Wholesale Pricing, NGA Take-Up and Competition (*)

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Abstract: Our market modelling approach aims at practically determining wholesale pricing policies for the switch from copper to fibre access networks. It asks which market equilibria for incumbents and entrants result from different combinations of copper and fibre wholesale access charges. We first calculate the relevant costs and the cost drivers for a representative European country which we call "Euroland". Network costs are derived for the investor and for competitors who base their business model on purchasing access from the incumbent. The cost modelling results feed into a model of competition between copper and Fibre to the Home (FTTH) with multiple competitors in order to capture aspects of the transition from copper to FTTH. We show the impact of wholesale prices for copper and fibre access on competition, retail prices and investment. The incentives for a switch from copper to fibre are largely preserved by an equal absolute reduction of both copper and fibre access charges and they are increased if the copper access charge is reduced by more than the fibre access charge. We find in a relatively simple calibrated model of competition for broadband service that substantial care must be taken in regulating the prices of inputs which are substitutes. In this calibrated model, small errors in the absolute price difference between these (even when the absolute level of one or the other price is correctly set) can lead to suboptimal outcomes. Our central result is that significant fibre investment can only be expected if the structure and level of wholesale prices is properly balanced.

Key words: Next Generation Access, FTTH, cost modelling, GPON, P2P, competition, welfare.

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Given the low coverage and penetration of fibre networks in Europe up to now, fostering fibre deployment requires large-scale infrastructure investments. In order to facilitate the deployment of Next Generation Access (NGA) and to encourage market investment in open and competitive networks, the European Commission has adopted the NGA recommendation to provide appropriate access remedies for an NGA environment.

Less attention has been given to the transition from copper to fibre access networks. What are the regulatory conditions that favour the transition and which conditions discourage it? In this paper we will primarily focus on the impact of access charges on the switch from copper to fibre. For this purpose we evaluate the interaction between regulated wholesale access charges for copper and fibre. Our market modelling approach asks which market equilibria for incumbents and entrants result from different combinations of copper and fibre wholesale access charges and what the properties of such equilibria are.

We generally treat the price of the wholesale product ("access charge") as a variable in order to determine the effects of changes in its level on the relevant outcome variables. However, two types of access charges are most relevant for each type of access provider.

First, for both copper and fibre to the home (FTTH) the access charge can be based on the traditional modified Greenfield (= scorched node) approach to long-run incremental costs (LRIC) of the access service, which contain the fixed and variable costs incurred by the incumbent for the FTTH access product.

Second, under the assumption that demand for copper networks is in a long-run decline, the copper access charge only has to cover those costs necessary to keep a copper access network going. Such costs are the short-run incremental costs (SRIC). In contrast, for FTTH access networks SRIC are not relevant, because these networks can safely be assumed as expanding. However, when building such networks the incumbent can use existing infrastructure from the copper access network. This leads to Brownfield (LRIC) costs as a relevant alternative to modified Greenfield LRIC for the case of FTTH access. The differences between these two costing approaches are explained below. SRIC and Brownfield LRIC are relevant because these costs are the crucial base for the incumbent's decisions whether to shut down the copper access network and switch to an FTTH access network or not. In our view special emphasis needs therefore to be given to the challenge of regulatory costing and pricing in case of a declining demand as can be observed for the copper access network in view of a switch to fibre that is desired by regulators and policy makers. A full-fledged welfare analysis of the switch from copper to fibre is beyond this paper because most of the effects are deemed to come from spillovers.

This paper is organized as follows: In the following section "Modelling the copper and the fibre access network" cost modelling approaches are briefly developed (details of the assumptions for the cost modelling can be found in HOERNIG *et al*., 2011 and 2010). We calculate the relevant costs and the cost drivers for a representative European country which we call "Euroland". Network costs are derived for the investor and for competitors who base their business model on the unbundling approach. In the section "Impact of wholesale prices on competition, investment and retail prices" we model the impact of wholesale prices by means of an oligopoly model which shows the results of the strategic interaction of market players. Some regulatory policy conclusions are drawn in the section "Conclusions".

■ Modelling the copper and the fibre access network

General approach

Our modelling approach captures essential aspects of competition in FTTH or copper-based markets, both on the wholesale and retail side. One firm (the "incumbent") owns and invests in a copper and/or FTTH access network, to which other firms ("entrants") must obtain access (by means of unbundling) in order to provide copper-based or NGA-based services. Entrants are assumed to be specialized in copper or fibre services and are otherwise symmetric. Thus, all copper entrants and all fibre entrants are the same. Entrants need to make their own investments to provide retail services based on copper or NGA wholesale access products but do not invest in the access network themselves. [1] We additionally consider a third

[1] The case of a competitor that invests in fibre is analysed in a second model in HOERNIG *et al*. (2011) where the incumbent is restricted to a copper access network, while an independent fibre investor (which could be an alternative telecommunications operator or an energy company) may or may not invest in fibre, thereby potentially driving out the copper incumbent. It turns out that an independent fibre investor requires special cost savings or other advantages in

vertically integrated broadband infrastructure provider ("cable"), to which no other firms have access.

To determine the relevant cost of the fibre network we applied an engineering bottom-up modelling approach. Because of resource constraints more simplified approaches are used for the copper and cable network costing. In the current paper we concentrate on a Brownfield scenario for fibre where the incumbent can make use of available infrastructure from legacy networks to deploy the fibre network. [2]

For modelling purposes we designed a hypothetical country for approximately 22 million households and business users or a population of around 40 million inhabitants. This country is referred to as "Euroland" and is characterised by 8 geotypes. A geotype is a cluster of Main Distribution Frames (MDF) with similar structural parameters that is primarily defined by population density (in this study "geotype" and "cluster" is used synonymously). The 8 geotypes vary in density, with Cluster 1 representing the densest parts of the largest cities in Europe, through to cluster 8 representing very sparsely populated regions in rural Europe with the lowest population density. The geotype characteristics have been determined from concrete geodata of several European countries for which nationwide access models were built. In that sense, Euroland is a generically representative European country. Because a fibre network is not viable in all clusters we focused the competition analysis on the most densely populated Clusters 1 (more than 4000 customers per km²) to Cluster 4 (between 470 and 800 customers per km²) of Euroland (making up 40% of the population).

order to outcompete the copper incumbent (who has such advantages investing in fibre). On top of that such an investor may face the threat of the incumbent preempting its investment thereby rendering it unprofitable. Since our cost modelling results indicate that more than a single fibre network can only survive in very densely populated areas, we only model single fibre networks.

[2] The model and the assumptions resemble those in a recently published study conducted for Vodafone on fibre architectures and competition. See HOERNIG *et al*. (2010). The primary differences are an improved optimization algorithm for cable sizes and increased asset lifetimes of passive infrastructure. In addition, we do not model in-house fibre cabling and accordingly have adjusted the Average Revenue Per User (ARPU). The fibre network is modeled on the basis of a Point-to-Point architecture as that is considered to represent the most future-proof technology and also enables efficient unbundling. GPON (Gigabit Passive Optical Networks) would result in slightly lower build costs – around 10% reduction. However, as discussed in the study HOERNIG *et al*. (2010), reduced costs would be more than counteracted by the more limited capacities of this network design and poorer competitive and retail dynamics. In HOERNIG *et al*. (2010 and 2011) Greenfield FTTH cost is calculated as base case but sensitivities on the impact of reusing existing infrastructure (Brownfield) are also conducted.

For competitors using wholesale access we have considered a fibre unbundling scenario for the Point-to-Point (P2P) network architecture in which a competitor rents the unbundled fibre loop and places an additional Optical Distribution Frame (ODF) of its own at rented collocation space in the Metropolitan Point of Presence (MPoP) [3] where it operates its own Ethernet Switch.

The FTTH network

In bottom up Greenfield LRIC modelling an investor is assumed to construct a new, state of the art forward looking fibre network, taking into account future demand. In the real world the investors often face the situation that locations and infrastructure already exist which may be reused by a new network generation in order to save investment. This will be considered in our modelling approach by taking the existing MDF locations as scorched nodes of the new network instead of optimizing over node locations. This is also known as the "modified" Greenfield approach.

The investor's decision nevertheless is driven by the level of (additional) investments he has to make, considering that there are existing ducts with sunk costs and spare capacity which could satisfy part of the demand of the new network, thus resulting in lower investment expenditures. This situation is captured by a Brownfield scenario in contrast to the above mentioned modified Greenfield scenario. The Brownfield case is characterized by reduced investment for the passive network components ducts, trenches and manholes by dedicated percentages. In HOERNIG *et al*. (2011) the cost model is described in detail including assumptions on Euroland, cost inputs and deployment.

The bottom-up model generated the following aggregate Brownfield cost functions for incumbent and entrant (purchasing access) for the first four clusters (see table 1). This is the input for the competition model.

For feeding inputs into the competition model properly we have divided the incumbent's operation into a Network Company (NetCo) and an Operating Company (OpCo) unit. The NetCo provides the passive access

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3 MPoPs are the access nodes equivalent to the MDF in a copper network. They are assumed to be located on existing MDF locations.

network [4] to entrants (and to its own downstream organization) and the OpCo [5] runs the active components of the network and markets it to customers (see HOERNIG *et al.*, 2010 and 2011, for further details). The wholesale access seeker also bears the OpCo's downstream cost elements which are largely similar to those of the incumbent but not identical. The difference is that we have accounted for a separate small ODF that the access seeker will install in addition to the incumbent.

Table 1 - Total monthly cost for the fibre network (Clusters 1-4)

	Fibre investor	*Fibre LLU entrant*
NetCo fixed cost	76mn€ Greenfield LRIC 62mn€Brownfield LRIC	0€
NetCo var. cost per customer	1.38€	(fibre LLU charge) 13.92€Greenfield LRIC 11.65€Brownfield LRIC
OpCo fixed cost	6.9mn€	7.6mn€
OpCo var. cost	13.22€	14.96€

Since access network fixed costs are large, the total costs per customer strongly depend on the number of customers served by the incumbent's network (wholesale and retail). Cost-based wholesale prices have been determined under the assumption that the incumbent's network operates at a 70% take-up, whether directly supplied or supplied through wholesaling, in the clusters served. For the aggregate of the first four clusters this monthly unbundling charge is 13.92€ with Greenfield and 11.65€ with Brownfield assumptions.

The copper access network

Due to resource constraints, a more simplified costing approach is used for the copper network than for FTTH. Based on the European requirement for cost-based regulated access charges we have opted for an approximation of copper network costs by basing them on the European

4 Civil works, duct, cable, manholes and sleeves for the access line between the customer and the MPoP as well as the ODF and the associated floorspace are a fixed cost for the NetCo and therefore not driven by the penetration. Costs driven by the actual number of subscribers arise on the network side ODF port and the wholesale-related cost.

5 The OpCo fixed cost is mainly composed of core and concentration network cost. The variable cost that is driven by the number of subscribers mainly relates to end user devices, Ethernet ports and retail cost.

average of monthly Local Loop Unbundling (LLU) charges of 8.55€. That means we take this LLU charge as a proxy for the incumbent's LRIC in Euroland. Therefore, the monthly fixed cost of operating the passive copper network that connects all of Euroland's 22 million customers to MDF locations is (in principle) 22 million times 8.55€. Since the competition model only considers the first four clusters we have derived cluster-specific LLU charges by weighting the average national charge with loop lengths, investment per meter and number of lines per cluster used in the fibre cost model. The resulting cluster-specific monthly copper network costs per line were turned into fixed cost per month for the NetCo of the copper incumbent.

Not surprisingly, in denser areas the incumbent produces at a monthly cost lower than a (nationally averaged) access charge that competitors may have to pay for unbundling. This implies positive wholesale profits for the incumbent in the competition model which only considers Clusters 1 to 4 at an averaged wholesale price of 8.55€. The aggregate cost functions for copper incumbent and entrant for the first four clusters are shown in table 2. This is the input for the competition model.

Table 2 - Total monthly cost for the copper network (Clusters 1-4)

	Copper incumbent	*Copper LLU entrant*
NetCo fixed cost	31 mn€ LRIC 6.2 mn€ SRIC	0€
NetCo var. Cost per customer	0.92€	(LLU charge) 8.55€ LRIC
OpCo fixed cost	7 mn€	7.6 mn€
OpCo var. cost	9€	9.68€

In view of the impending shut-down of the copper network, the incumbent's decision to switch from a copper to a fibre network does not depend on the LRIC replacement cost of the copper network but on the cost of operating and maintaining the copper network. These costs are called short run incremental costs (SRIC). The SRIC are basically the operating costs (OPEX) of the copper access network. To calculate the relevant level of these costs, we have analyzed three different cost models for Denmark [6], Italy [7] and Sweden [8] with a view towards the share of monthly OPEX as part

[6] The model analysed is publicly available from http://en.itst.dk/telecom-internet-regulation/smp-regulation/lraic/lraic-on-fixed-network/lraic-hybrid-model-2008-1/

[7] The model analysed is a model for a national copper rollout in Italy developed by WIK. This model is not publicly available.

of total LRIC (15%, 12% and 26% respectively). Based on the range of these findings we chose to base the SRIC in this model on 20% of the total LRIC cost.

The cable network

We have made the following simple cost assumptions for cable. The fixed costs of cable for Clusters 1-4 for both the access network and the core/concentration network are set at 20 million€ per month. This number may be on the low side for cable LRIC, since it compares to about 13 million€ SRIC for the copper incumbent or about 38 million€ LRIC for the copper incumbent [9] for the same set of clusters. It also compares to about 70 million€ Brownfield LRIC for the fibre incumbent or about 83 million€ Greenfield LRIC for the fibre incumbent. Since we primarily rely on the SRIC/Brownfield costs for the decision about switching from copper to fibre or leaving the market altogether, the fixed costs for cable appear reasonable. The fixed costs assumed for cable have no material impact on our equilibrium analysis. This is because we assume the presence of a cable competitor. Consequently, any change in cable costs only affects cable profit, but not prices, and hence also does not change the other firms' investment decisions. We further assume 10€ variable costs per cable subscriber for network and retail operation, which compares to 9.92€ for the copper incumbent and 14.60€ for the fibre incumbent.

■ Impact of wholesale prices on competition, investment and retail prices

Objective

Our approach towards market modelling combines our cost estimates with a model of competition between copper and FTTH with multiple

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[8] The model analysed is publicly available from http://www.pts.se/sv/Bransch/Telefoni/SMP---Prisreglering/Kalkylarbete-fasta-natet/Hybridmodellen/Hybridmodellen-2010/

[9] These cost are the sum of NetCo's and OpCo's fixed cost as presented in table 2. A similar calculation holds for the fibre incumbent's numbers.

competitors ("entrants" purchasing wholesale access) in order to show aspects of the transition from copper to FTTH, in particular how the transition depends on the regulated copper access charges for copper unbundling and on the regulated FTTH access charges for fibre unbundling.

The objective is to generate and compare the (potential) coexistence and relative shares of copper and FTTH and to determine market equilibria with end-user prices and profits for all firms.

The investment hurdles for FTTH against the preexisting copper access network are substantial. A major fraction of this difference is due to cheaper variable cost of copper (modem, distribution frame ports, DSLAM). The majority is driven by the substantial difference in monthly fixed network cost which in turn is due to different deployment methods and demand for copper and fibre and higher risk for fibre leading to a higher WACC. [10]

On top of having to pay the access charge entrants have a downstream variable cost disadvantage against incumbents of 1.74€ under fibre and 0.68€ under copper (due to wholesale sales cost and additional cost from ODF/MDF equipment duplication). Given the above cost considerations the market advantage of fibre in terms of consumer appreciation has to be large in order to succeed.

Modelling approach [11]

The theoretical model

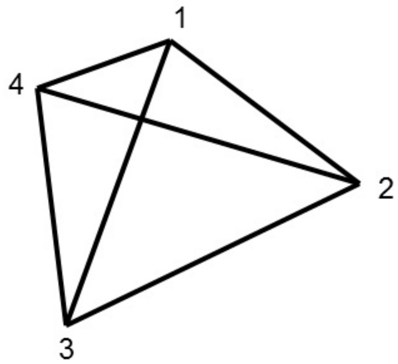
The challenge for building a competition model that captures the interaction of firms offering different types of services and differentiating brands within service groups is to characterize user preferences for services and firms and to derive demand. In particular, the simplest models consider only two "services". In order to accommodate multiple services, such as copper, fibre or cable retail offers of different firms, our modelling approach

[10] Fibre networks are only deployed with ducts whereas copper networks were often deployed as cheaper buried cable. For most LLU price decisions the demand taken into account is less than 100%. For the fibre network rollout it was assumed that 100% of customers had to be passed by the network but the cost is shared between only up to 70% of customers.

[11] The descriptions in this section are based on HOERNIG *et al*. (2010). A formal description of the competitive model is provided in the Annex of HOERNIG *et al*. (2011).

uses the "pyramid" model. [12] For each pair of services, there is a set of consumers who choose between them, and these consumers are (uniformly) distributed in their willingness to pay for one service rather than the other. Graphically this leads to a pyramid, as illustrated in figure 1, with each service located at one of the tips of the pyramid and consumers located along the edges. A single firm can control more than one service; in this case it is characterized by the location of its services and the corresponding consumer surplus, as described below.

Figure 1 - Preference space with four services



Demand

The services that firms offer are both "horizontally" and "vertically" differentiated. The former means that consumers differ in their evaluations of each firm's service offering, so some consumers will continue to purchase any given service even as its price rises above that of another. As a result, the market is imperfectly competitive and firms will enjoy positive markups. Vertical differentiation expresses differences in service quality and goodwill or brand recognition as perceived by consumers. In particular, as a firm's quality rises, holding all else constant, all consumers' valuations of the service rise.

In the model each active subscriber makes a first choice between two of the firms, and unless their offers are very unfavorable, he will choose one of the two. It is assumed that all pairs of preferred firms (before quality differences) are equally likely in the population, so that effectively each firm will compete with any other firm for consumers. Formally speaking, cross

[12] The pyramid model was first developed by UNGERN-STERNBERG (1991).

price elasticities are different from zero for all product pairs. Due to the assumption of uniform distributions of consumer tastes, the resulting demand function of each firm is linear in its own price and linear in the price of all other firms. This makes the analysis tractable and allows for explicit solutions

Equilibrium

We can think of our competitive game as consisting of five stages, which determine the order in which participants make their moves.

- Stage 0: There exists a copper incumbent in an equilibrium with entrants buying unbundled access at a given copper wholesale access charge. There also exists an additional network with a different technology (cable). This is a natural starting point that largely eliminates multiple equilibria.
- Stage 1: A planner decides on the access prices for copper and fibre access.
- Stage 2: The incumbent firm decides on investments in one of copper or FTTH access and in concentration/core network infrastructures, based on the restrictions and incentives provided by stages 0 and 1. [13]
- Stage 3: Potential access-dependent entrants in copper or fibre (depending on the decision previously made by the incumbent) decide whether to enter or not. Depending on their choice they will bear the cost of an entrant in copper or fibre.
- Stage 4: Entrants, the incumbent and the cable company compete for end-users in differentiated copper/FTTH markets using prices as strategic variables.

Setting wholesale access charges at stage 1 before the market players decide about their investments at stages 2 and 3 is natural in order to assess the long-term effects of the absolute and relative levels of wholesale access charges on network investments. At the same time the sequencing means that the planner is committed to the access charges. For stage 2 we assume that there can only be at most one operator investing in each type of access infrastructure. The model generates the switching point between fibre and copper, based on the most profitable choices for the incumbent.

[13] In HOERNIG *et al*. (2011) we also deal with the case of an integrated incumbent who offers both copper and fibre. Such integration turns out to be less profitable than single-service offerings in all the equilibria analysed.

At stage 4 all active firms compete in subscription fees at the retail level. The resulting market outcome is quantitatively modeled as the Nash equilibrium outcome of the resulting pricing game, from which subscriber numbers, profits, market shares, and retail prices are derived. [14] The model runs are repeated for each of the cases developed in stages 0-3. We allow for a non-specified process of entry and exit with the feature that all active entrants make profits and that any additional entry would lead to losses of all active entrants of an active access mode. Here we postulate that entrants correctly foresee the effect of entry (and the associated investment decisions) on the pricing decisions and, thus, on market outcome. Formally, and in line with the literature on industrial organization, the stronger notion of subgame perfect Nash equilibrium is used.

The competition at stage 4 will be in prices for differentiated products as described above. We model horizontally and vertically differentiated single-product and two-product incumbents. We cannot distinguish between different consumer types, such as households and business consumers.

Under our pyramid model total output is kept constant. So, competition is only for market shares. Since the firms in the market include the cable firm, our model has the feature that the sum of copper and/or FTTH subscription demands is variable. However, total demand for subscription (including cable) is fixed and assumed to be 95% of potential subscribers in the clusters considered. 5% of the population are assumed not to sign up for any fixed network but rather to stay without a connection or resort to mobile only.

QoS and willingness to pay in the basic model

While costs are given by the cost modelling described above, the demand data are generated by assumptions on certain parameter values. The most important demand-related parameters are:

The gross surplus S_i generated for consumers with the highest willingness to pay (WtP) for service i or firm i. This parameter expresses quality (QoS) and goodwill. The Si therefore capture vertical product differentiation. They are derived proportionally from assumed ARPUs discussed below.

[14] The Nash equilibrium is the standard solution concept used in the literature. It assures that firm decisions are mutually consistent.

The "transport costs" t_{ij} for consumers located between firms i and j. These reflect the decline in willingness to pay by consumers away from i and j. They express both the heterogeneity among consumers and the substitutability between the suppliers' services. The t_{ij} therefore capture horizontal product differentiation. The t_{ij} can in principle differ from each other and t_{ij} can differ from tji. We have used this feature to make product differentiation within the same technology less pronounced than product differentiation between different technologies.

The vertical product differentiation parameters for willingness to pay – here expressed as ARPUs – are provided in table 3. These ARPUs are composites of single, double, triple play and business users. It was assumed that FTTH customers are strongly demanding triple play packages while copper customers are dominantly using double play packages (e.g. share of triple play customers on FTTH 60% but only 5% on copper). Because of uncertainty about these values we made calculations for a range given below that reflect different customer valuation of copper and fibre.

Table 3 - ARPU assumptions for quantitative model

Incumbent FTTH	*Entrant FTTH*	*Incumbent Copper*	*Entrant Copper*	*Cable*
38.07€ - 42.05€	36.92€ - 40.79€	30.10€ - 34.08€	29.20€ - 33.06€	36.30€

The ranges in table 3 reflect sensitivity analyses around assumed values. In the following 'high', 'low' and 'intermediate' refer to endpoints and midpoints of the valuation ranges. Unless stated otherwise, the numbers presented in this paper are based on middle points of the ARPU range (intermediate valuation).

The value of the QoS differences between copper, cable and fibre that is expressed in the full range of ARPUs in the tables above may appear large and incumbency premia may appear small from today's perspective. However, it has to be kept in mind that we are considering situations with potentially full FTTH penetration, which could only happen several years from now. Then the share of customers with high-bandwidth demands and the prevalence of corresponding applications will likely be much higher than now. Thus, the premium for ultra-high bandwidth will also be much higher than now. In contrast, the incumbency premium, which includes both QoS differences and goodwill advantages of the incumbent, will likely become smaller, as time goes by. This justifies the small incumbency premium of 3% over entrants that we have chosen. [15]

■ Model runs on the variation of access charges

Results on performance variables and the switch from copper to fibre

This section provides the results of selected model runs from a much larger number of runs we performed. These examples appear to be most relevant for policy assessments. In the current section we consider variations of the copper access charge aC for given levels of the fibre access charge aF. In the following section we present results of parallel variations of both aC and aF.

First, the copper access charge is varied in eight stages from 1.71€ to 11.97€ (reference charge: 8.55€). [16] All other modelling parameters remain constant.

The integrated incumbent is assumed to always invest in the type of network that is most profitable for him, given the regulated access charges. Thus, a switch from copper to fibre occurs when fibre profits exceed copper profits for the same combination of access charges (aC, aF).

The switching points from copper to fibre are marked by a circle in the following in figure 2 and figure 3. They show a strong increase in the incumbent's copper profits from an increase in aC. As a result, copper is preferred by the incumbent if aC is sufficiently high. To the left of the vertical line marking the switching point in figure 2 fibre profits are higher than

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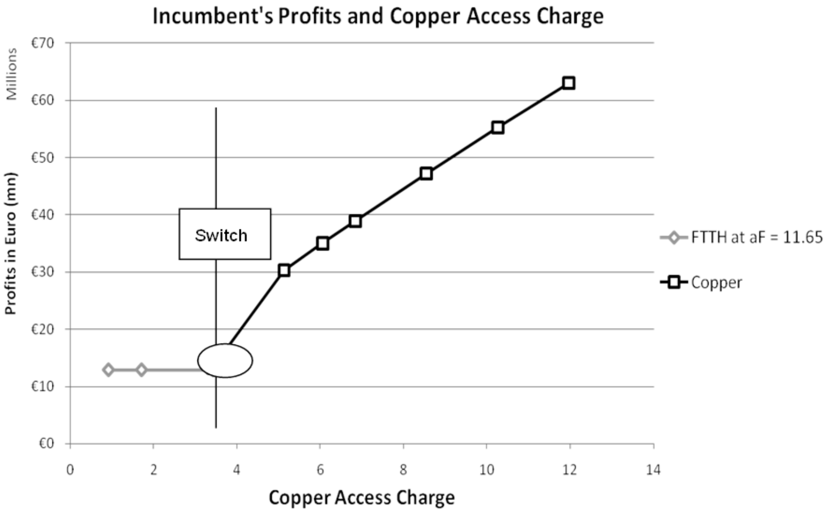
[15] In HOERNIG *et al*. (2011) we did some sensitivity testing of our results on vertical product differentiation. While all these results were intuitive, some counter-intuitive outcomes arose due to market entry and exit. For example, if copper is valued less the resulting downward shift in demand may support fewer entrants, which will then lead to a higher equilibrium price than before.

[16] The stages are generally defined by 20% increments or decrements starting from the 8.55€ level. Similarly, we mostly used 20% increments or decrements for fibre access charges starting from fibre LRIC of 13.92€. Thus, the second decimals are not shown for higher precision but only because they reflect 20% changes. The only exceptions from the 20% changes are made to include copper LRIC (6.06€), copper SRIC (1.95€) and fibre Brownfield (11.65€), each for Clusters 1 through 4.

copper profits, while to the right of the line copper profits are higher than fibre profits. [17] In contrast, aC does not influence profits from fibre. Instead, fibre profits depend on aF. An increase in aF increases the range where fibre is preferred.

Figure 2 - Incumbent's total profit under variation of aC for aF = Brownfield LRIC



Consequently, under aF = 11.65€ = Brownfield LRIC the switch from copper to fibre occurs below aC = 3.42€ (> SRIC = 1.95€), while under aF = 19.49€ the switch from copper to fibre occurs below aC = 8.55€. This also means that at today's copper access charges in Europe it would take fibre access charges above 19€ in order to induce incumbents to build fibre access networks. The resulting end-user prices for fibre would be above 42€ per month.

Figure 4 shows the effects of increases in aC on end-user prices of all types of firms and technologies. aF is given at Brownfield LRIC = 11.65€. This is the same case as the one depicted in figure 2. So, the switch between fibre and copper occurs at aC = 3.42€. This case is, among others, characterized by the fact that fibre attracts three entrants, while copper attracts four entrants at aC below 5.13€. Only at aC ≥ 5.13€ does the number of copper entrants drop to three.

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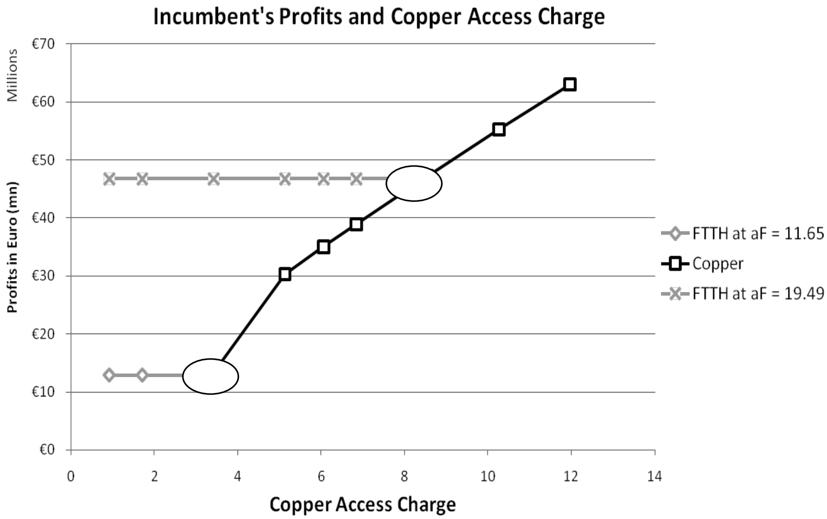
[17] This is strictly true only if at the switching point both profits are equal. Because we have changed aC in discrete steps this is generally not assured, but it holds almost precisely in this particular case.

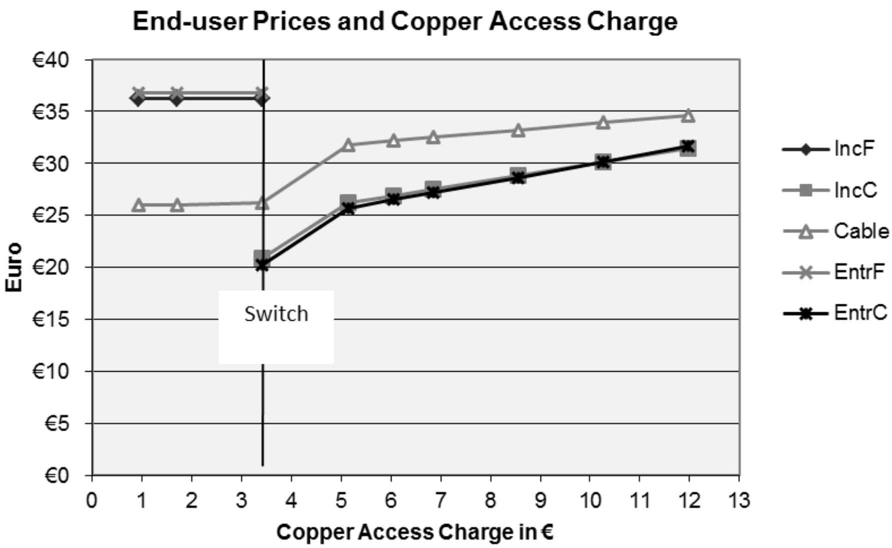
Figure 3 - Incumbent's total profit under variation of aC for two levels of aF



The most striking observation is that at the switch point from copper to fibre the retail price for fibre is about 15€ higher than the retail price for copper. How can this gap be sustainable? In our model we do not assume that customers simply switch and pay 15€ more for fibre. Rather, we compare equilibrium situations before and after a fibre build-out. The different customer valuations therefore reflect differences after consumers have been getting used to the value fibre provides. It also includes a change in the composition of services demanded, in particular away from single play towards triple play. In the section "Potential conflicts between the incumbent and customers on the decision to switch to fibre" we will address some of the adjustment issues more deeply.

The copper retail prices increase in aC. The increase is steeper if, as happens at aC = 5.13€, the number of entrants decreases. In that case the price increase is actually larger than the increase in aC. The fibre price is not affected by aC and is always higher than the copper price. Entrants always set their price close to that of the incumbent. Because of higher costs the price of fibre entrants can, in spite of lower valuation, be higher than that of the incumbent. The end-user price of cable increases in aC and is always below fibre prices and above copper prices. However, as aC increases, the gap between copper and cable prices narrows.

Figure 4 - End-user prices under variation of aC for aF = Brownfield LRIC = 11.65€



Summing up, since higher copper access charges increase profits from copper but leave fibre profits unaffected, an increase in aC reduces the incentives for a switch. In particular, at today's EU average aC of 8.55€ there would be little incentive for the incumbent to invest in fibre. Within the range analyzed wholesale profits strongly increase in aC, while retail profits and entrants' profits suffer, unless an increase in aC forces the exit of entrants. Since the effects of a change in the fibre access charge on the switch from copper to fibre are a mirror image of the effects of changes of the copper access charge, we do not provide those results here. Thus, an increase in aF relative to the fixed aC incentivizes the switch from copper to fibre in the same way as a decrease in aC relative to a fixed aF had in the previous assessment. [18]

Whilst the retail prices for the market as a whole are strongly influenced by the underlying wholesale charges, the presence of cable adds an additional constraint in that higher copper (and/or fibre) charges will cause some customers to migrate away from the incumbent towards what is viewed as a superior (or cheaper) technology. The effect of the presence of cable on the incumbent's incentive to invest in fibre turns out to be ambivalent, since it negatively affects both copper and fibre profits.

[18] There may be some difference due to entry and exit.

Results for a parallel variation of both copper and fibre access charges

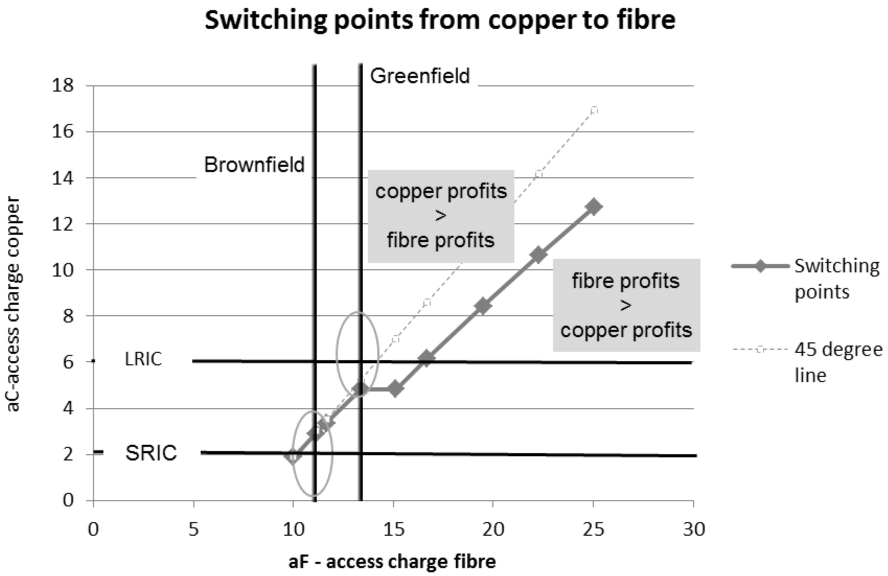
While the incumbent's profits always increase in the relevant wholesale access charge, the switch to fibre depends as much on the level of the other access charge. This led us to enquire about the effects of simultaneous changes of both access charges. Since various model runs suggest a parallel development of profits under parallel changes in both access charges, the switching points between copper and fiber should also follow a regular pattern. We therefore ran the model to establish the relationship between switching points and pairs of access charges. The model runs displayed so far were based on discrete variations in aC and aF, meaning that switch points were not necessarily exact. In contrast, we have now adjusted aC and aF in such a way that profits at the switch points are for all practical purposes equal for copper and fibre. Figure 5 presents the results as the solid upward-sloping curve representing (aF, aC) combinations for which a switch from copper to fibre occurs. For this figure SRIC/Brownfield costs are assumed along with an intermediate valuation of copper relative to fibre.

To the right of the solid upward-sloping curve fibre dominates and in the horizontal direction fibre profits are increasing. To the left of the solid upward-sloping curve copper dominates and in the vertical direction copper profits are increasing.

The lower oval in figure 5 represents SRIC/Brownfield access charges and the upper oval LRIC/Greenfield access charges. While the lower oval lies below the next switch point, the upper oval lies above the next switch point, due to the higher copper profits than fibre profits at those latter access charges. Thus, LRIC/Greenfield will not lead to a switch, while SRIC/Brownfield will.

The shape of the curve suggests that with a constant number of entrants the curve would be close to a straight line. The two kinks in the lower part of the curve are the result of the market exit of a copper entrant due to higher aC. With the same units of measurement on both axes the slope of the curve is a little less than 45 degrees. This happens because fibre profits increase slightly less in aF than copper profits increase in aC. The effect is enhanced by the exit of the copper entrant, which leads to a discontinuity of the curve, meaning that between aF = 13.37€ and aF = 15.13€ a copper access charge of aC = 4.84€ triggers no switch to fibre, while aC = 4.83€ does.

Figure 5 - Access charge combinations for which a switch from copper to fibre has occurred



The shape of figure 5 means that the incentives for a switch from copper to fibre are largely preserved by an equal absolute reduction of both copper and fibre access charges and they are increased if the copper access charge is reduced by more than the fibre access charge. The fact that the curve runs below the 45 degree line means that the gap between aC and aF necessary to trigger a switch from copper to fibre increases in the copper access charge. The curve in figure 5 would be shifted to the right (down) under a higher consumer valuation of copper and would be shifted to the left (up) under a lower consumer valuation of copper. Thus, under a higher valuation of copper a lower aC level is required for every given aF level in order to trigger a switch from copper to fibre. Vice versa, under a lower valuation of copper a higher aC level is required for every given aF level in order to not trigger a switch from copper to fibre.

Potential conflicts between the incumbent and customers on the decision to switch to fibre

We have assumed so far that (in the absence of an independent fibre investor) the decision to switch from copper to fibre is made solely by the incumbent and is based solely on the criterion of maximum expected profits under given wholesale access charges for copper and fibre. This led to the quite general result that only relatively low levels of aC vs. aF provide incentives for switching from copper to fibre. Such a switch, however, can lead to conflicts with consumers, who would like to stay with the copper network under the low end-user prices resulting from low levels of aC. Because of the assumption that the copper access network is switched off, once fibre access is installed, this conflict is not directly addressed by our competition model. The subscriptions that access network providers and entrants sell in the model are only differentiated by type of network and status as access network provider or entrant. A further differentiation by type or speed of service (within the same technology) would vastly increase the complexity of the model. Thus, the subscription services in our model have to be viewed as aggregates or composites of all the services offered by a supplier. This has been done explicitly for the derivation of ARPUs in table 3 above. It can therefore be expected that the suppliers offer specific price schedules for these different types of services in such a way that the average prices of the model outcomes result. In that sense, the model is fully compatible with an offer of lower-priced POTS or "virtual" copper services to end-users over the fibre network. However, if the difference between aC and aF is large enough the continuing users of POTS or "virtual" copper services would nevertheless experience some price increase.

An alternative to be suggested based on our modelling results is that the regulator leaves the wholesale copper access charges at their current level provided the incumbent commits to a fibre build-out over a pre-specified period. Any delays in this build-out would then trigger a pre-specified reduction in the copper access charge. [19] Thus, there would be a glide-path of declining copper access charges that the incumbent could prevent only by investing in fibre.

■ Conclusions

Obviously, the incumbent's profits are influenced by many factors (e.g. costs, market share, retail prices), wholesale access charges being only one of them. Our results, however, suggest that their influence can be substantial. The relative wholesale charges determine the profitability of one

19 Such an approach, however, requires additional policy tools to assure that the implied regulatory threat is credible. This is discussed further in NEU *et al*. (2011).

technology compared with another. We find in a relatively simple calibrated model of competition for broadband service that substantial care must be taken in regulating the prices of inputs which are substitutes. In this calibrated model, small errors in the absolute price difference between these (even when the absolute level of one or the other price is correctly set) can lead to suboptimal outcomes. Our central result is that significant fibre investment can only be expected if the structure and level of wholesale prices and the structure of competition are properly balanced. [20]

Since higher copper access charges increase profits from copper but leave fibre profits unaffected, high access charges for copper reduce the incentives for a switch. In particular, at today's nationally averaged copper access charge of 8.55€ within Europe there would be little incentive for the incumbents to invest in fibre. High levels of copper access charges generate negative incentives for incumbents to invest into fibre because of profit cannibalization from the copper network. The higher the valuation of fibre in terms of willingness to pay from users becomes, the lower the necessary difference of copper and fibre access charges will be in order to trigger a switch from copper to fibre.

Our model suggests that at copper access charges which would be conducive to fibre investment, the transition to cost-covering fibre prices could involve substantial increases in retail prices. It is important during the migration process to aim to avoid price shocks to end-users as the switch from copper to fibre occurs. This can be achieved by setting fibre charges at levels that generate ARPUs closer to those currently achieved with copper – customers could be migrated to the fibre-based products – taking advantage of the additional capacities – without any significant increases in broadband retail prices. Copper-based products could be withdrawn at the same time whilst offering, potentially for a limited period, virtual copper wholesale services for customers not receiving broadband. However, in order for this scenario to materialize, there must be actual action or at least a credible threat that copper charges will be reduced to levels which would stimulate fibre investment. Otherwise the investment – and migration issues concerned with it – will simply not occur.

20 An anonymous referee pointed out that it may be unrealistic to expect regulators to get the relationship between both prices right and that therefore only one such price should be regulated and act as an anchor for the other (unregulated) wholesale price. This may actually not be feasible under the European telecommunications framework. Our model runs also suggest that such anchor constraints on the unregulated service may be quite weak.

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