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Content providers and co-investment in broadband networks

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Abstract

In many countries, Next Generation Access networks (NGA) deployment and penetration rate proceed at a slower pace than expected. We argue that an *ex ante* contractual arrangement among access Internet Service Providers (ISPs) and Content Providers (CPs), which builds on the complementarity between infrastructure and content, can promote the roll out of NGA. Different from co-investment of ISPs, and from incentive policies based on access regulation, one such contract brings down the investment cost for the telecom industry, promotes end users' demand for improved connectivity, and internalizes investment externalities. We then study how the regulatory regime of the Internet affects firms' investment incentives. Using a simple model, we show that a departure from network neutrality, which allows the access ISP to negotiate with the CP a fee for priority delivery of content, has ambiguous effects on infrastructure investment. The ISP's and the CP's incentives to (co)-invest in NGA depend on the cost of investment and the CP's bargaining power *ex post* (when investment is sunk).

Keywords: Next Generation Access networks; Investment under uncertainty; *Ex-ante* and *ex-post* contracts; Network neutrality; Co-investment

JEL Classification: L13, L51, L96

*The views expressed in this paper are those of the authors only and not those of Telenor.

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1 Introduction

Next Generation Access networks (NGA) are widely recognized as a key factor to foster job creation and economic growth.[1] Nonetheless, in many countries, NGA deployment and penetration rate proceed at a slower pace and/or smaller extent than expected according to firms' investment plans and public targets.[2] We focus on three major causes for the slowdown of NGA development. First, NGA investment exhibits considerable sunk costs. Second, the return on investment is highly uncertain, depending on consumers' take up and valuation of NGA services. Third, NGA investment generates significant positive externalities to third parties, which may undermine the appropriability of returns on investment.

The policy issue at stake is to restore incentives to invest in ultra-fast broadband infrastructure. For this purpose, the EU Recommendation on NGA access (EC, 2010) advises that the wholesale price of access should include a 'risk premium' to compensate the investor for quantifiable risk. In the case where there is fully equivalent third-party access to NGA, the access price could be left to the market. These regulatory provisions intend to allow the investing firm to charge a high access price to rival (non-investing) firms, and thereby reduce the externalities created by the open access policy to NGA. Nonetheless, these provisions cannot remove all barriers to NGA investment. In fact, the sunk costs for the investor are not affected. As long as a high access price implies high retail prices, the uncertainty on demand for NGA services (depending on consumers' valuation of such services) even rises.

An emerging option for deploying NGA is co-investment (or 'risk sharing') of telecom operators, which jointly build network infrastructure and share physical access to the infrastructure. The EU supports this option as it advocates the removal of access obligations when the arrangement among co-investors ensures effective competition in wholesale and

[1] See e.g. the 'Digital Agenda for Europe' (http://ec.europa.eu/information_society/digital-agenda).

[2] The European Commission (EC, 2014) reports that, in the EU, NGA are much limited to urban areas. Moreover, the take up of fast broadband (at least 30 Mbps) falls well below coverage. Ultra-fast broadband (at least 100 Mbps) subscriptions are at 3% of homes, far behind the target of the EU Digital Agenda (50% of homes subscribing by 2020). In several countries, telecom operators have downgraded their initial plans to roll out the optical fiber to customer premises (Analysys Mason, 2012), thereby delivering fiber to the building (FTTB), or to the street cabinet (FTTC), instead of fiber to the home (FTTH).

retail markets (EC, 2010). Co-investment of telecom operators reduces the sunk cost and the risk for each of the investing firms, but it does not necessarily lead to more extensive NGA coverage. Indeed, it does not reduce either the *total* cost of investment for the telecom industry, or the *overall* risk of the investment inherent to demand uncertainty.

In this paper, we consider an alternative model of co-investment entailing the joint participation of telecom companies, or residential-access Internet Service Providers (ISPs), and Content and applications Providers (CPs).[3] The rationale is that there is a complementarity between content provision and demand for improved broadband connectivity.[4] Streaming video and communications applications have significantly raised web traffic, and thereby the need for higher capacity, higher speed broadband access networks to ensure quality of service provision. Thus, the business model of many commercial CPs relies on NGA deployment. On the other hand, consumers' take up of ultra-fast broadband access depends on the quality and variety of content, applications, and services.[5]

We argue that an *ex ante* contractual arrangement, which commits the CP (or CPs) to an upfront payment to the residential ISP (or ISPs) before the investment is undertaken, can suitably address market failures related to NGA deployment.[6] First, it reduces the total cost of investment for the telecom industry, since telecom companies share such cost with firms in complementary markets (i.e. CPs). Second, an *ex ante* contract between the ISP and the CP reduces the risk due to demand uncertainty. Indeed, when the CP

[3]For convenience, we will often refer to telecom companies as residential ISPs, or access ISPs.

[4]In a two-sided market perspective, residential ISPs are mediating platforms between subscribers, on the one side, and CPs, on the other side, with indirect network externalities between the two groups. Co-investment in infrastructure of platform providers and some platform users has been observed in other two-sided network industries, such as air transport. Fu *et al.* (2011) discuss several examples of joint investment in dedicated terminals by airlines and the main airports where they operate, both in the EU and the US.

[5]NGA subscriptions will increase steadily as long as end users realize that most innovative services (such as high definition IP TV, interactive gaming, cloud computing, and e-health) can only be provided over an upgraded broadband infrastructure. A study conducted in 2010 for the FCC, the US regulatory agency, estimated that the increase in US consumers' valuation for very fast (relative to fast) broadband access was still quite low, about $3 per month (Rosston *et al.*, 2010).

[6]In principle, there are alternative means to address (at least some of) these market failures. One is vertical integration between access ISPs and CPs, which implies an irreversible structural decision, and may raise antitrust concerns. Another one is using public subsidies, but governments often have tight budgets, or are prevented by regulation from participating in the investment financially (in the EU, governments should be allowed to invest under state aid rules; see EC, 2013). In what follows, we abstract from these means.

commits to participate in NGA investment *ex ante*, the CP also implicitly commits to provide complementary services that are made possible by the new network, which in turn increase NGA take up. Third, one such contract internalizes a substantial part of the externalities created by NGA investment. Due to the significant growth of video services and digital distribution of content, the Internet broadband network has become a high value-generating platform for CPs. Moreover, communications applications (that become more reliable on NGA) are disrupting ISPs' reliance on legacy voice and text revenues.

We then study how the regulatory regime of the Internet network affects ISPs' incentives to invest in NGA, and CPs' incentives to participate *ex ante* (i.e. before investment is made).

Over the past few years, there has been a fierce debate concerning the regime of Network Neutrality (NN), which has traditionally been in force. Under NN, residential ISPs do not charge CPs for the right to deliver content to their customer base (*termination fees*), or to have priority in delivery speed (*priority fees*).[7] This implies that the burden of costs for NGA investment is ultimately shifted to the access ISPs' retail customers. Advocates of NN, which typically include CPs, argue that NN preserves plurality on the Internet, alongside incentives for content innovation. Opponents to NN, which typically include ISPs, claim instead that additional compensation from CPs is vital to foster incentives to invest in upgraded broadband infrastructure, otherwise ISPs would face a typical free riding problem.[8]

We argue that a departure from NN, which allows access ISPs to charge CPs *ex post* (i.e. when investment is sunk), does not stimulate NGA investment *per se*. Indeed, it does not reduce the risk of investment due to demand uncertainty, and internalizes a small fraction of investment externalities. This is because access ISPs will not necessarily receive

[7]Some CPs have agreed to pay residential ISPs to avoid congestion at peering ports and obtain a direct connection to ISPs' local access networks. Paid peering agreements include the well-known cases of Netflix with Comcast and Verizon in the US, and several others (see e.g.: http://www.theverge.com/2014/5/22/5741748/google-fiber-netflix-isp-free-paid-peering). Such agreements are not touched upon by NN regulation, which only concerns local access networks.

[8]Policy makers agree that access ISPs should be prevented from blocking and/or throttling web traffic selectively. However, ISPs might be allowed to use non-discriminatory traffic management practices, and to differentiate their offers, for example by speed. Thus, ISPs might arrange deals with CPs to assure a certain quality of service, provided that these do not lead to quality degradation of the 'best effort' basic Internet.

high compensation, due to the CPs' bargaining power in negotiating *ex post* fees.[9] Since non-investing CPs retain some rents, the ISPs' investment suffers from the hold-up problem.

We illustrate our arguments through a stylized model with one residential ISP and one CP (we also discuss the case of multiple ISPs and CPs). We assume that the probability of success of NGA investment is higher if the CP participates *ex ante*. The rationale is that the quality of NGA depends on the offered services. In the absence of commitment by the CP, before investing the ISP cannot assess the quality of services that the CP will offer. We compare the regime of NN with the unregulated regime, where the ISP negotiates with the CP an *ex post* (termination or priority) fee.

We find that, if the CP participates *ex ante*, the incentives to invest in NGA are higher than in the case where it does not contribute at all, or (under reasonable assumptions) where it contributes *ex post*. Then, we study the CP's incentives for participating *ex ante*. In this framework, we show that a departure from NN may increase or decrease the ISP's and the CP's investment incentives, depending on the cost of infrastructure investment and the allocation of *ex post* bargaining power between firms.

This paper is organized as follows. Section 2 discusses the literature. Section 3 analyzes the case of co-investment of ISPs and CPs. Section 4 presents the model. Section 5 concludes.

2 Literature

Our paper lies at the intersection between the literature on NN and that on co-investment in NGA. In particular, the literature on NN has studied how NN regulation affects ISPs'

[9] Tim Wu, who coined the term 'Net Neutrality', predicts that negotiating fees *ex post* could backfire on access ISPs, since they could end up facing serious demands for money for CPs as Google to allow to be reached by ISPs' customers (New York Times, *Internet service providers pay more to travel in the express lanes*, February 3, 2014). Indeed, the ability of consumers to access Internet content, applications and services is one of the main reasons consumers are willing to pay ISPs. Thus, ISPs that have invested in NGA view the traffic growth driven by CPs as an opportunity, rather than an issue. For instance, in France, Bouygues Telecom has recently decided to include access to Spotify in the data buckets of its subscribers (Le Figaro, *Bouygues Telecom ajoute des bonus à ses forfaits*, January 15, 2015). Bouygues Telecom pays Spotify for the additional subscriptions generated by the availability of musical content . Similar offers have been made by Orange and SFR in France, and by Vodafone in Italy.

incentives to invest in infrastructure (for an extensive review, see Krämer *et al.*, 2013).

Some papers define NN as a non-discrimination rule. Thus, a departure from NN allows access ISPs to provide CPs with different service qualities at different fees. In this vein, Choi and Kim (2010) show that a monopolistic ISP might invest less in the absence of NN, because capacity expansion reduces the value of (and thus the fee for) the priority right.[10] Instead, Economides and Hermalin (2012) show that departing from NN unambiguously increases the ISP's incentives to invest, due to a 're-congestion effect' (since CPs on the fast lane generate more traffic). Bourreau *et al.* (2015) consider two competing ISPs, and show that, absent NN, ISPs have higher investment incentives and more CPs are active.

Other papers define NN as a zero-price rule. Thus, a departure from NN allows access ISPs to charge CPs for delivering content to their customer base.[11] Musacchio *et al.* (2009) consider multiple (local monopolists) ISPs and CPs. They show that investment may be higher in the unregulated regime, where positive termination fees compensate ISPs for low revenues from subscribers, while negative fees compensate CPs for low advertising revenues.

Baranes (2014) shows that there is a complementarity between content quality and infrastructure investment. Thus, high content quality may provide the ISP with high incentives to invest in the new technology, and the unregulated regime can strengthen this effect.[12]

All of these papers do not consider the case where CPs may have incentives to co-invest in NGA, particularly in response to a move to the unregulated regime (so as to avoid *ex post* fees). They also do not consider demand uncertainty inherent to NGA services.

Another relevant strand of literature studies co-investment of telecom operators in NGA, primarily as a means to bypass standard access price regulation.

[10] Choi and Kim (2010) point out that, in a non-neutral network, a similar hold-up problem can occur on the CPs' side. Indeed, CPs may under-invest in content, because ISPs would impose *ex post* fees that extract CPs' surplus from investment.

[11] Economides and Tåg (2012) focus on two-sided pricing issues that arise following a departure from NN. They show that more consumers can be attracted in the unregulated regime, because of a lower subscription price than under NN. Consequently, ISPs can extract additional revenues from CPs by raising termination fees. However, the authors build a static model that does not consider investment.

[12] On the other hand, Viard and Economides (2014) find that more content stimulates Internet adoption, which in turn increases the incentive to create content.

Inderst and Peitz (2012) model cost sharing agreements as long-run access contracts negotiated *ex ante*, in the absence of uncertainty. Compared to *ex post* access contracts, *ex ante* contracts increase NGA coverage and reduce investment duplication, but at the expense of reduced retail competition. Nitsche and Wiethaus (2011) build a model with uncertainty over the commercial success of NGA, so that co-investment allows firms to share the risk of investment. They find that, in a ranking of alternative scenarios, risk sharing combines relatively high *ex ante* investment incentives with strong *ex post* competitive intensity. Cambini and Silvestri (2013) show, however, that the outcome of risk sharing depends on the type of agreement among co-investors (in particular, the access price, if any, for insiders and outsiders of the agreement), and on the number of firms involved.

Inderst and Peitz (2014) find that, under uncertainty, *ex post* contracts may raise investment incentives relative to *ex ante* contracts if the investing firm has strong bargaining power. This occurs when, once the investment is made, the access seeker has high incentives to enter the network. Finally, Bourreau *et al.* (2013) show that co-investment raises NGA geographical coverage when it comes with high retail service differentiation and/or large cost savings. They also show that mandated access to NGA reduces incentives to co-invest.

Different from these papers, we assume that the probability of success of NGA depends on co-investment partners and, in particular, that it is higher when co-investors include CPs. Indeed, if CPs participate in the investment *ex ante*, then they commit to promptly provide and upgrade complementary services for the new technology.

3 Co-investment of ISPs and CPs

Co-investment (or 'risk sharing') entails an arrangement among a number of parties, which takes place before the investment is undertaken, for building the NGA.[13] Generally, co-

[13] Co-investment agreements have been used to build NGA in several countries, such as France, Germany, Netherlands, and Portugal (BEREC, 2012a). These horizontal agreements may involve access ISPs with different market power competing in the retail market, as well as utilities and local authorities.

investment schemes can take the form of a joint venture or a long-term contractual agreement.

In the case of a joint venture, the parties create a jointly controlled independent company that is responsible for building the infrastructure. The parties involved may hold different amounts of equity stakes in the new company, and thereby have different weights in the decision-making process, incur different levels of costs, and gain different shares of revenues.

Long-term (*ex ante*) contracts are cooperation agreements that do not imply the set up of a jointly controlled entity to build the network. These contracts usually include the transfer of indefeasible rights of use on a part of the infrastructure deployed. Thus, the access ISP in charge of the investment grants the right to use dark fiber, or an amount of capacity (including transmission equipment), or a network facility (such as ducts) for the economic lifetime of the asset. Generally, the ISP retains asset ownership and control. Long-term contracts may call for volume commitments and/or upfront payments (BEREC, 2012a).

Co-investment agreements may create cost efficiencies, but may facilitate collusion. Indeed, they could make it easier for co-investment partners to coordinate their actions to the detriment of consumers and late entrants (i.e. rivals that have not signed the agreement).[14]

Co-investment agreements among telecom operators reduce both the sunk costs and the risks incurred by each of the investing firms, and internalize investment externalities accruing to downstream rivals. However, such agreements do not always lead to more extensive NGA coverage. Indeed, they do not reduce either the total cost of investment for the telecom industry, or the overall risk of the investment inherent to demand uncertainty, and they do not internalize externalities to other firms in related markets.

An alternative model of co-investment that we intend to study involves access ISPs and CPs. We argue that one such model may address the main challenges of NGA deployment, and thereby raise investment incentives. Indeed, the CPs' *ex ante* participation may allow to collect the resources necessary to invest, reduce the overall risk of NGA investment, and

[14]The settlement of the risk sharing agreement is crucial. Thus, to ensure retail competition, firms could agree to split the costs, *ex ante*, based on their expected market shares (Nitsche and Wiethaus, 2011).

internalize investment externalities to firms in complementary markets.[15] Although these issues are closely related, we analyze each of them in separate subsections.

3.1 Sunk costs of investment

NGA investment entails high upfront sunk costs. For example, Analysys Mason (2012) has assessed that the baseline cost per home passed of the FTTH technology ranges from $600 to $750. It has also forecast that telcos in western Europe will incur $26.2 billion capital expenditure on NGA between 2012 and end of 2017 (but it has admitted for a high probability that investment plans will be delayed and spending postponed).

It follows that, to deploy NGA, investors need a huge amount of resources. Many large telecom operators in Europe claim that, although they have access to capital markets, their financial constraints will render large-scale infrastructure projects beyond their reach for years to come (FTTH Council Europe, 2012). Thus, in many countries the telecom industry might not be able to self-finance NGA investment. If governments have tight budgets, or are prevented from participating financially in the investment (see e.g. EC, 2013), we need to involve different players benefiting from improved broadband access.

Major commercial CPs have a high interest in the deployment of ultra-fast broadband, since they need a secure and reliable connection to deliver premium content to end users. Hence, a viable alternative to consider may be involving major commercial CPs in infrastructure investment. 'Pure' CPs, such as Google, Facebook, and Yahoo, offer a variety of services to end users largely free of charge, and earn revenues primarily from advertising. 'Hybrid' CPs, such as Apple, Amazon, eBay, and Netflix provide digital and non-digital services and content over the Internet by relying more on fees to end users and less on advertising.[16]

[15] Co-investment arrangements among access ISPs and CPs may still be unobserved in practice. This might be because CPs believe that NGA investment would occur even without their participation *ex ante*. Moreover, since ISPs and CPs have different assets and core businesses, they might hardly find a mutually acceptable rule for sharing the cost of infrastructure investment. Even if the relative benefits of co-investment were observable by the parties, they might not be verifiable in court.

[16] Clearly, CPs are not all the same. While major commercial CPs may have the motivations and the means to co-invest in NGA, some large CPs, like Wikipedia (which is currently the seventh web site in a global

Caves (2012) uses (with some caveats) market capitalization and financial data to gauge the relative profitability of access ISPs and CPs in the US. He reports that, in the period Q1:2011 – Q1:2012, the five largest US residential ISPs, which cover about 58% of the market, had a combined market capitalization of about $400 billion (including products, services, and assets different from pure ISP services). On the other hand, Google, Facebook, and Yahoo alone had a market capitalization of about $266 billion. Adding Apple and Amazon yielded a combined market capitalization of about $740 billion. As to financial data, aggregate ISPs' earnings before interest and taxes (EBIT) in 2012 were $16.7 billion, with an average operating margin of 21%, while the mere online advertising revenues for CPs were over $36 billion, and Google (the largest seller of online ads) reported operating margins above 30%.[17]

In short, major commercial CPs seem to have more financial stability than incumbent ISPs, so that the former can make investments and/or acquisitions with less use of leverage. If such CPs participate in NGA deployment, then it would be easier to collect the resources necessary to the costly investment. More importantly, co-investment of access ISPs and CPs reduces the total cost of investment for the telecom industry.

3.2 Demand uncertainty

On the demand side, the main risk of NGA investment is the risk of penetration or, in other words, the uncertainty over the actual use after the network has been deployed. Indeed, the economic value of NGA depends in part on the services that can be offered through the network. NGA may increase data transmission speeds up to 1 Gbit/s or more. It becomes thus possible to significantly improve end users' current experience with broadband use, as well as to provide end users with new value-added services (such as high definition IP TV and

traffic ranking; see: http://www.alexa.com/siteinfo/wikipedia.org), are non-commercial, since they are free for viewers and free of advertising. On the other hand, many small CPs (such as young start-up companies) have innovative ideas and services, but a constrained budget. Non-commercial CPs and (at least for a time period) start-up companies might be relieved of the burden of contributing *ex post* to NGA investment, should a departure from NN be allowed.

[17] AGCOM (2013) provides similar data for worldwide activities of the six main ISPs with European headquarters and of some of the major pure and hybrid CPs from Q1:2012 to Q1:2013.

interactive gaming, among others) that raise the perceived value of broadband infrastructure.

Ultimately, the availability and success of new services is essential to stimulate demand for (ultra)-fast broadband access (BEREC, 2012b). Indeed, large CPs have been driving the high increase in bandwidth-intensive multimedia applications over the Internet in recent years, which, in turn, have raised the need for an upgraded broadband access infrastructure.[18]

Residential-access ISPs and CPs have different core businesses, which are complementary for the success of NGA investment. While access ISPs have the expertise to roll out and manage the infrastructure, CPs are responsible for developing many of the services that will run on the network and affect consumers' willingness to pay (wtp) for accessing the network.

Generally, an incumbent ISP decides whether or not to invest in NGA under uncertainty. Indeed, the ISP cannot assess the quality and variety of complementary services, and thereby it cannot perfectly forecast market demand for improved broadband connectivity. If some CPs participate in the investment *ex ante* (i.e. co-invest with the ISP), then they are committed to make enhanced services and applications readily available to increase the value of the new network to consumers, and thus their own expected profit. In the case of co-investment, CPs may also lead the ISP to deploy the network technology and architecture that best fit the features and technical requirements of enhanced value-added services.

It follows that, if access ISPs and CPs co-invest, they would reduce the overall risk of the investment. This is different from a co-investment of telecom operators, which simply allows them to share (but not reduce) a given risk of investment. Consumers' demand for access to NGA would also increase because, when CPs share the burden of costs for NGA investment, access ISPs can set lower subscription prices. In addition, since part of the risk of the investment is shifted to CPs, the latter are committed to invest in developing new services and applications, so as to further increase end users' demand for ultra-fast broadband access.

[18]For instance, Sandvine estimates that Netflix alone accounts for 34.9% of downstream Internet traffic in peak evening hours in the US (Sandvine, 2014). It is also estimated that, when Google went down for a few minutes in August 2013, web traffic fell by 40% (see: https://engineering.gosquared.com/googles-downtime-40-drop-in-traffic). Cisco reports that global IP traffic has increased more than fivefold in the past five years, and will increase threefold over the next five years. Moreover, excluding peer-to-peer file sharing, IP video traffic will be 79% of all consumer Internet traffic in 2018 (Cisco, 2014).

3.3 Investment externalities

NGA investment generates significant externalities to third parties. In particular, major commercial CPs may receive high benefits from NGA deployment, since they have the chance to reliably offer value-added services, which in turn may prospectively secure high revenues from advertisers and/or consumers. These revenues depend on investment in the new technology, since the same services are less profitable in a congested network, where they cannot be delivered to end users with the appropriate quality level.

Although access ISPs incur the investment cost, they cannot share CPs' additional revenues from complementary services. In this sense, access ISPs argue that NGA deployment is a pure spillover to CPs.[19] Furthermore, some of the CPs' services are in close competition with ISPs' basic activities. Since those services are working even better on NGAs, the deployment of the new network has a business stealing effect on telecom operators. Indeed, ISPs' revenues from voice and messaging are rapidly diminishing because of the competitive pressure of VoIP and messaging apps.[20] While ISPs' revenues from data are still growing, they are likely to pick soon in developed countries (Chetan Sharma, 2012).

Finally, access ISPs may have low incentives to invest in NGA because of the hold-up problem. Even if two-sided pricing is allowed, given that the NGA has been deployed, large CPs may have high bargaining power in negotiating *ex post* fees for their content to be delivered or prioritized on the NGA. Actually, the new network has little value without (premium) content and applications. Thus, ISPs may have the incentive not to expand network capacity in the first place, so as to negotiate high *ex post* fees with CPs.

A co-investment plan involving access ISPs and CPs would allow to internalize these

[19] Telcos have often complained about lack of appropriability of the benefits yielded by NGA investment. These complaints lie at the heart of the fierce debate on NN regulation for the Internet, since the well-known statement of Ed Whitacre, AT&T's then CEO: "Now what they [i.e. CPs] would like to do is use my pipes free, but I ain't going to let them do that, because we have spent this capital and we have to have a return on it" (Business Week, *Interview with Ed Whitacre*, November 7, 2005).

[20] Mobilesquared reports that, in 2012, the over 900 million users of Skype spent over 1 billion minutes per day on peer-to-peer Skype-to-Skype free calls, and almost 40 million minutes per day of off-Skype calls charged to mobile or fixed-line (Mobilesquared, 2012).

externalities, thereby creating the right incentives to build the new infrastructure.

4 A simple model of co-investment of ISPs and CPs

In this section, we introduce a simple model to study firms' investment incentives, and provide the rationale for the access ISP and the CP to co-invest in NGA, depending on the regulatory regime of the Internet. For this purpose, we consider the interaction between a monopolistic ISP and a single CP in the broadband Internet market. In Section 4.4, we discuss when and how an industry structure with multiple ISPs and CPs would affect the results.[21]

Assume that the ISP invests in upgrading the quality of a non-duplicable access network, thereby bearing a fixed cost of investment I. We compare the regime of NN, where the access ISP cannot charge *ex post* the CP for delivering content to subscribers, with an unregulated regime, where the ISP negotiates an *ex post* fee with the CP.[22]

Under NN, the CP may take advantage of the ISP's investment *ex post* without paying any fee. In the unregulated regime, the CP may take advantage of NGA investment if it pays the ISP the *ex post* fee f (when investment is sunk). Under both regimes, the CP may decide to participate in the investment *ex ante* (i.e. to co-invest with the ISP). In such a case, the CP commits to an upfront payment F before the investment is made, where $F > 0$ (so that the ISP's investment cost becomes $I - F < I$).[23]

We model NGA deployment as a risky investment, because of uncertainty about consumers' demand for new value-added services. We assume that the probability of success (respectively, failure) of NGA investment is β_H (respectively, $1 - \beta_H$) as long as the CP

[21] In our model, firms' profits are in reduced form, and implicitly account for externalities between the two sides of the market. We do not carry out a comprehensive welfare analysis, which would require specific assumptions on demand, costs and the nature of competition.

[22] We can interpret the *ex post* fee as a 'termination fee' or a 'priority fee'. In the former case, the CP's outside option is to reach subscribers to the old technology, while, in the latter case, the CP's outside option is being served with best effort.

[23] We do not model the bargaining process between the ISP and the CP over *ex ante* and *ex post* fees. Thus, we solve the game by parameterizing the values of F and f. In Section 4.3, we discuss the likely outcome of *ex post* price negotiations, depending on the allocation of bargaining power between firms.

participates *ex ante*, while it is β_L (respectively, $1-\beta_L$) as long as the ISP invests and then the CP joins the NGA (in the unregulated regime, the CP thus pays the *ex post* fee, while, under NN, it does not pay at all). Since the value of NGA to consumers depends on the availability of content and the quality of content delivery, we assume that the investment is not successful as long as the CP does not reach NGA subscribers, or (in the unregulated regime) reaches them without priority, namely, with best effort quality.

We assume that $\beta_H > \beta_L$. Thus, if the access ISP sells in advance part of the capacity to a wholesale customer through a long-term contract, and the wholesale customer is the CP (rather than a different ISP), the overall risk of the investment is reduced or, equivalently, the probability of success is increased.[24] Let $\Delta\beta \equiv (\beta_H - \beta_L) > 0$ be the increase in the probability of success of NGA investment due to the CP's commitment.

Many of the complementary services that determine the quality of NGA are developed by the CP. If the CP participates *ex ante*, it has the incentive to promptly deliver enhanced services and applications to increase the value of the NGA to consumers (see Section 3.2). While the ISP still makes the investment decision under uncertainty, as market demand for the newly offered services is not known in advance, such uncertainty is reduced compared to the case where the CP merely contributes *ex post*.[25]

We consider the following three-stage game. At the first stage, the CP decides whether or not to sign a long-term contract with the access ISP that commits the CP to co-invest. In case of agreement, the CP makes the upfront payment F. At the second stage, the access ISP decides whether to undertake the (co)-investment or not (in the latter case, depending on stage one, the ISP may have to return F). At the third stage: i) absent co-investment, the CP decides whether to pay the (termination or priority) *ex post* fee f or not; ii) firms

[24] Existing co-investment models do not consider the complementary role of content and infrastructure, and do not allow for the probability of success of the investment to depend on co-investment partners. This follows from the assumption that all of the co-investing firms are ISPs.

[25] For simplicity, we model a static game. In a dynamic setting, we may think that the CP invests to upgrade existing complementary services, or develop new services that require higher download speed. These services will increase subscribers' demand for access to NGA gradually over time. Thus, the earlier the CP invests in content, the earlier subscribers' demand, and thus firms' profits, may start to rise. In this sense, parameters β_H and β_L in our static model are meant to capture some dynamic effects.

learn the state of demand (i.e. observe the success or failure of the investment) and realize profits. Note that, under NN, point i) at stage three does not apply.

4.1 Network Neutrality regime

Let us assume that NN is enforced, so that the access ISP cannot charge the CP for delivering content. At stage three, firm i ($i = ISP, CP$) makes gross profit π_H^i if the investment is successful, and π_L^i if the investment is not successful, or is not undertaken at all (and the old technology is still in place). We assume $\pi_H^i > \pi_L^i$, so that both firms make higher gross profit when NGA investment is successful. Indeed, the ISP can benefit from consumers' higher wtp for improved broadband connectivity, while the CP can benefit from higher advertising revenues or from consumers' higher wtp for premium content and applications. Let $\Delta\pi^i \equiv (\pi_H^i - \pi_L^i) > 0$ be firm i's (gross) profit gain from NGA deployment, $i = ISP, CP$.

At stage two, the access ISP decides whether to (co)-invest or not, depending on the CP's decision at stage one. Clearly, the ISP (co)-invests as long as the expected profit from (co)-investment is higher than the profit when it does not (co)-invest. Given that the CP has not paid F at stage one, the ISP invests if $\beta_L \pi_H^{ISP} + (1 - \beta_L)\, \pi_L^{ISP} - I \geq \pi_L^{ISP}$. Hence, the investment takes place as long as $I \leq \beta_L \left(\pi_H^{ISP} - \pi_L^{ISP}\right) = \beta_L \Delta\pi^{ISP} \equiv I_{NN}$. Instead, given that the CP has paid F at stage one, the ISP co-invests if $\beta_H \pi_H^{ISP} + (1 - \beta_H)\, \pi_L^{ISP} - (I - F) \geq \pi_L^{ISP}$, that is, as long as $I \leq \beta_H \left(\pi_H^{ISP} - \pi_L^{ISP}\right) + F = \beta_H \Delta\pi^{ISP} + F \equiv I_{EA}$.

Unsurprisingly, we find that $I_{EA} > I_{NN}$. This entails that, under NN, the access ISP's incentives to invest are higher when the CP participates in the investment *ex ante*. Indeed, the CP's *ex ante* participation reduces, on the one hand, the investment cost that the ISP has to bear (by an amount equal to F) and, on the other hand, the overall risk of the investment (or, equivalently, increases the probability of success of the investment up to β_H).

Moving backwards to stage one, we can study the CP's incentives to co-invest. First, if $I \leq I_{NN}$, the CP anticipates that the investment takes place whether or not it participates *ex ante*. However, the CP is still willing to participate *ex ante* if its expected profit from paying

F is higher than the one from not paying, that is, if $\beta_H \pi_H^{CP} + (1-\beta_H)\,\pi_L^{CP} - F \geq \beta_L \pi_H^{CP} + (1-\beta_L)\,\pi_L^{CP}$. This condition holds as long as $F \leq (\beta_H - \beta_L)\left(\pi_H^{CP} - \pi_L^{CP}\right) = \Delta\beta\Delta\pi^{CP} \equiv F_1$, namely, the *ex ante* fee is not too high. Note that the critical value F_1 that induces the CP to co-invest rises with the increase in the probability of success of NGA investment due to the CP's commitment (while F_1 goes to zero if the CP's *ex ante* participation is almost irrelevant to the success of investment), and with the CP's (gross) profit gain from NGA deployment.

If instead $I_{NN} < I \leq I_{EA}$, the CP anticipates that the investment takes place only if it pays the *ex ante* fee. Hence, the CP is willing to pay F if $\beta_H \pi_H^{CP} + (1-\beta_H)\,\pi_L^{CP} - F \geq \pi_L^{CP}$, where π_L^{CP} is here the CP's profit in the absence of investment (i.e. with the old technology). This condition holds as long as $F \leq \beta_H\left(\pi_H^{CP} - \pi_L^{CP}\right) = \beta_H \Delta\pi^{CP} \equiv F_2$, where F_2 rises with β_H and $\Delta\pi^{CP}$. We find that $F_1 < F_2$, meaning that the CP may be willing to pay a higher *ex ante* fee if participation is necessary for investment to occur. In other words, the CP is more willing to co-invest when otherwise the new network would not be deployed at all.

In some real-world cases, we observe that CPs do participate in ISPs' investments, or undertake infrastructure investment on their own, even if they are not charged priority or termination fees (since the Internet is 'neutral'). For instance, some large CPs (such as Amazon, Google, and Netflix) have developed their Content Delivery Networks to bypass transit providers and serve their content to end users more efficiently and effectively. Moreover, the case of Google Fiber shows that large CPs may be interested in undertaking broadband investment in the last mile. In particular, Google has been deploying a super-fast fiber access network in several US cities, particularly where dark fiber had already been laid.[26]

4.2 Unregulated regime

Consider now the case of a departure from NN. Thus, the access ISP can charge the CP an *ex post* fee for delivering or prioritizing its content on the NGA.

At stage three, firm i's gross profit if the CP has not paid either F or f, or if the investment

[26]For further details on the development plan of Google Fiber, see: https://fiber.google.com/newcities/.

is not successful, is π_L^i, $i = ISP, CP$ (we assume that an NGA without content has little value to consumers). Instead, firm i can make gross profit π_H^i with probability β_L if the CP pays f after the access ISP has invested, or with probability β_H if the CP pays F *ex ante*.

First, assume that the CP has not paid F at stage one. Then, if the ISP has invested at stage two, the CP is willing to pay f at stage three if $\beta_L \pi_H^{CP} + (1-\beta_L)\pi_L^{CP} - f \geq \pi_L^{CP}$, that is, as long as $f \leq \beta_L \left(\pi_H^{CP} - \pi_L^{CP}\right) = \beta_L \Delta\pi^{CP} \equiv f_{EP}$, where $f_{EP} > 0$. Since $\beta_L \pi_H^{ISP} + (1-\beta_L)\pi_L^{ISP} + f \geq \pi_L^{ISP}$ then, when the investment is sunk, the ISP is better off by charging an affordable f to the CP. In fact, once the investment is made, the ISP would even be willing to pay up to $\beta_L \Delta\pi^{ISP}$ to have the chance to deliver content to NGA subscribers, in order to gain π_H^{ISP} with probability β_L. At stage two, we study the ISP's incentives to invest. We find that the ISP invests if $\beta_L \pi_H^{ISP} + (1-\beta_L)\pi_L^{ISP} + f - I \geq \pi_L^{ISP}$, that is, as long as $I \leq \beta_L \left(\pi_H^{ISP} - \pi_L^{ISP}\right) + f = \beta_L \Delta\pi^{ISP} + f \equiv I_{EP}$ (with $f \leq f_{EP}$).

Now, assume that the CP has co-invested (by paying the *ex ante* fee F) at stage one. Then, at stage three, firms simply realize profits. At stage two, as under NN, the ISP co-invests if $\beta_H \pi_H^{ISP} + (1-\beta_H)\pi_L^{ISP} - (I - F) \geq \pi_L^{ISP}$, that is, as long as $I \leq I_{EA}$.

Let us compare the critical values I_{EA} and I_{EP}, so as to study whether, in the unregulated regime, the ISP has higher incentives to invest when the CP participates *ex ante* or rather contributes *ex post*. We find that $I_{EA} > I_{EP}$, and thus the ISP invests more when the CP participates *ex ante*, as long as $F > f - (\beta_H - \beta_L)\left(\pi_H^{ISP} - \pi_L^{ISP}\right) = f - \Delta\beta\Delta\pi^{ISP}$. Hence, a sufficient (but not necessary) condition for $I_{EA} > I_{EP}$ to hold is $F > f$. Observe that, if $F \leq f$, the CP would always co-invest, since this is cheaper than contributing *ex post*, and raises the probability of success of the investment. Hereafter, we discard this trivial outcome, and focus on the case where $F > f$, so that $I_{EA} > I_{EP}$ holds.[27] In this case, the CP's *ex ante* participation increases the ISP's expected profit from investment. On the one hand, since $F > f$, it reduces the cost of investment for the ISP and, on the other hand, it raises the probability of success of the investment relative to the CP's *ex post* contribution.

[27] The opposite situation where $I_{EA} \leq I_{EP}$ would occur only in the extreme case where f is significantly higher than F (formally, $f \geq F + (\beta_H - \beta_L)\left(\pi_H^{ISP} - \pi_L^{ISP}\right) = F + \Delta\beta\Delta\pi^{ISP}$ must hold).

Result 1 follows from the second stage of the game in the regulated regime (Section 4.1) and in the unregulated regime (this Section), and summarizes the related findings.

Result 1. *If the CP participates in the investment ex ante, the incentives to invest in NGA are higher than in the case where it does not contribute at all, or (under reasonable assumptions) where it contributes ex post.*

At stage one, we can study the CP's incentives to co-invest. First, assume that $I \leq I_{EP}$, so that the investment takes place if the CP pays either *ex ante* or *ex post*. In this case, the CP participates *ex ante*, instead of contributing *ex post*, if the expected profit from paying F is higher than the one from paying f, that is, if $\beta_H \pi_H^{CP} + (1-\beta_H)\,\pi_L^{CP} - F \geq \beta_L \pi_H^{CP} + (1-\beta_L)\,\pi_L^{CP} - f$. This condition holds as long as $F \leq (\beta_H - \beta_L)\left(\pi_H^{CP} - \pi_L^{CP}\right) + f = \Delta\beta\Delta\pi^{CP} + f \equiv F_3$. Since F_3 rises with f, then the higher the *ex post* fee, the higher the fee the CP is willing to pay *ex ante*.

If instead $I_{EP} < I \leq I_{EA}$, then the CP anticipates that the NGA is deployed only in case of co-investment. Hence, the CP's expected profit from paying F is $\beta_H \pi_H^{CP} + (1-\beta_H)\,\pi_L^{CP} - F$, otherwise it is π_L^{CP}. Therefore, the CP decides to co-invest as long as $F \leq F_2$. Finally, if $I > I_{EA}$ then the ISP does not invest at all, and thereby the CP does not participate *ex ante*.

4.3 Comparison of the two regimes

In this Section, we compare the results obtained when NN is enforced (Section 4.1) and when it is not (Section 4.2), to study how the regulatory regime affects firms' incentives to invest.

Consider first the ISP's investment incentives. Let us start by assuming that the CP has not co-invested at stage one. We compare the upper bound of the investment cost for NGA to be deployed respectively under NN, I_{NN}, and when NN is removed and the CP pays the *ex post* fee, I_{EP}. We find that $I_{NN} \leq I_{EP}$ as long as $f \geq 0$, otherwise $I_{NN} > I_{EP}$ holds. Intuitively, a positive *ex post* fee increases the ISP's incentives to invest compared to the case where the CP pays no fee. Note, however, that the *ex post* fee can in principle be negative. In

such a case, the ISP pays the CP to have the chance to deliver content to NGA subscribers.[28] We thus find the opposite result that the ISP has higher investment incentives under NN.

While endogenizing the *ex post* fee is beyond the scope of our paper, we point out that the value of f can be found as the outcome of a Nash bargaining process between the ISP and the CP when NGA investment is sunk. Given the outside options for the ISP and the CP, the outcome of price negotiations depends on firms' bargaining power *ex post*. If all the bargaining power is on the ISP's side, then we have $f = \beta_L \Delta\pi^{CP} \equiv f_{EP} > 0$, that is, the ISP can charge the maximum affordable f to the CP (see Section 4.2). If instead all the bargaining power is on the CP's side, then the *ex post* fee becomes $f = -\beta_L \Delta\pi^{ISP} < 0$, meaning that the ISP pays the CP to be allowed to deliver content to NGA subscribers (see Section 4.2). Thus, the CP can extract via the *ex post* fee the ISP's expected gain from NGA investment, which is equal to the additional gross profit from investment $\Delta\pi^{ISP}$, provided that it is successful (when the CP contributes *ex post*, this occurs with probability β_L).

Generally, f lies between the two extremes above. Let λ ($0 \leq \lambda \leq 1$) denote the CP's bargaining power *ex post*. Then, we can write $f = \left[-\beta_L \Delta\pi^{ISP}\right]^{\lambda} \left[\beta_L \Delta\pi^{CP}\right]^{(1-\lambda)}$. Since $f < 0$ when $\lambda = 1$, then, for continuity, the *ex post* fee remains negative if the ISP has some bargaining power, but the CP's bargaining power is high enough. This might be the case if firms negotiate fees when NGA investment is sunk, because the CP's contribution is key to the success of investment. On the other hand, if the CP's bargaining power *ex post* is sufficiently low, the ISP can charge a positive *ex post* fee.

Let us now assume that the CP has co-invested at stage one. We compare the upper bound of the investment cost for NGA to be deployed with and without NN, which is equal to I_{EA} independent of the regulatory regime. Thus, given that the CP co-invests, departing from NN does not affect the ISP's incentives to (co)-invest in infrastructure.

[28] The air transport industry sheds some light on this issue. Spare capacity has induced several EU regional airports to attract traffic from airlines. As a result, in many of these airports, a single carrier operates the great bulk of traffic, and thereby has high bargaining power in negotiating prices of airport services. A well-known case is Charleroi airport, which signed an agreement with Ryanair including substantial discounts in landing and ground handling charges, as well as subsidies to cover some fixed costs of the airline (EC, 2004).

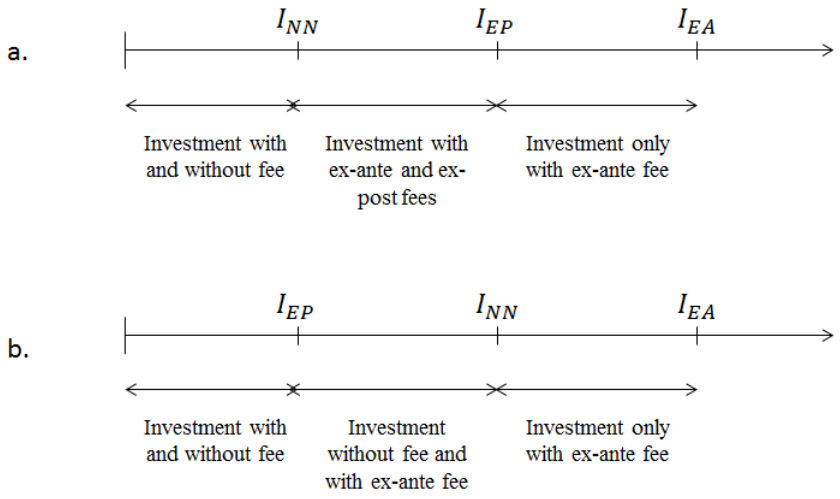

Figure 1: ISP's incentives to invest in infrastructure as a function of the regulatory regime.

Figure 1 illustrates our findings as a function of the regulatory regime, depending on the values of I, F, and f (recall that we assume $F > 0$ and $F > f$). Panel (a) displays the case where $f \geq 0$, while panel (b) displays the case where $f < 0$. We can interpret the value of the *ex post* fee as a measure of the CP's bargaining power when investment is sunk. In this sense, a positive (respectively, negative) fee reflects that the CP has low (respectively, high) bargaining power *ex post*. Result 2 summarizes our findings.

Result 2. *If the CP participates in the investment ex ante, the regulatory regime does not affect the ISP's incentives to (co)-invest in infrastructure. If, instead, the CP contributes to the investment ex post, the regulatory regime has ambiguous effects on the ISP's incentives to invest. In particular, departing from network neutrality may increase (respectively, reduce) investment incentives if the CP has low (respectively, high) bargaining power ex post.*

Let us now investigate whether and when the CP decides to participate in the investment *ex ante*, by comparing the CP's incentives to co-invest in the two regulatory regimes.

First, assume $f \geq 0$, so that $I_{NN} < I_{EP} < I_{EA}$. Consider the case where $I \leq I_{NN}$, namely, the cost of investment is so low that the ISP deploys the NGA independent of the CP's contribution. We have shown that, in this case, the CP decides to co-invest as long

as $F \leq \Delta\beta\Delta\pi^{CP} \equiv F_1$ under NN (Section 4.1) and $F \leq \Delta\beta\Delta\pi^{CP} + f \equiv F_3$ when NN is removed (Section 4.2). Given that $f \geq 0$, we easily verify that $F_3 \geq F_1$. Under NN, the CP can take advantage of NGA for free. If instead NN is removed, the CP has to pay the *ex post* fee to have its content delivered or prioritized on the NGA. Hence, the option of not participating *ex ante* is less attractive, since the CP cannot free-ride on the ISP's investment. This means that removing NN provides the CP with higher incentives to co-invest in NGA.

Consider now the case where $I_{NN} < I \leq I_{EP}$. For intermediate costs of investment, the ISP invests only if it can charge the CP either an *ex ante* or an *ex post* fee. We have shown that, in this case, the CP co-invests as long as $F \leq \beta_H \Delta\pi^{CP} \equiv F_2$ under NN (Section 4.1) and $F \leq \Delta\beta\Delta\pi^{CP} + f \equiv F_3$ when NN is removed (Section 4.2). Since $f \leq f_{EP}$ must hold (Section 4.2), we find that $F_2 \geq F_3$. Hence, for intermediate costs of investment, the CP has higher incentives to co-invest under NN. The rationale is that the CP's *ex ante* participation is essential to deploy the NGA under NN, but not in the unregulated regime.

Finally, consider the case where $I_{EP} < I \leq I_{EA}$. In such a case, the cost of investment is so high that, in either regime, the NGA can be deployed only if the CP participates *ex ante*. Thus, the CP is willing to co-invest as long as $F \leq F_2$, independent of the regulatory regime.

Assume, instead, that $f < 0$, so that $I_{EP} < I_{NN} < I_{EA}$ holds. If $I \leq I_{EP}$, the ISP invests with or without fees. Then, the CP is willing to co-invest up to F_1 under NN (Section 4.1) and to F_3 in the unregulated regime (Section 4.2). Given that $f < 0$, we now find that $F_3 < F_1$. Since the NGA is deployed in any case, and the CP has high bargaining power in negotiating the *ex post* fee f (to the extent that it charges the ISP for its content), the CP's incentive to co-invest is lower in the unregulated regime than under NN.

If instead $I_{EP} < I \leq I_{NN}$, the ISP invests without fees, or with an *ex ante* fee, but not with an *ex post* fee (because $f < 0$). Then, the CP co-invests up to F_1 under NN (Section 4.1), or to F_2 in the unregulated regime (Section 4.2). Since $f < 0$, we now find that $F_1 < F_2$. In the unregulated regime, the NGA can be deployed only if the CP participates *ex ante*, otherwise the CP's high bargaining power *ex post* precludes investment at all. Conversely,

(a)

	$I \leq I_{NN}$	$I_{NN} < I \leq I_{EP}$	$I_{EP} < I \leq I_{EA}$
NN	$F \leq F_1$	$F \leq F_2$	$F \leq F_2$
UR	$F \leq F_3$	$F \leq F_3$	$F \leq F_2$
NN Vs UR	$F_1 < F_3$	$F_2 > F_3$	$F_2 = F_2$

(b)

	$I \leq I_{EP}$	$I_{EP} < I \leq I_{NN}$	$I_{NN} < I \leq I_{EA}$
NN	$F \leq F_1$	$F \leq F_1$	$F \leq F_2$
UR	$F \leq F_3$	$F \leq F_2$	$F \leq F_2$
NN Vs UR	$F_1 > F_3$	$F_1 < F_2$	$F_2 = F_2$

Table 1: CP's incentives to co-invest in infrastructure as a function of the regulatory regime. UR stands for the Unregulated Regime. .

under NN, the ISP invests alone. Hence, the CP has higher incentives to co-invest in the unregulated regime. Finally, if $I > I_{NN}$, the ISP invests only if the CP participates *ex ante*. Thus, the CP co-invests as long as $F \leq F_2$ under both regulatory regimes.

Table 1 summarizes our findings as a function of the regulatory regime, depending on I, F, and f (where $F > 0$ and $F > f$). Panel (a) displays the case where $f \geq 0$, while panel (b) displays the case where $f < 0$. We can interpret the cost of investment as a measure of the credibility that the ISP invests *alone*. In this sense, a low (respectively, high) investment cost reflects a high (respectively, low) credibility of investment. We conclude what follows.

Result 3. *The regulatory regime has ambiguous effects on the CP's incentives to co-invest in infrastructure. In particular, departing from network neutrality raises co-investment incentives if the credibility of investment is high and the CP has low bargaining power ex post, or if the credibility of investment is low and the CP has high bargaining power ex post.*

To summarize, we cannot find a simple relationship between the regulatory regime and the incentives to invest in infrastructure. Contrary to common wisdom, in some cases the ISP may invest more under NN than in the unregulated regime, while the CP may be more willing to invest (in infrastructure) when NN is removed than when it is enforced.

As to the ISP, this depends on the fact that content is essential to increase the probability of success of the investment, and thereby the CP has high bargaining power in price negotiations when investment is sunk. As to the CP, given that NN is removed (and the ISP may charge the CP a positive *ex post* fee), the CP may find it profitable to participate in the investment *ex ante*, particularly if co-investment is essential to foster NGA deployment.

4.4 Discussion

Our stylized model has a number of limitations. First, we have considered a monopolistic access ISP. This is actually the case in some countries, or in some areas within a country, both in the EU and the US. However, in other countries or areas there is competition among access ISPs. Thus, we should consider how firms' incentives to invest are affected when more than one ISP could in principle upgrade broadband infrastructure.

In such a model, there might be free-riding among ISPs. If the incumbent ISP invests, then other ISPs might benefit from investment by purchasing access to the upgraded network without incurring the cost of deployment. This in turn could dampen the incumbent's investment in the first place. On the other hand, with multiple ISPs there is the chance that some of them are able to coordinate and co-invest in NGA, in order to share (but not reduce) the total cost and risk of deployment.

Competition among ISPs could reduce their bargaining power in negotiating (priority or termination) fees to their networks. In fact, the CP has a number of alternative sources available to reach end users. Moreover, access ISPs might compete to gain the exclusive right to deliver some premium content, and thereby raise market share to the detriment of rivals.

For simplicity, to emphasize the key role of large CPs on the Internet, we have considered a monopolistic CP. Let us briefly investigate the effects of competition in content provision.[29]

[29] We have solved an alternative model specification with two CPs competing to deliver content to end users. We have assumed that, compared to monopoly, competition erodes each CP's profit when both CPs are on the same upgraded access network. We have found that, for some parameterizations, the main qualitative results of the basic model are not affected. In a nutshell, these parameterizations ensure that, when departing from NN, only one CP gets priority on the upgraded network (unless both CPs co-invest with the ISP in the

For clarity of exposition, we consider the case of priority fees (rather than termination fees), which is the most likely to occur in practice, should a departure from NN be allowed.

The presence of multiple CPs may introduce an alternative form of free-riding within the group of CPs. Each single CP may have less incentives to participate in the investment *ex ante*, since it may prefer to wait for some other (group of) CPs to take the risk of commitment.[30] Hence, a CP would be willing to co-invest provided that it has a risk premium.

For instance, the ISP could threaten to charge high *ex post* fees for prioritization. This threat would be credible as long as bandwidth is relatively scarce even after capacity expansion, so that CPs that have not committed *ex ante* would have to strongly compete *ex post* to get the priority lane.[31] If CPs offer similar content and applications, the monopolistic ISP would have strong bargaining power in price negotiations with any of the CPs. On the other hand, a specific CP may still have bargaining power as long as it offers premium content, while the rival CP's content is an inferior substitute.

Finally, we have not explicitly considered the case where CPs invest in innovation of content and applications. Content innovation is essential to increase the probability of success of NGA, and thereby raise CPs' expected profit from co-investment in infrastructure. In a model extension that considers investment in content, we might assess the magnitude of the effect of content innovation on the probability of success of NGA investment (the difference among β_H and β_L in the model). In a more general model, we can expect not only that the investment in content would have virtuous effects on the investment in infrastructure but also the other way around. In this framework, we cannot provide a unique prediction on the impact of the regulatory regime on CPs' incentives to invest in content. Indeed, content

NGA). For brevity, we omit the formal details, which can be obtained from the authors on request.

[30] A similar issue arises when the ISP has invested in the NGA, and sells the priority right *ex post* non-exclusively. In such a case, CPs may coordinate on a 'delayed-purchase' equilibrium in which no CP purchases the priority right. Then, the ISP may prefer selling the priority right to a restricted number of CPs, for example through an ascending bid auction (see Choi and Kim, 2010). We argue that, in a long run perspective, this issue would reduce the ISP's incentives to expand capacity, unless the ISP negotiates the priority right with CPs *ex ante* (i.e. before investing).

[31] However, restricting access to the priority lane would raise significant, and possibly unfair, entry barriers in the content market, and, indirectly, in the broadband access market.

innovation may be higher or lower in the unregulated regime than under NN, depending on the credibility of investment in both content innovation and ultra-fast broadband infrastructure, as well as on firms' bargaining power *ex post*.

In terms of policy implications, this reasoning removes the presumption that regulatory agencies should enforce the regime of NN on the ground that it fosters CPs' incentives to invest in content innovation. Actually, an implication of Result 3 in Section 4.3 should be that departing from NN may increase, rather than reduce, investment in content.

5 Conclusions

We have argued that *ex ante* contractual arrangements among residential-access ISPs and CPs can foster the deployment of upgraded broadband access networks, since they may create a predictable and stable environment for ISPs and CPs to invest and innovate. Indeed, an NGA co-investment plan involving access ISPs and CPs brings down the investment cost for the telecom industry, promotes end users' demand for improved connectivity, and internalizes investment externalities. *Ex ante* contracts among access ISPs and CPs are particularly desirable when NGA deployment imposes considerable sunk costs on ISPs with financial constraints (so that they can hardly self-finance investment), governments have tight budgets, and there is high uncertainty on demand for NGA services.

Encouraging co-investment of access ISPs and CPs would ideally complement standard demand-side and supply-side remedies to increase ultra-fast broadband coverage and penetration rate. We have shown that, under some circumstances, a first step in this direction is to define 'two-sided' regulation models that allow ISPs and CPs to agree deals for prioritization of certain services over upgraded access networks. If access ISPs can charge (positive) *ex post* fees for delivering CPs' content to NGA subscribers, then CPs may have higher incentives to participate in the investment *ex ante*, because they anticipate that they will not have the chance to free-ride on ISPs' investment (as they may instead have under NN). In particular,

deviating from NN promotes investment if either co-investment is essential to foster NGA deployment (since both the cost of investment and CPs' bargaining power *ex post* are high), or it is a means to raise the probability of success of NGA investment, while avoiding high *ex post* fees (when both the cost of investment and CPs' bargaining power *ex post* are low).

However, we have also shown that simply departing from NN could not be enough to provide access ISPs with sufficient incentives to invest in infrastructure, due to the typical hold-up problem. Since the value of NGA depends on the complementary services offered by CPs, the latter may have high bargaining power in negotiating fees for their content to be delivered to NGA subscribers when investment is sunk. Thus, contrary to common wisdom, access ISPs' investment incentives may be lower in the unregulated regime than under NN.

In such a case, to strengthen access ISPs' bargaining power *ex post* (and thereby foster investment), national governments may decide to prescribe minimal levels for *ex-post* (termination or priority) fees.[32] Alternatively, CPs may be encouraged to co-invest if they receive a sort of risk premium for participating in the investment, such as a time period in which they have the priority right in delivery speed to NGA subscribers at privileged conditions. National governments in the EU are currently discussing whether and how to tax large multinational CPs for the revenues they collect in each Member State. In this framework, governments might introduce fiscal incentives to induce CPs to participate *ex ante* in the deployment of NGA in their respective countries.

As long as CPs participate in the investment *ex ante*, or contribute *ex post*, NGA subscription prices may decline, thereby further sustaining end users' demand for ultra-fast broadband access. The upgrading of broadband infrastructure may also induce investment in content, since content quality and variety is related to the quality of the network.

One critical issue is how to set access conditions to NGA for late and small entrants (both ISPs and CPs) that have not participated *ex ante*. While it is essential that access to NGA

[32]National governments may even negotiate (termination or priority) fees with large multinational CPs on behalf of local ISPs. Similarly, national governments often negotiate drug prices with pharmaceutical companies on behalf of health insurance organizations.

be safeguarded, *ex post* access conditions should not be too favorable not to undermine *ex ante* investment incentives. It is also essential to maintain the open Internet and allocate a sufficient amount of bandwidth to services and applications less sensitive to quality degradation. Thus, *ex post* access conditions for large commercial CPs may be different from those for small or non commercial CPs.

Despite potential shortcomings, co-investment plans of access ISPs and CPs may represent a long run 'win-win' equilibrium for the evolving telecom industry. More generally, incumbent ISPs and large CPs should consider close interaction in defining new business models that serve mutual interests, while ensuring the maximum value for society.

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