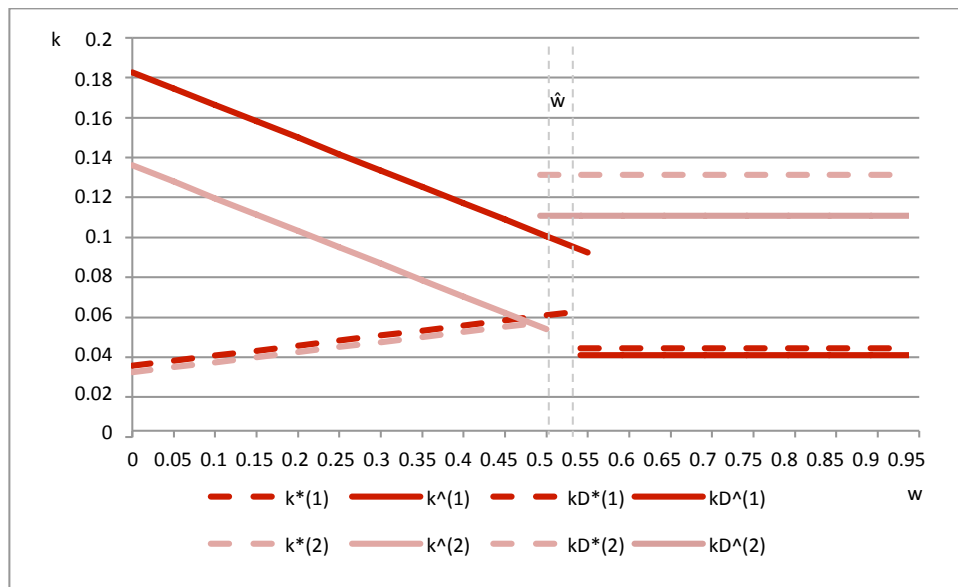
A direct relationship between the social optimum in the presence of an entrant and in a duopoly situation does not exist.

The level of *substitution* amplifies the negative effect of access fee on investment. The stronger the substitution between firms' products (i.e., more intense price competition), the more the telecom firm invests even in the presence of a lower access fee: the telecom firm needs to compete by means of quality. And vice versa, the more firms' products are differentiated from each other, the more the telecom firm's investment incentives erode by a lower access fee.

Finally and similarly to the individual optimum, the *original quality difference* provides stronger investment incentives when the telecom firm only competes with the cable company. In a duopoly situation when the quality difference is positive, the incumbent invests substantially more than in the presence of an entrant.

Comparing the socially optimal level of investment with the individual optimum is not straightforward since a closed form for the difference does not exist. Therefore, I use numerical calibration to demonstrate the deviation from the social optimum for some arbitrarily chosen parameter values.

Figure 6 The difference between the individual and socially optimal level of investment\*



\* In the numerical example, it is assumed that  $\gamma = 1, \sigma = 1, \mu = 0.5, \beta_i = 0$ . In scenario (1),  $k_0 - k_C = 0$  and in scenario (2),  $k_0 - k_C = -0.5$ .

Figure 6 illustrates the optimal level of investment in the individual equilibrium and the social optimum in two scenarios. In scenario 1, the original quality difference between networks is negligible ( $\Delta k = k_0 - k_C = 0$ ). Dark red lines represent these optimal investment curves. In scenario 2, the cable network has a higher original quality ( $\Delta k = -0.5$ ). The light red lines illustrate these investment curves.



The figure shows that the original difference in network quality has opposing effects on the optimal level of investment in the two market structures: when an entrant is present and when it is absent. The following proposition concludes on this relationship.

**Proposition 3** *For a given access prices, the incumbent's investment is not optimal from a social welfare point of view. Low access prices yield in underinvestment as the entrant's access payments compensate the incumbent for the loss due to having lower network quality. When the access price reaches the exclusionary level, the incumbent overinvests to be able to keep on competing with the cable company.*

As the proposition states, the incumbent's individual choice for quality differs from the welfare-maximizing quality. This difference is present for all levels of regulated access fees, which calls upon the reconsideration of access regulation. In the extension of this baseline model, several forms of access settlements will be considered (see for instance Nitsche & Wiethaus (2011) and Cambini & Silvestri (2012) as the basis for such analysis).

Even though the figure does not include brand loyalty, brand loyalty is expected to affect the individual and socially optimal investment level somewhat differently than  $\Delta k$ . A larger advantage of the telecom firm reduces competition on the retail market. It implies that even in the absence of an entrant, the incumbent firm needs to compete less with the cable company to maintain its market share. This advantage compensates the incumbent for a loss due to lower original quality.

## 6. Conclusions

In the current paper, I analyzed investments in quality upgrade by an incumbent telecommunications firm in the presence of infrastructure-based competition and asymmetric regulation. The following questions were of particular interest:

- What is the role of infrastructure-based competition in the development of broadband quality?
- How does asymmetric regulation influence future investments in NGNs, in particular in the presence of uncertainty?
- What is the effect of asymmetric regulation on network quality, broadband market structure, and welfare?

From the analysis that is based on a Spokes location model for product differentiation, I conclude first that competition between infrastructures has a stronger effect on network quality upgrades if an entrant is excluded from the market. Second, a large original difference between network quality at the advantage of the cable company may lead to substantially higher market shares for the cable firm in the presence of access regulation. A higher access fee may even lead to the exclusion of the entrant. The more uncertain the return on investments is, the more likely that the telecom firm cannot invest in quality upgrades, thus further reducing its position in the market. Finally, the incumbent telecom firm receives access revenues from the entrant, which reduces its incentives to keep the quality up with the cable firm. However, if only two vertically integrated firms compete in

the market, the telecom firm needs to upgrade its network not to lose market shares for the cable company.

Several directions are interesting for the extension of this model. In this baseline model, I assumed one entrant. The Spokes model can be extended by  $N$  entrants that provide differentiated products (e.g. similarly to Jeanjean 2012 but in the presence of uncertainty). The results on investment incentives depend in this case on how much the presence of several entrants will erode funding for the incumbent firm. Second, in this baseline model, I assumed that the regulator determines the access fee ex ante and that is exogenous. Proposition 3 raises a relevant theme that has not been analyzed in this paper: the optimal level of access charge and the consideration of different regulatory regimes. The analyses can be extended in line with Nitsche & Wiethaus (2011) and Cambini & Silvestri (2012). In the case of regulatory holiday, the methodology in Douven et al. (2010) can be a relevant starting point for determining the outcomes of negotiation between the incumbent and the entrant. Finally, the paper can be extended by network upgrades by the cable firm. In this case, stronger competition in network quality can be expected than in the baseline model.

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