# Access regulation and the transition towards Next Generation Access Networks

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## Abstract

This thesis studies the coherences between access regulation and the investment incentives of players in the fixed broadband market. More specifically, it focuses on the transition period towards Next Generation Access Networks and aims to answer the question: 'Should access regulation be applied to New Generation Access Networks?'.

A dynamic model is used that distinguishes between two different networks: a copper and fibre network. The incumbent is vertically integrated on a copper network and the entrant can either enter (i) service-based by buying access from the incumbent's network, or (ii) infrastructure-based by investing in its own fibre network. Moreover, the incumbent is able to invest in his own fibre network as well. The players base their investment decisions on the access charges set in the market and the strategies of the other player.

It is shown that once the entrant is able to invest in fibre, the access charges set by the social planner and unregulated incumbent change significantly. In a static setting, the unregulated incumbent forecloses the entrant by setting high access charges, while in a dynamic setting he opens up his network to the entrant by setting low access charges. In this way, he prevents competition from a high quality network and safeguards his position in the market. The social planner, on the other hand, sets low access charges in a static setting so that the entrant enters the market and deadweight losses can be reduced, while he may be triggered to set high access charges in a dynamic setting in order to stimulate both players to invest in their own fibre network. In this way, the social planner generates highest demand increases and the benefits to society outweigh the cost of having two fibre networks.

Futhermore, it also shown that the demand effect of investing in fibre and the cost of providing access incurred by the incumbent for each unit of access sold to the entrant, greatly influence the access charges set by the social planner and unregulated incumbent.

Overall, access regulation is preferred as the unregulated incumbent sets either too low or too high access charges from a social planner's point of view. Moreover, the social planner needs to take into account dynamic efficiency when committing to access charges.

# Table of Contents

# 1 Introduction

The European telecom market has undergone rapid changes over the last years. Technologies are constantly changing and improving, which make it possible for telecom operators as well as cable companies to offer enhanced services to end-users. End-users benefit from amongst others increased speeds and choice of services. However, these changes have consequences for competition and regulation in the market.

The European Commission argues that telecom services are vital for productivity growth and make a huge contribution to the European economy. Besides business users, an increasing amount of citizens rely on it for accessing their bank accounts, health related issues and government services. In the future, more and better services will be demanded which requires increasing use of bandwidth. In order to safeguard competition in the market so that competitive prices, increased quality and choice of services, and innovation prevail, the European Commission applies sector specific regulation to the telecom market. Moreover, the Commission has developed a Digital Agenda for Europe to be achieved by 2020.

The telecom market consists of the fixed and mobile telecom market. A service offered via a fixed network must be initiated or received at the end-users' premises whereas a service offered via a mobile network can be initiated or received by an individual handset at any place in which the network operates (ACMA, n.d.). The regulation applied by the European Commission mainly concerns the fixed telecom market as this market exhibits high and non-transitory barriers to entry. On the contrary, the mobile telecom market is not dominated by incumbents and is seen as rather competitive in each Member State (European Commission, n.d.).

For this reason, the remainder of this thesis will merely concern the European fixed telecom market. This market includes television, fixed telephony and fixed internet and end-users can subscribe to one, two or three of these services from a provider (European Commission, n.d.). Moreover, due to the perceived importance of broadband for the growth of the European economy the main focus will be on the fixed broadband market.

The aim of this thesis is to contribute to the discussion of whether and how access regulation should be applied to New Generation Access Networks (NGANs). More specifically, the model presented in this thesis will focus on the transition period towards NGANs and the coherences between access regulation applied to a copper and fibre network and investments incentives of an incumbent and entrant. The model is inspired by a model developed by Bourreau and Dogan (2005). Yet, the model in this thesis assumes that both the incumbent and entrant are able to invest in fibre and distinguishes between a copper and fibre network. Moreover, it shows that both a social planner and unregulated incumbent change the access charges they set, once the entrant is able to invest in fibre.

In order to answer the question: 'Should access regulation be applied to NGANs?', this thesis will start by giving a general overview of the characteristics of the fixed broadband markets in EU Member States and the regulations applied to the sector. Then, the introduction of NGANs will be elaborated upon and its implications for competition and regulation in the market. Afterwards, a model will be developed to dig deeper into the coherences between access regulation and investment incentives of market players. Finally, the results, conclusions, and recommendations will be presented.

## 2 Literature Overview

This chapter will give a general overview of the fixed broadband markets in EU Member States, their characteristics and regulations, and will elaborate on the transition from copper networks towards NGANs.

### 2.1 Fixed broadband market

The fixed broadband market has specific characteristics that may impede competition in the market. As shown in Figure 1, fixed broadband networks consist of (multiple) local access exchanges linked together by a transmission backhaul network, i.e. the core exchange (ACMA, n.d.). The local access exchanges are generally referred to as the 'local loop' and represent the 'last mile' of a fixed network and thus are directly linked to the end-users' premises. Therefore, the local loop is an essential facility for reaching end-users. However, it is this part of the network that requires the largest chunk of investments. For alternative operators it is not feasible to replicate this facility within a reasonable time frame and therefore the fixed broadband market is considered to be a natural monopoly in which the incumbent owns the bottleneck facility, the local loop (Valletti, 2003).

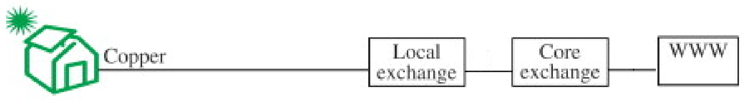


**Figure 1: Fixed (copper) broadband network (Cave, 2010)**

The market exhibits economies of scale as large fixed and sunk costs have to be incurred to build the infrastructure needed to provide services and products to end-users (Christodoulou & Vlahos, 2001) Additionally, the market exhibits economies of scope as a consequence of the vertical integration of incumbent firms. Consequently, incumbents may have an incentive to preempt competition so as to retain their market shares and profits by amongst others setting prices below costs, quality and/or price discrimination and refusal of providing access to alternative operators (Valletti, 2003). Another danger is the risk of excessive pricing because the assets providing services cannot be replicated (Cave, 2006). On top of that, operators are able to lock-in customers. Customers generally do not switch providers very often due to for example a lack of transparency or additional costs (Klemperer, 1995). Therefore, firms who act first are believed to have a first mover advantage in attracting (and keeping) customers.

It becomes clear that the market will experience a lack of both service-based and infrastructure-based competition without regulation. Service-based competition takes places when the entrant uses the infrastructure of the incumbent to offer his services to end-users, while infrastructure-based competition takes place when the entrant builds its own infrastructure (Bourreau & Dogan, 2004). It is believed that infrastructure-based competition will result in more product differentiation than service-based competition as firms gain control over their own network (Bourreau et al., 2004; Bourreau, Dogan & Manant, 2010).

In order to stimulate service-based and infrastructure-based competition in the fixed broadband market, European regulators have focused on increasing bottleneck competition. Regulation

2887/2000 on unbundled access to the local loop imposed mandatory Local Loop Unbundling (LLU)[1] for incumbents with significant market power, which implied that alternative operators were granted access to the incumbent's network to offer their services to end-users. In 2001, National Regulatory Authorities (NRAs) started to enforce availability of the access to the incumbent's network at multiple levels of which shared and full LLU were mandatory by Regulation 2887/2000 (Bacache, Bourreau & Gaudin, 2010). Besides, some Member States also decided to regulate resale and bitstream access.

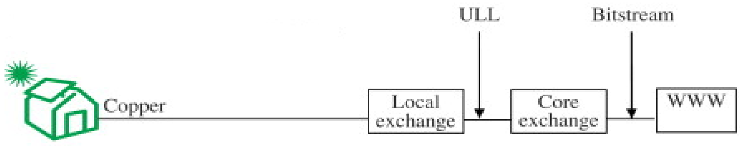


**Figure 2: Fixed (copper) broadband network after Regulation 2887/2000 (Cave, 2010)**

Figure 2 shows where in the network LLU (ULL in Figure 2) and bitstream access are offered. Resale access requires the least amount of investments to be made by alternative operators. With this type of access, alternative operators "buy the broadband service of the incumbent on a wholesale basis and commercialize this service to customers under their own brand names" (Bacache, Bourreau & Gaudin, 2012; p. 4). Bitstream access occurs when the incumbent provides third parties with access to its broadband network. In this case, alternative operators "need to invest in a data (IP) network of their own" (Bachache et al., 2012; p.4). These two types of wholesale access require low amounts of investments to be made by alternative operators (Distaso et al., 2008). By buying these types of wholesale access, they have the opportunity to build up a customer base and reputation, and to receive information about market dynamics. The learning effect that occurs makes sure they have the resources to invest in their own infrastructure at lower risk at a later point in time. Alternatively, operators who have already invested in some infrastructure generally choose for shared or full LLU. Shared and full LLU access both require a "sufficiently widespread network in order to reach the local exchanges of the incumbent" (Distaso et al., 2008; p.3). The difference is that with shared LLU the incumbent is still in control of the copper line as alternative operators only rent the upper bandwidth of the line, whereas with full LLU alternative operators obtain full control of the copper line (Bacache et al., 2012).

Although opening up the incumbent's network to alternative operators seems straightforward in theory, regulators have experienced difficulties in regulating the bottleneck in practice due to problems related to asymmetric information between regulators, alternative operators and (regulated) incumbents. Regulators do not have full knowledge of firm-specific costs, demand for services, strategies and so forth, which makes it hard to set the right access prices. In order to align all interests, incentive regulation (such as price caps) might be necessary to apply on top of access regulation. Incentive regulation, however, will not be the main focus of this thesis.

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[1] Retrieved from: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2000:336:0004:0008:EN:PDF

## 2.2 Ladder of investment approach

As mentioned before, regulators want to stimulate service-based and infrastructure-based competition in the market. One-way access, i.e. providing challengers with access to the incumbent's network, has been a first step in safeguarding service-based competition and to obtain static efficiency. However, establishing infrastructure-based competition and obtaining dynamic efficiency has been rather difficult. In order to give alternative operators and incumbents the right investment incentives towards infrastructure-based competition, European telecom regulators have embraced the ladder of investment (LOI) approach, proposed by Cave with a report to the European Commission in 2001 (Bourreau et al., 2010). The approach is mentioned in Article 7 of the Electronic Communications Framework Directive (2002/21/EC); the main EU regulatory instrument governing electronic communications. The article exists of pro-competitive incentives in order to establish effective competition on a specific market so that ex-ante regulation can be withdrawn (European Commission, 2002). One of these pro-competitive incentives is to allow new market entrants to offer their services initially via the infrastructure of the existing operator. The revenue generated by new market entrants should allow them to "climb the ladder of investment" and finally to invest in their own infrastructure. As soon as competing infrastructures are realized**,** access regulation will be phased out**,** leaving the market subject to competition law only.[2]

The LOI approach thus considers service-based competition as a stepping stone to infrastructure-based competition. The intuition behind this approach is that the regulator begins by setting low access prices in order to encourage service-based competition. Then, once challengers have gained a customer base and information on the market, they can move up the ladder of investment and invest in their own facilities (Bourreau et al., 2004; Bourreau et al., 2010). Subsequently, the regulator should increase the access prices in order to encourage the alternative operator to climb to the next rung of the ladder i.e. burn up the rung on which they were standing (Bacache et al., 2010). Ultimately, when having reached the final rung of the ladder, the next step for alternative operators is to finalize their own network and operate independently.

### 2.2.1 Implementation of the LOI

A majority of the EU Member States has adopted the intuition behind the LOI approach, but experienced difficulties in setting the right access price and determining the development of the access price over time. A major challenge has been to choose the right type(s) of access to regulate. Alternative operators are generally situated on different rungs of the ladder, i.e. have already invested in own assets or not, and thus require different incentives to (further) climb the ladder (Bourreau et al, 2010). However, setting different access prices for alternative operators situated on different rungs of the ladder and late comers "would probably be (i) illegal as it would encourage discrimination between market players and (ii) counterproductive as favorable conditions for late comers will slow down the process of competitive investment" (Cave, 2004; p.24). Therefore, regulators remain with the dilemma where and when to apply access regulation.

Cave (2004) proposed a method to overcome this dilemma. He suggested "a relative ranking of the replicability of assets that can be 'bought or made'" (Cave, 2004; p.19). This resulted in the ladder of

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[2] Retrieved from: http://ec.europa.eu/competition/sectors/telecommunications/legislation.html

replicability for broadband that can be found in Figure 3. The local loop is referred to as a non-replicable asset and is therefore situated on the last rung of the ladder.

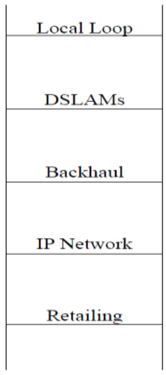


**Figure 3: Ladder of replicability for broadband (Cave, 2004)**

Cave (2004) suggests that the decision where to apply regulation should be based on an analysis of the scale and prospects of the alternative operators at various points, with a bias in favor of those more advanced in their infrastructure deployments. When having chosen the right rung of the ladder, Cave (2004) argues that NRAs have to analyze the investment potential of actual and potential alternative operators at that rung followed by deciding on the type of intervention to be used. Regulators can either choose to intervene with price or quantity instruments. The latter is also referred to as sunset clauses or temporary mandated access. Subsequently, regulators have to make sure that alternative operators continue climbing the ladder and hence the intervention has to be adjusted (through raising prices or ceasing mandatory access) after a pre-determined period of time. Moreover, policy makers and regulators have to make a credible commitment to the policy so that the intervention has the desired effect on competition in the market.

### 2.2.2 Evaluation of access regulation

Opponents of the LOI approach argue that regulators are not capable of applying this kind of dynamic access regulation to the fixed broadband market due to time and resource constraints (Oldale & Padilla, 2004). Accordingly, the lack of time and resources makes it hard for regulators to overcome asymmetric information in the market. Others (Distaso et al. 2008; Bourreau et al. 2010) are afraid that access regulation might deter infrastructure investment by both incumbents and challengers. If the access price is set too low, challengers have no incentive to climb the ladder as the opportunity cost is too high (Bourreau & Dogan, 2005). Yet, incumbents favor a low access price as this will prevent infrastructure-based competition and will safeguard their market position. Nonetheless, a low access price leads to lower profits for incumbents and thus their incentives to invest decrease as well (Bourreau et al, 2005). Therefore, regulators that want to apply access regulation face a fierce trade off between static and dynamic efficiency (Bourreau et al. 2005; Distaso et al. 2008).

Vogelsang (2010) argues that access regulation can enhance and accelerate investment (in bottleneck and bottleneck bypass infrastructure) for two reasons: (i) it lowers the price of output thereby increasing "the demanded output quantity and consequently the capacity required to produce this output" (p.5) and, (ii) it enhances competition which "fires up the race for new bottleneck investment between the incumbent and the alternative operators (by creating alternative operators with less of a cannibalization problem than the incumbent)"(p.5). On the other hand, regulation can reduce and deter investments for two other reasons: (i) it "lowers the expected investment returns, going along with increases or decreases in risks due to the truncation of uncertain investment outcomes that are caused by price constraints" (p.5) and, (ii) the lack of commitment of regulators can be counterproductive (Vogelsang, 2010).

Friederiszick, Grajek & Röller (2008) studied the relationship between access regulation and infrastructure investment in the telecom sector. They found that access regulation discourages infrastructure investments by entrants but does not affect incumbents in fixed-line telecommunications (Friederiszick et al, 2008). Alternatively, Bourreau et al. (2010) argue that infrastructure competition will only prevail if (i) the replacement effect, i.e. the low incentives of alternative operators to invest in their own infrastructure due to low access prices, is neutralized and (ii) regulators have the instruments to neutralize this replacement effect so as to induce alternative operators to climb the ladder. As may be recalled, the instruments proposed by Cave (2001) are price and quantity instruments. Most of the studies conducted on these instruments, support the former instrument, namely that an increasing access price over time may indeed neutralize the replacement effect over time (Bourreau et al. 2005; Bourreau et al. 2010; Avenali, Matteucci & Reverberi 2010; Gayle and Weisman 2007). On the other hand, Gayle et al. (2007) argue that increasing rather than decreasing the access prices can discourage investment. Quantity instruments, or sunset clauses, are proven to be ineffective if the competition between the incumbent and the alternative operator is more intense under infrastucture-based competition than under service-based competition (Bourreau and Dogan, 2006). The underlying reason is that the incumbent provides favorable access conditions to challengers - after the removal of the sunset clause - if he faces the threat of infrastructure-based entry. Similarly, Avenali et al. (2010) show that a sunset clause discourages infrastructure-based entry, thereby making it counterproductive.

No conclusive answer can be found in the literature with respect to the functioning of the LOI. Waverman, Meschi, Reillier & Dasgupta (2007) found evidence that lower local loop prices cause strong substitution from broadband offers over alternative platforms towards LLU-based broadband offers, which results in substantially lower investments in alternative access platforms (Waverman et al., 2007). This is not compatible with the LOI approach. However, they also warn for the risk associated with an improper implementation of the approach in Europe as this may result in a technologically stagnant market place (Waverman et al., 2007). Likewise, Bourreau et al. (2012) found no ladder effect between local loop unbundling (LLU) and new infrastructure lines, but did find a moderate ladder effect between bitstream access lines and LLU lines. As a consequence, the LOI seems to work up until the last rung of the ladder but the next step of infrastructure-based competition has not been realized.

A question that can be raised is if access regulation has benefited end-users in terms of prices, choice and quality of services. Distaso et al. (2008) showed that low prices for unbundled access raise broadband penetration. This relationship is particularly strong when the DSL market is less concentrated. However, regulated incumbents complain that access regulation stifles their investment incentives (Vogelsang, 2010). This results in possible delays of investments in upgrades of networks, cost-reducing investments and so on, which in turn leads to higher prices, lower quality of services and less innovation than could have been achieved without regulation. Wallsten (2006) showed that extensive unbundling mandates and some types of price regulation on the incumbent can reduce broadband investment incentives and penetration, while regulations involving easier interconnection with the incumbent can increase investment. Additionally, Vareda & Hoernig (2007) state that the aggregate effect of unbundling on total investment is ambiguous as unbundling may lower the incumbent's incentives to invest in quality upgrades, but raises their incentives to invest in cost-reduction-based investments. Cambini and Jiang (2009) state in their literature overview of broadband investment and regulation, that optimal access charges should appropriately take into account the investment risk in order to provide reasonable investment incentives to the incumbents.

The implementation of the LOI in current access networks was intended to reduce the need for future regulation in the fixed broadband sector. By achieving a high level of competition across the value chain, next generation technology could be made contestable (Cave, 2004). A race among competitors to create the new technology would be created (Cave, 2004), which in turn would stimulate self-regulation and reduce the need for regulatory interventions. Nevertheless, the regulation of NGANs is still a topic of debate, which suggests new technology is not yet made contestable and the desired level of competition has not been achieved in current networks. Therefore, it seems likely that NGANs will be regulated in the future as well.

The following section will explain the working of NGANs and the main differences with copper networks. Also, the transition towards and regulation of NGANs will be elaborated upon.

## 2.3 Next Generation Access Networks

NGANs offer new types of access and abandon old ones at the same time. Figure 4 and 5 show the working of two kinds of NGANs: Fibre-to-the-Node (FttN) and Fibre-to-the-Premises (FttP) respectively.

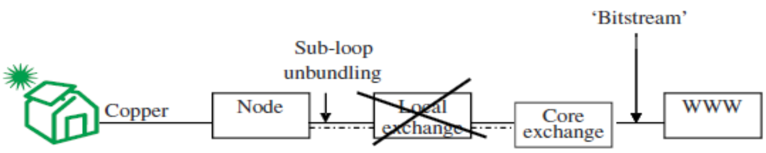


**Figure 4: Fibre-to-the-Node (Cave, 2010)**

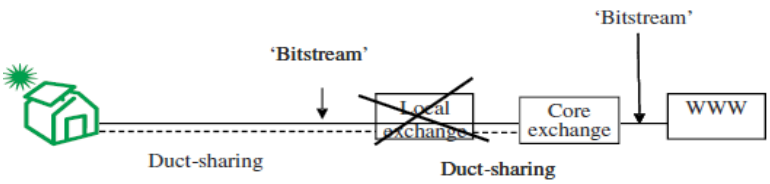


**Figure 5: Fibre-to-the-Premises (Cave, 2010)**

As can be seen from the figures 4 and 5 above, the main differences between current (copper) networks and NGANs are (Cave, 2010):

- removal (in many places) of the unbundled local loop at the exchange;

- greater emphasis (where the fibre network is of the FttN variety) on the sub loop from the cabinet to the customer's premises;
- greater attention paid to ducts, as a means by which competitors can get access either to the sub loop or to customers' premises and;
- replacement of bitstream by a more flexible active line access product.

The change that has the biggest consequence is the removal of the unbundled local loop. The removal involves that challengers must either move up the ladder closer to the customer (to the sub loop or owned/rented duct) or down a rung to the bitstream/active line access product (Cave, 2010). Cave (2010), however, argues that once challengers decide to move down a rung they still have the possibility to reclimb the ladder because they are able to capture a larger share of the growing fibre market. Morever, despite of the fact that the local loop of a fibre network is different from a copper network, social planners still believe that it is possible to open up fibre networks to alternative operators. Therefore, they still refer to the local loop even though they are talking about a fibre network. The local loop again refers to 'last mile' needed to reach the end-users'premises.

Additionally, the transition to NGANs involves the cannibalization of profits earned on copper networks. When introducing NGANs, operators fear their current networks will become redundant. The new networks can offer much faster broadband connections to the benefit of customers. Accordingly, incumbents and challengers who have been climbing the ladder are afraid their customers will switch to NGANs after the introduction of these networks, which means the investments made in their current networks cannot be recouped as profits will be foregone. The investments in current networks are sunk, whereas NGANs are still under construction and (full) investments are not yet made. Therefore, players in the market have an incentive to delay the introduction of NGANs and the migration of their customers to a time that suits them best (Bourreau, Cambini & Hoernig, 2012).

Nonetheless, policy makers and regulators have an incentive to mitigate this delay as NGANs are expected to bring a broad range of indirect revenues due to the much higher speeds this technology can offer compared to current (upgraded) networks. These indirect revenues include amongst others efficiency gains, attracting new businesses and the associated employment growth (Tahon et al., 2011). At the same time, regulators want to diminish the duplication of cost for society of having both a copper and fibre network in the same geographical area, which involves a limitation of the period customers migrate from the old network to the new network (Cave, 2010). As a result, in addition to thinking vertically (about movements up any given ladder) regulators have to start thinking horizontally (about movements from one ladder to another) (Cave, 2010).

### 2.3.1 Investment decisions in the transition period

Regulators thus face the trade off between promoting competition on the new network and creating incentives to build it in the first place (Cave, 2010). Building a NGAN involves a large chunk of investments and thus a large customer base is needed to recoup the investments. Economies of scale are said to be even more prevalendt in NGANs than in current networks and high market shares are needed to make the NGAN economically feasible. In addition, rolling out a NGAN is a time-consuming task and a large region cannot be covered at once due to timing and resource constraints (Casier, 2009). As a consequence, the most profitable areas will be rolled out first.

Obviously, the transition from old networks to NGANs will not happen from one day to the other. New investments will not immediately replace the old network as a consequence of: (i) “the regulatory constraints on copper networks, which rule out an immediate switch-off of the old network; (ii) the uncertainties about demand and investment costs, which call for a progressive investment strategy; and (iii) the financial market constraints that imply that roll-out must be phased” (Bourreau et al., 2012; p.400). As a result, a phase in which both networks operate simultaneously will prevail.

An accompanying problem is the possibility that old and new networks will be regulated with different sets of rules (Bourreau et al., 2012). This implies that the decision to invest in NGANs not only depends on the set of rules applied to NGANs, but also on the set of rules applied to old networks (Bourreau et al., 2012). The EU recommendation on regulated access to NGANs states that (i) current regulation on the copper network should be maintained and (ii) a new set of rules should be introduced to facilitate the migration from old to new infrastructures (Bourreau et al., 2012). Yet, they do not account for the interdependency of the regulations of these two networks nor the impact of access regulation on the incentives to invest in new infrastructure (Bourreau et al., 2012). Interdependency can lead to incompatible behavior of incumbents and challengers with respect to investments in NGANs. For example, when the access price on the old network is high, incumbents have an incentive to delay investments in NGANs so as to retain their profits, whereas challengers may have an incentive to invest in NGANs because their opportunity cost decreases. On the other hand, high access prices on the NGAN encourage incumbents to invest in NGAN (Bourreau et al. 2012). Therefore, “the interdependency becomes fundamental if the regulator imposes ex ante access obligations to NGANs” (Bourreau et al., 2012; p.403).

In order to understand the relationship between access regulation and investment incentives and its implications for society more thoroughly, theoretical entry models found in the literature will be introduced in the following section.

## 2.4 Entry models in telecom

Several entry models to model competition between an incumbent firm and an entrant firm in the telecom market have been proposed. These models differ in the assumptions they make and the focus they have.

Bourreau et al. (2005) use “a dynamic model of technology adoption and study the incentives of the entrant to lease loops and compete service-based and/or to build up a new and more efficient infrastructure and compete facility-based, given the rental price” (p.173). They show that the incumbent sets too low access charges for its loops and therefore the entrant adopts the new technology too late from a social welfare point of view. Moreover, “the distortion may appear not only on the timing of the technology but also on the type (quality) of the new technology to be adopted” (Bourreau et al. 2005; p. 173). In addition, they show that while regulating access charges may suffice to achieve highest social welfare, sunset clauses do not improve social welfare.

Manenti & Scialà (2010) model competition between an incumbent and an entrant firm, where both operators may invest in the provision of next generation services before retail competition takes place. The entrant can enter with own infrastructure or by using the incumbent’s network. In the latter case, the entrant is not able to invest in advanced technologies, whereas the incumbent is always able to upgrade its network to offer enhanced services to its customers. Accordingly, Manenti et al. (2010) study the impact of access regulation on the type of entry and the amount of firm's investments. Consistently with the existing literature, they find that the incumbent forecloses entry by setting a sufficiently high access price in case of unregulated access. As a result, the possibility of inefficient infrastructure-based entry rises. In case of ex-post access regulation, service-based entry might occur even when infrastructure-based entry would have been optimal. Consequently, regulatory failures might emerge as the desired infrastructure-based entry would have occurred without regulation. These regulatory failures, however, can be reduced by adopting ex-ante regulation.

Kotakorpi (2006) analyzes the effect of access regulation on a local telecommunications network provider's incentive to invest in infrastructure. Kotakorpi (2006) considers a vertically integrated incumbent who provides network access to a fringe of rival operators in the retail sector and assume that the regulator cannot commit to an access pricing regime prior to the incumbent's investment decision. Accordingly, Kotakorpi (2006) finds that spillovers to rivals' demand reduce investment when access prices are regulated. The intuition behind this result is that the incumbent is not allowed to make a profit on access provision and therefore investment incentives are lower than in the absence of regulation. Further, if rivals benefit more from the investment than the incumbent as a result of spillover effects, no investment takes place. Therefore, investments are below the social optimum and the underinvestment problem may have negative effects on the viability of competition. Additionally, Katokorpi (2006) finds that in the presence of access regulation, rivals are most likely to be foreclosed precisely when they would bring highest benefits to consumers.

De Bijl & Peitz (2004) analyze a repeated setting of an asymmetric, differentiated telecom market with an incumbent and entrant. The entrant may roll out its own network or use parts of the incumbent's network. The incumbent is established in the market, while the entrant gradually builds up a track record for quality. De Bijl et al. (2004) argue that a higher access charge for the local loop creates a transfer of surplus from consumers to the incumbent. Yet, they state that the exact regulatory implications depend on the policy goals. In case, the access charge should also cover fixed costs of the incumbent, an access charge higher than marginal costs may be called for. Valletti (2003) agrees that different policy objectives lead to alternative ways of calculating optimal access charges. Valletti (2003) argues that whenever possible, the use of access pricing as an instrument for the promotion of too many goals should be resisted.

Obviously, access regulation has a major impact on market structure and outcomes. Nevertheless, the theoretical models do not lead to a conclusive answer with respect to whether access regulation leads to better outcomes for society than a situation without regulation. Moreover, most of the models focus on service-based and infrastructure-based entry, while in reality infrastructure-based entry in the copper market has not been very common in EU Member States. As may be recalled, the local loop of the copper network requires a large chunk of investments, thereby making it not feasible to replicate. As a result, alternative operators generally enter the copper market by using the incumbent's network. Further, the majority of the models focuses on one network and does not distinguish between a copper network and NGAN. In reality, the NGAN is a totally new network and therefore both incumbents and entrants need to invest in infrastructure to be able to serve end-users via this type of technology.

For these reasons, a new model will be developed in the following section to get a clear understanding of the effects of access regulation in the transition period towards NGANs. The model will distinguish between two networks: a copper and fibre network. Moreover, access regulation will refer to one type of access or one rung of the ladder of investment: the local loop, as all EU Member States are obliged to regulate this type of access. The aim is to get a better understanding of whether access regulation promotes competition in the fixed broadband market and to show how market players respond to access charges set by the social planner on different networks. Getting better insights into the coherences between access regulation and investment incentives of both incumbents and entrants can contribute to the discussion of whether and how access regulation should be applied to NGANs.

# 3 Model

In the remainder of this thesis a model will be presented in order to get a clear understanding of the dynamics and coherences between the investment incentives of players in the fixed broadband market and the access charges set by the social planner on different networks, i.e. copper and NGA networks. This chapter will present the model description.

## 3.1 Model description

The model will consider a game of two players that offer telecommunication services to end users: an incumbent denoted by $I$ and an entrant denoted by $E$. Besides, two technologies will be considered from which the players can offer services to end-users: a copper network and a fibre-to-the-home network. The fibre network can offer higher quality of services to end-users than the copper network, and therefore end-users value services from the fibre network more. However, rolling out the fibre network is costly.

*Firms:* The incumbent owns a copper network. Besides offering services to end-users, he also offers access to its network to the entrant. Moreover, in case the incumbent decides to invest in a new fibre network he can again offer both retail services to end-users and access to the entrant. The investment cost of the copper network are considered sunk. However, the incumbent has to incur fixed investment cost of $F_I$ in order to build the necessary infrastructure for fibre.

The entrant does not possess infrastructure yet and can enter the market in two ways: either by buying access from the incumbent's network, i.e. service-based entry, or by investing in its own fibre network, i.e. infrastructure-based entry. Service-based entry does not lead to quality differences in the services offered to end-users as the services are offered from the same network. Infrastructure-based entry, on the other hand, can lead to quality differences between the services provided by the two players. Furthermore, service-based entry can only occur if the local loop is unbundled, while infrastructure-based entry can always occur.

It is assumed economically infeasible for the entrant to invest in a copper network due to duplication of cost and the large chunk of investments needed to build the last mile, i.e. the local loop. So, infrastructure-based competition is only possible if the entrant invests in fibre. Moreover, both ways of entering involve cost for the entrant. In order to be able to offer end-users services when buying access from the incumbent, the entrant incurs fixed cost ($F_{Ea}$) so as to reach the local exchanges of the incumbent. These fixed cost are assumed to be equal on the copper and fibre network. Alternatively, investing in a fibre network brings along fixed cost of $F_E$, where $F_E > F_{Ea}$.

Additionally, the variable cost of both the entrant and incumbent are assumed to be zero, but the incumbent incurs cost of providing access ($c \geq 0$) for each unit of access sold to the entrant, which is assumed to be equal on the copper and fibre network. Also, if $E$ decides to buy access to $I$'s network $E$ has to pay an access charge ($a_c$ and $a_f$ on the copper and fibre network respectively) to $I$ for each unit of output sold to its end-users. It is assumed that $a \geq 0$.

*Social planner:* The social planner (SP) decides to impose mandatory unbundling of the local loops of the incumbent. Therefore, the social planner sets the access charges to be paid per unit of access bought on the copper and fibre network. The social planner sets the access charges ex-ante and thus before firms undertake their investments.

*Consumers:* It is assumed that the whole market remains covered during the game. Moreover, consumers value services from the fibre network more than services from the copper network and therefore investing in fibre brings along demand increases. The following utility function is assumed for all consumers,

$$U(q_I, q_E) = Aq_I + Aq_E + \beta q_I(x_I + x_I x_E) + \beta q_E(x_E + x_I) - \frac{1}{2}(q_I^2 + q_E^2 + 2q_I q_E)$$

where $\beta \in [0,1]$ represents the demand effect and positive spillover effect and thus are assumed to be equal for simplicity, $x_I$ and $x_E$ refer to the investments of $I$ and $E$ respectively where $x_i = 1$ if player $i \in [I, E]$ invests and $x_i = 0$ if player $i \in [I, E]$ does not invest, and $A > 0$ refers to the absolute advantages which are assumed to be equal on all networks and for all players.

From the utility function it becomes clear that the pattern of investments influences the demand structure. A fibre network can offer higher quality of services than a copper network. Consumers value higher quality of services and therefore, in case a player decides to invest in fibre ($x_i = 1$), the demand function of this player will shift upward by $\beta$. Also, investments of one player influence the demand function of the other. In case the incumbent invests and the entrant decides to buy access, the entrant will have a positive spillover from investments made by the incumbent as the entrant is able to offer higher quality of services to its end-users as well by using the fibre network of the incumbent. Moreover, if both players invest, they have positive spillovers from each other as they stimulate each other to invest so as to offer superior services. Also, with increased quality of services, more and advanced services can be offered via for example the internet. Additionally, it is believed that infrastructure-based competition brings more benefits to society than service-based competition. $\beta$ thus reflects complementarity. Ceteris paribus, if both players invest in fibre, the highest demand effect can be achieved. Apart from positive spillovers, also negative spillovers can appear. In case the incumbent keeps offering services via its copper network and the entrant invests in fibre, the incumbent will incur negative spillovers as the entrant is able to offer higher quality of services than the incumbent can reach with its copper network.

*The timing of the game:* The timing of the game is shown in Figure 6 (p.19).

1. In this stage of the game, the access charges on the copper and fibre network are set by the social planner.

2. The second stage of the game concerns the incumbent's investment decision. Therefore, in Figure 6, $x_I$ represents $I$'s strategies: $x_I = 0$ if $I$ stays at the copper network and $x_I = 1$ if $I$ invests in a fibre network.

3. In the third stage of the game, the entrant decides how to enter the market. Thus, in Figure 6, $x_E$ represents $E$'s strategies: $x_E = 0$ if $E$ buys access to either the copper or fibre network of $I$ and $x_E = 1$ if $E$ invests in a fibre network.

4. In the last stage of the game, the players compete à la Cournot. Cournot competition is played because it is assumed that it takes time and resources for the entrant to change production quantities and thus the entrant is restricted by the quantities he sets in the market.

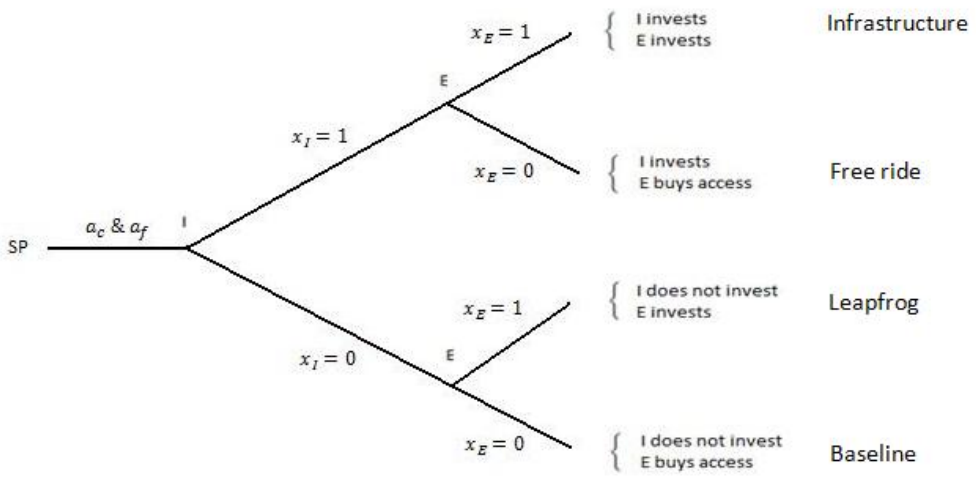


**Figure 6: Game tree**

In the remainder of this thesis the names that are shown in Figure 6 for each sub game will be used to refer to the individual sub games. The sub game Baseline refers to the starting point and involves no investments in fibre. In the sub game Leapfrog, the entrant invests in fibre while the incumbent stays at the copper network. Thus, the entrant can leapfrog the incumbent and gain a first-mover advantage. Alternatively, in the sub game Free ride, the incumbent is the only player who invests in fibre and the entrant benefits from the investments made by the incumbent and thus free rides on these investments. Lastly, in the sub game Infrastructure both players invest in fibre and compete with their own fibre technologies.

The following parameters are assumed to be fixed throughout the remainder of this thesis and equal to:

| Parameter | Value |
|---|---|
| A | 40 |
| $\beta$ | 0.8 |
| $F_{Ea}$ | 1 |
| $F_I$ and $F_E$ | 20 |

The model will distinguish between two scenarios with respect to the cost of providing access: a scenario with low cost of providing access, i.e. $c = 0.25$ and a scenario with high cost of providing access, i.e. $c = 8$. In the first scenario, the incumbent is able to make a profit on providing access, while in the latter scenario he makes a loss on providing access.

Furthermore, a sensitivity analysis of the demand effect will be added in order to derive how the demand effect changes the outcomes of the game. The sensitivity analysis takes into account a low demand effect ($\beta = 0.3$), while the model presented above focuses on a high demand effect, ($\beta = 0.8$).

Now, it is possible to derive $I$'s and $E$'s demand functions.

## 3.2 Demand functions

The utility function derived in the previous section leads to the following demand functions for the incumbent and entrant respectively,

$$p_I = A + \beta(x_I + x_I x_E) - q_I - q_E$$

$$p_E = A + \beta(x_E + x_I) - q_E - q_I$$

As explained before, both players benefit from increased demand if they decide to invest in fibre. However, in case the entrant invests in fibre and the incumbent stays at the copper network, the incumbent does not benefit from increased demand as he is not able to offer increased quality of services to its end-users. This explains the product term ($x_I x_E$) in the incumbent's demand function. The entrant, on the other hand, does benefit from increased demand if he buys access from the incumbent's fibre network. The reason for this is that the entrant provides services from the same high quality (fibre) network. So, the entrant's demand increases ($x_I$) as he uses the incumbent's fibre technology.

Obviously, the game in which both players invest generates the highest demand increase, followed by the game in which the incumbent invests and the entrant buys access from the incumbent's fibre network. In the remaining two games, the incumbent stays at the copper network which implies that his end-users do not benefit from increased quality of services and therefore total demand is lower than in the games in which all end-users can enjoy increased quality of services.

## 3.3 Myopic access charges

First, the optimal access charges set by the social planner in a static setting are determined. In this setting, the social planner is myopic and decides the investments assuming investments ($x_I$ and $x_{E)}$ are fixed. Consequently, the social planner only sets access charges in cases where the entrant does not invest and thus buys access on the copper and fibre network.

As a result, the optimal access charges on the copper and fibre network set by the social planner are equal to[3],

$$a = 6c - A - \beta x_I$$

For $c \geq \frac{1}{4}(A + \beta x_I)$, these access charges are equal or higher than the level of the access charge that forecloses the entrant ($a^f$),

$$a \geq \frac{1}{2}(A + \beta x_I) = a^f \; for \; c \geq \frac{1}{4}(A + \beta x_I)$$

In this case, the social planner will not allow for access as providing access is too expensive and the entrant is too inefficient.

For $c \leq \frac{1}{6}(A + \beta x_I)$, the access charges will be negative and thus can be interpreted as a subsidy to the entrant,

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[3] The derivations of the optimal access charges in a static setting can be found in the Appendix on page 51

$$a \leq 0 \; for \; c \leq \frac{1}{6}(A + \beta x_I)$$

However, it is assumed that the access charges cannot be negative and so $a = 0$ for $c \leq \frac{1}{6}(A + \beta x_I)$. Therefore, for low access costs, the entrant receives free access so that he enters the market. Consequently, competition increases, and prices and deadweight losses decrease.

For intermediate ranges of the access cost, the access charges can be below marginal cost in order to enhance competition or above marginal cost to discourage entry.

The access charges set by the social planner lead to the following total welfare functions ($TW$) in both sub games,

$$TW \; = \frac{1}{2}A^2 + \beta x_I(A + \frac{1}{2}\beta) - c(A + \beta x_I - 2c_a) - F_I x_I - F_{Ea}$$

Now that the demand functions and the socially optimal access charges in a static setting have been derived, the game that was introduced in section 3.1 can be solved by using backwards induction.

# 4 Analysis

In this chapter, the model will be solved. Backwards induction is used to solve the game and thus the last stage of the game will be solved first. In this last stage of the game, the incumbent and entrant will compete à la Cournot.

## 4.1 The fourth stage of the game: Cournot competition

Table 1 summarizes the pay offs earned in each sub game after Cournot competition has taken place.[4]

| *Payoffs in each sub game* | | **E's strategies** | |
|---|---|---|---|
| | | $x_E = 0$ | $x_E = 1$ |
| **I's strategies** | $x_I = 0$ | *Baseline*<br>$I = (\frac{A + a_c}{3})^2 + (a_c - c)(\frac{A - 2a_c}{3})$<br>$E = (\frac{A - 2a_c}{3})^2 - F_{Ea}$ | *Leapfrog*<br>$I = (\frac{A - \beta}{3})^2$<br>$E = (\frac{A + 2\beta}{3})^2 - F_E$ |
| | $x_I = 1$ | *Free ride*<br>$I = (\frac{A + \beta + a_f}{3})^2 + (a_f - c)(\frac{A + \beta - 2a_f}{3}) - F_I$<br>$E = (\frac{A + \beta - 2a_f}{3})^2 - F_{Ea}$ | *Infrastructure*<br>$I = (\frac{A + 2\beta}{3})^2 - F_I$<br>$E = (\frac{A + 2\beta}{3})^2 - F_E$ |

**Table 1: Pay offs after Cournot competition**

Only if both players invest, an equilibrium is reached where both players charge the same end-user price and share the market equally. In the games where the entrant buys access, the end-user prices are equal, but the incumbent serves a larger share of the market. Instead, in the game where the incumbent stays at the copper network and the entrant invests, the entrant is able to charge a higher end-user price as well as to serve a larger share of the market due to the fact that he is able to provide higher quality of services than the incumbent is able to do.

In the following section, the solving of the game will continue by deriving the entrant's decision in the third stage of the game.

## 4.2 The third stage of the game: the entrant's decision

The next question is whether the entrant will invest in fibre or buy access from the incumbent. This decision clearly depends on the payoffs earned by the entrant in both situations. Table 2 (p.23) shows the entrant's investment decision in two situations: (i) the incumbent does not invest and (ii) the incumbent invests.[5]

[4] The derivations of the solutions of the final stage of the game can be found in the Appendix on page 52

[5] The derivations of the solutions of the entrant's decision can be found in the Appendix on page 53

| | E invests if and only if: |
|---|---|
| *I does not invest* | $F_E \leq \frac{4}{9}a_c(A-a_c)+\frac{4}{9}\beta(A+\beta)+F_{Ea}$ |
| *I invests* | $F_E \leq \frac{4}{9}a_f\left(A+\beta-a_f\right)+\frac{1}{3}\beta\left(\frac{2}{3}A+\beta\right)+F_{Ea}$ |

**Table 2: The entrant's investment incentives**

***Discussion of the entrant's decision***

The investment incentives of the entrant in both situations are equal if no demand effect or positive spillovers exist ($\beta = 0$) and $a_c = a_f$. A higher demand effect implies that the upper bound of the fixed cost of investing in fibre increases. Therefore, if the demand effect increases the entrant is willing to pay higher investment costs and thus his incentives to invest increase. However, the demand effect is less strong if the incumbent invests in fibre as well, which in turn makes it harder to convince the entrant to invest himself as he benefits from spillovers. Alternatively, a higher access charge decreases the upper bound of the fixed cost of investing thereby discouraging investments. Yet, this upper bound increases when the demand effect and the absolute advantage outweigh the increase in the access charge. Thus, the entrant will only invest in case it brings increased benefits to him. This implies that in some cases the entrant might not invest although the access charge on copper and/or fibre increases.

Furthermore, it is possible to express the equations in Table 2 as a function of the access charges. By doing this, the access charges on copper and fibre so that the entrant will invest are determined. These access charges are equal to[6],

$$0.25 \leq a_{Ec} \leq 39.75$$

$$0.65 \leq a_{Ef} \leq 40.15$$

Where $Ec$ refers to the access charge on the copper network so that the entrant invests and $Ef$ refers to the access charge on the fibre network so that the entrant invests.

Hence, (i) if the incumbent stays at the copper network, the entrant will invest if and only if $0.25 \leq a_c \leq 39.75$; and (ii) if the incumbent invests, the entrant will invest if and only if $0.65 \leq$ *af≤40.15.*

The critical values of the access charges for each demand effect are shown in Figure 7 (p.24). The access charge on the fibre network is higher than the access charge on the copper network for each (positive) demand effect. From this, it can be concluded that the entrant has lower incentives to invest on the fibre network, because the lower bound of the access charge so that he invests is higher. An explanation of this result is that the entrant benefits from investment spillovers of

[6] The derivations of these access charges can be found in the Appendix on page 54

investments made by the incumbent on the fibre network regardless of the way he enters the market, while he does not benefit from spillovers on the copper network.

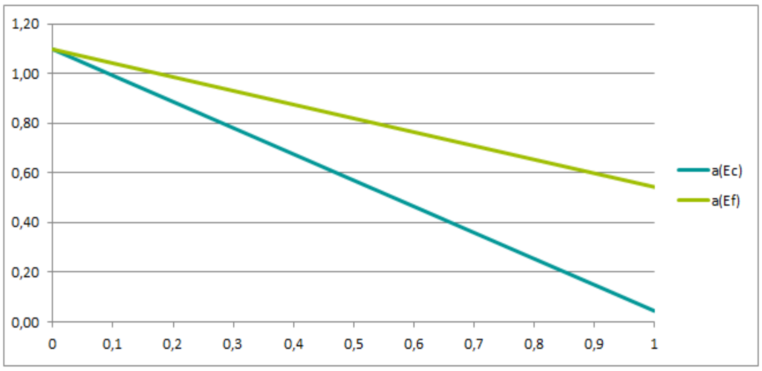


**Figure 7: Access charges so that the entrant invests ($a_E$) for each demand effect ($\beta \in [0, 1]$)**

## 4.3 The second stage of the game: the incumbent's decision

The second stage of the game concerns the incumbent's investment decision. The question is whether he will stay at the current copper network or invest in a new fibre network. Again, the decision to invest depends on the payoffs earned by the incumbent in both situations.[7]

| | **I invests if and only if:** |
|---|---|
| *E buys access on both networks* | $F_I \leq \frac{5}{9}a_f\left(A+\beta+\frac{6}{5}c-a_f\right)-\frac{1}{3}\beta c+\beta\left(\frac{2}{9}A+\beta\right)-\frac{5}{9}a_c\left(A-\frac{6}{5}c-a_c\right)$ |
| *E buys access on copper and invests on fibre* | $F_I \leq \frac{5}{9}a_c\left(a_c-A-\frac{6}{5}c\right)+\frac{1}{3}Ac+\frac{4}{9}\beta(A+\beta)$ |
| *E invests on copper and buys access on fibre* | $F_I \leq \frac{5}{9}a_f\left(A+\beta+\frac{6}{5}c-a_f\right)-\frac{1}{3}c(A+\beta)+\frac{4}{9}A\beta$ |
| *E invests on both networks* | $F_I \leq \frac{1}{3}\beta(2A+\beta)$ |

**Table 3: The incumbent's investment incentives**

### *Discussion of the incumbent's decision*

In case the entrant buys access irrespectively of the incumbent's decision to invest or not, the decision of the incumbent depends on the difference between the access charges paid on both networks and the investment cost. When the investment cost is lower than the difference between the access revenue from the fibre network and the access revenue from the copper network, the incumbent can make a profit by investing in fibre. Thus, the incumbent will be stimulated to invest if the difference between these access charges increases. However, the demand effect influences the incentives to invest as well. If this effect is significantly high, the incumbent will invest in fibre even

[7] The derivations of the solutions of the incumbent's decision can be found in the Appendix on page 54

when the access charge earned on this network is lower than the charge earned on the copper network. On the other hand, positive spillovers to the entrant's demand will discourage investments.

If the entrant invests if the incumbent stays at the copper network and buys access if the incumbent invests, the investment incentives of the incumbent depend on the access charge set on the fibre network and the investment cost of building a fibre network. The total access revenue earned on this network needs to outweigh the investment cost so as to convince the incumbent to invest. Additionally, the demand effect and negative spillovers have a stimulating effect on investing in fibre.

If the entrant buys access on copper and invests on fibre, the incumbent's investment incentives increase with the demand effect. However, a high access charge on copper discourages his investments in fibre. Also, in case the entrant invests on both networks, the investment incentives of the incumbent are highly influenced by the demand effect. The benefits need to outweigh the investment cost.

Furthermore, there exists an increasing relationship between the cost of providing access and the investment incentives of the incumbent. When the cost of providing access increases, the incumbent incurs less benefits of providing access and thus is encouraged to invest. This effect is stronger in case the demand effect and absolute advantage are high. However, this effect is less strong if the access charge earned per unit of access sold is sufficiently high.

What becomes clear is that the incumbent has higher incentives to invest in fibre when the entrant invests than when the entrant decides to buy access from the incumbent. This is rather straightforward as the incumbent earns access revenue if the entrant buys access and therefore the opportunity cost of investing increases.

By plugging the lower bounds of the access charges so that the entrant invests, i.e. $a_{Ec} = 0.25$ and $a_{Ef} = 0.65$, into the equations of the investment incentives of the incumbent in Table 3 (p.24), the strategies of the incumbent given these access charges are determined. Consequently, it is possible to determine in what sub game the players end up for each combination of access charges. Figure 8 shows these sub games.

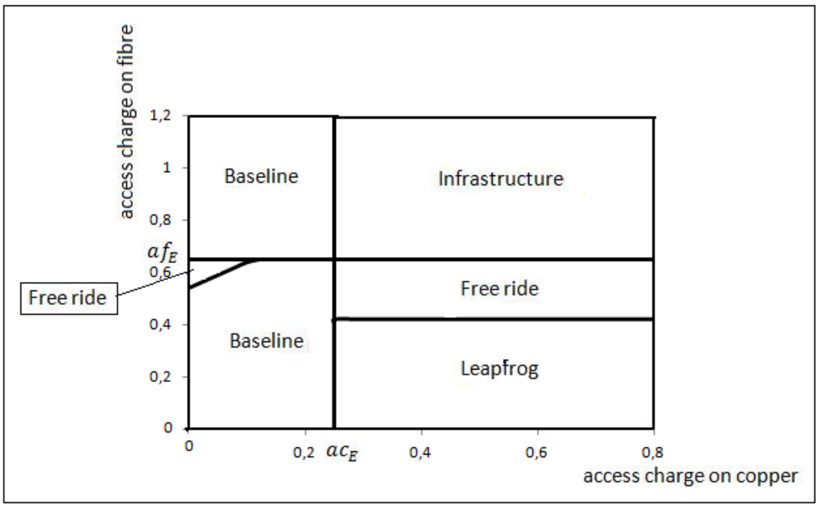


**Figure 8: Sub games for each combination of access charges**

## 4.4 The first stage of the game: the social planner's decision

The social planner's goal is to set the access charges so that total welfare is maximized. Moreover, by setting the access charges before investments take place, the social planner is able to influence investments made by both players in the market. Hence, the social planner will take dynamic efficiency into account.

In previous sections, the utility function and profit functions have been determined and thus it is possible to derive consumer and producer surplus and eventually total welfare in each sub game[8]. Table 4 shows the welfare functions obtained in each sub game.

| Total welfare in each sub game | | E's strategies | |
|---|---|---|---|
| | | $x_E = 0$ | $x_E = 1$ |
| I's strategies | $x_I = 0$ | $\frac{4}{9}A^2 - \frac{1}{9}Aa_c - \frac{1}{18}{a_c}^2 - \frac{1}{3}c(A-2a_c) - F_{Ea}$ | $\frac{4}{9}A^2 + \frac{4}{9}A\beta + \frac{11}{18}\beta^2 - F_E$ |
| | $x_I = 1$ | $\frac{4}{9}(A^2 + 2A\beta + \beta^2) - \frac{4}{9}a_f(\frac{1}{2}a_f + A + \beta) - \frac{1}{3}c(A + \beta - 2a_f) - (F_{Ea} + F_I)$ | $\frac{4}{9}A^2 + \frac{16}{9}A\beta + \frac{16}{9}\beta^2 - (F_E + F_I)$ |

**Table 4: Total welfare in each sub game**

Again, in what follows the following parameters will be set fixed: $A = 40, \beta = 0.8, c = 0.25, F_{Ea} = 1, F = 20$.

In Figure 8 (p.25), the investment incentives of both players were showed graphically and thus the sub games in which the players end up for each combination of access charges was shown. Next, the social planner will compare the local optima of each sub game in order to determine which sub game generates highest social welfare. Consequently, the social planner will set the access charges in such a way so that the sub game with highest social welfare will be played.

The access charges that generate highest social welfare in a static setting, i.e. in the sub games where the entrant buys access, have already been determined in chapter 3. Recall that the social planner will set the following access charges in these sub games,

$$ {a_c}^{ST} = 6c - A $$

$$ {a_f}^{ST} = 6c - A - \beta $$

again $c$ refers to the copper network ,$f$ refers to the fibre network and $ST$ to the static setting.

Next, the two scenarios introduced in the model description will be distinguished: scenario 1 includes low cost of providing access, i.e., $c = 0.25$, and scenario 2 includes high cost of providing access, i.e. $c = 8$.

[8] The derivations of the welfare functions in each sub game can be found in the Appendix on page 55

#### 4.4.1 Scenario 1: Low cost of providing access

Figure 9 is based on the fixed parameters determined before and includes the optimal access charges set by the social planner in a static setting. Moreover, it shows the direction of the local optima in each sub game.

Based on the parameter assumptions, the access charges in a static setting will be negative and thus below zero. Yet, it is assumed that the access charges cannot be a transfer from the incumbent to the entrant and thus the social planner will generate highest welfare in these sub games (i.e. Baseline and Free ride) by setting the access charges as low as possible and thus on the boundaries. Therefore, in Baseline the access charge on copper will be set equal to 0. Additionally, in Free ride the access charge on fibre will be set equal to 0.54 and $a_c = 0$ or equal to 0.42 if $a_c \geq 0.25$.

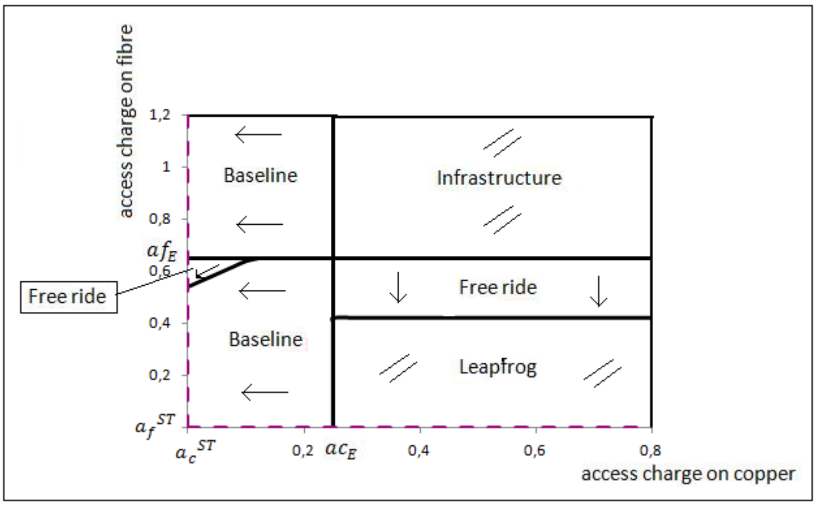


**Figure 9: Sub games including myopic access charges**

In Leapfrog and Infrastructure, social welfare is constant and the same for each combination of access charges as the demand effect is set fixed. Yet, social welfare is higher if both players invest, and thus in Infrastructure, than if only the entrant invests, i.e. in Leapfrog.

Subsequently, the social planner will compare welfare generated in each sub game. A simple comparison shows that the game in which both players invest generates higher welfare than the games in which the entrant buys access given the assumptions made.[9] The intuition behind this is that the demand effects the two players generate by investing in fibre and therefore the benefits to society outweigh the cost of having two fibre networks. Thus, the social planner will make sure the sub game Infrastructure will be played. The social planner can achieve this by setting the access charges equal to,

$$a_c > 0.25$$

$$a_f > 0.65$$

where $c$ refers to the copper network and $f$ refers to the fibre network.

[9] The values of total welfare in each sub game can be found in the Appendix on page 56

### 4.4.2 Scenario 2: High cost of providing access

Now, the game is played while taking into account a higher cost of providing access, $c = 8$, in order to see how a higher cost of access influences the outcomes of the game. If $c = 8$, the access charges set in a static setting will be positive. However, the access charges that convince the entrant to invest will not change as the entrant's decision to invest does not depend on the cost of providing access.

Figure 10 shows the sub games that are played for each combination of access charges. Notice that the remaining parameters did not change and thus have the same values as in the previous game.

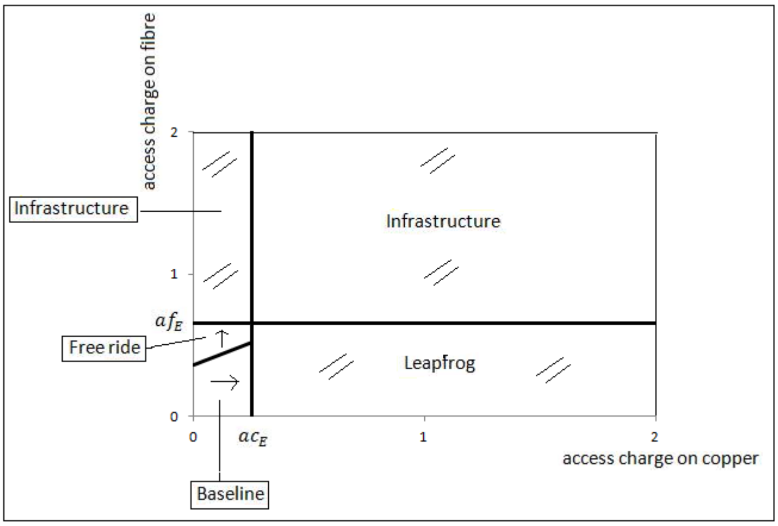


**Figure 10: Sub games for high cost of providing access**

As can be seen from the figure, the sub games that are played differ from the previous game. The reason for this is that the incumbent makes a loss on providing access when the cost of providing access is this high for low values of the access charges on copper and fibre. Therefore, the incumbent prefers infrastructure-based competition, where he preferred service-based competition before. Also, for low access charges on fibre he prefers to end up in Leapfrog instead of Free ride and thus does not invest in fibre.

Given the assumptions and high cost of providing access, highest social welfare in the games where the entrant buys access (Baseline and Free ride) is again played on the boundaries. However, in this case the upper boundaries generate highest welfare instead of the lower boundaries (see directions of local optima in each sub game in Figure 10). Therefore, the social planner will set the access charges as high as possible in the sub games Baseline and Free ride. Again, total welfare is constant in Leapfrog and Infrastructure as the demand effect is set fixed.

A simple comparison of the values of social welfare generated in each sub game shows that highest social welfare is obtained in the game Infrastructure and thus in the same sub game as in the previous case.[10] The social planner will set the access charge on the fibre network so as to make sure both players invest,

$$a_f > 0.65$$

[10] The values of total welfare in each sub game can be found in the Appendix on page 56

where $f$ refers to the fibre network. Note that the access charge on the copper network does not influence the investment incentives of the players for a fibre charge higher than 0.65.

From this it can be concluded that, regardless of the level of the cost of providing access, the social planner prefers infrastructure-based competition given the assumptions (i.e. high demand effect) made. The social planner thus stimulates both players to invest in their own fibre network by setting relatively high access charges.

*Proposition 1: For a high demand effect, the social planner prefers infrastructure-based competition irrespective of the level of the cost of providing access.*

## 4.5 Model with unregulated access charges

In order to get to know if access regulation is socially desirable, a model without mandatory unbundling of the incumbent's local loop will be solved in this section. In this case, the unregulated incumbent decides to provide access to the entrant or not and thus the incumbent instead of the social planner commits to a set of access charges.

The unregulated incumbent will only provide access if he earns more profits from doing so and thus the incumbent will influence the entrant´s investments in such a way so that his own profits will be maximized.

First, the access charges set by a myopic incumbent will be calculated. In this case, the incumbent does not take into account dynamic efficiency. The static access charges will generate highest profit for the incumbent in the sub games where the entrant buys access, i.e. in Baseline and Free ride. In deciding what access charges to set in a static setting, the incumbent will maximize his profits in Baseline and Free ride with respect to the access charges. This leads to,

$$a^{ur} = \frac{1}{2}(A + \beta x_I) + \frac{3}{5}c$$

where $a^{ur}$ shows the access charges set by the incumbent on the copper and fibre network, with $ur$ referring to an unregulated situation.

However, recall that the levels of the access charges that foreclose the entrant are equal to,

$$a^f = \frac{1}{2}(A + \beta x_I)$$

where $a^f$ is the level of the access charges above which the entrant will be foreclosed on the copper and fibre network.

When comparing the foreclosure levels of the access charges with the access charges set by the incumbent, it can be concluded that the entrant will be foreclosed by the incumbent as $a^{ur} \geq a^f$ for $c \geq 0$. The intuition behind this is that the incumbent is a monopolist in the static situation and can never earn more than the monopoly profit. As the cost of providing access is positive, he does not earn more than the monopoly profit by providing access to the entrant and therefore the incumbent will foreclose entry so as to safeguard his position in the market.

Additionally, when comparing the myopic access charges set by the unregulated incumbent and the social planner, it becomes clear that the unregulated incumbent sets higher access charges than the social planner. The incumbent acts as a monopolist and maximizes his own profits by foreclosing entry, while the social planner may find it beneficial to provide access to the entrant.

*Proposition 2: In a static setting, the unregulated incumbent sets higher access charges than the social planner prefers.*

The two scenarios with respect to the cost of providing access that have been described in the previous section with access regulation will also be described in the unregulated situation. First, the scenario with low cost of providing access will be explained.

### 4.5.1 Scenario 1: Low cost of providing access

Given the parameter assumptions and $c = 0.25$, Figure 8 (p.25) showed in which sub game the players end up for each combination of access charges. It is known that the incumbent wants to maximize its profits and therefore will set the access charges as high as possible in the sub games where the entrant buys access. Therefore, in the sub game Baseline the access charge on copper will be equal to $0.25 - \varphi$, and in the sub game Free ride the access charge on fibre will be set equal to $0.65 - \varphi$, where $\varphi$ is a negligible number.

Consequently, the incumbent will compare the profits generated in each sub game and will decide on what access charges to set. A simple comparison of the profits earned in each sub game leads to highest profits obtained in the sub game Baseline and thus in the game where the entrant buys access on the copper network.[11] Therefore, the incumbent will set the access charge on copper equal to,

$$a_c = 0.25 - \varphi$$

The level of the access charge on fibre does not influence the solution of the game as a copper charge of $0.25 - \varphi$ will make sure the players end up in the sub game Baseline.

Obviously, the incumbent will not foreclose the entrant as he now takes into account dynamic efficiency. By setting this access charge on copper, the incumbent will make sure the entrant does not invest in fibre and thus will prevent leapfrogging or infrastructure-based competition.

### 4.5.2 Scenario 2: High cost of providing access

When comparing this result to a situation where the cost of providing access is higher and equal to $c = 8$, the solution of the game with unregulated access charges changes. Again, the incumbent prefers to set the access charges as high as possible in Baseline and Free ride so as to maximize his profits. However, in these sub games, the access charges do not cover the cost of providing access and thus the incumbent makes a loss on providing access. Therefore, when comparing profits earned in each sub game, the incumbent prefers to end up in the sub game Infrastructure.[12] This is the same

[11] The values of the profit of the incumbent in each sub game can be found in the Appendix on page 57

[12] The values of the profit of the incumbent in each sub game can be found in the Appendix on page 57

result as was found in a situation with access regulation and thus the social planner and incumbent will end up in the same sub game for high cost of providing access. Also, the incumbent will set the access charge on the fibre network equal to,

$$a_f > 0.65$$

Again, the access charge on the copper network does not influence the investment incentives of the players for an access charge on the fibre network higher than 0.65.

Still, the question remains if the incumbent prefers to open up its network to the entrant in the first place.

Without unbundling, the incumbent is able to earn monopoly profits if the entrant decides not to enter the market. These monopoly profits are equal to, [13]

$$\pi_I^{M^*} = (\frac{A + \beta x_I}{2})^2 - F_I x_I$$

For low cost of providing access, the following holds,

$$\pi_I^M \geq \pi_I^S \geq \pi_I^I$$

where $M$ refers to profits earned in a monopoly situation, $S$ to profits earned under service-based competition, and $I$ to profits earned under infrastructure-based competition.

Hence, the incumbent would be better off in the market alone and thus as a monopolist. This implies that if the entrant had not been able to invest in more advanced technology, the incumbent would have denied unbundled access to its local loop and thus preempted competition. However, in the model, the entrant is able to bypass the incumbent by investing in a fibre network. This changes the preferences of the incumbent as the incumbent earns even less money if infrastructure-based competition prevails. Therefore, the incumbent prefers unbundled access to its local loop and he would set the access charges on the copper and fibre network so that the entrant would buy access from the incumbent´s copper network. Thus in this scenario, the incumbent would stick to the strategy determined before and will set the following access charge on the copper network so as to end up in the sub game Baseline,

$$a_c = 0.25 - \varphi$$

Alternatively, for high cost of providing access the following holds,

$$\pi_I^M \geq \pi_I^I \geq \pi_I^S$$

Again, the incumbent prefers to act as a monopolist, but he understand the entrant is able to bypass him by investing in his own fibre network. Although, service-based competition leads to lowest profits, the incumbent prefers to open up his network and to set the access charges in order to influence the entrant's investment incentives. The incumbent wants to end up in the sub game Infrastructure, but by denying access it is also possible that he ends up in the sub game Leapfrog.

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[13] The derivations of the monopoly case can be found in the Appendix on page 57

Therefore, in order to safeguard his profits, the incumbent will stick to the strategy determined before and sets the following access charge on fibre,

$$a_f > 0.65$$

Note that the access charge on the copper network does not influence the investment incentives of the players for a fibre charge higher than 0.65.

*Proposition 3: The unregulated incumbent forecloses entry in a static setting, while he opens up his network to the entrant in a dynamic setting.*

Obviously, the strategies of the incumbent change with the level of the cost of providing access as these costs influence the revenue the incumbent earns on providing access. It becomes clear that in the dynamic setting and for low cost of providing access the unregulated incumbent prefers service-based competition and achieves this by setting low access charges, while the social planner prefers infrastructure-based competition and sets higher access charges. Alternatively, for high cost of providing access, the unregulated incumbent and social planner prefer the same sub game and set the same access charges.

*Proposition 4: In the dynamic setting and for low cost of providing access, the unregulated incumbent sets lower access charges than the social planner prefers, while in the dynamic setting and for high cost of providing access, the unregulated incumbent and social planner set the same access charges.*

## 4.6 Sensitivity analysis

This section will provide a sensitivity analysis of the propositions found in previous sections. This sensitivity analysis will focus on the demand effect as this is the most important decision variable for both players.

In previous sections, a demand effect of 0.8 was taken into account. For this demand effect, infrastructure-based competition was socially desirable irrespective of the level of the cost of providing access. For the sensitivity analysis, an alternative scenario with a lower demand effect, i.e. $\beta = 0.3$, will be studied. The remaining parameter assumptions remain unchanged.

### 4.6.1 Scenario 1: Low cost of providing access

In the first scenario, the cost of providing access is equal to 0.25 per unit of access sold. This leads to the sub games played for each combination of access charges given in Figure 11 (p.33).

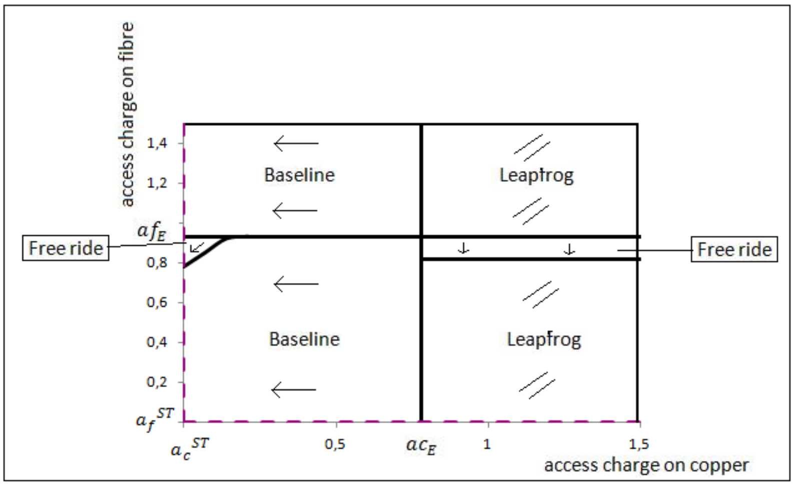


**Figure 11: Sub games for a low demand effect and low cost**

The most important change with respect to the previous situation is that the sub game Infrastructure will not be played at all. The demand effect is too low to convince both players to invest. Therefore, the solutions of the game will change. Again, the arrows in the figure refer to the direction of the local optima and total welfare is constant in Leapfrog. In this situation, the social planner generates highest social welfare in the sub game Baseline.[14] The demand expansion of investing in fibre is too low to stimulate one or two of the players to invest. Consequently, the social planner will set,

$$a_c = 0$$

Also, the social planner will make sure that the access charge on fibre will not be between 0.78 and 0.93 as this would convince the incumbent to invest, while investments in fibre are not socially desirable.

The unregulated incumbent prefers to end up in the same sub game as the social planner as this would give him access revenue without the need to invest in fibre. However, the incumbent generates highest profits in this sub game by setting the access charge on copper as high as possible and thus equal to,

$$a_c = 0.78 - \varphi$$

The level of the access charge on fibre does not influence the solution of the game as a copper charge of 0.78 will make sure the players end up in the sub game Baseline and thus investments by the entrant are prevented. As in the previous section, the incumbent prefers to open up his network for low cost of providing access as denying access would lead to fewer profits.

### 4.6.2 Scenario 2: High cost of providing access

Alternatively, for higher cost of providing access, i.e. $c = 8$, Figure 12 (p.33) shows the sub games for each combination of access charges.

[14] The values of total welfare and the profit of the incumbent in each sub game can be found in the Appendix on page 57

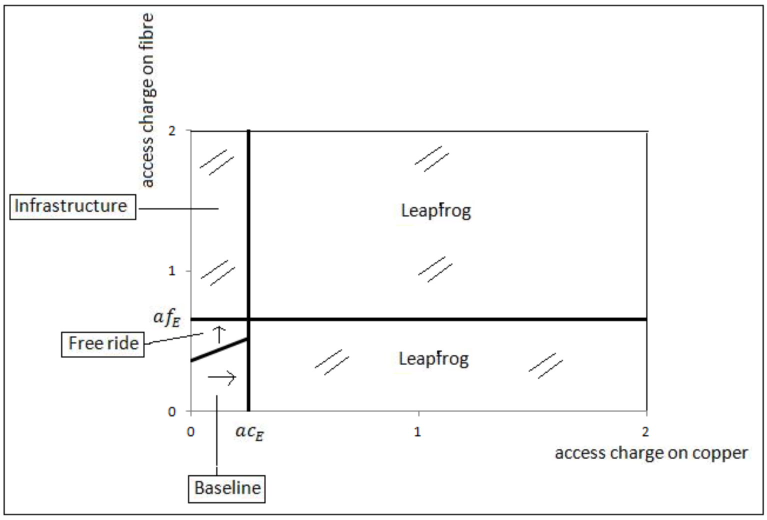


**Figure 12: Sub games for a low demand effect and high cost**

In this case, the social planner prefers to end up in the sub game Leapfrog and thus prefers the entrant to invest, while the incumbent stays at the copper network[15] as the incumbent makes a loss on providing access. Investments of both players involve high cost, which outweigh the benefits of an increased demand effect. Hence, the social planner will set,

$$a_c > 0.78$$

and the access charge on fibre does not influence the results.

Again, the unregulated incumbent has the same preferences as the social planner. The reason for this is that the incumbent makes a loss on providing access and the fixed cost of investing does not outweigh the benefits of having a fibre network. Therefore, also the incumbent will set,

$$a_c > 0.78$$

Like in the previous section, also for high cost of providing access, the incumbent prefers to open up his network to the entrant so as to make sure the sub game Leapfrog prevails instead of another sub game.

*Proposition 5: In a dynamic setting and for a low demand effect, the incumbent and social planner have the same preferences with respect to the sub game in which they would like to end up irrespective of the level of the cost of providing access. Yet, the access charges they, independently, set to accomplish ending up in this sub game do not always coincide.*

## 4.7 Comparison of solutions found with and without access regulation

From the above, it can be concluded that the level of the demand effect indeed influences the strategies of the players in the market significantly. Therefore, the solutions of the game, both with

[15] The values of total welfare and the profit of the incumbent in each sub game can be found in the Appendix on page 57

and without access regulation, differ for different demand effects. Moreover, the access charges set by a social planner and unregulated incumbent differ in a static and dynamic setting.

For a low demand effect and low cost of providing access the social planner prefers service-based competition, while for a low demand effect and high cost of providing access the social planner prefers investments by only one player in the market. Alternatively, for a high demand effect the social planner prefers infrastructure-based competition irrespective of the level of the cost of providing access.

The unregulated incumbent's preferences are equal to the social planner's preferences except for the case where the demand effect is high and the cost of providing access is low. In this case, the incumbent prefers service-based competition instead of infrastructure-based competition.

Table 5 summarizes the dynamic access charges set by the social planner (SP, with access regulation) and incumbent (I, without access regulation) in each situation.

| | **Low demand effect** | **High demand effect** |
|---|---|---|
| **Low cost of providing access** | SP prefers Baseline: $a_c = 0$<br>I prefers Baseline: $a_c = 0.78 - \varphi$ | SP prefers Infrastructure: $a_c > 0.25$, $a_f > 0.25$<br>I prefers Baseline: $a_c = 0.25 - \varphi$ |
| **High cost of providing access** | SP prefers Leapfrog: $a_c > 0.78$<br>I prefers Leapfrog: $a_c > 0.78$ | SP prefers Infrastructure: $a_f > 0.65$<br>I prefers Infrastructure: $a_f > 0.65$ |

**Table 5: Dynamic access charges & sub games $I$ and $SP$ prefer**

From this table it can be seen that for a low demand effect and low cost of providing access the same sub game (Baseline) will be played, but the unregulated incumbent sets higher access charges than the social planner in order to maximize his profits in Baseline. Yet, the access charge is still low enough to prevent the entrant to invest in fibre. Still, a situation without access regulation is not socially desirable as deadweight losses increase due to the maximization of the incumbent's profits.

Also, for a high demand effect and low cost of providing access, a situation without access regulation is not socially desirable as the unregulated incumbent sets access charges that are too low in order to prevent the entrant to invest in fibre and to end up in Baseline. The social planner, on the other hand, stimulates investments by the entrant so as to end up in Infrastructure and thus a situation without access regulation leads to fewer investments than what is socially desirable.

*Proposition 6: In the dynamic setting and for low cost of providing access, access regulation is socially desirable irrespective of the demand effect of investing in fibre.*

Yet, for high cost of providing access the social planner and incumbent will end up in the same sub game (i.e. Infrastructure) by setting similar access charges. The cost of providing access is too high, which discourages service-based competition from a social and unregulated incumbent's point of view. In this case, a situation without access regulation might be socially desirable, especially in case regulation brings along cost and distorts the market. Yet, the model did not include cost of regulation and therefore the social planner is indifferent between a situation with or without access regulation for high cost of providing access.

*Proposition 7: In the dynamic setting and for high cost of providing access, the social planner is indifferent between applying access regulation or not irrespective of the demand effect of investing in fibre.*

Additionally, the access charges in a static and dynamic setting can be compared. Table 8 shows the access charges set by a social planner (SP) and unregulated incumbent (I) in a static setting.

| | **Low demand effect** | **High demand effect** |
|---|---|---|
| **Low cost of providing access** | SP: $a_c = 0, a_f = 0$<br>I: $a_c = 20.15, a_f = 20.30$ | SP: $a_c = 0, a_f = 0$<br>I: $a_c = 20.15, a_f = 20.55$ |
| **High cost of providing access** | SP: $a_c = 8, a_f = 7.7$<br>I: $a_c = 24.8, a_f = 24.95$ | SP: $a_c = 8, a_f = 7.2$<br>I: $a_c = 24.8, a_f = 25.2$ |

**Table 6: Static access charges with and without access regulation**

From Proposition 2 it is already know that the unregulated incumbent sets higher myopic access charges than the social planner. When comparing the static access charges to the dynamic setting, the unregulated incumbent also sets higher dynamic access charges for a low demand effect and low cost of providing access and creates deadweight losses. Yet, for a high demand effect and low cost of providing access, the social planner sets higher dynamic access charges than the unregulated incumbent. When investments come into play, the unregulated incumbent prefers to open up his network so as to prevent leapfrogging or infrastructure-based competition and thus does not foreclose the entrant anymore and sets lower access charges. The social planner benefits from high demand effects and sets higher charges than what would have been socially desirable in the static setting so as to make sure both players invest. Hence, access charges set in a static and dynamic setting differ substantially.

*Proposition 8: The entrant's possibility to invest in fibre change the access charges set by the social planner and unregulated incumbent substantially.*

## 4.8 Extension of the model: committing to access charges

In the extension of the model, only the model with access regulation and a high demand effect (i.e. $\beta = 0.8$) will be discussed. The following assumptions are added to the original model description:

1) In the first period (year 1) it is not possible to build a fibre network and therefore the entrant can only enter the market by buying access from the incumbent's copper network (i.e. Baseline will be played in year 1)
2) The social planner commits to the access charge on copper set in the first period and thus cannot adapt this access charge in the second period (year 2), when fibre is introduced

Now, the social planner has to take into account that his actions in the first period influence the sub games to be played in the second period. In order to determine which access charges the social planner will set, welfare obtained in the two periods has to be maximized. The discount factor is assumed to be 5% per year and the following simplified formula is used to calculate total welfare over two years:

$$TW = W(a_c) + \frac{W(a_c,\ a_f)}{1.05}$$

Again, the two scenarios with respect to the level of the cost of providing access will be distinguished.

**4.8.1 Scenario 1: Low cost of providing access**

Before, the social planner would set the access charges equal to,

$$a_c > 0.25$$

$$a_f > 0.65$$

so that both players invest in fibre. However, now it is not possible for the players to invest in fibre in the first period and the players end up in Baseline in this period. Still, the social planner can decide what access charge on copper to set in the first period. By setting the access charge on copper as low as possible highest social welfare can be obtained in Baseline. However, a higher access charge on copper can stimulate the players to invest in the second period. Thus, the social planner can obtain static efficiency in the first period by setting an access charge on copper as low as possible, but needs to set a higher charge in this first period in order to obtain dynamic efficiency in the second period. Therefore, the social planner faces a fierce trade off between static and dynamic efficiency.

The following combinations of sub games in the first and second period, respectively, can be played: 'Baseline-Baseline', 'Baseline-Leapfrog', 'Baseline-Free ride' and 'Baseline-Infrastructure'. The social planner will choose the combination of access charges that generates highest total welfare over the two periods.

When comparing total welfare generated in each combination of sub games over the two periods, it becomes clear that the social planner generates highest welfare when the players play Baseline in year 1 and Infrastructure in year 2.[16] Therefore, the social planner has to set the access charge on copper higher in year 1 than what would have been socially optimal when only taking into account one period, in order to end up in the sub game Infrastructure in the second period. Given a period of two years, in the first period the social planner needs to set the access charge on copper equal to,

$$a_c = 0.25 + \varphi$$

where $\varphi$ is again a negligible number.

[16] The derivations of this result can be found in the Appendix on page 58

This access charge reduces static efficiency and the incumbent's incentives to invest as he is able to earn higher access revenue. Yet, the high access charge on copper stimulates the entrant to invest in the second period.

As the social planner is commited to the copper access charge and cannot change it in the second period, the social planner has to set the access charge on fibre sufficiently high in the second period so that the both players end up in Infrastructure. In the second period the social planner will set the access charges equal to,

$$a_c = 0.25 + \varphi$$

$$a_f > 0.65$$

When comparing this result to the results found when taking into account only one period, it becomes clear that the value of the access charge on copper matters when taking into account two periods. This charge has to be set as low as possible so that high welfare is obtained in the first period, but has to be set high enough at the same time so that both players invest in the second period. When only taking one period into account, the values of the access charges did not matter as long as they were set high enough so that both players were stimulated to invest.

#### 4.8.2 Scenario 2: High cost of providing access

With only one period, the social planner set the access charges equal to,

$$a_f > 0.65$$

The access charge on copper did not matter as the access charge on fibre was set sufficiently high so that both players were stimulated to invest.

With two periods, the social planner will compare total welfare obtained in the two periods just like in the previous section. Again social welfare is maximized when the players play Baseline in the first period and Infrastructure in the second period.[17] It is known from the previous section that for high cost of providing access the optimal access charges in a static setting are positive. As the players can only play Baseline in the first period and cannot invest in fibre, the social planner will set the access charge on copper equal to the optimal access charge in a static setting. Note that this is the opposite of the copper access charge with low cost of providing access, as in this case the copper charge was set as low as possible.

Setting the access charge on copper equal to the optimal access charge in a static setting will already make sure the entrant invests in fibre in the second period as the benefits of investing outweigh the cost. Moreover, in order to convince the incumbent to invest as well in the second period, the access charge on fibre has to be set high enough. In conclusion, the social planner will set the following access charges for high cost of providing access,

$$a_c = 8 = a_c^*$$

$$a_f > 0.65$$

[17] The derivations of this result can be found in the Appendix on page 58

Again, it is important to attach a certain value to the access charge on copper in the first period so as to make sure highest welfare is obtained in this period.

Obviously, the access charge set in the first period has a huge impact on investments in the second period and thus it is important that social planners take this into account when committing to access charges.

*Proposition 9: Committing to access charges can influence investments in new technologies significantly.*

# 5 Discussion of Results

Two models have been compared: a model with regulated access charges and a model with unregulated access charges. In the model with access regulation, the social planner set the access charges so that total welfare was maximized, while without access regulation, the unregulated incumbent set the access charges so that his profits were maximized. The models distinguished between two different networks: a copper and fibre network. The incumbent was vertically integrated on the copper network and the entrant could either enter (i) service-based by buying access from the incumbent's network, or (ii) infrastructure-based by investing in its own fibre network. Moreover, the incumbent was able to invest in his own fibre network as well. The players based their investment decisions on the access charges set in the market and the strategies of the other player.

In both models, the access charges set on copper and fibre in a static and dynamic setting have been derived. An important result is that the access charges set by the social planner and unregulated incumbent differ in both settings.

***Static setting***
In the static setting, the unregulated incumbent sets higher access charges than the social planner. The unregulated incumbent can earn highest profits, i.e. monopoly profits, by foreclosing entry and therefore does not opens up his network to the entrant and sets the access charges on copper and fibre equal to the foreclosure levels. The social planner, on the other hand, sets lower access charges so that the entrant enters the market, competition prevails and deadweight losses can be reduced.

***Dynamic setting***
Yet, in the dynamic setting, the investment incentives of the entrant are taken into account, which changes the behaviors of the social planner and unregulated incumbent. The models distinguished between high and low demand effects and high and low cost of providing access. The demand effect refers to increases in demand as a consequence of investing in fibre. The cost of providing access refers to the cost incurred by the incumbent per unit of access sold.

For low cost of providing access, the preferences of the social planner and unregulated incumbent with respect to the access charges are not aligned. The social planner will set lower access charges than the unregulated incumbent if the demand effect is low, although they both want service-based competition on the copper network to prevail. The intuition behind this is that the social planner diminishes deadweight losses by setting the access charge on copper as low as possible. The benefits of investing do not outweigh the cost and therefore investments are not socially desirable. The unregulated incumbent, however, maximizes his own profits by setting the access charge on copper as high as possible. Yet, he will not set this access charge too high as this would trigger investments in fibre by the entrant. Consequently, the access charge set by the unregulated incumbent creates deadweight losses and access regulation is preferred.

Alternatively, for a high demand effect, the access charges set by the social planner are higher than the charges set by the unregulated incumbent. This finding is in accordance with the results found by Bourreau et al. (2005). For a demand effect this high, the social planner prefers infrastructure-based competition as the benefits to society are high and outweigh the cost of having two fibre networks.

The players stimulate each other to invest, and thus complement each other, resulting in the highest demand increase that can be achieved. For high access charges, the profits of the players do not depend on the access charges anymore as no one buys access. Without this high access charge, the entrant will not adopt the new technology or too late, meanwhile total welfare would improve significantly by adopting the new technology. Hence, the access charges need to increase in order to stimulate infrastructure-based competition. This is in accordance with the intuition behind the LOI approach: increasing access charges stimulate infrastructure-based competition.

Nevertheless, the unregulated incumbent still prefers service-based competition on the copper network although the demand effect of investing is high. The incumbent does not want to lose his position in the market and thus prevents leapfrogging and competition from a higher quality network. Moreover, he earns high revenues from providing access as the cost of providing access is low and is discouraged to invest due to the high positive spillovers to the entrant´s demand. Thus, while the social planner wants to accelerate investments by setting high access charges, the unregulated incumbent sets low access charges to safeguard his current position in the market. The charges set by the unregulated incumbent lead to fewer investments than what is socially desirable and the entrant adopts the technology too late from a social planner's point of view. Thus, access regulation is preferred.

For high cost of providing access, the preferences of the social planner and unregulated incumbent are aligned. Depending on the demand effect, they prefer infrastructure-based competition or leapfrogging and set high access charges so that the entrant is stimulated to invest in fibre. Due to the high cost of providing access, the incumbent makes a loss on providing access and is better off if infrastructure-based competition prevails (high demand effect) or may even be better off in case only the entrant invests (low demand effect). From a social planner's point of view, infrastructure-based competition is preferred as it would be inefficient to provide access to the entrant. Infrastructure-based competition enhances competition and diminishes deadweight losses. Yet, for a low demand effect, the incumbent does not find it worthwhile to invest and the social planner is not able to stimulate him to invest. Therefore, in this case, highest welfare is obtained if only the entrant invests.

***Comparison of static and dynamic setting***

From the above it becomes clear that for low cost of providing access the unregulated incumbent forecloses entry in a static setting, while he opens up his network in a dynamic setting so that service-based competition prevails and the entrant does not invest in fibre.

The social planner, on the other hand, is highly influenced by the demand effect of investing in fibre. If the demand effect is high, investments by both players are preferred and the social planner sets higher access charges than in the static setting, while for a low demand effect the social planner makes sure no investments take place and sets lower access charges than in the static setting. Overall, access regulation is preferred for low cost of providing access regardless of the demand effect.

For high cost of providing access, however, the social planner and unregulated incumbent prefer investments in fibre by either one or both players depending on the demand effect and achieve this by setting the same access charges. These charges are higher than the social planner would set in a static setting and may be equal to the access charges the unregulated incumbent sets in a static setting. The latter is explained by the fact that the unregulated incumbent forecloses entry in a static setting and prefers investments by the entrant in a dynamic setting. By setting the access charge equal to the foreclosure level in the dynamic setting, the incumbent makes sure the entrant bypasses the infrastructure of the incumbent by investing in its own fibre network.

As the access charges set by the unregulated incumbent and social planner are the same in the dynamic setting regardless of the demand effect, the social planner is indifferent between applying access regulation or not. Yet, in case access regulation brings along cost and distorts the market, self-regulation of the market would be socially desirable for high cost of providing access.

Moreover, it becomes clear that when access regulation is applied, the social planner should properly take into account the demand effect and cost of providing access. These variables change the investment incentives of the players in the market and the optimal investments from a welfare point of view significantly. This may imply that different countries or regions may call for different combinations of access charges. For example, in dense areas the cost of providing access may be lower than in less dense areas as the end-users' premises are closer to the local exchanges or because more premises are reached from one local exchange. Also, demand effects depend on amongst others the technology being adapted, the amount of end-users that can be reached and network effects. In the Netherlands, the demand expansions are proven to be higher in smaller villages than in large cities. The reason for this is that people know each other well in small villages and stimulate each other to connect to the new network via word-of-mouth advertisement. Therefore, in order to achieve optimal investments and highest social welfare, it may be socially desirable to adopt different strategies for different regions and countries. Yet, this kind of dynamic access regulation may be hard to apply in practice due to practices related to discrimination and information asymmetries.

***Committing to access charges***

Another result was found in the extension of the model. Here, the social planner was committed to the access charge on copper set in the first period and could not adapt this charge with the introduction of fibre. Consequently, the social planner faced a fierce trade off between static efficiency in the first period and dynamic efficiency in the second period.

For low cost of providing access, the social planner prefers to set the access charge on copper as low as possible so as to obtain high welfare in the first period, but at the same time this charge has to be high enough so that the entrant is convinced to invest in the second period. Alternatively, for high cost of providing access, the social planner will set the access charge on copper high so that the incumbent is able to earn some revenue in the first period. In addition, this high access charge makes sure the entrant invests in the second period.

Moreover, the access charge set on fibre with the introduction of fibre will influence the investment made by the incumbent. In case, the social planner prefers both players to invest, this fibre charge has to be set high enough.

From this it becomes clear that a low access charge on copper in the first period guarantees static efficiency, but a higher access charge stimulates dynamic efficiency in the second period. Hence, the social planner has to carefully take into account the implications of committing to access charges.

While committing to access charges makes sure players behave in a socially desirable way, these same access charges can influence the investments made in new technologies significantly. Therefore, instead of only taking into account static efficiency, the social planner needs to consider dynamic efficiency.

***Coherences between access charges***

Another implication of the results found is that the access charge set on the fibre network does not have to be higher than the access charge set on the copper network in order to convince the players to invest, as was argued by Bourreau et al (2012). Rather, it becomes clear that the investment incentives of the players in the market do not always depend on both access charges. As long as one of the access charges is below or above a certain threshold level the players will refrain from investing or alternatively, invest in fibre. The access charge on copper or fibre has to be low enough to stimulate the entrant to buy access, or high enough to convince the entrant to invest. Subsequently, the incumbent will be stimulated to invest or not depending on the strategies of the entrant. Moreover, even when the access charges are set equal, both players may still be stimulated to invest as long as they are set high enough.

# 6 Conclusion

## 6.1 Conclusions and recommendations

The research question of this thesis was ´Should access regulation be applied to NGANs?’. Given the results of the analysis, the answer to this question is yes.

The models developed to answer this question, described the investment incentives of an incumbent and entrant in the transition period towards NGANs. The models distinguished between a regulated and unregulated situation. The results showed that especially for low cost of providing access, a situation in which an unregulated incumbent can set the access charges on copper and fibre is not socially desirable. The unregulated incumbent will set the access charges either too low from a social point of view as the incumbent wants to prevent investments by the entrant, or too high as the incumbent solely takes into account his own profit maximization. Therefore, the social planner can achieve higher social welfare. For high cost of providing access, the social planner is indifferent between applying access regulation or not, as the social planner and unregulated incumbent prefer the same amount of investments and achieve this by setting identical access charges. The reason why the unregulated incumbent’s interests are aligned with the interests of the social planner is that the incumbent makes a loss on providing access and thus prefers the entrant to invest and not to buy access from his network. In case access regulation brings along cost and increases inefficiencies in the market, self-regulation may be socially desirable for high cost of providing access. However, cost of regulation was not included in the model.

The entrant´s possibility to invest in fibre changed the access charges set by a social planner and unregulated incumbent significantly. In a static setting, the unregulated incumbent forecloses the entrant by setting high access charges. In this way, the incumbent makes sure he earns the highest possible profits, i.e. the monopoly profits. When taking into account the investment incentives of the entrant however, the incumbent opens up his network by setting lower access charges so as to make sure the entrant does not bypass his infrastructure by investing in his own fibre network. Thus, the incumbent makes sure no competition from a higher quality network prevails. The social planner, on the other hand, may set higher access charges in a dynamic setting than in a static setting. When investments in fibre bring along a high demand expansion, the social planner may be triggered to stimulate both players to invest in fibre. The social planner achieves this by setting high access charges on copper and fibre. Yet, in the static setting, the social planner would set lower access charges so as to make sure the entrant enters, competition prevails and deadweight losses can be reduced.

The demand effect of investing in fibre changes the investment incentives of the players in the market and therefore the access charges set by a social planner and unregulated incumbent. For a high demand effect, the social planner prefers infrastructure-based competition, while the unregulated incumbent may prefer service-based competition on the copper network as positive spillovers to the entrant’s demand and investment cost outweigh the benefits of investing. For a low demand effect, the social planner and unregulated incumbent both prefer service-based competition on the copper network, but set different access charges to achieve this.

Also, the cost of providing access influence the access charges set by a social planner and unregulated incumbent. For high cost of providing access, they both stimulate investments as the incumbent makes a loss on providing access, while for low cost of providing access service-based competition may be called for.

As the demand effect and cost of providing access influence investment incentives of players in the market and therefore the access charges set by a social planner significantly, setting different combinations of access charges for different regions and/or countries depending on these variables may be socially desirable. By doing this, inefficiencies are reduced, and optimal investments and highest social welfare achieved. Yet, in practice, it might be difficult to apply different sets of rules to for example a less densely and densely populated area due to information asymmetries and discrimination practices.

Finally, the social planner has to carefully take into account the implications of committing to access charges. If the regulator commits to a rather low access charge on one network, it may impede investments in new technologies. Therefore, the social planner faces a fierce trade off between static efficiency in the short term and dynamic efficiency in the long term. The social planner has to set clear policy goals for the short and long term, and include the effects on dynamic efficiency when setting access charges on current networks. Only by doing this, a future with constantly developing and improving technologies is encouraged, productivity growth and innovation is stimulated and the increasing use and demand for bandwidth is met.

## 6.2 Limitations and future research

Just like almost any other model in the literature, the model presented in this thesis includes some limitations.

***Cannibalization***

As mentioned in the literature overview, incumbents are hesitant to investing in a new technology due to the cannibalization of their old network. This network will become redundant and profits foregone. Therefore, incumbents have an incentive to delay investments and to benefit from the old networks as long as possible. The model does not include this cannibalization problem. However, even with cannibalization in mind, incumbents may still be stimulated to invest if their rivals invest as they are not able to compete on (at least) an equal level playing field if they refrain from investing.

***Pressure from other players in the market***

In reality, more than two players can exist in a market, which all put pressure to invest on each other. In the Netherlands, for example, not only telecom operators, but also cable companies, municipalities and private parties influence the investment incentives of the incumbent.

***Asymmetric information***

Oldale & Padilla (2004) mentioned that it is difficult for social planners to set the right access charges due to time and resource constraints. Accordingly, social planners cannot overcome the asymmetric information in the market. This also applies to the results of this model. It is rather difficult for the social planner, if not impossible, to discover the exact demand effect, spillovers, cost of providing access, fixed cost and absolute advantage. Therefore, it is only possible to approach these variables as much as possible and to set the access charges according to the estimates. Moreover, incentive regulation on top of access regulation may be called for.

***Switching cost***

As may be recalled from the literature overview, consumers do not easily switch providers in the broadband market. This may be caused by a lack of transparency, associated cost or for example time constraints. Therefore, a demand effect due to investments in fibre is not as straightforward as in the model. Also, consumers may stay with their current provider and thus do not buy from the entrant the moment he enters the market. Switching cost are not included in the model for simplicity, but they may alter the obtained solutions and intuitions.

***Assumptions***

Additionally, the assumptions made in the model simplify the derivations of the solutions, but also make the results less realistic. Marginal cost of operating the network is usually not equal to zero and the fibre network might have a lower or higher absolute advantage than the copper network. However, these assumptions were required to obtain straightforward results. Also, the model does not lose its generality by making these assumptions.

***Two networks can operate simultaneously***

The model assumed that once the incumbent invested in fibre his copper network was not in use anymore. However, in reality the incumbent can operate both networks simultaneously, especially in the transition period towards NGANs. Also, the entrant can buy access from both the copper and fibre network or invest in fibre and buy access from the incumbent's copper network. Therefore, players can have revenues from both networks at the same time. Yet, the assumption was made for simplicity and with the future in mind. At one point, the copper network will not be used anymore as consumers prefer the higher quality network. Moreover, the incumbent will use the copper network as long as he makes profits on this network, but will switch to the fibre network once he starts to make losses.

***Entrant and providing access***

In case, the entrant invests first he is able to provide access to the incumbent. This is not included in the model. However, the solution would have been the same as in the game where the incumbent provides access to the entrant on the fibre network. Thus, the entrant would have been the incumbent in this case.

***Large area cannot be covered at once***

Rolling out a NGAN is costly and time-consuming and therefore players in the market will most likely refrain from rolling out a large area at once. Instead, they will start with the most profitable ones. The model did not take this into account and assumed that the NGAN was rolled out at once.

***Replacement effect***

Bourreau et al. (2005) suggest that access regulation delays the adoption of new technologies by entrants. However, the model does not include this so-called replacement effect. In reality, it is possible that the entrant first buys access to the local loop and invests later on, however this is not possible in the model presented in this thesis. Yet, the model considers a completely new network on which the entrant can gain a first-mover advantage as well. Moreover, both players need to invest in their reputation on the fibre market. Therefore, as the players begin on an equal level playing field in the fibre market, the entrant might be more tempted to invest immediately in his own fibre network, which abolishes the replacement effect.

Overall, future research can complete the model presented in this thesis by including the above mentioned limitations. In my opinion, cannibalization, pressure from other players, and switching cost are the most important variables to include in a future model. With respect to the incumbent, cannibalization and switching cost may discourage his investments, while pressure from other players may encourage investments in fibre so as to gain a first-mover-advantage.

The entrant, on the other hand, is stimulated to invest by cannibalization as he is able to steal the incumbent's end-users with his own fibre network. Also, pressure from other players may encourage investments by the entrant to make sure he is the first player to invest. Switching cost, however, may discourage the entrant's investments as these costs make it hard to capture end-users and to earn revenue.

In conclusion, taking into account i) cannibalization, ii) switching cost and iii) pressure from other players in the market, will give additional insights and contribute to the intuition behind the access charges set by the social planner presented in this thesis.

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# 8 Appendix

## 8.1 Static setting

### 8.1.1 Myopic access charges

$$U(q_I, q_E) = Aq_I + Aq_E + \beta q_I(x_I + x_I x_E) + \beta q_E(x_E + x_I) - \frac{1}{2}(q_I^2 + q_E^2 + 2q_I q_E)$$

***Access charge on copper network***

$$x_I = x_E = 0$$

$$U(q_I, q_E) = Aq_I + Aq_E - \frac{1}{2}(q_I^2 + q_E^2 + 2q_I q_E)$$

$$Total\ welfare = CS + \pi_I + \pi_E$$

$$\leftrightarrow$$

$$Aq_I + Aq_E - \frac{1}{2}(q_I^2 + q_E^2 + 2q_I q_E) - p_I q_I - p_E q_E + p_I q_I + (a_c - c)q_E + p_E q_E - a_c q_E - F_{Ea}$$

$$\leftrightarrow$$

$$Aq_I + Aq_E - \frac{1}{2}(q_I^2 + q_E^2 + 2q_I q_E) - cq_E - F_{Ea}$$

Social planner maximizes this function with respect to $a_c$:

$$\frac{\partial TW}{\partial a_c} = A\frac{\partial q_I}{\partial a_c} + A\frac{\partial q_E}{\partial a_c} - \frac{1}{2}\left(2q_I\frac{\partial q_I}{\partial a_c} + 2q_E\frac{\partial q_E}{\partial a_c} + 2(q_I\frac{\partial q_E}{\partial a_c} + \frac{\partial q_I}{\partial a_c}q_E)\right) - c\frac{\partial q_E}{\partial a_c}$$

$$\frac{\partial q_I}{\partial a_c} = \frac{1}{3}$$

$$\frac{\partial q_E}{\partial a_c} = \frac{-2}{3}$$

$$Thus,$$

$$-\frac{1}{3}A - \left(\frac{A + a_c}{9}\right) + \left(\frac{2A - 4a_c}{9}\right) + \left(\frac{2A + 2a_c}{9}\right) - \left(\frac{A - 2a_c}{9}\right) + \frac{2}{3}c$$

$$\leftrightarrow$$

$$a_c{}^{ST} = 6c - A$$

***Access charge on fibre network***

$$x_I = 1\ and\ x_E = 0$$

$$U(q_I, q_E) = Aq_I + Aq_E + \beta q_I + \beta q_E - \frac{1}{2}(q_I^2 + q_E^2 + 2q_I q_E)$$

$$Total\ welfare = CS + \pi_I + \pi_E$$

$$\leftrightarrow$$

$$Aq_I + Aq_E + \beta q_I + \beta q_E - \frac{1}{2}(q_I^2 + q_E^2 + 2q_I q_E) - p_I q_I - p_E q_E + p_I q_I + (a_f - c)q_E - F_I + p_E q_E - a_f q_E - F_{Ea}$$

$$\leftrightarrow$$

$$Aq_I + Aq_E + \beta q_I + \beta q_E - \frac{1}{2}(q_I^2 + q_E^2 + 2q_I q_E) - cq_E - F_I - F_{Ea}$$

Social planner maximizes this function with respect to $a_f$:

$$\frac{\partial TW}{\partial a_f} = A\frac{\partial q_I}{\partial a_f} + A\frac{\partial q_E}{\partial a_f} + \beta\frac{\partial q_I}{\partial a_f} + \beta\frac{\partial q_E}{\partial a_f} - \frac{1}{2}\left(2q_I\frac{\partial q_I}{\partial a_f} + 2q_E\frac{\partial q_E}{\partial a_f} + 2(q_I\frac{\partial q_E}{\partial a_f} + \frac{\partial q_I}{\partial a_f}q_E)\right) - c\frac{\partial q_E}{\partial a_f}$$

$$\frac{\partial q_I}{\partial a_f} = \frac{1}{3}$$

$$\frac{\partial q_E}{\partial a_f} = \frac{-2}{3}$$

$$\leftrightarrow$$

$$-\frac{1}{3}A - \frac{1}{3}\beta - \left(\frac{A + \beta + a_f}{9}\right) + \left(\frac{2A + 2\beta - 4a_f}{9}\right) + \left(\frac{2A + 2\beta + 2a_f}{9}\right) - \left(\frac{A + \beta - 2a_f}{9}\right) + \frac{2}{3}c$$

$$\leftrightarrow$$

$${a_f}^{ST} = 6c - A - \beta$$

## 8.2 Model with access regulation

### 8.2.1 Cournot competition

***Cournot competition in Baseline***

Maximizing $\pi_i$ with respect to $q_i$ gives,

$$q_1^* = \frac{A + a_c}{3} = p_1^* = p_2^*$$

$$q_2^* = \frac{A - 2a_c}{3}$$

Plugging $q_i^*$ and $p_i^*$ into $\pi_i$ gives,

$$\pi_1^* = (\frac{A + a_c}{3})^2 + (a_c - c)(\frac{A - 2a_c}{3})$$

$$\pi_2^* = (\frac{A - 2a_c}{3})^2 - F_{Ea}$$

***Cournot competition in Leapfrog***

Maximizing $\pi_i$with respect to $q_i$ gives,

$$q_1^* = \frac{A-\beta}{3} = p_1^*$$

$$q_2^* = \frac{A+2\beta}{3} = p_2^*$$

Plugging $q_i^*$and $p_i^*$ into $\pi_i$ gives,

$$\pi_1^* = (\frac{A-\beta}{3})^2$$

$$\pi_2^* = (\frac{A+2\beta}{3})^2 - F_E$$

***Cournot competition in Free ride***

Maximizing $\pi_i$ with respect to $q_i$ gives,

$$q_1^* = \frac{A+\beta+a_f}{3} = p_1^* = p_2^*$$

$$q_2^* = \frac{A+\beta-2a_f}{3}$$

Plugging $q_i^*$ and $p_i^*$ into $\pi_i$ gives,

$$\pi_1^* = (\frac{A+\beta+a_f}{3})^2 + (a_f - c)(\frac{A+\beta-2a_f}{3}) - F_I$$

$$\pi_2^* = (\frac{A+\beta-2a_f}{3})^2 - F_{Ea}$$

***Cournot competition in Infrastructure***

Maximizing $\pi_i$ with respect to $q_i$ gives,

$$q_1^* = \frac{A+2\beta}{3} = q_2^* = p_1^* = p_2^*$$

Plugging $q_i^*$ and $p_i^*$ into $\pi_i$ gives,

$$\pi_1^* = (\frac{A+2\beta}{3})^2 - F_I$$

$$\pi_2^* = (\frac{A+2\beta}{3})^2 - F_E$$

**8.2.2 The entrant's decision**

***The incumbent invests in fibre***

$$\left(\frac{A+2\beta}{3}\right)^2 - F_E \geq \left(\frac{A+\beta-2a_f}{3}\right)^2 - F_{Ea}$$

$$(A+2\beta)(A+2\beta)-9F_E \geq (A+\beta-2a_f)(A+\beta-2a_f)-\ 9F_{Ea}$$

$$F_E \leq \frac{4}{9}a_f(A+\beta-a_f)+\frac{1}{3}\beta\left(\frac{2}{3}A+\beta\right)+F_{Ea}$$

***The incumbent stays at the copper network***

$$\left(\frac{A+2\beta}{3}\right)^2-\ F_E \geq \left(\frac{A-2a_c}{3}\right)^2-F_{Ea}$$

$$(A+2\beta)(A+2\beta)-\ 9F_E \geq (A-2a_c)(A-2a_c)-9F_{Ea}$$

$$F_E \leq \frac{4}{9}a_c(A-a_c)+\frac{4}{9}\beta(A+\beta)+F_{Ea}$$

### 8.2.3 Access charges so that the entrant invests

***Access charge on copper***

$$F_E \leq \frac{4}{9}a_c(A-a_c)+\frac{4}{9}\beta(A+\beta)+F_{Ea}$$

$$a_c(A-a_c)+\beta(A+\beta)+2\frac{1}{4}F_{Ea}-2\frac{1}{4}F_E$$

$$a_{Ec}=\frac{-A\pm\sqrt{A^2+4\beta A+4\beta^2+9F_{Ea}-9F_E}}{-2}$$

For $A=40, \beta=0.8, F=20, F_{Ea}=1$, the access charge is equal to: $0.25 \leq a_{Ec} \leq 39.75$

***Access charge on fibre***

$$F_E \leq \frac{4}{9}a_f(A+\beta-a_f)+\frac{1}{3}\beta\left(\frac{2}{3}A+\beta\right)+F_{Ea}$$

$$a_f(A+\beta-a_f)+\frac{3}{4}\beta\left(\frac{2}{3}A+\beta\right)+2\frac{1}{4}F_{Ea}-2\frac{1}{4}F_E$$

$$a_{Ef}=\frac{-A-\beta\pm\sqrt{A^2+3\beta A+4\beta^2+9F_{Ea}-9F_E}}{-2}$$

For $A=40, \beta=0.8, F=20, F_{Ea}=1$, the access charge is equal to: $0.65 \leq a_{Ef} \leq 40.15$

### 8.2.4 The incumbent's decision

***The entrant buys access on both networks***

$$(\frac{A+\beta+a_f}{3})^2+(a_f-c)(\frac{A+\beta-2a_f}{3})-F_I \geq (\frac{A+a_c}{3})^2+(a_c-c)(\frac{A-2a_c}{3})$$

$$(A+\beta+a_f)(A+\beta+a_f)+3(a_f-c)(A+\beta-2a_f)-9F_I$$
$$\geq (A+a_c)(A+a_c)+3(a_c-c)(A-2a_c)$$

$$F_I \leq \frac{5}{9}a_f\left(A+\beta+\frac{6}{5}c-a_f\right)-\frac{1}{3}\beta c_a+\beta\left(\frac{2}{9}A+\beta\right)-\frac{5}{9}a_c\left(A-\frac{6}{5}c-a_c\right)$$

***The entrant invests on copper and buys access on fibre***

$$(\frac{A+\beta+a_f}{3})^2+(a_f-c)(\frac{A+\beta-2a_f}{3})-F_I \geq \left(\frac{A-\beta}{3}\right)^2$$

$$(A+\beta+a_f)(A+\beta+a_f)+3(a_f-c)(A+\beta-2a_f)-9F_I \geq (A-\beta)(A-\beta)$$

$$F_I \leq -\frac{5}{9}a_f\left(a_f-A-\beta-\frac{6}{5}c\right)-\frac{1}{3}c(A+\beta)+\frac{4}{9}A\beta$$

***The entrant invests on both networks***

$$(\frac{A+2\beta}{3})^2 \ -F_I \geq \left(\frac{A-\beta}{3}\right)^2$$

$$(A+2\beta)(A+2\beta)-9F_I \geq (A-\beta)(A-\beta)$$

$$F_I \leq \frac{1}{3}\beta(2A+\beta)$$

**8.2.5 Total welfare in each sub game**

$$U(q_I,q_E)=Aq_I+Aq_E+\beta q_I(x_I+x_I x_E)+\beta q_E(x_E+x_I)-\frac{1}{2}(q_I^2+q_E^2+2q_I q_E)$$

***Baseline***

$$TW=Aq_I+Aq_E-\frac{1}{2}(q_I^2+q_E^2+2q_I q_E)-cq_E-F_{Ea}$$

$$q_1^*=\frac{A+a_c}{3}$$

$$q_2^*=\frac{A-2a_c}{3}$$

- $TW=(4A^2-Aa_c-\frac{1}{2}{a_c}^2-3c(A-2a_c)-9F_{Ea})/9$

***Leapfrog***

$$TW=Aq_I+Aq_E+\beta q_E-\frac{1}{2}(q_I^2+q_E^2+2q_I q_E)-F_E$$

$$q_1^*=(\frac{A-\beta}{3})$$

$$q_2^*=(\frac{A+2\beta}{3})$$

- $TW=(4A^2+4A\beta+5\frac{1}{2}\beta^2-9F_E)/9$

***Free ride***

$$TW=Aq_I+Aq_E+\beta q_I+\beta q_E-\frac{1}{2}(q_I^2+q_E^2+2q_I q_E)-cq_E-F_{Ea}-F_I$$

$$q_1^*=\frac{(A+\beta+a_f)}{3}$$

$$q_2^* = \frac{(A + \beta - 2a_f)}{3}$$

- $TW = (4A^2 + 8A\beta + 4\beta^2 - a_f(\frac{1}{2}a_f + A + \beta) - 3c(A + \beta - 2a_f) - 9(F_{Ea} + F_I))/9$

***Infrastructure***

$$TW = Aq_I + Aq_E + 2\beta q_I + 2\beta q_E - \frac{1}{2}(q_I^2 + q_E^2 + 2q_I q_E) - F_E - F_I$$

$$q_1^* = \frac{(A + 2\beta)}{3}$$

$$q_2^* = \frac{A + 2\beta}{3}$$

- $TW = (4A^2 + 16A\beta + 16\beta^2 - 9(F_E + F_I))/9$

### 8.2.6 Values of total welfare in each sub game

***High demand effect and low cost of providing access***

$$\boldsymbol{Baseline}: TW = 706.78$$

$$\boldsymbol{Leapfrog}: TW = 705.72$$

$$\boldsymbol{Free\ ride}: TW = 707.85$$

$$\boldsymbol{Infrastructure}: TW = 729.14$$

***High demand effect and high cost of providing access***

$$\boldsymbol{Baseline}: TW = 603.66$$

$$\boldsymbol{Leapfrog}: TW = 705.72$$

$$\boldsymbol{Free\ ride}: TW = 610.54$$

$$\boldsymbol{Infrastructure}: TW = 729.14$$

## 8.3 Model without access regulation

$$U(q_1, q_2) = Aq_1 + \beta q_1 x_1 - \frac{1}{2}q_1^2$$

$$P_I^M = A + \beta x_1 - q_I$$

$$\pi_I^M = (A + \beta x_1 - q_I)q_I$$

$$q_I^{M*} = \frac{A + \beta x_1}{2} = p_I^{M*}$$

$$\pi_I^{M*} = (\frac{A + \beta x_1}{2})^2$$

$$TW = \frac{3}{8}A^2 + \frac{3}{4}A\beta x_1 + \frac{3}{8}\beta^2 {x_1}^2$$

**8.3.1 Values of the profit of incumbent in each sub game**

***High demand effect and low cost of providing access***

$$\boldsymbol{Baseline}: \pi_I = 180.01$$

$$\boldsymbol{Leapfrog}: \pi_I = 170.74$$

$$\boldsymbol{Free\ ride}: \pi_I = 176.17$$

$$\boldsymbol{Infrastructure}: \pi_I = 172.82$$

***High demand effect and high cost of providing access***

$$\boldsymbol{Baseline}: \pi_I = 77.97$$

$$\boldsymbol{Leapfrog}: \pi_I = 170.74$$

$$\boldsymbol{Free\ ride}: \pi_I = 74.13$$

$$\boldsymbol{Infrastructure}: \pi_I = 172.82$$

## 8.4 Sensitivity analysis

***Low demand effect and low cost of providing access***

Total welfare:

$$\boldsymbol{Baseline}: TW = 706.78$$

$$\boldsymbol{Leapfrog}: TW = 696.50$$

$$\boldsymbol{Free\ ride}: TW = 694.06$$

$$\boldsymbol{Infrastructure}: TW = 692.60$$

Profit incumbent:

$$\boldsymbol{Baseline}: \pi_I = 191.61$$

$$\boldsymbol{Leapfrog}: \pi_I = 175.12$$

$$\boldsymbol{Free\ ride}: \pi_I = 177.63$$

$$\boldsymbol{Infrastructure}: \pi_I = 163.15$$

***Low demand effect and high cost of providing access***

Total welfare:

$$\boldsymbol{Baseline}: TW = 604.11$$

$$\boldsymbol{Leapfrog}: TW = 696.50$$

$$\boldsymbol{Free\ ride}: TW = 594.10$$

$$\boldsymbol{Infrastructure}: TW = 692.60$$

Profit incumbent:

$$\boldsymbol{Baseline}: \pi_I = 92.31$$

$$\boldsymbol{Leapfrog}: \pi_I = 175.12$$

$$\boldsymbol{Free\ ride}:\ \pi_I = 78.34$$

$$\boldsymbol{Infrastructure}: \pi_I = 163.15$$

## 8.5 Extension of the model: committing to access charges

***Low cost of providing access***

Baseline-Baseline:

$$a_c = 0$$

$$TW = 706.78 + \frac{706.78}{1.05} = 1379.90$$

Baseline-Leapfrog:

$$a_c = 0.26$$

$$TW = 705.66 + \frac{705.72}{1.05} = 1377.78$$

Baseline-Free ride:

$$a_c = 0.26$$

$$a_f = 0.42$$

$$TW = 705.66 + \frac{707.85}{1.05} = 1379.81$$

Baseline-Infrastructure:

$$a_c = 0.26$$

$$TW = 705.66 + \frac{729.14}{1.05} = 1400.08$$

***High cost of providing access***

Baseline-Baseline:

$$a_c = 0.25$$

$$TW = 603.66 + \frac{603.66}{1.05} = 1178.58$$

Baseline-Leapfrog:

$$a_c = 8$$

$$TW = 607 + \frac{705.72}{1.05} = 1279.12$$

Baseline-Free ride:

$$a_c = 0.25$$

$$a_f = 0.65$$

$$TW = 603.66 + \frac{610.54}{1.05} = 1185.13$$

Baseline-Infrastructure:

$$a_c = 8$$

$$TW = 607 + \frac{729.14}{1.05} = 1301.48$$