Neumann, Karl-Heinz; Vogelsang, Ingo

Conference Paper

How to price the unbundled local loop in the transition from copper to fiber access networks?

24th European Regional Conference of the International Telecommunications Society (ITS): "Technology, Investment and Uncertainty", Florence, Italy, 20th-23rd October, 2013

Provided in Cooperation with:
International Telecommunications Society (ITS)

Telecommunications Policy ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at SciVerse ScienceDirect

Telecommunications Policy

URL: www.elsevier.com/locate/telpol

How to price the unbundled local loop in the transition from copper to fiber access networks?

Karl-Heinz Neumann [a], Ingo Vogelsang [b,*]

[a] WIK-Consult GmbH, Rhöndorfer Straße 68, 53604 Bad Honnef, Germany
[b] Department of Economics, Boston University, 270 Bay State Road, Boston, MA 02215, USA

ARTICLE INFO

Keywords:
Copper access
Fiber to the home (FTTH)
Modern equivalent asset
Long-run incremental costs (LRIC)
Performance delta

ABSTRACT

In many countries worldwide access networks are in the transition from copper to fiber access. During the transition phase copper and fiber networks are operated in parallel. All regulators facing this situation of technological change have to decide how to price unbundled access to the copper loop in this transition phase. Should they keep the usual forward looking long-run incremental cost standard charge, or should they move to some different approach? The authors propose to price copper access based on the modern equivalent asset (MEA) of fiber access. Since fiber access is superior to copper access, the cost of fiber access (as a basis for pricing copper access) should, however, be corrected by the performance delta between copper and fiber access.

Instead of using quality of service (QoS) differences, the authors determine the performance delta based on the market valuation of services provided over the copper and fiber access represented by the end-user prices of services and corrected by cost differences downstream of the access provision. Under this approach an access seeker becomes indifferent (on the margin) between using the copper or the fiber access network and wholesale pricing (or regulation) becomes competitively neutral towards technology choice between copper and fiber access and does not distort the platform competition towards cable.

To test its practicability numerical simulations of the approach are performed by means of a quantitative competition model. The model analysis suggests that the approach leads to unique and robust results. Its main conclusion is that the method tends to be conservative relative to the theoretical case of pure vertical product differentiation, meaning that the measured performance delta underestimates the theoretical performance delta.

1. Introduction

In many countries worldwide access networks are in the transition from copper to fiber access. There is either a partial upgrade in the form of fiber to the node (FTTN) which entails a substitution of the feeder part of the network through fiber or a full substitution of the copper access network by means of a fiber to the home (FTTH) architecture. The transition process occurs gradually and will take more than a decade to be completed. The tendency that fiber goes deeper into the access network seems to be irreversible. In any case, during the transition phase copper and fiber networks are operated in parallel.

* Corresponding author. Tel.: +1 617 353 2996.
E-mail address: vogelsan@bu.edu (I. Vogelsang).

0308-5961/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.telpol.2013.05.011

All regulators facing this situation of technological change have to answer the question how to price unbundled access to the copper loop in this transition phase. Should they keep the usual forward looking long-run incremental cost standard based on the current cost of replacing the copper access network for determining the copper access charge? Or should they move to an approach where fiber access is regarded as the modern equivalent asset (MEA) to copper access and the wholesale price for copper access is determined on the basis of the forward-looking long-run average incremental costs (FL-LRIC or simply LRIC)[1] of fiber access?

This decision has to be taken in order to facilitate the deployment of next generation access networks (NGA), to encourage market investment in open and competitive networks and at the same time to meet the welfare targets such that the outcome is in the long term interest of users.

This article presents a novel solution to the problem mentioned above. It is to price copper access based on the modern equivalent asset of fiber access. Since fiber access is superior to copper access, the cost of fiber access (as a basis for pricing copper access) should, however, be corrected by the performance delta between copper and fiber access. Such a performance delta often is quantified on the basis of capacity, bandwidth or quality of service (QoS) difference. The paper shows that such approaches are inappropriate to solve the economic issues of pricing. Instead, the approach determines the performance delta based on the market valuation of services provided over the copper and fiber access represented by the end-user prices of services and corrected by cost differences downstream of the access provision. An access seeker then becomes indifferent (on the margin) between using the copper or the fiber access network and wholesale pricing (or regulation) becomes neutral towards technology choice. This MEA approach is competitively neutral between copper and fiber access. Competitive neutrality is chosen as the performance criterion, because regulators commonly use it and because it best reflects the "equivalence" of the MEA.

To test its practicability the approach has been numerically simulated by means of a quantitative competition model. The model analysis generates unique and robust results. It also provides some further considerations about how to apply the approach in practice. The paper presents major results of these model calculations and draws recommendations to regulators on the implementation of the pricing approach.

2. FL-LRIC as a commonly used cost standard[2]

2.1. Characterization of FL-LRIC

The provision that the wholesale bottleneck services are to be offered at a cost-oriented basis has been implemented under the FL-LRIC standard within European Member States.[3] FL-LRIC as a long-run measure aims at the costs of efficient production of units where those variable and fixed costs are included which are essential for a group of services.[4] Consequently, outdated technologies and inefficiently incurred costs like redundant manpower are not reflected. "Forward-looking long-run" means that the time span of new investments is included in the cost consideration. It also means that all inputs are generally considered as variable. In the forward-looking approach only the actual (forecasted) operating costs are considered, hence the equipment is assessed at the replacement value and over-capacities are usually not taken into account.[5] The costs also include a reasonable profit depending on the risk of the investment and reflected in the cost of capital. In order to calculate the *average* incremental costs per loop, the sum of the costs considered are divided by the (actual or forecasted) loops. From an economic perspective, FL-LRIC results in wholesale access charges above short-run marginal cost, since adequate fixed and common costs of production are also included.

It is well-known that, in a perfectly competitive market with U-shaped average cost curves and free entry, prices equal short-run marginal costs and, in the long-run, equal long-run average costs and long-run marginal costs. These conditions are not feasible in markets with extensive economies of scale and scope. Nevertheless, achieving the next best to the perfectly competitive standard would be desirable. Markets characterized by scale and scope economies would yield long-run competitive prices between long-run incremental costs and long-run stand-alone costs (SAC).[6] FL-LRIC always fulfill this condition and in growing markets are therefore always compatible with this competitive standard. FL-LRIC will therefore allow as many entrants in the market as are warranted by economies of scale downstream in retail markets.

FL-LRIC will generally cover all costs that are expected over the lifetime of the assets and include mark-ups for common costs. Wholesale charges at FL-LRIC levels will therefore provide correct expansion and replacement investment incentives for bottleneck assets of the incumbent. Higher than cost-covering charges would lead to less investment because of the reduction in downstream demand associated with higher downstream prices that especially competitors would have to charge. Lower charges would lead to lower investments on the part of the bottleneck provider because of insufficient cost

[1] The abbreviation FL-LRAIC would be correct, but FL-LRIC is the more familiar usage.

[2] This part of the paper relies on Briglauer and Vogelsang (2011) and Hoernig et al. (2011).

[3] See Cullen International (2007); the methodologies mandated by European regulators differ somewhat with respect to cost bases and cost standards.

[4] See IRG—Independent Regulators Group (2000).

[5] See Evans and Guthrie (2005) for the inclusion of optimally planned excess capacity under the heading of "optimized deprival value". Mandy and Sharkey (2003) calculate the effect of lumpiness on FL-LRIC.

[6] Stand-alone costs are the costs incurred by a firm producing only the single service in question (therefore not benefiting from economies of scope/ synergies if any).

Please cite this article as: Neumann, K.-H., & Vogelsang, I. How to price the unbundled local loop in the transition from copper to fiber access networks? *Telecommunications Policy* (2013), http://dx.doi.org/10.1016/j.telpol.2013.05.011

coverage.[7] Under cost and/or demand uncertainty a buffer may be necessary to cover for estimation risks. It is usually assumed that investment risks of the incumbent are correctly covered in the weighted average cost of capital (WACC) used for the FL-LRIC calculation.[8]

To conclude, FL-LRIC has proved to be quite valuable in setting regulated prices, in particular prices for wholesale services in markets under expansion. Conceptually, it is the cost standard on which, at least on average, prices are based that would obtain under effective competition. Prices set this way provide entrants with the necessary information in respect of buy-or-make decisions regarding their own infrastructure investment and at the same time provide incumbents with correct signals regarding their investment decisions. They assure (if properly applied) entrants the opportunity to take advantage of the business prospects offered by growing retail markets on essentially an equal footing with the incumbent. In the final analysis, they are one of the cornerstones assuring that consumers will get the best deal.

2.2. Regulatory practice

European National Regulatory Agencies (NRAs) show relatively clear preferences regarding price control methods, cost base and accounting methodologies for regulating the unbundled wholesale access charge. The degree of harmonization of methodologies for key wholesale markets seems high as BEREC (2011) points out in its latest Regulatory Accounting report. The analysis shows a clear preference for cost orientation, a trend towards using current cost accounting (CCA) and a fairly even distribution of LRIC and fully distributed costing (FDC) methods.

27 countries[9] participated in the BEREC (2011) survey for the year 2011. 19 NRAs out of the 27 countries reported CCA to be their cost base for unbundled access. 5 NRAs reported historic costs as their relevant cost base and 1 NRA reported to use a different cost base. CCA is by far the most commonly used cost base methodology applied. The most commonly used accounting methodology in 2011 and in the previous years is LRIC. 64% of the NRAs are applying LRIC for wholesale products in market 4 and 36% are applying FDC.

European NRAs so far prefer CCA as a cost base combined with LRIC as the costing methodology and cost orientation as the price control method for unbundled wholesale access.

While many European NRAs still apply the traditional FL-LRIC method to determine ULL prices, some of them have responded to the situation of decreasing demand for copper access and adapted their previous regulated pricing regime. Two prominent examples should be mentioned here.

The most radical change has been adopted by the Swedish regulator PTS in 2011 in a country with a significant deployment of fiber. Since then PTS considers fiber and wireless technologies to be the MEA for copper access technology. This means, if an operator were faced with the decision to roll-out an access network in Sweden, it would choose a fiber-based instead of a copper-based network. Consequently, the LRIC model only uses fiber access technology to calculate the costs for both, copper and fiber-based wholesale access services. PTS sets a single national price for fully unbundled copper access which is an average of the costs of deploying fiber in the four geotypes where fiber is actually deployed in Sweden. In calculating copper access charges PTS does not take into consideration any performance (or value) differences between copper and fiber access.

The intensive ongoing fiber roll-out activities also motivated the French regulator ARCEP to adopt a new wholesale pricing regime for copper access. Within its current costing approach ARCEP first drastically reduced the remaining lifetime of copper cables to 13 years and extended the economic lifetime of ducts (which are also used for deploying fiber) from 40 to 50 years. The combined effect of both measures result in a downward pressure to copper access prices. Additionally, ARCEP changed the allocation rules for shared use of ducts. The costs for ducts are now allocated between fiber and copper access according to the number of customers using either technology and not to the physical space actually used by each technology. The new allocation rules are not cost-based (which would require an allocation according to physical space actually used) but represent a type of value of service pricing. This would initially include a cross-subsidization of fiber by copper access, because there are very few active fiber lines and many active copper lines to start with. Over time the cost allocation rule applied brings the allocation of costs closer to the actual capacity used and closer to the actual costs caused by fiber.

3. Pitfalls of applying FL-LRIC to copper-based access[10]

Applying FL-LRIC to copper-based access at this time of declining volumes due to substitution of copper by fiber and upgraded cable is made inappropriate by at least three developments. The first is that the use of FL-LRIC is conceptually based on an expanding market, where additional capacity is being installed. The market for copper-based access, however,

[7] This argument is explained more extensively in Vogelsang (2012).

[8] This article only considers the appropriate level of a regulated wholesale access charge that is levied on a wholesale access service on a pay-as-you-go basis. Alternative access arrangements, such as investment sharing may or may not provide better investment incentives. See, for example, Nitsche and Wiethaus (2010).

[9] The countries contributing included the 27 EU Member States plus Iceland, Norway, Switzerland and Croatia. The following numbers only refer to countries which participated in the survey in each year.

[10] The presentation in this section draws on Briglauer and Vogelsang (2011).

Please cite this article as: Neumann, K.-H., & Vogelsang, I. How to price the unbundled local loop in the transition from copper to fiber access networks? *Telecommunications Policy* (2013), http://dx.doi.org/10.1016/j.telpol.2013.05.011

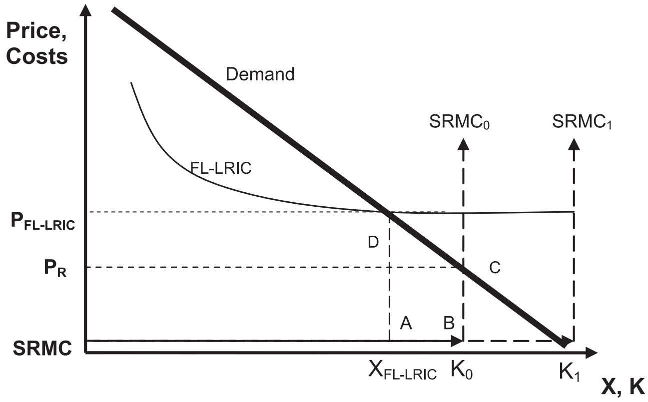

Fig. 1. Welfare loss under excess capacity when access is regulated at FL-LRIC.

is shrinking and appears to continue to shrink, due to substitution from cable TV and, more recently, fiber. Since a large portion of the copper-related costs are sunk and therefore overcapacities develop, true forward-looking costs will therefore be much lower than FL-LRIC as traditionally calculated by NRAs. Some cost calculation approaches applied by NRAs signal increasing (unit) costs in case of decreasing demand. The second development, relevant if FL-LRIC are then still being used, is that increasing input costs (in particular copper) and loss of economies of scale would lead to increasing charges for access. As a result, incumbents offering wholesale access under such charges would be over-recovering their investments, which have largely been incurred in the past at lower costs.[11] Third, the notion of FL-LRIC is based on a replacement by the most modern technology. Copper access, however, does not appear to be the most modern access technology anymore. One can therefore argue that FL-LRIC should be calculated for a MEA rather than for copper.

Fig. 1 shows the extent of allocative inefficiencies (area ABCD) when cost-based access charges ($P_{\text{FL-LRIC}}$) are to be maintained with excess capacities ($K_0 > X_{\text{FL-LRIC}}$). As Fig. 1 indicates, there might be a positive rationing price $P_r < P_{\text{FL-LRIC}}$ where existing capacity (K_0) is fully employed. But in fixed networks one might also end up in a situation with capacity exceeding demand at any positive rationing price ($K_1 >$ Demand ($P_r = 0$)). Allocative inefficiencies thus increase with the amount of excess capacity. In a situation where there was fierce inter-modal competition retail prices would be driven down to short-run marginal costs (*SRMC*), which is usually prevented by some form of ex ante regulation/margin-squeeze tests. But even at these prices, as just mentioned, excess capacity may prevail. Incumbents can respond to this downward pressure on retail prices because of the typically high share of sunk investments in network industries such as communications. Given the long-run market demand decline, sunk costs have then become irrelevant for pricing decisions, both from the point of view of fixed-network operators and from that of efficiency considerations.

Relying on the FL-LRIC standard alone would induce unnecessary over-capacities and allocative inefficiencies in copper networks. Furthermore, such an approach is likely to lead either to margin squeeze and the exit of competition or distortions between different technologies. To avoid such a "vicious circle" one has to look for more suitable forms of access regulation which allow for a lowering of wholesale charges and increased pricing flexibility at the retail level.

The approach to be presented in Section 4 solves the three shortcomings of copper FL-LRIC. It is based on the proposition that (properly calculated) FL-LRIC for fiber access as the modern equivalent technology best serves the regulatory objectives. Copper access pricing then is derived from this baseline.

4. The proposal: pricing based on the MEA approach

4.1. Characterization of a performance delta

Copper access networks continue to be in use but they are largely sunk and almost nobody invests in new copper access networks, because they are being replaced by superior alternatives, such as FTTH and mobile broadband. These new access technologies therefore represent the MEA for copper access. At the same time, these new access technologies provide additional and superior services. A common feature of a MEA is to be less expensive than the old technology. This feature does not necessarily hold here but rather the main advantage of the new technologies is that consumers prefer them to copper access even at a higher price. This article concentrates on FTTH as the relevant MEA and makes the case that the proper MEA calculation requires taking care of both the access cost differences and the differences in services provided. The latter is called the performance delta ($\Delta perf$). Thus, based on the LRIC for FTTH the MEA for copper access would be

[11] Incumbents in this situation have not usually been known to voluntarily offer the wholesale service at a lower price in order to increase wholesale sales.

Please cite this article as: Neumann, K.-H., & Vogelsang, I. How to price the unbundled local loop in the transition from copper to fiber access networks? *Telecommunications Policy* (2013), http://dx.doi.org/10.1016/j.telpol.2013.05.011

$\text{LRIC}_{\text{MEA}}=\text{LRIC}_{\text{FTTH}}-\Delta perf$. Contrary to the measurement of $\text{LRIC}_{\text{FTTH}}$, for which bottom-up cost models exist, there is as of now no established methodology for measuring $\Delta perf$.

The most straightforward approach to measuring $\Delta perf$ would be based on well-known quality indicators of both types of access networks, among which bandwidth sticks out.[12] The problem with such a measurement based on quality indicators is that it is very imperfectly related to the monetary values which users attribute to the different access services and which are relevant for the $\Delta perf$ in the MEA calculation. In particular, FTTH bandwidths tend to be (sometimes large) multiples of copper bandwidths, while at least today the value differences are much smaller. Also, bandwidth is not the only relevant component of quality differences between the two technologies so that various quality indicators would need to be aggregated into a single $\Delta perf$ measurement. Presumably, the only sensible way this can be done is based on consumer valuations in markets.

Market prices (to the extent available) are the most acceptable scale for economists to measure value differences. To the extent market prices are not available value differences may be extracted from observations of related goods and services. Applied to the case of wholesale copper and fiber access networks two methods are considered. The first method applies "hedonic pricing" techniques (pioneered by Rosen (1974)) to the services provided with copper and FTTH access, while the second method is based on actual prices in the retail markets served by copper and fiber access lines.

The "hedonic pricing" method consists of five steps. In the first step the prices of services supplied via copper access lines are derived (econometrically) from end-user prices of copper access bundles observed in markets. These services could, for example, be voice, TV and internet or single-play, double-play and triple-play bundles. In the second step the weights of these services in copper access would be estimated and thereby the value of copper access established. In the third step a market analysis would be used for determining the weights of these services under FTTH access. In the fourth step the aggregated value of these services in FTTH access would be calculated as the value of FTTH access. In the last step the difference between the results of steps 4 and 2 would be used to determine the $\Delta perf$. While this method does not require an observation of market prices for FTTH access, it requires substantial data on copper pricing and it requires quantitative analysis of weights for services provided by FTTH.

A more direct method is proposed here that, however, requires the observation of retail market prices for both copper and FTTH access. It is based on the philosophy that the method for determining $\Delta perf$ must answer the question: Which wholesale access charge a_C for copper access makes the wholesale user (an alternative service provider or the – vertically separated – downstream division of the incumbent)[13] indifferent between buying copper access at a_C and buying FTTH access at $a_F=\text{LRIC}_{\text{FTTH}}$? The resulting $\Delta perf$ then solves $a_C=\text{LRIC}_{\text{FTTH}}-\Delta perf$.

Thus, the a_C determined that way is competitively neutral between copper and FTTH access technologies provided that FTTH access is offered competitively (at LRIC prices). This is justified by the fact that the copper access network is largely sunk so that its forward-looking costs are indeterminate between the short-run incremental costs (SRIC) of running the network (including the capital costs of the resale value of the remaining assets) and the LRIC of building a new network. Choosing the $\Delta perf$ the way described above strikes the right balance for the regulated copper access network between staying idle because of a too high access charge and foregoing access revenue because of a too low access charge (assuming that no market power can be exercised).

The philosophy behind the measurement of $\Delta perf$ is that it should establish the value difference between copper and FTTH access for the specific purpose, for which the MEA analogy is used, and that purpose is regulated wholesale access. This means that the $\Delta perf$ is not directly given by the price differences between the respective retail access products. Rather, these retail prices are only an important ingredient, because the demand for wholesale access is derived from the demand for retail access. However, assuming competitive retail markets the relevant $\Delta perf$ based on the competitors' derived demand for the wholesale access product has to include in addition to the difference in the retail prices the difference in costs incurred downstream from the wholesale product (if there is any). As a result, the indifference postulated above translates to Eq. (1):

$$p_F-C_{\text{Fdownstream}}-\text{FL}-\text{LRIC}_{\text{FTTH}}=p_C-C_{\text{Cdownstream}}-a_C=p_C-C_{\text{Cdownstream}}\underbrace{-\text{FL}-\text{LRIC}_{\text{FTTH}}+\Delta perf}_{-ac} \tag{1}$$

Here $C_{\text{Fdownstream}}$ and $C_{\text{Cdownstream}}$ are the average downstream variable costs of providing FTTH and copper at retail. The equation implies

$$\Delta perf=(p_F-p_C)-(C_{\text{Fdownstream}}-C_{\text{Cdownstream}}), \tag{2}$$

which is the difference between the downstream markups of copper and FTTH. This specifically neglects any fixed costs downstream, which are irrelevant for price setting but could be relevant for entry and exit decisions of alternative service providers.

[12] The following arguments only concern demand side differences between copper and fiber access, while the issue of downstream cost differences is taken up at the end of this section.

[13] As shown in Section 4.3.3 the measurement results for $\Delta perf$ may differ between entrants' and incumbent's prices.

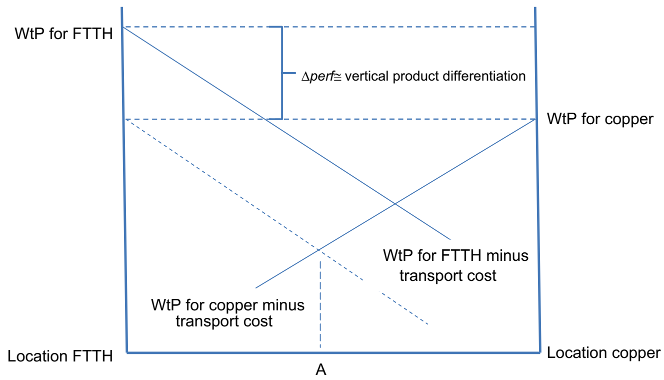

Fig. 2. Illustration of $\Delta perf$ in a simple Hotelling model.

4.2. *Properties of the performance delta in idealized settings*

What properties does the chosen $\Delta perf$ have in idealized regulatory and market settings? Ideal would be a perfect MEA, defined by the property that the two services are perfect substitutes at prices that reflect $\Delta perf$.[14] This view of the MEA is related to but not the same as vertical product differentiation, which is defined by the property that all consumers value one service (FTTH) higher than the other (copper) so that there is a well-defined quality advantage.

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. The main approach to this has been the Hotelling model, which customarily assumes that the consumers and two competing firms are located along a line with fixed length. Neglecting the downstream cost differences used in the above definition of $\Delta perf$, Fig. 2 illustrates some relationships between the MEA approach and product differentiation in the context of a simple Hotelling model. The bold horizontal line is the Hotelling line representing the location of the two qualities "FTTH" and "copper" on both ends. The vertical lines measure willingness to pay (WtP) of consumers for the two services at their respective locations. Users are distributed along the horizontal line and their WtP for each of the services is given by the WtP at the location of the service minus the "transport costs" from the service location to the users. With positive transport costs the WtP for each service is given by the continuous downward-sloped line originating at that service. In contrast, the two horizontal dashed lines represent the case of zero transport costs. In this case the difference in WtP characterizes a perfect MEA and pure vertical product differentiation in the sense that all users prefer FTTH by the same amount. However, this is a very restrictive case, because, due to the zero transport costs, all consumers are the same.[15]

For illustrative purposes only the prices for both services are here assumed to be the same. Otherwise, the WtP would have to be interpreted net of the prices asked by the service providers (as is done in the mathematical Appendix A to this paper). Because the slopes of the WtP lines induce horizontal product differentiation they are here called the "horizontal product differentiation parameters" and the vertical intercepts are called the "vertical product differentiation parameters", also referred to below as the "theoretical $\Delta perf$".

In case of a perfect MEA there exists a certain price difference $\Delta perf$ with the property that at a smaller price difference only the higher-valued service (FTTH) is demanded and at any larger price difference only the lower-valued service (copper) is demanded. An equilibrium, in which both services are traded, therefore implies that the price difference between FTTH and copper, $p_F - p_C$, exactly equals $\Delta perf$. It is clear that downstream cost differences are easily included here for measuring the respective derived demands for the wholesale products.

However, copper and FTTH access are characterized by both vertical and horizontal product differentiation. In contrast to the case of a perfect MEA price differences do not have to equal $\Delta perf$ now in order for both services to be traded side by side. There are customers buying the higher-valued service even if the price difference is greater than the theoretical $\Delta perf$ (that would result from only vertical differentiation) and there are customers who buy the lower-valued service even if the price difference is smaller than the theoretical $\Delta perf$. In this case there exists no thoroughly clean measurement of $\Delta perf$.

As can be seen from Fig. 2 above, a restriction of output for FTTH to points left of A leads to WtP differences (and therefore observed price differences), which are larger than the theoretical $\Delta perf$. Thus, the market price for FTTH is raised by a market power effect so that $p_F - p_C > \Delta perf$. If one now uses the measured price difference as the value of $\Delta perf$ one ends up at an access charge a_C that is smaller than it should have been.[16]

[14] An imperfect MEA could be characterized by the property that FTTH access (at an access charge equal $\text{LRIC}_{\text{FTTH}}$) is in the same relevant market as copper access after applying $\Delta perf$ to the copper access charge.

[15] This observation is due to an anonymous referee.

[16] This implication may, however, have positive welfare effects. It generates an indirect pricing constraint on the fiber access service which is in particular relevant if fiber access is unregulated.

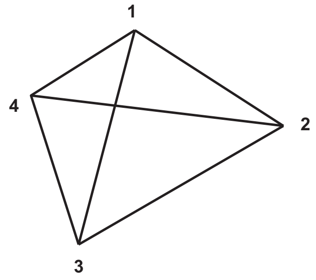

Fig. 3. Preference space with $n=4$ firms/services.

Summing up, the end-user prices reflect $\Delta perf$ perfectly if there is only vertical product differentiation with the same WtP of all users and without downstream cost differences and if both services are actually traded in markets. Pure horizontal differentiation would at equal quantities lead to zero $\Delta perf$ but could be nonzero otherwise. If horizontal and vertical product differentiation interact then

- Market power in the FTTH (wholesale and/or retail) markets increases the measured compared to the theoretical $\Delta perf$.
- Market power in the copper retail market (by analogy) reduces the measured compared to the theoretical $\Delta perf$.
- Penetration pricing in the FTTH (wholesale and/or retail) markets (by analogy) reduces the measured $\Delta perf$ compared to the theoretical $\Delta perf$.

4.3. Applying the MEA concept in numerical simulation exercises

4.3.1. Characterization

The illustration of idealized demand settings indicated the workability of the $\Delta perf$ concept but also showed that it cannot work perfectly. Numerical simulation exercises are therefore performed with the goal of answering the following questions:

- What market adaptations will be triggered by this method starting from some status quo? The answer to this question is important because any actually observed market prices will at least initially start with some other a_C and with FTTH prices that may not derive from $a_F = \text{LRIC}_{\text{FTTH}}$.
- How are the results influenced by non-competitive markets with horizontal product differentiation? This is important for assessing if actual measurements are likely to over- or under-estimate the theoretical $\Delta perf$.
- Are the results consistent and intuitively appealing and do they conform to theoretical expectations?

The simulations use a competition model originally developed in Hoernig et al. (2010) and extended in Hoernig et al. (2011). It was constructed for a hypothetical country called "Euroland", which combines population and geo data of several European countries. Only the regions (clusters) with the highest population density are considered for the simulations. The competition model uses firm-specific cost functions largely derived from cost modeling and that uses specific assumptions about demand functions. The FTTH access network is assumed to use point-to-point technology. Costs consist of fixed costs per month for each region plus variable costs per subscriber.[17]

The competition model is an extension of the traditional Hotelling model to more than two firms (pyramid model by Von Ungern-Sternberg (1991)).[18] For each pair of services, there is a set of consumers who choose between these two products 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 Fig. 3, with each service located at one of the tips of the pyramid.

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 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. In spite of advances in empirical demand estimation that allow for more flexible demand specifications, the linear demand system remains popular in empirical research.

The competitive game consists of four stages, which determine the order in which participants make their moves.

- *Stage 1*: A planner decides on the wholesale access prices for copper and fiber access.
- *Stage 2*: The incumbent firm decides on investments in copper and/or FTTH access and in concentration/core network infrastructures, based on the restrictions and incentives provided by stage 1. Also, a cable firm decides about investment

[17] The cost modeling approach is described in Hoernig et al. (2012).
[18] For a theoretical derivation of the model see Appendix A of this paper.

Table 1
Highest WtP assumptions for quantitative model (S_i).

Incumbent FTTH	Entrant FTTH	Incumbent copper	Entrant copper	Cable
90.00€	87.30€	73.00€	70.81€	82.00€

in cable infrastructure. This additional network operator adds realism to the model and assures that the total quantity for the sum of copper and fiber subscriptions varies in the prices.

- *Stage 3*: One entrant each in copper and in fiber enters and they also decide on their level and type of investment. Their choices and incentives are based on the decisions made in earlier stages.
- *Stage 4*: Entrants, the cable company and the incumbent compete for end-users in differentiated copper/FTTH/cable 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 at most one operator is assumed to be investing in each type of access infrastructure. In case of an integrated incumbent, who offers both copper and fiber there will only be one concentration/core network, whose fixed costs are split between the two services.

At stage 3 the level of investments by competitors is derived from the cost model, assuming full penetration of each active entrant. Competitors enter either using copper or fiber access technology. In order to facilitate comparisons and eliminate cases with viable entrants only for one of the two technologies one competitor each are assumed for the simulations rather than solving for free-entry equilibria.

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.[19] Because of the fixed location of firms at the nodes of the pyramid the equilibria of this model generally exist (and are generally unique). However, it can occur that a service drives out another service. For example, at low transport costs a service with higher WtP (and not equally higher marginal costs) can maximize profits by capturing all customers of the other service. This is somewhat similar to the case of a pure Bertrand model. In the simulations transport costs were set high enough to assure interior solutions. It can also happen that transport costs are so high, that some customers are not served because their WtP is too low. This would lead to incomplete coverage and to local monopolies. This did not happen in any of the model runs attempted for this article.

Under the pyramid model total output is kept constant. So, competition is only for market shares. Since the firms in the market include the cable firm, 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 is assumed not to sign up for any fixed network but rather to stay without a connection or resort to mobile only.

4.3.2. QoS and willingness to pay in the basic model

While costs are given by the cost model described in Hoernig et al. (2011), 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 S_i therefore capture vertical product differentiation.

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 t_{ji}. This feature is used to make product differentiation within the same technology less pronounced than product differentiation between different technologies. For the standard model runs the transport costs are set at $t_{ij}=t_{ji}=1/37{,}000$ if i and j are on different networks and $t_{ij}=t_{ji}=1/92{,}500$ if i and j are on the same network. These numbers were chosen to generate consistency in the quantitative model and acceptable demand elasticities.

The vertical product differentiation parameters for highest WtP (S_i) are provided in Table 1.

These WtP levels (for consumers with the highest WtP for each of the services) were chosen in order to generate end-user prices in a realistic range. The WtP differences between copper and FTTH access are intentionally large in order to produce clear results for the model. They may be lower in reality.

The cost model showed downstream costs for FTTH to be 4.22€ (5.28€) higher than for copper for the incumbent (alternative service provider).[20] Thus, the theoretical $\Delta perf$ derived under the assumption of only vertical product

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

[20] Higher downstream costs for FTTH include customer premises equipment costs and higher costs for Ethernet ports. Entrants also incur additional optical distribution frame costs.

Table 2
End-user prices resulting from a_C=13.92€ and a_C=3.98€.

	Incumbent-fiber	Incumbent-copper	Incumbent-cable	1 Fibre entrant	1 Copper entrant
a_C=13.92€	46.82€	36.73€	37.52€	45.77€	35.28€
a_C=3.98€	43.87€	32.08€	35.51€	43.89€	28.66€

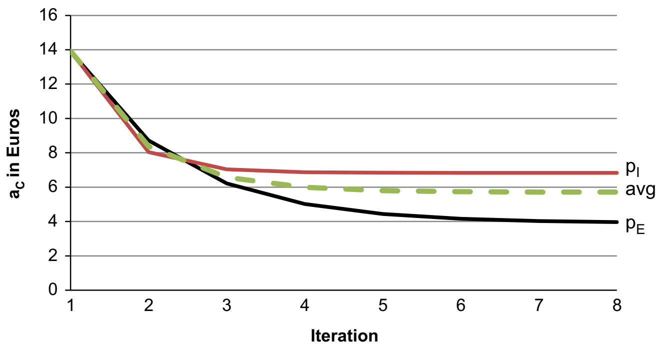

Fig. 4. Convergence of a_C for averages of incumbent's and entrants' end-user prices (p_E and p_I).

differentiation should be $\Delta perf$=(90€–73€)–4.22€=12.78€ for the incumbent and $\Delta perf$=(87.00€–70.81€)–5.28€=11.21€ for the alternative service providers.

4.3.3. Standard model runs

The model was run with an integrated incumbent offering both copper and FTTH wholesale and retail and with one independent alternative service provider for each copper and FTTH retail access. There is also an alternative infrastructure provider (cable), which does not offer wholesale access and offers a substitute for both copper and FTTH.

The initial access charge for FTTH, a_F, is given from the cost model runs for $\text{LRIC}_{\text{FTTH}}$ and is a_F=€13.92. For simplicity the starting copper access charge was set at a_C=13.92€ also. This is as if the performance delta were zero to begin with. In subsequent model runs a_F remains the same, but a_C is recalculated using the results of stage 4 of the previous model run.

The result of the initial model run is given in the first row of Table 2. Based on the entrants' end-user prices and downstream cost differences one gets $\Delta perf$=45.77€–35.28€–5.28€=5.21€. Therefore the measured copper MEA costs are a_C= 13.92€–5.21€=8.71€. The model run was now iterated by setting a_C=8.71€, while leaving a_F=13.92€. This resulted in a new equilibrium a_C=6.21€, which became the starting a_C for the next iteration, as shown in Fig. 4 as the line p_E; after several iterations the process thus generated converged to a_C=3.98€. The equilibrium prices at the point of convergence are given in the second row of Table 2.

Although the resulting a_C appears to be a very low value, it is still above the value, which would have resulted under the theoretical $\Delta perf$. The measured $\Delta perf$ at the point of convergence is 13.92€–3.98€=9.94€, while the theoretical $\Delta perf$ was 11.21€, which would have resulted in a_C=13.92€–11.21€=2.71€.

It is obvious from Table 2 that the incumbent's copper and FTTH prices differ by less than the entrants‘ prices. Thus, one should expect a different $\Delta perf$ for the incumbent's prices than that found in Table 2. The incumbent's pricing strategy certainly differs from that of the alternative service providers and from that used by us for establishing $\Delta perf$. In particular, the incumbent (although under vertical accounting separation in the quantitative model) pursues both a vertically and horizontally integrated profit maximization approach. This also means that the opportunity cost of the inputs providing wholesale to competitors differs from the price the incumbent charges these competitors by a factor known as the diversion ratio.[21] Only if the diversion ratio equals one will the two be the same (DeGraba, 2003). In the current model, because of the presence of a cable network, the diversion ratio is below one. This makes the incumbent's downstream division live with a lower margin than the alternative service providers. However, in terms of end-user prices part of that effect is compensated by higher WtP for the incumbent's services, while it is exacerbated by lower downstream costs. Integrated profit maximization further reduces cannibalization tendencies leading to less price differences.

The resulting convergence process using the incumbent's prices (p_I), compared to using the entrants‘ prices (p_E) is also shown in Fig. 4. Interestingly, based on the incumbent's prices the process converges faster, but – as expected – to a substantially higher level. The faster convergence even means that for the first iteration the resulting a_C is smaller than under entrants‘ prices. At the point of convergence the resulting a_C=6.84€ is much larger than under the theoretical $\Delta perf$=90.00€–73.00€–4.22€=12.78€, which would result in a_C=13.92€–12.78€=1.14€.

[21] The diversion ratio expresses what part of its end-user sales the incumbent loses to alternative service providers by marginally increasing its retail price.

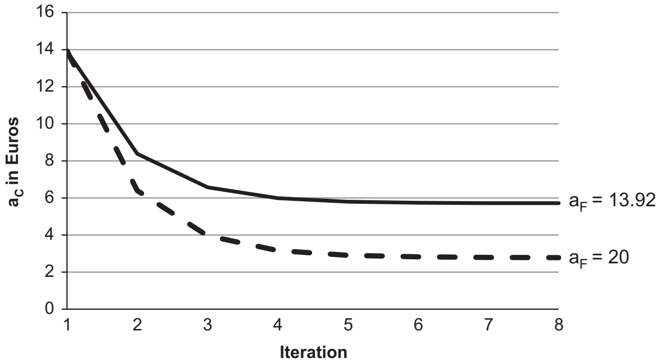

Fig. 5. Effect on a_C of FTTH wholesale market power of the incumbent.

The difference in results between using entrants' and incumbent's prices suggests averaging both for practical applications. This is justified because it uses all market data and, in particular, includes a full representation of the customers of both copper and FTTH. The same type of iterative process was therefore performed for the a_C values derived from the price averages and downstream cost averages of entrants and incumbent (unweighted). As Fig. 4 shows for the line "avg", the somewhat surprising result is that the resulting averages are larger than the average of the previous results. In particular, the process converges to a_C=5.72€ instead of the 5.40€ that would have resulted from averaging the previous outcomes. The converged value is much larger than the a_C that would result for the theoretical averaged $\Delta perf$: a_C=5.72€ $\gg$ (2.72€+1.14€)/2 = 1.93€.

Many additional model runs were done with diverse parameters, such as WtP levels, transport costs, a_F, initial a_C levels, fixed costs, variable costs and number of competitors. All these runs have one property in common. The resulting a_C levels always converge quite quickly to a level that is independent of the starting value and independent of whether one starts the process above or below the level of convergence. This property is explained as follows. W.l.o.g. assume that the $\Delta perf$ at the first iteration is large enough for the resulting a_C to lie below the starting level. As a consequence, both the incumbent and the copper entrant will lower their copper retail prices because their marginal (opportunity) costs have decreased. Because of substitution between copper and FTTH the effective demand for FTTH will decrease, which leads to a reduction in FTTH retail prices for both incumbent and FTTH entrant. However, these price decreases will be less than those for copper. This results because of imperfect substitution and because there has been no cost reduction for FTTH. The measured $\Delta perf$ will therefore increase but by less than in the previous iteration. The same argument can be made for the case that after the first iteration a_C has increased compared to the starting value.[22]

The main result besides the convergence has been so far that measured $\Delta perf$ was always smaller than the theoretical $\Delta perf$ based on the pure vertical differentiation assumed in the demand model. This, however, could change with increased market power for FTTH.

4.3.4. The effect of market power on the modeling results

As already shown in the idealized demand setting the effect of market power in the FTTH market[23] could lead to an overestimation of $\Delta perf$ because of the price increase for FTTH associated with it. This case was addressed in two types of model runs. First, market power of the incumbent is assumed for FTTH wholesale access (leading to $a_F > \mathrm{LRIC}_{\mathrm{FTTH}}$) and, second, asymmetric market power in the FTTH retail market is treated.

Market power in the FTTH wholesale market can be exercised if FTTH wholesale access is not regulated. Using the same demand and cost assumptions and assuming the same presence of market participants as before in the standard model runs a_F is now increased to a_F=20.00€, while $\mathrm{LRIC}_{\mathrm{FTTH}}$=13.92€ remains as before. Fig. 5 compares this case to the case of a_F=13.92€, both based on using price and cost averages of entrants and incumbent.

As theoretically predicted the resulting a_C values are lower than before. The convergent value is a_C=2.78€ $\ll$ 5.72€ resulting before without market power. However, the difference 5.72€−2.78€ = 2.94€ is substantially smaller than the difference between the a_F levels 20.00€−13.92€ = 6.08€. The reasons for this are (a) that under market power a marginal cost increase is not fully converted into a price increase and (b) that retail copper prices will also increase if FTTH retail prices increase. For the same reason the converged a_C still stays well above the a_C that would result under the theoretical averaged $\Delta perf$: a_C=2.78€ > (2.72€+1.14€)/2 = 1.93€. However, it is clear that at some level of the exercise of market power (e.g., for a_C=30.00€) this would no longer hold.

[22] Technically, the process described is one of finding a fixed point. One starts from some equilibrium that has not yet been influenced by the MEA method and end up with an equilibrium, in which the method comes fully to bear and which maps into itself.

[23] Some market power (i.e., price > marginal costs) is the natural result of horizontal product differentiation. Rather, here we mean asymmetric market power exercised by the incumbent.

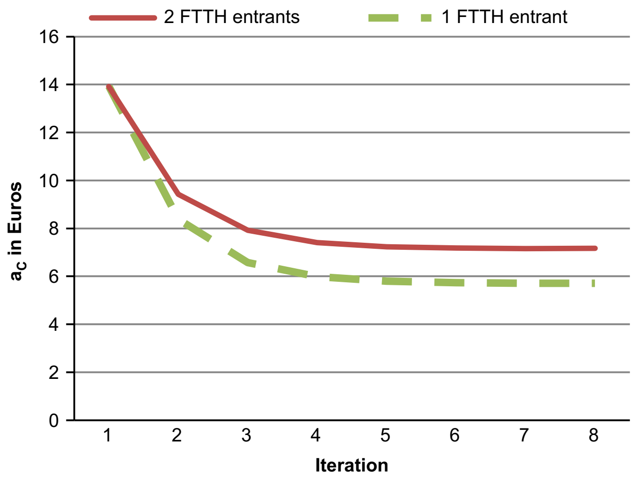

Fig. 6. Effect on a_C of more competition in FTTH retail markets.

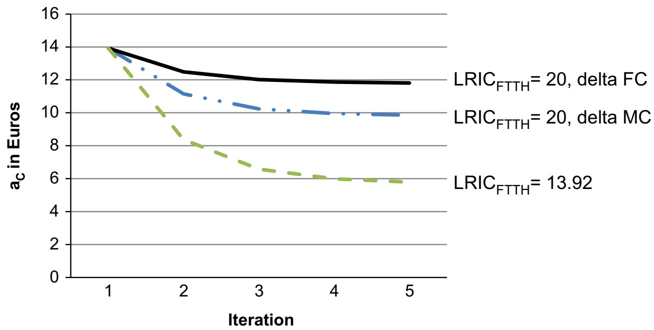

Fig. 7. Effects on a_C of an increase of $LRIC_{FTTH}$.

Market power in the FTTH retail market is treated by increasing the number of entrants from 1 to 2. Thus, the assumption is that with only one entrant more market power is exercised downstream than with two entrants. In this case, the standard model runs represent more market power than the additional model run, both of which are presented in Fig. 6, which shows the case of increased competition in the retail FTTH markets. The a_C level now converges to a higher value a_C=7.17€ > 5.72€.

These results easily extend with a reverse sign to the case of more or less retail competition in copper markets and to penetration pricing in the FTTH markets.

4.3.5. *Consistency checks for cost and demand changes*

Consistency checks were performed on the effects of cost and demand changes for the resulting outcomes. The most important ingredient for the MEA-derivation besides $\Delta perf$ is the value of $LRIC_{FTTH}$. Clearly, the resulting a_C should increase in $LRIC_{FTTH}$. The effects of increasing $LRIC_{FTTH}$ from 13.92€ to 20.00€ are shown in Fig. 7 compared to the case of $LRIC_{FTTH}$=13.92€. It turns out that the size of the effect of the change in $LRIC_{FTTH}$ depends on the nature of the cost change. If the cost change is entirely due to an increase in fixed capital costs the resulting a_C at the point of convergence increases by 6.06€ from 5.72€ to 11.78€, which almost exactly equals the average cost increase of 6.08€. In contrast, the increase in a_C is only 4.10€ from 5.72€ to 9.82€ if the cost increase is entirely due to an increase in marginal costs. In reality one would rather expect a large increase in fixed costs, because that would be associated with changes in terrain or population density, while the marginal costs are comparatively small and do not vary much by region.[24] Thus, the clear result is that cost changes in the FTTH part of the network will trigger changes in a_C of a similar magnitude, but they may be dampened somewhat.

One of the main components of the pricing part of $\Delta perf$ is the WtP difference (from Table 1) relevant for vertical product differentiation.[25] So far the WtP for FTTH was set at 90€ and for copper at 73€. Additional model runs with WtP for FTTH at 85€ and for copper at 78€ are shown in Fig. 8 in comparison. This increases the converged level of a_C from an average of 5.72€ to 12.20€. Thus, while the theoretical $\Delta perf$ is reduced by 10€ the converged value of a_C only increases by 6.48€. The

[24] Since our model is not dynamic "increases in costs" have to be interpreted in a comparative statics sense.

[25] In additional model runs the cost differences downstream between copper and FTTH and between incumbent and entrants were eliminated. The results very much mimic the outcome of the standard model adjusted for the lack of cost differences.

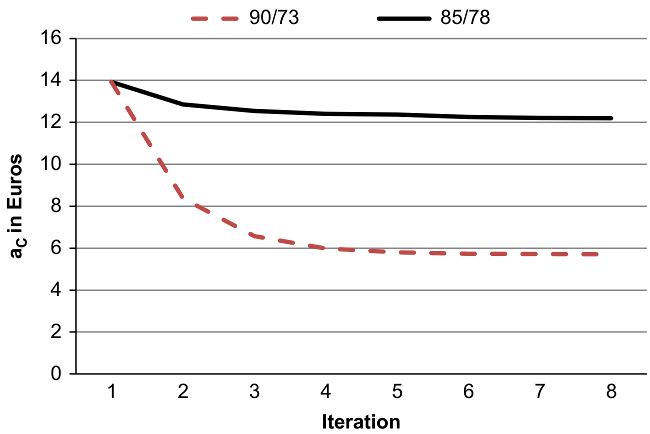

Fig. 8. Effect on a_C of a reduction in the relative WtP for FTTH.

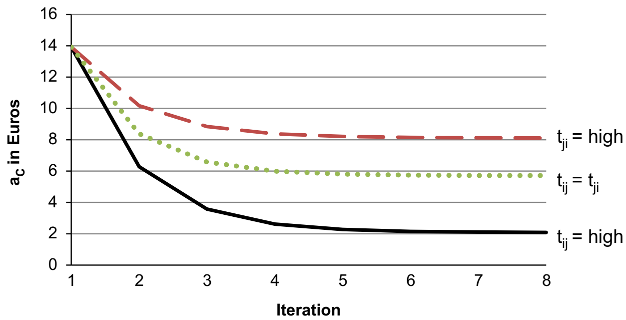

Fig. 9. Effects of asymmetric demand slopes on a_C.

value of 12.20€, however, is still above the a_C that would result from the theoretical $\Delta perf$: 12.20€ > 13.92€–(85€–78€) +(5.28€+4.22€)/2 = 10.67€.

Further model runs were concerned with variations in the horizontal demand differentiation parameters. A general reduction (increase) in differentiation leaves the convergent outcomes almost unaffected, but convergence speed is increased (reduced). In order to change the convergent outcome one has to introduce asymmetries between the substitution parameters (slopes). This is not something that is usually done in Hotelling-type models. However it is feasible in this setting. The asymmetry was applied only to the substitution parameters between the copper/cable and FTTH suppliers and therefore not to the relationship between the other suppliers and cable or between copper incumbent and copper entrant or FTTH incumbent and FTTH entrant. If for customers located between the FTTH and copper/cable nodes the slope of the demand for FTTH is increased the measured $\Delta perf$ is reduced, while it is increased if the measured slope of the demand for copper/cable is increased. This was compared to a base case, where t_{ij} = 1/37,000 if i and j are on different access networks and t_{ij} = 1/92,500 if i and j are on the same network. In the alternative model runs first only t_{ij} and then only t_{ji} were doubled only for i = FTTH and j = copper or cable. As shown in Fig. 9, the increase in t_{ij} leads to a convergence outcome of a_C = 8.12€, while the second increase in t_{ji} leads to a convergence outcome of a_C = 2.09€.

These twofold increases in slope were meant to produce an extensive asymmetry. They compare to the convergence outcome of the basic symmetric model run of a_C = 5.66€ and to the a_C = 1.93€ for the theoretical $\Delta perf$. Thus, even a substantial asymmetry hardly leads to an overestimation compared to the theoretical $\Delta perf$. However, a further doubling of the relevant t_{ji} would have that result.

4.3.6. Conclusions from the model runs

The model provided very consistent results, in line with theoretical expectations. Two main conclusions emerge from the model runs.

The first is that for any given a_F the resulting a_C converges to a particular value that is independent of the starting a_C. The convergence was almost complete after 2–3 model iterations with a reduction in the remaining difference of 50–75% per period from the converged value. This means that for practical implementation the process can be started at current a_C levels and will generate a glide path to a stable new level. The glide path means that there will not be a sudden large change in a_C immediately after the method is implemented. Rather, the adaptation will be gradual.

Please cite this article as: Neumann, K.-H., & Vogelsang, I. How to price the unbundled local loop in the transition from copper to fiber access networks? *Telecommunications Policy* (2013), http://dx.doi.org/10.1016/j.telpol.2013.05.011

The second main conclusion is that the method tends to be conservative relative to the theoretical case of pure vertical product differentiation, meaning that the measured $\Delta perf$ underestimates the theoretical $\Delta perf$. Thus, the incumbent will likely receive a higher a_C than theoretically correct. The measured $\Delta perf$ is likely to be smaller because of

- Horizontal product differentiation;
- Penetration pricing for FTTH;
- An averaging of prices and downstream cost differences of incumbent and entrants (if such averaging is performed);
- An automatic glide path that keeps a_C higher at the beginning.

In contrast, the $\Delta perf$ could be overestimated if the incumbent (or someone else) exercises market power in the FTTH markets. However, this exercise of market power needs to be substantial before it overcomes the before-mentioned effects. At the same time the reduction in a_C resulting from this market power may prevent the incumbent from exercising it.

The $\Delta perf$ could also be overestimated if there is a strong asymmetry in the horizontal product differentiation parameters (slopes). This is quite unlikely to occur.

Thus, in general one can expect the glide path generated by the approach to end at a level that is higher than under only vertical product differentiation.

4.4. *Concerns and necessary steps for practical implementation*

There are four main concerns for practical application of the MEA-approach analyzed. They are (1) strategic behavior of market participants, (2) availability of price data, for FTTH in particular, (3) availability of cost data, for FTTH and for downstream services in particular, and (4) proper upper and lower bounds for a_C.

4.4.1. *Strategic behavior of market participants*

Any regulatory approach may be undermined by strategic behavior, mostly by the regulated firm. The MEA approach suggested here is dynamic in the sense that the current price for wholesale copper access is made dependent on the observed previous retail prices for copper and FTTH access (which are assumed to be unregulated). If, for example, the incumbent charges a lower than profit-maximizing FTTH price and/or higher than profit-maximizing copper price today this will lead to a higher regulated a_C for the next period. Clearly, the incumbent would thereby be sacrificing profits today in order to gain profits later from the higher a_C, which will trigger higher retail prices as well as generate more wholesale profits. Without further strategic behavior and without the exit of other firms the process would revert to lower a_C levels in the future, ending in a cycle (from the convergence result). Only if such a cycle were profitable or if successful predation were profitable would such strategic behavior be undertaken. This cannot be analyzed with the model but it is unlikely to be profitable for two reasons. First, the cycle takes time so that the additional profits have to be discounted. This is part of the traditional argument against the rationality of predation. Second, the incumbent only receives 50% weight in the averaging procedure for determining a_C. This acts like a 50% discount rate and substantially strengthens the previous argument. It also argues against using the incumbent's market share as a weight for determining the pricing averages when calculating a_C. One signal that such strategic behavior could be occurring would be a margin squeeze for FTTH. Without a price increase of copper access at the retail level this would lead to a margin squeeze for copper as well. Thus, a margin squeeze for copper should be disallowed via setting an upper bound for a_C.

A somewhat similar argument for strategic behavior could be made for the alternative service providers for copper access, who could reduce their copper retail prices in order to gain a future reduction in a_C. This argument is even weaker than that for the incumbent, because there can be no predation. Therefore, the probability of such type of strategic behavior is low.

4.4.2. *Availability of price data*

FTTH has very low penetration rates in many countries. Reliable FTTH retail prices cannot therefore be expected everywhere. In such a case it may be necessary to import price data from countries with higher FTTH penetration and with longer FTTH experience.[26] Such prices, however, do not easily translate via exchange rates or purchasing power parities. In particular, the absolute differences between FTTH and copper prices may not be very meaningful. In contrast, the ratio between FTTH and copper prices is likely to be much more robust, because it does not require any exchange rates. This suggests considering properties of using the price and cost ratios instead of price and cost differences for determining $\Delta perf$.

Based on ratios a_C should be determined as

$$a_C = \mathrm{LRIC}_{\mathrm{FTTH}}(1-\Delta perf) \tag{3}$$

and

$$\Delta perf = ((p_F - C_{\mathrm{Fdownstream}}) - (p_C - C_{\mathrm{Cdownstream}}))/(p_F - C_{\mathrm{Fdownstream}}), \tag{4}$$

[26] Using foreign price data also means that the market conditions in those countries are deemed acceptable.

which imply

$$a_C = \text{FL–LRIC}_{\text{FTTH}}(p_C - C_{\text{Cdownstream}})/(p_F - C_{\text{Fdownstream}}). \tag{5}$$

While the determination of a_C using price and cost differences leads to the same absolute markup for copper and FTTH at the retail level, the ratio method only leads to the same relative markup. Because a_C will be smaller than $\text{LRIC}_{\text{FTTH}}$ the ratio method will therefore lead to lower markups for copper and also to higher a_C levels. Using the ratio method will therefore tend to understate the measured $\Delta perf$ compared to the theoretical $\Delta perf$.

4.4.3. Availability of cost data

Cost data for FTTH are substantially less available than cost data for copper access. However, several bottom-up cost models exist that could be used by regulators.

The other cost data needed concern downstream costs for copper and FTTH. Most of these downstream costs are likely to be similar (e.g., marketing and sales costs) but there will be some differences, such as higher CPE costs and higher costs for Ethernet ports incurred for FTTH. The costing exercise only needs to calculate these differences.

4.4.4. Lower and upper bounds for a_C

As the simulations showed for some extreme cases, the resulting a_C at convergence could be very low (in case of very high WtP differences and/or exercise of market power for FTTH) or very high (in case of penetration pricing for FTTH and/or low WtP differences). Both of these results may be unacceptable.

In the first case of a very low resulting a_C copper access should actually no longer be offered. However, one should leave that to the market and set a lower bound for a_C that covers the incumbent's costs of continuing operation. These costs are SRIC plus the apportioned value of capital costs of assets that could otherwise be sold in second-hand markets.

In the second case of a very high resulting a_C FTTH access would not really be the MEA for copper access. This would hold if the resulting a_C exceeded the copper LRIC_C. Thus, $a_C = \text{LRIC}_C$ (including some common costs) would have to form an upper bound for the a_C values.

4.5. Conjectured efficiency and investment properties

Being competitively neutral does not mean that using the described MEA approach will necessarily lead to a static welfare optimum or to dynamically efficient investment incentives.

It is hard to evaluate static welfare effects of the MEA method, because neither it nor the traditional LRIC approach uses Ramsey pricing markups on marginal costs. Compared to the use of traditional LRIC-based access charges the overall markups on both fiber and copper will be reduced under the MEA approach. The net effect on welfare will therefore be ambiguous, but the MEA method would improve consumer welfare over traditional LRIC-based prices. This is also borne out by the quantitative model results, where under the standard model runs over all iterations total welfare declined by about 0.5%, while consumer surplus increased by about 10%.

In a world with expected parallel operation of copper and fiber access networks over a long time span the investment incentive properties of the relationship between copper and fiber access charges depend on the interaction of two effects, called replacement effect and migration effect (Bourreau, Cambini, & Dogan, 2012).

The replacement effect calls for a large enough difference between the copper and fiber access charge so that profits from copper alone are lower than profits from operating both a copper and a fiber access network. That means replacing copper with fiber needs to be sufficiently profitable in order to induce fiber investment. The MEA approach provides for such an access charge difference, although it is likely to be smaller than it would be if only the replacement effect were operating.

The migration effect calls for small enough price differences between copper and fiber access so that end-users have incentives to switch from copper to fiber, once fiber is offered. Because it is based on indifference between copper and fiber the MEA approach leads to price differences that are precisely based on such a consideration. It is not tilted in favor of fiber, though. However, with the expected underestimation of the measured as compared to the theoretical performance delta a preference for fiber should result, which would favor fiber investment.

5. Conclusions

Most European regulators still apply FL-LRIC principles to calculate the copper access charges. This article has made the case that this pricing principle is no longer adequate due to the decreasing demand for copper access and the transition from copper to fiber access. FL-LRIC was designed for a market environment which actually no longer prevails in the access market. Some regulators have reacted and either capped the copper access charge, are gradually reducing it or are treating fiber access as the modern equivalent asset to copper access.

This article developed and presented a novel solution to optimal pricing of copper access in the transition to fiber access. To become competitively and technologically neutral, copper access should be based on the cost of fiber access corrected by the performance delta between copper and fiber access. The performance delta should be derived from the market valuation of services provided over copper and fiber access represented by the end-user prices of services and corrected by cost differences down stream of the access provision.

According to the analysis the probability of market participants (incumbent and/or competitors) to strategically distort retail prices to influence copper access charges to their favor under the MEA approach is limited. Applying the MEA approach converges to the appropriate performance delta in a few steps independent of the starting point of the approach. If proper retail price data are not available or not yet stable enough, regulators should rely on international benchmarking values from countries which have introduced fiber access early. To avoid potential distortions, regulators should use the short-run incremental cost of copper access (including the value of capital costs of assets that could otherwise be sold) as lower bound of the relevant wholesale price and the LRIC of copper access as its upper bound.

Summing up the properties of the method, it will improve consumer welfare over the traditional LRIC approach and will balance the replacement and migration effects for fiber investment.

Acknowledgments

The original idea for our proposal has been developed in the study “Analyse von alternativen Methoden zur Preisregulierung”, which the current authors together with Werner Neu have conducted for the Swiss regulator BAKOM in May 2012. We are grateful to the guest editor, two insightful referees and Steffen Hoernig for helpful comments that substantially improved the paper.

Appendix A. Theoretical background for the competition model (without cable)[27]

A.1 Firms

The market is assumed to consist of a vertically integrated firm, the “incumbent”, who runs both a FTTH and a copper access infrastructure, $m_1 \geq 0$ “FTTH entrants” who use access to the FTTH infrastructure, and $m_2 \geq 0$ “copper entrants” who use the copper infrastructure. The difference between retail products based on FTTH or copper access is captured by a higher gross surplus for consumers from FTTH access. The incumbent offers both FTTH- and copper-based retail products and gives both types of wholesale access. He takes these facts into account when setting his retail prices such as to maximize the sum of profits from his retail and wholesale businesses. The wholesale access prices are assumed to be exogenously fixed by a regulator.

The total number of products present at the retail level is $n = 2 + m_1 + m_2$. The retail products of the incumbent are numbered as products $i = 1$ (fiber) and $i = 2$ (copper), those of FTTH entrants $i = 3, \ldots, m_1 + 2$, and those of copper entrants as $i = m_1 + 3, \ldots, n$.

A.2 Consumers, and some technical notation

There are N consumers who opt between pairs of products and subscribe to some product in equilibrium. Each product is located at one of the n nodes of a complete graph (i.e. all n nodes are linked pair-wise to each other by lines) of size N which describes consumers' space of preferences over which they are uniformly distributed. The length of each line is $l = 2N/n(n-1)$. Horizontal differentiation on the line between firms i and j is modeled in generalized Hotelling fashion as follows: A consumer at distance d to firm i has ”transport cost”, i.e. disutility of not being able to buy his perfect match, of $t_{ij}d$, while his transport cost for buying from firm j is $t_{ji}(l-d)$. A lower value of t_{ij} indicates that product i is more attractive. While in the standard Hotelling model $t_{ij} = t_{ji}$, the current model allows for these transport costs to differ by direction.

The following technical notation will be very useful below to solve the model. Let e_i, $i = 1, \ldots, n$, be the ith unit vector, $E_0 = e_1 + e_2$, $E_1 = \Sigma_{i=3}^{2+m_1} e_i$ and $E_2 = \Sigma_{3+m_1}^{n} e_i$, E be the $(n \times 1)$ vector of ones and I the $(n \times n)$ identity matrix.

Let $\sigma_{ij} = \sigma_{ji} = 1/(t_{ij} + t_{ji})$ and $\tau_{ij} = t_{ji}\sigma_{ij}$. The former will be the resulting ”standard” Hotelling differentiation parameter on the line between products i and j, while τ_{ij} will denote product i's subscriber share at equal net surplus on the same line. Let $T_i = l\,\Sigma_{j \neq i}\tau_{ij}$ denote the corresponding total of subscribers for product i if all firms were to offer the same net surplus to consumers.

Let X^{int}, X^{sep} and Y be $(n \times n)$ -matrices with entries $X_{ii}^{\text{int}} = X_{ii}^{sep} = Y_{ii} = \Sigma_{j \neq i}\sigma_{ij}$ for all $i = 1, \ldots, n$; for $j \neq i$ let $X_{12}^{\text{int}} = X_{21}^{\text{int}} = -\sigma_{12}$ and $X_{ij}^{\text{int}} = 0$ otherwise; $X_{ij}^{sep} = 0$ and $Y_{ij} = -\sigma_{ij}$ for all $j \neq i$. Let Γ^{int} be an $(n \times n)$ -matrix whose two first rows are equal to those of Y while the rest is zero, and Γ^{sep} be equal to Γ^{int} with elements corresponding to different platforms set to zero. That is, $\Gamma_{12}^{sep} = \Gamma_{1j}^{sep} = 0$ for all $j = 3, \ldots, m_1 + 2$, and $\Gamma_{21}^{sep} = \Gamma_{2j}^{sep} = 0$ for all $j = m_1 + 3, \ldots, n$.

A.3 Subscriber numbers

The number of subscribers of product i is $q_i \geq 0$, with $\sum_{i=1}^{n} q_i N$, and market shares are $s_i = q_i/N$. Subscribers of firm i receive a net surplus[28] of $w_i = S_i - f_i$, where S_i is the surplus from buying product i (a vertical differentiation parameter

[27] This Appendix A is taken from Hoernig et al. (2011).

[28] “Net” here means “after having paid the end-user price”.

derived from quality and brand image), and f_i is the monthly subscription fee. The S_i are large enough so that all consumers subscribe, with

$$S = S_1 e_1 + S_2 e_2 + S_F E_1 + S_C E_2$$

and $S_1 > S_2,\ S_F > S_C$.

Throughout no segment ij shall be cornered by one of the firms, thus the indifferent consumer on line ij is located in its interior, at a distance x_{ij} from firm i defined by

$$S_i - f_i - t_{ij} x_{ij} = S_j - f_j - t_{ji}(l - x_{ij}).$$

Solving for x_{ij} yields firm i's part of segment ij as

$$x_{ij} = \tau_{ij} l + \sigma_{ij}(S_i - f_i - S_j + f_j).$$

Summing subscribers over segments yields firm i's subscriber number

$$q_i = \sum_{j \neq i} x_{ij} = T_i + \sum_{j \neq i} \sigma_{ij}(S_i - f_i - S_j + f_j).$$

with $\partial q_i / \partial f_i = -\sum_{j \neq i} \sigma_{ij}$ and $\partial q_i / \partial f_j = \sigma_{ij}$, product i's own- and cross-elasticities of demand are

$$\varepsilon_{ii} = -\frac{f_i}{q_i} \sum_{j \neq i} \sigma_{ij}, \quad \varepsilon_{ij} = \frac{f_j}{q_i} \sigma_{ij}.$$

Let T, f and q be the $(n \times 1)$ vectors of T_i, f_i and q_i. Then one can write

$$q = T + Y(S - f).$$

Consumer surplus is:

$$CS = q'(S - f) - \sum_{i=1}^{n} \sum_{j \neq i} t_{ij} \int_0^{x_{ij}} x\, dx = q'(S - f) - \frac{1}{2} \sum_{i=1}^{n} \sum_{j \neq i} t_{ij} x_{ij}^2$$

A.4 Costs, access and profits

Firms have fixed retail cost

$$K = K_1 e_1 + K_2 e_2 + K_F E_1 + K_C E_2$$

and marginal per subscription retail cost of

$$c = c_1 e_1 + c_2 e_2 + c_F E_1 + c_C E_2.$$

These retail costs are assumed to contain any infrastructure-related cost not attributable to the wholesale FTTH infrastructure.

The wholesale cost of the infrastructure are fixed costs K_{01} and K_{02} for the fiber and copper parts, respectively, and marginal per retail client cost

$$k_1 = k_F(e_1 + E_1), \quad k_2 = k_C(e_2 + E_2), \quad k = k_1 + k_2,$$

i.e. FTTH and copper access have different costs for the infrastructure owner.

The wholesale access corresponding to retail product i is charged according to a two-part tariff $A_i + a_i q_i$, where $A_i = 0$ if the tariff is linear, and

$$\tilde{a}_1 = a_F(e_1 + E_1),\ \tilde{a}_2 = a_C(e_2 + E_2),\ \tilde{a} = \tilde{a}_1 + \tilde{a}_2$$
$$\tilde{A}_1 = A_F(e_1 + E_1),\ \tilde{A}_2 = A_C(e_2 + E_2),\ \tilde{A} = \tilde{A}_1 + \tilde{A}_2.$$

Product i's retail profits are $(i = 1, \ldots, n)$

$$\pi_i = (f_i - a_i - c_i)\, q_i - K_i - A_i.$$

Wholesale profits, including access payments by the network owner i to himself, are

$$\pi^{Wi} = q'(\tilde{a}_i - k_i) + E' \tilde{A}_i - K_{0i}.$$

A horizontally integrated incumbent has total profit $\pi^I = \pi_1 + \pi_2 + \pi^{W1} + \pi^{W2}$. Total welfare is given by

$$W = CS + \sum_{i=1}^{n} \pi_i + \pi^{W1} + \pi^{W2}.$$

A.5 Equilibrium subscription fees

Entrant i's ($i \geq 3$) first-order condition for profit-maximization becomes

$$\frac{\partial \pi_i}{\partial f_i} = q_i + (f_i - a_i - c_i)\frac{\partial q_i}{\partial f_i} = q_i - (f_i - a_i - c_i)\sum_{j \neq i}\sigma_{ij} = 0.$$

A.5.1 A horizontally integrated incumbent

The horizontally integrated incumbent's first-order conditions for profit-maximization, taking into account both retail products $i, k \in \{1, 2\}$, $k \neq i$, and wholesale access, are

$$\begin{aligned}\frac{\partial \pi^I}{\partial f_i} &= q_i + (f_i - a_i - c_i)\frac{\partial q_i}{\partial f_i} + (f_k - a_k - c_k)\frac{\partial q_k}{\partial f_i} + \frac{\partial q'}{\partial f_i}(a - k) \\ &= q_i - (f_i - a_i - c_i)\sum_{j \neq i}\sigma_{ij} + (f_k - a_k - c_k)\sigma_{ik} - e'_i Y(\tilde{a} - k) = 0.\end{aligned}$$

For the following let $X = X^{\text{int}}$ and $\Gamma = \Gamma^{\text{int}}$.

A.5.2 Horizontally separated access network providers

On the other hand, the horizontally separated access network provider i's ($i = 1,\ 2$) first-order condition is

$$\frac{\partial(\pi_i + \pi^{Wi})}{\partial f_i} = q_i + (f_i - a_i - c_i)\frac{\partial q_i}{\partial f_i} + \frac{\partial q'}{\partial f_i}(\tilde{a}_i - k_i) = q_i - (f_i - a_i - c_i)\sum_{j \neq i}\sigma_{ij} - e'_i Y(\tilde{a}_i - k_i) = 0.$$

In this case let $X = X^{sep}$ and $\Gamma = \Gamma^{sep}$

A.5.3 Determination of equilibrium prices

With the corresponding definitions of X and Γ, stacking all n first-order conditions leads to:

$$q - X(f - \tilde{a} - c) - \Gamma(\tilde{a} - k) = 0.$$

Solving for f leads to equilibrium fees

$$f^* = (X + Y)^{-1}[T + YS + X(\tilde{a} + c) - \Gamma(\tilde{a} - k)].$$

References

BEREC (2011). *Regulatory accounting in practice 2011*. *BEREC Report BoR*, 1134 October.

Bourreau, M., Cambini, C., & Dogan, P. (2012). Access pricing, competition, and incentives to migrate from "old" to "new" technology. *International Journal of Industrial Organization*, *30*, 713–723.

Briglauer, W., & Vogelsang, I. (2011). The need for a new approach to regulating fixed networks. *Telecommunications Policy*, *35*(2), 102–114.

Cullen International (2007). Cross country analysis—Cost accounting systems for fixed wholesale services. Available from: ⟨http://www.cullen-international.com/documents/cullen/⟩.

DeGraba, P. (2003). A bottleneck input supplier's opportunity cost of competing downstream. *Journal of Regulatory Economics*, *23*, 287–297.

Evans, L. T., & Guthrie, G. A. (2005). Risk price regulation, and irreversible investment. *International Journal of Industrial Organization*, *23*, 109–128.

Hoernig, S., Jay, S., Neu, W., Neumann, K.-H., Plückebaum, T., & Vogelsang, I. (2012). Wholesale pricing, NGA take-up and competition. *Communications and Strategies*, *86*(2), 153–174.

Hoernig, S., Jay, S., Neu, W., Neumann, K. -H., Plückebaum, T., & Vogelsang, I. (2011). Wholesale pricing, NGA take-up and competition. Bad Honnef 2011. Available from: www.wik.org.

Hoernig, S., Jay, S., Neumann, K. -H., Peitz, M., Plückebaum, T., & Vogelsang, I. (2010). Architectures and competitive models in fiber networks. Bad Honnef 2010. Available from: www.wik.org and www.vodafone.com/eu.

IRG—Independent Regulators Group (2000). Principles of implementation and best practice regarding FL-LRIC cost modelling. Available from: ⟨http://irgis.icp.pt/site/en/areas_doc.asp?id=277⟩.

Mandy, D. M., & Sharkey, W. W. (2003). Dynamic pricing and investment from static proxy models. *Review of Network Economics*, *2*, 403–439.

Nitsche, R.,Wiethaus, L. (2010). NGA: Access regulation, investment, and welfare —Model based comparative analysis. ESMT No. WP-110-02.

Rosen, S. (1974). Hedonic prices and implicit markets: product differentiation in pure competition. *Journal of Political Economy*, *82*, 34–55.

Vogelsang, I. (2012). Incentive regulation, investments and technological change. In G. R. Faulhaber, G. Madden, & J. Petchey (Eds.), *Regulation and the performance of communication and information networks*. Cheltenham, UK: Edward Elgar. Chapter 4.

Von Ungern-Sternberg, T. (1991). Monopolistic competition in the pyramid. *Journal of Industrial Economics*, *39*, 355–368.