Working Paper

No. 3

Copper to Fibre Migration: Regulated Access Fees Incentivising Migration

Fabian Eltges
Dr. Niklas Fourberg
Dr. Lukas Wiewiorra

June 2022

IMPRINT

WIK WORKING PAPER

Published by:
WIK Wissenschaftliches Institut für Infrastruktur
und Kommunikationsdienste GmbH
Rhöndorfer Str. 68, 53604 Bad Honnef, Germany
Phone: +49 2224 9225-0
Fax: +49 2224 9225-63
E-Mail: info@wik.org
www.wik.org

Persons authorised to sign on behalf of the organisation

General Manager and Director	Dr Cara Schwarz-Schilling
Director	Alex Kalevi Dieke
Director and Head of Department Network and Costs	Dr Thomas Plückebaum
Director and Head of Department Regulation and Competition	Dr Bernd Sörries
Head of Administration	Karl-Hubert Strüver
Chairperson of the Supervisory Board	Dr Daniela Brönstrup
Registered at:	Amtsgericht Siegburg, HRB 7225
Tax No.:	222/5751/0722
VAT-ID:	DE 123 383 795

Copper to Fibre Migration: Regulated Access Fees Incentivising Migration

Fabian Eltges[1,*] Niklas Fourberg[1,2,†] Lukas Wiewiorra[1,‡]

[1] Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste (WIK)
[2] Duesseldorf Institute for Competition Economics (DICE)

June 10, 2022

Abstract

Consumer sided demand migration from legacy to fibre telecommunication technologies is a key challenge in today's economic policy. We adapt Chen and Riordan (2007) Spokes Model of spatial competition to capture a duopolistic multi-product firm setting in which an incumbent operator and an entrant firm simultaneously offer both a fibre and a copper based product. Consumer preferences are uniformly distributed over the preference space consisting of four spokes (2 products of 2 suppliers). The novelty of our approach is that we allow for a per-unit access fee which is paid by the entrant to the incumbent as prerequisite for offering its own copper based end-user product. Using the access fee as a strategic variable for either the incumbent or a regulating social planner, we compare different scenarios to investigate its role as a potential instrument to induce copper to fibre migration. We find that the access fee acts as an asymmetric cost pass-through for the entrant to promote its fibre product at the expense of its copper access. Furthermore, the socially optimal fee will be either identical to the private solution or smaller, if consumer preferences are strong. If one considers demand for fibre products as the desired objective, our results suggest that the privately chosen access fee already implies full copper to fibre migration. However, if a social planner is responsible for setting access fees, the fee can be utilised to increase demand for fibre products beyond the socially (welfare) desirable level.

*Email: F.Eltges@wik.org; Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste (WIK), Rhöndorfer Str. 68, 53604 Bad Honnef, Germany.

†Email: N.Fourberg@wik.org; Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste (WIK), Rhöndorfer Str. 68, 53604 Bad Honnef, Germany.

‡Email: L.Wiewiorra@wik.org; Wissenschaftliches Institut für Infrastruktur und Kommunikationsdienste (WIK), Rhöndorfer Str. 68, 53604 Bad Honnef, Germany.

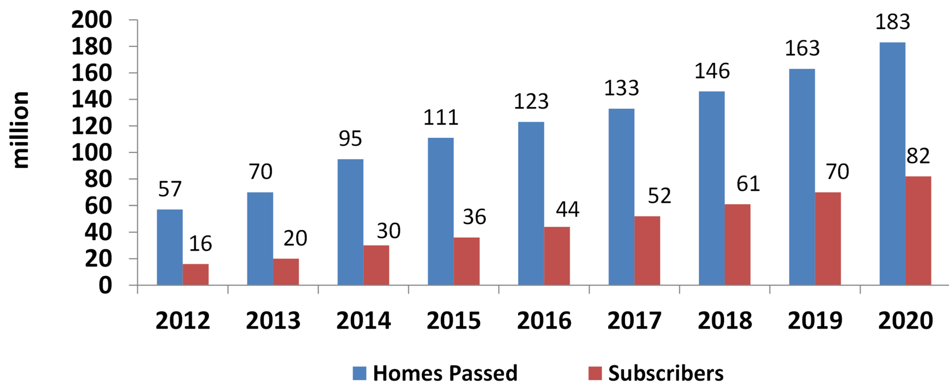
1 Introduction

Investments into fibre infrastructure have increased in the past decades throughout the European Union. According to a recent OECD statistic, cable remains the dominant fixed-line broadband technology in OECD countries, accounting for 34% of subscriptions. However, with an increase of 5.6% in 2020, fibre is steadily replacing DSL subscriptions, which have dropped by 10% over the past two years. This roll-out has been accompanied by discussions on how to foster the investment in and take-up of this future-proof infrastructure further.

Many initial considerations have focused on creating a regulatory environment which favours deployment of fibre infrastructure as prerequisite of actual fibre take-up. Besides this focus on roll-out, European and national broadband goals are increasingly shifting the focus from mere availability of fibre to active usage of this technology. As stated by the European Parliament (2018) in the European Electronic Communications Code: "The regulatory framework should, in addition to the existing three primary objectives of promoting competition, the internal market and end-user interests, pursue an additional connectivity objective, articulated in terms of outcomes: widespread access to and take-up of very high capacity networks for all citizens of the Union and Union businesses [...]". Moreover, authorities explicitly state take-up as part of their broadband goals also on a national level. A growing number of thus far ten European member states have included take-up goals as part of their national broadband plans.[1]

On an European level, it becomes evident that the mere existence of a fibre-based network is a necessary yet not sufficient condition for their active usage. While the availability of FTTH/B networks has reached a relevant coverage, subscription numbers still fall short as Figure 1 shows.

Figure 1: FTTH/B homes passed and subscriptions based on 39 European countries



Therefore, current political and regulatory frameworks are indeed successful in achieving the goal of incentivising fibre deployment but are rather ineffective in improving the actual adoption of fibre where the technology is already available. This issue has also been

[1] These are Bulgaria, Croatia, Estonia, France, Lithuania, Malta, The Netherlands, Romania, Slovakia and Spain according to the European Commission (2020).

the subject of a public consultation in the context of the French LLU decision in 2020. The French National Regulatory Authority discussed the evolution of LLU prices in the context of migrating access lines from copper to fibre. As Neumann *et al.* (2020) put it in the given context: "This [...] means that even where fibre is available the majority of users still satisfy their communications demand by using Orange's copper network and not the fibre networks. [...] A gap between demand and supply of fibre is not in line with the targets of the French fibre infrastructure policy and it is not in line with the economically efficient outcome".

This paper aims at contributing to the literature on demand sided fibre adoption and copper to fibre migration. While existing literature has primarily been focused on induced migration under the lens of investments and deployment, one can observe that fibre take-up as a consequence of only investments into the infrastructure cannot be taken for granted.

In an effort to fill this research gap, we set out to analyse fibre take-up effects with respect to a wholesale access fee based on the existing legacy copper infrastructure. Our theoretical approach models the competition between asymmetric market participants, that is, an incumbent and an entrant firm. Both firms offer a copper-based and a fibre-based access product to consumers whose product preferences are uniformly distributed over a horizontal space according to a Spokes model in the spirit of Chen and Riordan (2007). Firm asymmetries materialise in the payment of a per-unit access fee from the access seeking entrant to the access granting incumbent. Access fees accrue only for the entrant's copper product. In different scenarios, we investigate the extent to which the access fee can be utilised by either the incumbent or a political decision maker to pursue different objectives, e.g., maximisation of profits, social welfare or demand migration to fibre technologies.

The remainder of the paper is structured as follows. Section 2 provides an overview over the related literature while Section 3 develops the main model and Section 4 provides a historic competitive benchmark without the existence of fibre access. Subsequently, Section 5 develops the privately and socially optimal equilibrium results and elaborates on welfare implications. Based on these results, Section 6 exclusively discusses the steering of fibre take-up through means of the access fee. Finally, Section 7 concludes.

2 Literature

The analysis of market conditions in the transition from a copper to fibre network has been subject to various research projects mostly relying on theoretical models. In the context of fibre take-up and adoption, previous approaches regularly rely on variations of the Hotelling framework of horizontal competition (Hotelling, 1929). The thematic focus is either on the implications of a copper access charge or fibre access charge on the investment into an FTTH network and not take-up. The literature identified a trade-off between dynamic and static efficiency when assessing fibre access charges and their relation to investment incentives. Static efficiency is reached in a case of low access prices increasing competition yet undermining incentives for the network operators to invest in an FTTH network or expanding existing footprint therefore decreasing dynamic efficiency (Flacher and Jennequin, 2014). The authors focus their analysis on the fibre segment of the market and confirm the decrease of investment incentives in the case where the fibre network is accessible at regulated fees. Also they show that the total welfare is higher in the unregulated scenario. In order to counter-steer the effect of decreased investment incentives, they suggest to combine access regulation with geographic coverage commitments. The authors assume the revenues on the copper segment of the businesses to be zero and assume the fibre network and price setting to be dependent on investments into the fibre network. We will abstract from such assumptions as we will consider the copper business segment as historically relevant for operators' revenues and therefore pricing decisions. Additionally, we will consider investments to be irrelevant for pricing as we intend to focus on consumer rather than operators' migration incentives.

Bourreau *et al.* (2012) have identified three counter-steering effects of the "Replacement Effect", "Wholesale Revenue Effect" and "Business Migration Effect" when analysing the impact of copper access charges on investment incentives. The authors apply a model containing investment costs and investment modeling in order to investigate conflicting effects of investment incentives caused by access regulation of two coexisting infrastructures. They find that an access fee on the old network will increase the incumbent's profit only to a certain limit as the wholesale buyers will at this limit either not continue purchasing access or invest into an FTTH-network. The latter will depend on the degree of NGA (Next Generation Access)-coverage of the incumbent which the entrant will only contest if the incumbent's NGA-footprint is relatively small. Also they show that in this case of a small incumbent's footprint, the entrant will roll-out an NGA-network and act just like a monopolist would even though to some extent the entrant will have duplicated the incumbent's NGA-network. The extent of the incumbent's footprint the entrant will be willing to conquest is depending on the access fee. A higher access fee incentivises the alternative network operator (ANO) to invest and compete with the incumbent to a greater extent. The authors define this effect of ANOs being triggered to invest into infrastructure as access charges increase as "Replacement Effect". The authors find two more effects that occur when assessing investment incentives of incumbents and ANOs as simultaneously to the replacement effect, a high copper access charge hampers investments by the incumbent as his investments would be followed by investments of the ANOs which again would lead to reduced wholesale revenues. Bourreau *et al.* (2012) label this effect as the "Wholesale Revenue Effect". They identify a third investment effect, which affects customer-sided migration. They label this effect as the "Business Migration Effect". At a high copper access charge, retail prices are high as well which incentivises end customers to migrate towards the retail product of higher quality as price difference is relatively small. While the approach of Bourreau *et al.* (2012) is closest to our research intention of analysing the impact of a copper access fee on migration, we shall focus on the consumer-sided effects of their analysis applying a different model approach free of investments. As investments of one operator may exclude roll-out of the other one, we shall not consider investments as we intend not to limit consumer migration streams by availability.

Jeanjean and Liang (2012) employ a variation of the Hotelling model with vertical and horizontal competition in order to investigate the impact of wholesale copper fees on fibre investments. Vertical competition is captured in additional value which is being attributed to the fibre product by end users. The authors investigate competition of two operators in a situation where the copper-operating incumbent, an alternative network operator (ANO) or both may invest into fibre infrastructure. They find that under the assumption of perfect competition, i.e. $t = 0$, the market share of copper is smaller if the incumbent invests into fibre and the ANO does not. Also they find, an increase in copper access charges would increase incentives for one of two operators to invest into fibre but decrease incentives for both operators to invest simultaneously. Further, under the assumption that copper and fibre customers are segmented strongly by their individual preference for copper or fibre, i.e. consumers regard copper and fibre as very different, the higher the copper access charge is, the greater is their incentive to migrate to fibre. In that case, an increase of copper access charges increases the ANOs incentives to invest. Given that the authors make their analysis based on a single horizontal preference space, they are limited to comparing two products at a time. We shed further light on consumer implications as allow consumers to choose between four offers simultaneously by applying a variation of the Spokes model in spirit of Chen and Riordan (2007) with four products of copper and fibre offered each by an incumbent and an entrant.

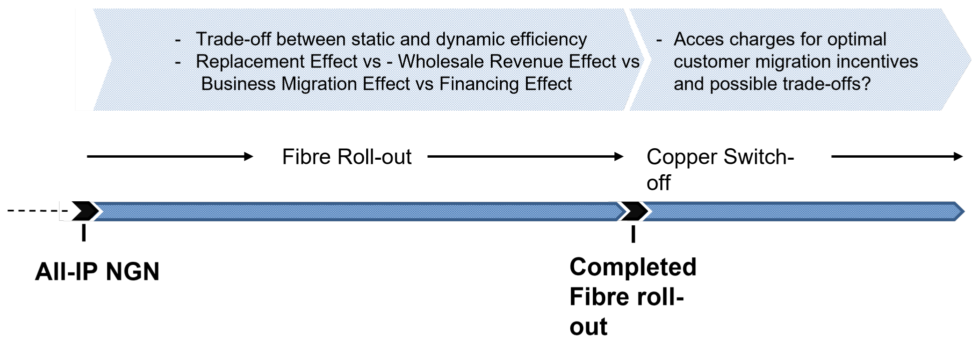
Tselekounis *et al.* (2014) have been the first to analyse competition between two firms which both may offer copper and fibre based services simultaneously. While (Jeanjean and Liang, 2012) assume that as soon as one operator had invested into fibre, service provisioning on copper was stopped, Tselekounis *et al.* (2014) seek to determine the copper and fibre wholesale access charges which incentivise fibre investment without distorting competition. They find that the incentives for the incumbent to invest into fibre infrastructure are optimal when access to the copper network is priced at provisioning costs and the fibre access is priced at the level which maximises the incumbent's profit. This finding follows the assumption that maximising the incumbents profits will lead to him investing into fibre. They find that the fibre access charge maximising the incumbent's profits at a given copper wholesale charge is reached when the margins from providing FTTH services perfectly outweigh the effect of customers preferring the copper based product amid high end customer prices for the fibre based product. Tselekounis *et al.* (2014) employ a similar approach as Jeanjean and Liang (2012) for their analysis of investment implications and competition of copper and/or fibre access charges. Again we expand the analysis to a setting where copper and fibre products of two operators are in simultaneous competition with one another.

The Spokes model which we will employ in our analysis was also the basis for the analysis of coexistence of copper and fibre infrastructures in Brito and Tselekounis (2017).

The authors apply a model variation with 4 spokes and two operators offering each a product based on a fibre and on a copper network. While in their model the access to the copper network is free of charge, access to the fibre network requires paying a wholesale access fee by one operator the other. Their analysis focuses on the effect of multi-product competition on the operator's profits under access regulation to the fibre network. They find that an increase in the fibre wholesale access fee increases the entrant's profit as the copper product becomes more attractive to consumers at high prices for the fibre product while the incumbent's profit was U-shaped in the fibre access fee. Furthermore, they find conditions where regulator and incumbent would apply the same fibre access fee. Our approach is similar but employs an inverse implementation of the access fee. The copper network will be subject to access regulation while two operators will be assumed to have rolled out a fibre network, which as a consequence will be free of access charges and investments will be considered sunk. We assume such setting to be more applicable to the current situation of roll-out and to be suitable for our purpose of analysing the influence of the copper wholesale access fee on customer migration.

While the existing literature mostly investigates how to maximise FTTH investment and solving trad-offs of static efficiency, our research aim concerns demand side migration. Effects of the wholesale access fee are developed with a focus on resulting firm and consumer behaviour in different regulatory settings. Therefore, this paper adds to the existing literature by investigating another stage on the timeline where NRAs already successfully maximised incentives for fibre investments, but actual take-up is lacking (Figure 2.

Figure 2: Temporal research target within the deployment evolution



One could argue that where incumbents are the investor of fibre infrastructure, there may be an intrinsic incentive for that operator to switch off the legacy network in order to save operation costs. Yet Tenbrock *et al.* (2020) find that this incentive diminishes over time as expenditures of the operation of both networks will converge. Therefore, the longer networks coexist, the lower the intrinsic motivation for an incumbent to migrate his consumers may become, which as a consequence, may have to be finally induced by policy makers.

3 The Model

Our main model relies on a modified version of Chen and Riordan (2007) model. In the classic Spokes model, every product specification is located on one of N spokes. If only two product specifications at two firms are considered, the Spokes model collapses to the standard Hotelling model , which only captures the price and location decisions of two competitors. In our setting we capture a real world market scenario where

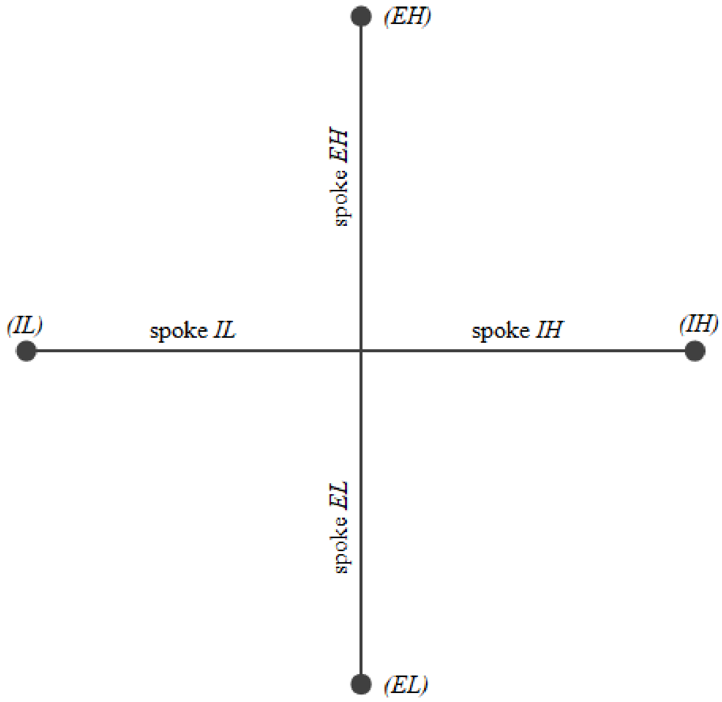
1) the copper network is not switched off immediately as soon as fibre has been rolled out and

2) the adoption of existing fibre infrastructure is influenced by the (potentially regulated) access fee for the legacy copper network due to duplication of infrastructure.

This realistically resembles a scenario in which network infrastructure has been fully deployed and each consumer household has access to all four products. Given this, we abstract from any prior deployment costs which can be considered to be sunk and are not decision relevant for the following competitive behaviour. In real world telecommunication markets a multitude of smaller firms or ISPs use an incumbent's legacy copper network and, correspondingly, are subjected to access charge in order to provide services to their end-users. However, without loss of generality, we restrict the analysis to an asymmetric competition scenario between $K = 2$ firms. A firm k takes either the role of an incumbent $k = I$ who offers own products and simultaneously grants wholesale access to its own copper network for an access seeking entrant $k = E$. This asymmetric duopolistic structure is already sufficient to reveal the pricing incentives that originate from the wholesale access fee w.

Unlike to the analysis of Brito and Tselekounis (2017) in which access to the copper network is possible at zero costs for both firms, we consider the copper based product to be accessible to the entrant at an access charge while the fibre network had been rolled out by both the incumbent and the entrant. Due to this, both the incumbent and the entrant offer a fibre product of higher quality $j = H$ without any surcharges and a copper baseline-product $j = L$, for which the entrant is charged. Hence, each product jk is perfectly identified. We model the wholesale access fee w, with $w > 0$, to be a positive per-unit payment that is only dependent on the realised demand of the entrant's copper demand and may not exceed the entrant's selling price of the copper product such that $w < p_{EL}$. Apart from w we abstract from any other cost parameters and fix marginal costs of serving a consumer to be zero. Dependent on the policy scenario in question, w is either chosen privately by the incumbent or by a welfare maximizing social planner. However, both firms set prices for their respective end-user products p_{jk}, with $j \in \{I, E\}$, $k \in \{H, L\}$. Naturally, we assume that firms maximize their horizontal product heterogeneity and, thus, spatial distance, such that their products are located at the respected endpoints of their spokes which is displayed in Figure 3.

Figure 3: Horizontal preference space of main model specification



Consumer mass is normalized to unity and their respective product preferences are uniformly distributed across the whole preference space, that is, all four spokes (see Figure 3). We follow the standard configuration of Chen and Riordan (2007) and assign spatial addresses to the spoke endpoints of either 0 or 1, which consequences the midpoint of all spokes to be located at $x^M = 0.5$. Our main model captures consumer preferences for all four product configurations and, hence, features $N = 4$ spokes. A respective consumer's location in the preference space is determined by a vector (l_{jk}, x_{jk}), where l_{jk} is the spoke the consumer is located on and x_{jk} represents the distance Δ_{jk} to the product variety of jk, that is, the endpoint of the spoke l_{jk}. Given that preferences for all other products are symmetric, the spatial distance for any consumer (l_{jk}, x_{jk}) to an alternative product $j^{'}k^{'}$, $j^{'} \neq j$, $k^{'} \neq k$, is determined by $\Delta_{j^{'}k^{'}} = 1 - x_{jk}$ and goes through the midpoint x^M. Purchasing a product that does not perfectly match a consumer's product preference involves positive and linear transportation costs of t, $t > 0$. Since travel distance is lowest, product jk is consumer (l_{jk}, x_{jk})'s first preferred product option. Each consumer also has a second preferred option when making a purchasing decision. This second preferred product can be any $j^{'}k^{'}$ of the remaining three, which is determined by nature's draw with probability $\frac{1}{N-1}$.

Both the first and second preferred product provide a base utility of v if purchased, which can be interpreted as the benefit of having internet access irrespective of the underlying technology. v is assumed to be high enough such that every consumer buys and fulfills her unit demand.[2] Additionally, we also introduce a technology specific quality

[2]In the context of internet accesses it is reasonable to assume that each consumer will only purchase

parameter δ_k to account for fibre-based services' superior quality. Without loss of generality, we normalize $\delta_L = 0$ and $\delta_H = \delta$, such that a fibre consumer receives a positive utility premium of δ, with $\delta > 0$, as the incremental quality advantage compared to a copper tariff.[3] Furthermore, we restrict $\delta < 3t$ to ensure internal solutions of optimal prices. This implies that the incremental quality advantage of fibre tariffs may not be too large in comparison to consumers' inherent product preferences. Finally, consumers pay a product price of p_{jk} such that total utility is determined as follows.

$$U_{l_{jk},x_{jk},j'k'} = \begin{cases} v + \delta - t \cdot x_{jk} - p_{jk} & \text{if purchasing product} jk, \\ v + \delta - t \cdot (1 - x_{jk}) - p_{j'k'} & \text{otherwise.} \end{cases} \quad (1)$$

Brito and Tselekounis (2017) divide the total population of consumers into two subpopulations, each caring only for one of two options at a time . Either consumers prefer a specific firm and decide solely between the lower or higher quality product of this supplier, or they rather prefer a distinct technology and make the decision between two suppliers. This assumption, however, is rather restrictive since it implicitly rules out consumers who are indifferent between products that differ in both the firm and technology dimension. We relax this assumption in our model implementation since it would limit channels of demand migration a priori and stands in stark contrast to our research objective.

Following Equation 1, the location of a consumer $(l_{jk}, \widehat{x}_{jk}, j^{'}k^{'})$ who is indifferent between her first preferred product option jk and another randomly chosen second alternative $j^{'}k^{'}$ is given by Equation 2.

$$(l_{jk}, \widehat{x}_{jk}, j^{'}k^{'}) = \frac{1}{2} + \frac{(p_{j'k'} - p_{jk}) + (\delta_k - \delta_{k'})}{2t} \quad (2)$$

In our setting, every extreme product preference is offered by one of the firms, that is, every spoke end-point coincides also with a firm location. Given this, every consumer's first- and also second preferred product option is always available for purchase. Hence, we can neglect cases of unpopulated spokes from Chen and Riordan (2007). Consequently, the demand for product jk can be determined to be as follows.

$$q_{jk} = \frac{2}{N}\frac{1}{N-1} \sum_{j'k' \neq jk, j'k' \in \{1,\ldots,K\}} \max\left\{ \min\left\{ \frac{1}{2} + \frac{(p_{j'k'} - p_{jk}) + (\delta_k - \delta_{k'})}{2t} \right\}, 0 \right\} \quad (3)$$

Due to the asymmetry in the wholesale access fee w, the profit functions of the access granting incumbent and the access seeking entrant differ in this regard. For the sake of

exactly one unit.

[3]With technology specificity of δ_k we mean that consumers have no differentiated valuation of copper and fibre products offered by both operators in terms of perceived quality. This assumption is justified by the fact that the entrant has to buy access to the legacy copper network of the incumbent and therefore the quality of the underlying network is identical for customers of both companies. Furthermore, we abstract from any form of strategic quality degradation or sabotage by the incumbent.

a better understanding of the firm asymmetries, we iterate over the full set of firm and product varieties, that is, $j \in \{I, E\}$,$k \in \{H, L\}$, in the remainder of the paper. In this way, firms profits are determined in the following as:

$$\pi_I = p_{IH} \cdot q_{IH} + p_{IL} \cdot q_{IL} + w \cdot q_{EL} \tag{4}$$

$$\pi_E = p_{EH} \cdot q_{EH} + (p_{EL} - w) \cdot q_{EL} \tag{5}$$

As the incumbent operates the legacy copper network, the entrant has to buy access from the incumbent via the access fee w. Therefore, the incumbent receives, in addition to its own profit streams, also payments dependent on the entrant's demand for its copper based product. Hence, the entrant can only fully extract the rents from its own fibre product since profits from copper services are partially expropriated by the incumbent via w. This difference in economic value between the entrant's two demand segments gives rise to the key pricing incentives in this model.

We assume that competition within this model framework takes place sequentially. First, w is set either privately by the incumbent or by a social planner. Subsequently, firms choose their prices and , finally, consumers make their purchasing decision and demands realise. This sequence of strategic interaction is the most realistic implementation since wholesale access prices are determined for a specific period in advance and are thus common knowledge to all participating agents. Hence, a simultaneous optimization with respect to the access fee w and product prices p_{jk} would be mathematically possible but unrealistic, irrespective of whom is choosing w.

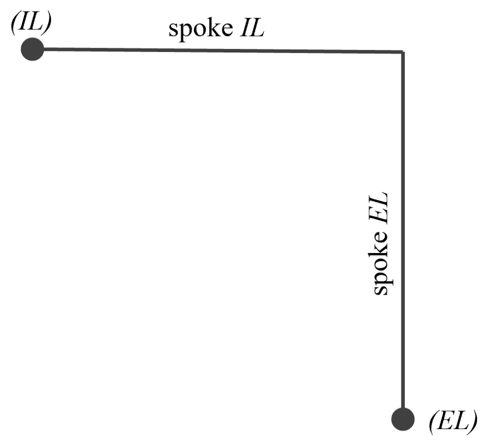
The remainder of the model analysis is structured as follows. First, we will derive a reduced version of only $N^R = 2$ spokes which only includes copper based products and also exhibits only product preferences for those. This serves as a historic benchmark, comparable to the early days of market liberalisation, in which fibre technologies were not yet present as an end-user access technology and consumer preferences have not yet been developed in this direction. However, network access fees were already utilized back then in order to enable service based competition for end-users. This historic scenario serves as a benchmark against which the equilibrium solutions of the main model can be compared.

Subsequently, we derive the private equilibrium solution to the main model specification from Figure 3. Core feature of this analysis is that w is a strategic decision variable of the incumbent. Finally, we investigate the scenario in which w is set strategically by a welfare maximising social planner. Comparative analyses to the private solution shed light on the different incentives when deciding on w. Furthermore, we extent the analysis and conjecture on a social planner's ability to use the access fee to strategically optimise objective functions other than social welfare, e.g., minimising (maximising) copper- (fibre-) demand.

4 Historic Copper Case

In the legacy copper network of scenario 1, the Spokes model collapses to the standard Hotelling framework with $N^R = 2$ spokes as is displayed in Figure 4.

Figure 4: Horizontal preference space of reduced (copper-only) model



In line with the standard Hotelling results, the demand functions for both companies can be formulated to be:

$$q_{IL}^R = \frac{1}{2} + \frac{(p_{EL}^R - p_{IL}^R)}{2t}, \qquad q_{EL}^R = \frac{1}{2} + \frac{(p_{IL}^R - p_{EL}^R)}{2t} \ . \tag{6}$$

The profit functions of both firms again exhibit the asymmetry in the payment of the access fee w^R:

$$\pi_I^R = p_{IL}^R \cdot q_{IL}^R + w^R \cdot q_{EL}^R, \qquad \pi_E^R = p_{EL}^R - w^R \cdot q_{EL}^R \ . \tag{7}$$

The resulting equilibrium prices for both firms are then

$$p_{IL}^{R*} = w^R + t, \qquad p_{EL}^{R*} = w^R + t \ . \tag{8}$$

at which both firms serve exactly half of the market and firms receive profits of

$$\pi_I^{R*} = w^R + \frac{t}{2}, \qquad \pi_E^{R*} = \frac{t}{2} \ . \tag{9}$$

Since both prices are symmetrically shifted upwards by the access fee, the incumbent is able to fully extract this pricing premium of size w^R. The entrant's profit is independent of the wholesale access fee which implies that she is able to fully pass on the access costs to the consumers. One can see from this that the private incentives of the incumbent are to choose an arbitrarily high w^R since its profits are strictly increasing in it. Aggregated consumer- and producer surplus equate to

$$CS^R = v - \frac{5t}{4} - w^R, \qquad \Pi^R = w^R + t \tag{10}$$

in this scenario which together form the social welfare of

$$W^R = v - \frac{t}{4} \ . \tag{11}$$

Critically, total welfare is independent of the access fee such that the access fee solely acts as a price premium that is fully passed onto consumers. Hence, it characterizes as a transfer payment and is welfare neutral. However, this hinges mainly on the full coverage assumption which determines that the base value of having internet access v is always sufficiently high enough to motivate a purchase. While demand for being connected to the internet can be indeed considered as near perfectly inelastic, in reality, the social planner or regulator would prefer a more symmetric distribution of producer- and consumer-rents rather than be only concerned with total welfare. As the welfare is neutral with respect to w^R, he can do so at no additional costs. Thus, this benchmark of a historic copper-based product- and preference- space again motivates the need to engage in access fee regulation.

Result 1: *Total welfare in the historic pure copper competition is independent of the access fee w^R. However, this in turn also motivates the social planner to regulate w in order to avoid a very asymmetric distribution of consumer- and producer rents.*

Given that the entrant's price p_{EL}^{R*} increases monotonically also in w^R, her profits are strictly positive and a drop-out from the market will not occur. Relaxing the full coverage condition, however, would change this result. Since equilibrium prices are symmetric, the consumer who realises the lowest utility in equilibrium is the one who experiences the highest transportation costs, that is, at location of 0.5. Consequently, this consumer would drop out first if v would be bounded. To ensure participation of this consumer, the access fee must not exceed $\overline{w}^R$ which is determined as

$$w^R \leq \overline{w}^R = v - \frac{3t}{2} \ . \tag{12}$$

At $\overline{w}^R$ the utility of the consumer farthest away from any of the products becomes zero. Therefore, if w^R exceeds this level, this would imply that demand for both products would decrease at the same rate since prices are symmetric. [4]

5 Coexistence of Copper and Fibre

Outside the historic scenario, the higher quality fibre products become available to the consumer base as two network operators have found a specific area viable to each roll

[4] In reality access fees are based on complex cost-based models to determine a reasonable price that covers the provision costs of the incumbent to its network. However, even if there is an absolute upper bound to the valuation of consumers $\overline{v}$, our assumption could be easily adapted to the upper bound of consumer's valuations exceeding this cost-based threshold. In other words, consumers are assumed to be willing to cover the factual costs of providing internet access to their home.

out a congruent fibre network. Such a scenario is applicable to European highly densely populated areas of today like metropolitan cities or areas in which co-investment models have successfully been applied. Additionally, this scenario can equally be interpreted as the ultimate future situation in which fibre access has been sufficiently supplied by more than one operator and competition takes place on infrastructure level while the copper network has not yet been switched off. This setting is described by our main model specification (Figure 3) which exhibits two products offered by $K = 2$ firms located on $N = 4$ spokes.

5.1 Equilibrium and Private Incentives of the Access Fee

In the second scenario the wholesale access fee w is a strategic decision variable of the incumbent. After this choice is made, the realisation becomes common knowledge and product prices are determined under complete information. Given this, we set out and solve for the equilibrium solution by applying backward induction. Using a product jk's demand function from (3) and firms' profit functions in (4) and (5) for optimisation, one arrives at the set of first order conditions (FOCs) which is given below.

$$\begin{aligned}
p_{IH} &= \frac{t}{2} + \frac{\delta}{3} + \frac{w}{6} + \frac{p_{EH} + p_{EL}}{6} + \frac{p_{IL}}{3} \\
p_{IL} &= \frac{t}{2} + \frac{\delta}{3} + \frac{w}{6} + \frac{p_{EH} + p_{EL}}{6} + \frac{p_{IH}}{3} \\
p_{EH} &= \frac{t}{2} + \frac{\delta}{3} + \frac{w}{6} + \frac{p_{IH} + p_{IL}}{6} + \frac{p_{EL}}{3} \\
p_{EL} &= \frac{t}{2} + \frac{\delta}{3} + \frac{w}{6} + \frac{p_{IH} + p_{IL}}{6} + \frac{p_{EH}}{3}
\end{aligned} \tag{13}$$

It becomes apparent that each rival's product prices are increasing product jk's price in a symmetric fashion. However, intra-brand competition towards the respective other product of the same supplier is less of a concern as price increases in $p_{jk'}$ are discounted at twice the rate when deciding on p_{jk}.

Intuitively, δ increases the price of the higher quality fibre products and affects prices of copper based products negatively. Additionally, the more pronounced consumer preferences are, that is, the larger t , the higher are product prices which is the standard result of horizontal differentiation.

Comparative statics of prices with respect to the access fee w are more nuanced and will be discussed on the basis of prices which solve the system of FOCs in (13). Naturally, the solutions to this system depend only on the remaining decision variable of w and can also be characterised as reaction functions in this regard. These can be calculated to be the following:

$$p_{IH}(w) = \frac{3t}{2} + \frac{\delta}{4} + \frac{w}{2} \ , \tag{14}$$
$$p_{IL}(w) = \frac{3t}{2} - \frac{\delta}{4} + \frac{w}{2} \ ,$$
$$p_{EH}(w) = \frac{3t}{2} + \frac{\delta}{4} + \frac{w}{4} \ ,$$
$$p_{EL}(w) = \frac{3t}{2} - \frac{\delta}{4} + \frac{3w}{4} \ .$$

The comparative effect of the access fee in product prices is twofold. First, it acts as a positive pricing premium for all four product configurations which is passed-through to consumers, although it is actually only paid by the entrant. This closely resembles the positive pricing effect already known from the historic copper case and can be traced back to the perfectly inelastic demand and the absence of losses at the extensive margin when making the pricing decision.

Second, the pass-through of the wholesale access fee is symmetric for the incumbent but asymmetric for the entrant to the effect that $\frac{\partial p_{EL}}{\partial w} > \frac{\partial p_{EH}}{\partial w}$. Intuitively, the entrant tries to promote its fibre product with a lower price compared to its own copper based one. In this way the entrant can economise on wholesale costs and boost the demand for its own fibre product of which he can extract rents fully. This demand steering effect through w of the entrant is the driving force of equilibrium solutions and characterises our second main result.

Result 2: *The wholesale access fee w gives rise to a demand steering effect by the entrant as she passes on the wholesale access costs towards consumers in an asymmetric manner. Precisely, it holds that $\frac{\partial p_{EL}}{\partial w} > \frac{\partial p_{EH}}{\partial w}$. In doing so, demand for the entrant's fibre product is promoted at the expense of the entrant's own, less lucrative, copper product.*

Using prices from (14) one can derive the resulting product demands in dependence of the access fee to be

$$q_{IH}(w) = \frac{1}{4} + \frac{\delta}{12t} \ , \tag{15}$$
$$q_{IL}(w) = \frac{1}{4} - \frac{\delta}{12t} \ ,$$
$$q_{EH}(w) = \frac{1}{4} + \frac{\delta + w}{12t} \ ,$$
$$q_{EL}(w) = \frac{1}{4} - \frac{\delta + w}{12t} \ .$$

Two aspects are noteworthy here. First, fibre products benefit from an increased demand based on the technology's quality advantage δ relative to consumer preferences t while copper products' demand suffers. This manifests in the term of $\frac{\delta}{12t}$ which is either added or subtracted from $\frac{1}{4}$ as the symmetrical demand split between all four product configurations.

Second, demand for the incumbent's products is independent from w, while demands for the entrant's products are not. Recall from prices in (14) that w serves as a pricing premium which is passed onto consumers for all products. While the incumbent lifts prices symmetrically by $\frac{w}{2}$, the entrant distributes these premiums asymmetrically to promote its fibre product. However, on average, all product prices increase by $\frac{w}{2}$ such that no competitive effects in resulting demand shifts materialize with respect to this level. Hence, only the asymmetric pass-through of the entrant persists and is reflected in a bonus (malus) to its fibre (copper) demand. The independence of the incumbent's copper demand of w implies that there is a certain share of consumers that will always stick to the lower value product of $jk = IL$. Therefore, a total adoption of the fibre infrastructure will not be achievable by changes in w, only by changes in δ and t. We formulate these observations as our third main result.

Result 3: *Demand for the incumbent's products is independent of w. Hence, demand shifts within those consumer bases can only be induced by the relation between the quality advantage of fibre products δ and the intensity of consumer preferences t. Demand effects through higher levels of w materialise in the form of migration from the entrant's own copper product towards her fibre product as a result of asymmetric pass-through.*

The incumbent's demand function for the copper product is also the origin of our initial restriction on the incremental quality advantage of fibre products in the form of $\delta \leq 3t$. This exactly satisfies non-negativity of the second expression in (15) as it solely depends on the relation of quality advantage and intensity of consumer preferences and is unaffected by w. However, the other non-negativity restriction that originates from the last expression in (15) is $q_{EL} \geq 0$, which requires

$$w \leq 3t - \delta \ . \tag{16}$$

This condition depends on the access fee and therefore may restrict the strategic choice of w, irrespective of who chooses it. This condition effectively provides an upper bound on the access fee, which must not be exceeded to ensure non-negativity of demands.

Based on the above, one can formulate the incumbent's and entrant's profit functions in dependence on the access fee w to be the following:

$$\pi_I(w) = \frac{\delta^2 + 18t^2}{24t} - \frac{w^2}{12t} - \frac{w(\delta - 6t)}{12t}, \qquad \pi_E(w) = \frac{\delta^2 + 18t^2}{24t} + \frac{w^2}{24t} - \frac{w\delta}{12t} \ . \tag{17}$$

It is apparent, that the entrant's profits are strictly increasing in w, while the incumbent's are not. The access fee positively influences own product prices as well as the margin the incumbent gets from the entrant's copper demand. However, the size of the entrant's copper demand from which she can extract w is negatively affected. This constitutes a classic trade-off between profits at the extensive and intensive margin. Differentiating the incumbent's profits from (17) with respect to w, provides the unbounded private optimal value of the access fee which maximises incumbent's profits w^* as follows.

$$w^* = 3t - \frac{\delta}{2} \tag{18}$$

However, this unbounded private optimal access fee w^* always exceeds and, thus, violates the above elaborated ex-post restriction of $q_{EL} \geq 0$ provided in (16).[5] Consequently, the incumbent would charge a wholesale price as corner solution that just satisfies this restriction and implies zero demand for the entrant's copper product. We define this bounded private choice as w^B which can be calculated to be

$$w^B = 3t - \delta\ . \tag{19}$$

Hence, the incumbent's private choice of the access fee w^B already implies a full migration of demand away from the entrant's copper product as this necessarily aligns with the entrant's pricing incentives. The relation between w^B as corner solution at the demand restriction and w^* as the unbounded private optimum is also displayed in Figure 5 below for values of $t = 1$, $\delta = 1.8$ which satisfy the ex-ante parameter condition of $\delta \leq 3t$. Intuitively, w^B increases in t since consumer preferences are more pronounced and demand for copper is less price sensitive. Contrarily, a larger level of δ has a negative impact as it implies a stronger quality advantage of fibre which results in consumers substituting away from copper more willingly (more elastic reaction to price components).

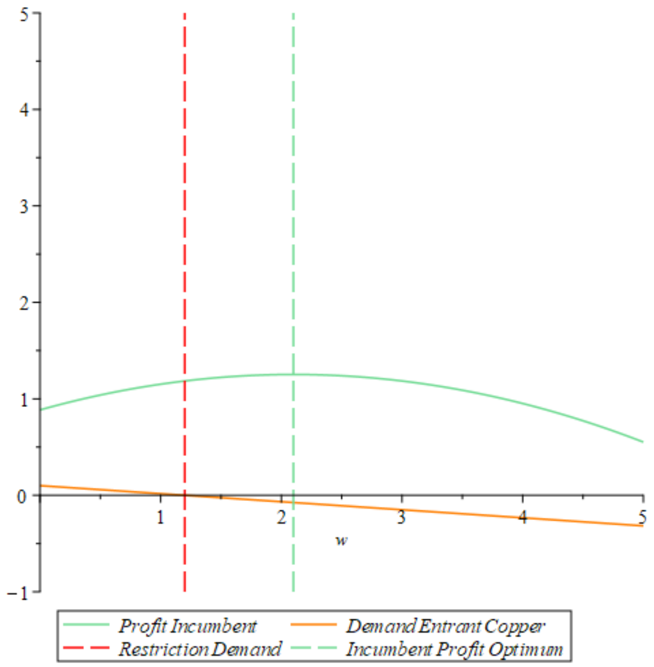
Result 4: *The bounded private optimal wholesale access fee w^B implies a zero demand for the entrant's copper product. A strong pass-through of access costs by the entrant leads to a full migration away from its own copper tariff.*

5.2 Social Incentives of the Access Fee and Welfare

While market prices are exclusive strategic firm decisions, determining the access fee may be the responsibility of a regulatory agency which acts as a social planner. Ruling out any dual mandate in the objective of this social planner, we assume that the relevant objective function is social welfare as the aggregate of consumer and producer surplus. While the former is determined by summing both expressions in (17), the latter is calculated as the sum of all consumer utilities from each pairwise spoke comparison displayed below.

[5] The restriction of non-negativity of entrant's copper demand is simultaneously also strictly more binding then the restriction of $P_{EL} \geq w^*$ which ensures that an entrant's profit margin is non-negative.

Figure 5: Unbounded and bounded private optimal access fee ($t = 1$, $\delta = 1.8$)



$$CS = \sum_{j'k' \neq jk, j'k' \in \{1,\ldots,K\}} \frac{2}{N} \frac{1}{N-1} \int_0^{(l_{jk}, \widehat{x}_{jk,j'k'})} v + \delta_k - t \cdot x_{jk} - p_{jk} \, dx \tag{20}$$

Together with the aggregated producer profits, the access fee dependent welfare is determined by

$$W(w) = \frac{\delta^2}{8t} + \frac{\delta(w + 12t)}{24t} - \frac{12t^2 - 48v \cdot t + w^2}{48t} \tag{21}$$

Differentiation with respect to w and solving the resulting FOC produces the socially optimal access fee as follows.

$$w^{SP} = \delta \tag{22}$$

Hence, the socially optimal level of the access fee w^{SP} corresponds to the incremental quality advantage of the fibre technology δ. Consequently, the larger the utility benefits from fibre are, the higher the social choice of w which intensifies the copper to fibre migration between the entrant's products (see from (15)). This dynamic stands in contrast to the privately chosen access fee w^B which depends negatively on δ (see from (19)).

Result 5: *The socially optimal access fee w^{SP} equals the incremental quality advantage of fibre technology. Hence, the social planner is influencing copper to fibre migration demand shifts between entrant's products positively.*

If one compares the socially optimal access fee w^{SP} to the bounded private one w^B of the incumbent, another distinction can be made. Since the bounded private choice w^B is characterised by a corner solution, we must only consider situations in which $w^{SP} \leq w^B$ which can be formulated to be

$$\delta \leq \frac{3}{2}t\,. \tag{23}$$

Compared to our ex-ante restriction on the parameter space of $\delta \leq 3t$, the condition in (23) is more binding, however, violating this inequality would again imply negative demands for the entrant's copper products. This case is highlighted by Figure 6 in which we preserve our previous parameter choices of $t = 1$, $\delta = 1.8$ from Figure 5 which violate the condition presented in (23).

Figure 6: Socially optimal access fee in relation to private choice ($t = 1$, $\delta = 1.8$)

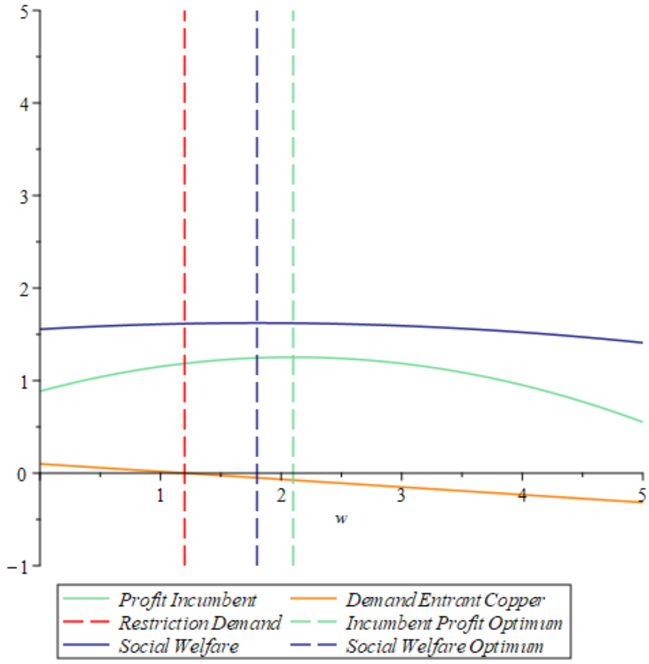
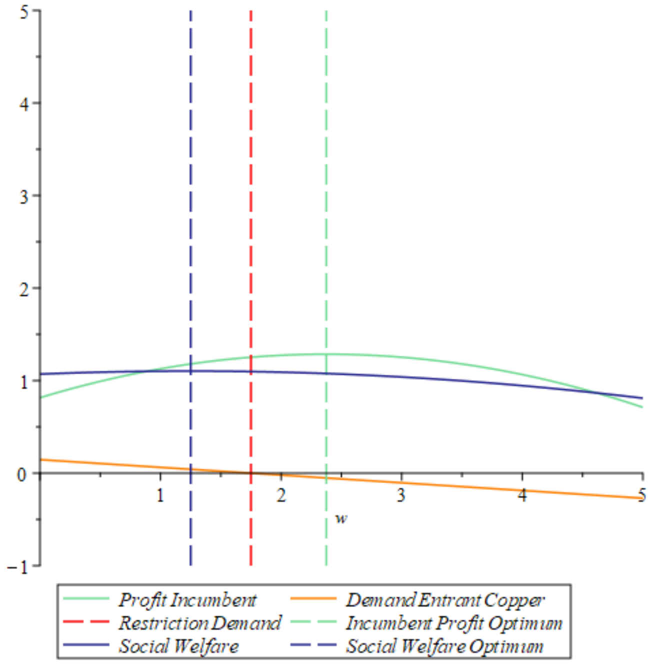


Figure 6 shows how in this case the socially optimal access fee w^{SP} (blue-dashed) is indeed lower compared to the unbounded private choice w^* (green-dashed), but simultaneously exceeds the bounded private choice w^B (red-dashed). Hence, we have to restrict our welfare analysis to the parameter space of $\delta \leq \frac{3t}{2}$, which allows for situations in which the social planner will either set an identical access fee w^{SP} if Equation (23) holds with equality or one that is lower compared to the bounded private choice w^B. Figure 7 illustrates this case for the parameter composition of $t = 1$, $\delta = 1.25$ which satisfies (23) and features a socially optimal access fee which is lower than the private solution.

The restriction of (23) can be interpreted as follows. If δ as the quality advantage of fibre products is relatively large, that is, the restriction from (23) is close to equality, the social planner chooses a higher access fee (blue-dashed line closer to red-dashed) in or-

Figure 7: Socially optimal access fee in relation to private choice II($t = 1$, $\delta = 1.25$)



der to enhance copper to fibre migration between the entrant's products. In other words, it is socially desirable that as much consumers as possible benefit from the added utility component of δ compared to the cost of choosing a product that is farther away from one's original preference t. However, if δ is relatively small compared to t, that is, the restriction from (23) is easily satisfied, the gains outweigh the incurred transportation costs only to a lesser degree and the socially optimal access fee w^{SP} shrinks (blue-dashed line to the left away from red-dash).

Result 6: *The socially optimal access fee w^{SP} equals the bounded private choice w^B if $\delta = \frac{3t}{2}$ and is lower than w^B if $\delta < \frac{3t}{2}$. For values of δ that exceed this threshold, non-negativity of entrant's copper demand would be violated. Within this threshold, the larger (smaller) the quality advantage of fibre δ in relation to the intensity of consumer preferences t, the higher (lower) is the socially optimal access fee w^{SP} to foster (deter from) the copper to fibre migration between the entrant's products.*

6 Maximising Fibre Adoption as Objective

The question of whether the access fee can be utilised as a tool to strategically motivate copper switch-off and promote fibre adoption can be also answered based on our findings. If neither firm profits nor social welfare are relevant optimisation targets but only realised fibre demand is the objective, the private choice of the incumbent w^B will already produce the highest demand for fibre products for any given parameterisation of δ and t. Recall, that the incumbent's bounded choice of the access fee w^B is characterised by a corner solution that implies copper demand of the entrant to be zero. In other words, consumers with an inherent preference for copper access have fully migrated away to one of the other three available products. The increased transportation costs of these consumers, that is, the disutility they incur from migrating away is compensated by either a lower price or an added utility benefit in the form of δ in case they chose to buy a fibre product (as their second product preference). The residual copper demand for the incumbent's product is, however, unaffected by the access fee and is only dependent on the relation of δ and t. Against this backdrop, the argument for regulatory intervention with the sole aim to promote fibre adoption cannot be supported based on our results.

Realistically, the intervention of a social planner in setting and overseeing wholesale access prices is nevertheless warranted for a plethora of other reasons, among which foreclosure avoidance, ensuring consumer choice and competition for end-users are the most prominent. The need for this has been also highlighted by our results to the historic copper benchmark in Section 4. Provided that a social planner is involved in setting the access fee, there is room to strategically use this as tool to steer copper to fibre migration. If the quality advantage of fibre is relatively small compared to consumer preferences, that is, $\delta < \frac{3t}{2}$ from (23) holds, the access fee that optimises social welfare $w^{SP} = \delta$ is smaller than the bounded private choice of $w^B = 3t - \delta$ (see Figure 7). Recall, that the entrant's copper demand is still positive at such an level of w until the access fee converges to w^B. Hence, the distance Δw defined as

$$\Delta w = w^B - w^{SP} = 3t - 2\delta \tag{24}$$

between the two access fee choices provides room for the regulator to increase copper to fibre migration between the entrant's products further, starting from the social optimum. Naturally, this comes at the cost of welfare as marginal social costs outweigh marginal social gains at this point. Based on this, we formulate our seventh main result.

Result 7: *The potential to use the access fee as a tool to optimise fibre take-up is twofold. First, the bounded private choice of the access fee w^B already implies full copper to fibre migration between the entrant's products. The residual copper demand of the incumbent is not addressable via the access fee. Second, if a regulator or social planner is already in charge of setting and overseeing wholesale access, there is room for strategically promoting fibre migration via the access fee (if $\delta < \frac{3t}{2}$). Starting from the socially optimal access fee w^{SP}, $\Delta w = 3t - 2\delta$ shows how much the access fee must be increased to enforce full copper to fibre migration between the entrant's products. However, this implies welfare losses as marginal efficiency is no longer satisfied at these values of w.*

7 Conclusion

The theoretical approach of this paper analyses competition between four network access products operated by two asymmetric firms, an incumbent and an entrant. Both firms offer a copper-based and a fibre-based access product to consumers whose product preferences are uniformly distributed over a horizontal space according to a Spokes model. Firm asymmetries materialise in the payment of a per-unit access fee from the access seeking entrant to the access granting incumbent. Access fees accrue only for the entrant's copper product. In different scenarios, we investigate the extent to which the access fee can be utilised by either the incumbent or a social planner to pursue different objectives, e.g., maximisation of profits, social welfare and migration to fibre technologies.

We find the following results. First, access costs of the entrant are passed through to its product prices in an asymmetric manner. The access fee is borne to a higher degree by consumers of the entrant's copper product while fibre customers are being subsidised. Hence, the entrant uses the access fee to actively steer its own copper consumers away to promote demand for its fibre tariff. In contrast to this, demand for the incumbent's products is independent of the access fee as pass-through on product prices is symmetric.

Second, the profit maximising access fee chosen by the incumbent is characterised as a corner solution and implies that the entrant's demand for its copper product is zero. This is due to the asymmetric pass-through of the access fee which leads to a situation in which all consumers with an entrant-copper preference have fully migrated away to one of the other alternatives. Those consumers are willing to do so because their disutility from incurring higher transportation costs is outweighed by a more attractive price or a utility benefit in form of fibre's quality advantage if they choose to migrate to fibre. In contrast to the privately chosen access fee, the socially optimal choice with respect to welfare depends positively on fibre products' quality advantage. Intuitively, the social planner will increase its access fee if benefits of fibre increase in order to enforce the copper to fibre migration between the entrant's products.

Third, given model restrictions, the socially optimal access fee is either identical to or smaller than the private choice of the incumbent. Within the valid parameter range of our model specification, the following applies: The larger (smaller) the quality advantage of fibre in relation to the intensity of consumer preferences, the higher (lower) is the socially optimal access fee with the aim to foster (deter from) the copper to fibre migration between the entrant's products.

Last, the potential to utilise the access fee as a tool to optimise fibre take-up is twofold. On the one hand, the private choice of the access fee by the incumbent already implies full copper to fibre migration between the entrant's products while the residual demand for the incumbent's copper product is not addressable via the access fee. Based only on this, intervention is not necessarily warranted. On the other hand, if a regulator or social planner is already in charge of setting and overseeing wholesale access, which is the case in reality, there is room for improvement. Starting from the socially optimal access fee, we provide a parameter range by which the fee may be increased to enforce a higher fibre take-up. Naturally, this departure from the socially optimal choice implies overall welfare losses.

Our findings are relevant for political decision-making on promoting fibre adoption by the means of the copper wholesale fee. We inform about the limitations of such a measure and characterise the trade-offs for fibre adoption under different parameterisations.

References

Bourreau, M., Cambini, C. and Doğan, P. (2012). Access pricing, competition, and incentives to migrate from "old" to "new" technology. *International Journal of Industrial Organization*, **30** (6), 713–723.

Brito, D. and Tselekounis, M. (2017). On the impact of input prices on an entrant's profit under multi-product competition. *Review of Industrial Organization*, **50** (1), 105–125.

Chen, Y. and Riordan, M. H. (2007). Price and variety in the spokes model. *The Economic Journal*, **117** (522), 897–921.

European Commission (2020). Shaping europe's digital future. *Digital Innovation Hubs (DIHs) in Europe*.

European Parliament (2018). Establishing the european electronic communications code. *Publication 2018/1972*.

Flacher, D. and Jennequin, H. (2014). Access regulation and geographic deployment of a new generation infrastructure. *Telecommunications Policy*, **38** (8-9), 741–759.

Hotelling, H. (1929). Stability in competition, 39 econ. *J*, **41** (10.2307), 222421441.

Jeanjean, F. and Liang, J. (2012). Role of access charges in the migration from copper to ftth. *International Journal of Management and Network Economics*, **2** (3), 298–317.

Neumann, K.-H., Plückebaum, T., Schäfer, S. and Eltges, F. (2020). Copper switch-off, fibre takeup and ull tariffs in france. *Study on behalf of Iliad, Bad Honnef*, **9**.

Tenbrock, S., Knips, J. and Wernick, C. (2020). Status quo der abschaltung der kupfernetzinfrastruktur in der eu. *WIK Diskussionsbeitrag*.

Tselekounis, M., Orfanou, G. and Varoutas, D. (2014). Coexistence of copper and fiber unbundling: Access charges and investment incentives. *Calgary: International Telecommunications Society (ITS)*.

WIK Wissenschaftliches Institut für Infrastruktur
und Kommunikationsdienste GmbH
Rhöndorfer Str. 68, 53604 Bad Honnef, Germany
www.wik.org