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TECHNOLOGY INVESTMENT AND ALTERNATIVE REGULATORY REGIMES WITH DEMAND UNCERTAINTY

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Technology Investment and Alternative Regulatory Regimes with Demand Uncertainty

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Abstract

A vertically integrated incumbent and an OLO (Other Licensed Operator) dynamically compete in the market for broadband access. The incumbent has the option to invest in building a Next Generation Network that covers all urban areas with similar demand structures. The investment return in terms of demand increase is uncertain. We compare the impact of different access price regulation regimes - full regulation, partial regulation (only the copper network is regulated), risk sharing - on investment incentives and social welfare. We find that, compared to Foros (2004), the OLO gets better access condition in case of partial regulation and exclusion does not necessarily happen in equilibrium even if the incumbent has more ability than the OLO. Moreover, risk sharing emerges as the most preferable regime both from a consumer and a social welfare perspective for a large range of parameters.

Keywords: Investment, Regulation, Access pricing, New Technology, Risk Sharing
JEL Classification: L51, L96

1 Introduction

Telecommunications markets are experiencing a period of drastic technological development. The possibility to build a so-called Next Generation Network (NGN) gives firms the chance to exploit extremely faster transmission and thereby enrich their offer with more interactive and sophisticated services. However, the actual existence and importance of a demand for NGN applications is still uncertain[1]. The technology has been available for a while now, but given the high fixed costs needed to build the necessary infrastructure, and the risks connected to it due to the uncertain demand for ultra-broadband services, the NGN deployment goes very slowly all over the world.

The vexing issue as to how to provide firms with enough investment incentives, while eventually reserving the benefits of the network development for final consumers, is highly debated by industry actors, regulators and scholars. In particular, access regulation is widely argued about its potential discouraging effect on regulated firms' investment. When obliged to share its network elements with facilities-free rivals at a regulated access price, the incumbent may feel reluctant to invest in NGN because of the spillover effect enjoyed by the Other Licensed Operators (OLO). For these reasons, access regulation, mainly in the form of mandatory unbundling, may induce less or later incumbent's investment compared to an unregulated scenario, but also compared to the socially desired level (Chang et al. (2003); Crandall and Singer (2003); Ingraham and Sidak (2003); Bourreau and Dogan (2005); McFadden et al. (2005); Pindyck (2007); Grajek and Röller (2011)). The European Commission seems to acknowledge these concerns for future investments in NGN. In the recent Recommendation C(2010) 6223 on "Regulated Access to NGANs" (September 2010), the possibility of relaxing - if not eliminating - ex ante regulation when a risk sharing agreement backs up the deployment of NGN is openly considered.

The issue of broadband investment and regulation has attracted and still attracts a lot of research attention.[2] Our paper contributes to this strand of literature by addressing the issue of access price setting when the incumbent has the option to invest in NGN and investment returns in terms of demand increase are uncertain. Using a model where a vertically integrated incumbent and an OLO dynamically compete in the market for broadband access, we analyse the effect of three different access regimes on the incentives to invest by the incumbent: full regulation (mandatory unbundling for NGN), partial regulation (no mandatory unbundling for NGN) and risk sharing. We then compare their

[1]See for instance TheEconomist (2010) about lack of demand for NGN services in the US.

[2]Cambini and Jiang (2009) provide a review of the theoretical and empirical literature on broadband investment and access regulation.

impact on social welfare, balancing the effect of each regulatory regime on static and dynamic efficiency.

In our paper, we follow the original set-up of broadband investment and access regulation developed by Foros (2004)[3]. We develop a model with two firms having different ability to offer value-added services, and analyse the impact of access price regulation on the incumbent investment's incentive. Differently from Foros (2004), however, we adopt a dynamic model of technology adoption and we include demand uncertainty over value-added NGN services. Considering that NGN investment might fail to expand market demand, we also assume that the OLO might possibly switch back to the copper network if there is no demand for NGN applications and the access to copper is cheaper. We then conduct our analysis comparing the impact on investment of three alternative access regimes. In this respect, the paper closer to ours is Nitsche and Wiethaus (2011). The authors analyse a simple two stage framework with identical firms, where the incumbent is the only firm entitled with investment option and there is uncertainty over the investment success in terms of demand increase. Their work compares different modes of regulation - access price based on costs, risk sharing and regulatory holiday - as of the extent of investment and consumer welfare outcomes. There are several differences between our work and Nitsche and Wiethaus (2011)'s work. First, in their model, following Klumpp and Su (2010), the access charge is determined *ex-post* from the equilibrium quantities, in a way that permits a partial allocation of the fixed costs borne by the incumbent. In our model, we take a different stand towards the case of regulated access price, in that the regulator establishes *ex-ante* the level of access price, via first-order conditions. The benchmark case for access regulation in our model is a strict marginal cost-based rule, as in much of the literature in this field (Foros (2004), Kotakorpi (2006) for instance). Second, our setting is dynamic and we investigate the timing of investment in a context with demand uncertainty, rather than the extent of the investment. Moreover, we are able to carry out a complete welfare analysis, whereas Nitsche and Wiethaus (2011)'s work only gives an overview of the different modes of regulation's implications in terms of consumer welfare. Lastly, our model includes quality differentiation *à la* Foros and considers the its impact on the equilibrium results, while Nitsche and Wiethaus (2011)'s setting implies undifferentiated firms.

[3] A similar approach has been recently used by Mizuno and Yoshino (2012). In their model the authors analyse the incumbent's incentive to invest under regulatory non-commitment, generalizing the results by Foros (2004). In our paper, instead, we use a dynamic investment model and demand uncertainty and we also compare different regulatory regimes in terms of welfare. Our analysis is thus complementary to the Mizuno and Yoshino's one.

Existing literature already analyses the impact of uncertainty on the timing of telecommunications infrastructure development using dynamic race models between incumbent and entrant operators and focuses on specific access pricing regimes, mainly regulatory holidays (see, for example, Hori and Mizuno (2006), Hori and Mizuno (2009), Gans (2001), Gans (2007)) and Vareda and Hoernig (2010)). In our model, in contrast, we consider uncertainty in a dynamic setting but we focus on services-based competition while taking into account different possible regulatory regimes.

Our paper also differs from a recent strand of studies that analyse the investment game where both the incumbent and entrants have the option to invest. Brito et al. (2010b)'s paper examines the incentives of a vertically integrated firm (regulated at wholesale level) to invest in and to give access to a new (upgraded) wholesale technology that is not subject to access regulation. Bourreau, Cambini and Dogan (2011) and Inderst and Peitz (2011) analyse the incentives to migrate from an old technology to a new one, and how wholesale access conditions affect this migration. Finally, Manenti and Scialà (2011) study the impact of access regulation on entrant and incumbent's investment and show that, in absence of regulation, the incumbent would set an access charge to a new infrastructure in order to prevent resale based entry and this overstimulated entrant's investment that might turn out to be socially inefficient.

Our model reveals that the differences in ability to provide value-added services and their absolute values with respect to the overall level of demand highly affects the investment choice. Since we include the possibility for the OLO to switch back to the copper network instead of leaving the market *tout court* as an alternative to the NGN, we find that the OLO gets better access condition in case of partial regulation and there are cases in which, in contrast to Foros (2004), exclusion does not happen in equilibrium even if the incumbent has more ability than the OLO. In case of mandatory switch to the NGN, we find that the OLO remains active in the market if and only if its ability to provide value-added services is higher than the incumbent's one. The equilibrium results show that investment is always made later than the social optimum level and that uncertainty has the effect of delaying the investment even further. Due to a combination of competitive intensity and investment incentives, we find that risk sharing is the most preferable regime from a consumer welfare perspective, but also from a total welfare perspective for a large range of parameters.

The remainder of the paper is organized as follows. Section 2 introduces the model and the main findings under the three different regulatory regimes. Section 3 summarizes the paper and concludes.

2 The Model

We first present the basic features of the model. Then we present the results of partial regulation (where only the legacy network's access is regulated), full regulation (access to the legacy network and NGN are both regulated) and risk sharing regimes. Finally we illustrate welfare comparisons between the different cases.

2.1 The Basic Framework

Two firms compete downstream for the provision of broadband connectivity. One firm is a vertically integrated incumbent, who owns the existing infrastructure, constituted by the copper network, and has the obligation to unbundle the network elements to its competitor under access regulation. The access fee to the existing infrastructure is assumed to be regulated at cost. The second firm is a downstream competitor, leasing lines from the incumbent. Both firms provide the same services via the existing network, e.g. the conventional PC-centric services like www and email.

The incumbent firm has the option to invest in building a Next Generation Network (NGN). Such networks allow firms for a drastic improvement of the services provided, e.g. more speed in data transmission, enabling interactive TV-centric and gaming broadband services, IP-based and high definition TV, more capacity and faster connectivity.

The incumbent can decide at any time whether to invest in NGN or keep on using the copper network. Its investment choice is a one-time decision and it cannot be updated in a later period. Once it decides to invest, the incumbent must build a network that covers the entire market. In this paper, when we talk about the entire market, we refer to regions that present roughly similar demand structures, in which there is uncertainty about NGN success. The rival can then decide whether to stay with the copper network, or to ask the incumbent for access to the NGN by paying an access fee. Alternatively, the incumbent and the entrant can jointly undertake and share the cost of the investment under a risk sharing agreement. In this case, we assume that each operator can use the NGN without having to make further payments for access.

Broadband services are sold by both operators to end-users at a fixed subscription fee independent of actual usage and time connected. Hence firms face downward sloping demand curves. Services provided by the two firms through the legacy network made of copper are perfect substitutes. The adoption of NGN enriches the retail offer with value-added services. Market success of NGN in terms of demand increase is uncertain. If the investment turns out to be successful, the opportunity to obtain value-added services increases consumers' willingness to pay and shifts demand curves upwards for both firms.

Consumers' quality perception of the value-added services is differentiated between the two firms, so the respective market shares will be affected. In case of failure, there is no shift in demand.

We assume that retailers compete à la Cournot and the quantity they sell is interpreted as the number of subscriptions. We assume that the access to the legacy copper network is regulated at cost and there is no regulation in the retail market. Access pricing is the only regulatory tool in the context here, and, since the existing regulatory methods are designed for linear access pricing, we assume a linear access price. Furthermore, in line with the existing EU regulatory framework, we assume that access charge to the new broadband network, in case of full regulation, has to cover at least operating (marginal) cost (i.e. that the access charge cannot be set below cost).[4] Moreover, the regulator has imperfect ability to make credible commitment before the incumbent invests. More specifically, the regulator is able to commit to a certain regulatory regime (full or partial regulation), but he cannot *ex-ante* commit on the exact level of the access charge on NGN. Therefore it is impossible for the regulator and the firms to contract the level of the access charge before the NGN is deployed, though the firm knows that in case of regulation the access charge will at least cover (marginal) cost[5].

The timing of the model is as following[6]:

Stage 0 At any time, the incumbent firm (together with the OLO, in case of risk sharing) decides whether to invest in building a NGN or staying with the copper network;

Stage 1 In case of full access regulation (partial access regulation), the regulator (the incumbent firm) chooses the access price the OLO has to pay to use the NGN;

Stage 2

- At any time after the access conditions have become common knowledge, the OLO decides whether to keep on using the legacy network or upgrade and ask access to the NGN;
- The state of demand is revealed and the two firms compete à la Cournot in the retail market.

Notice that in the risk sharing case, Stage 1 and the first bullet point of Stage 2 are

[4]As we will show in next paragraphs, this restriction, aside from being more realistic, is due to the OLO's option to switch back to the old "copper" network. To make our analysis more complete, we will relax this assumption in Subsection 2.2.1, imposing to the OLO a mandatory switch to the NGN.

[5]Brito et al. (2010a) consider how two-part tariffs can mitigate the regulatory commitment problem.

[6]A similar structure of the game has been adopted by Mizuno and Yoshino (2012)

absent.

Also notice that the OLO's decision to use the NGN appears somehow flexible: it can decide to use the NGN immediately after the investment is deployed, and before the state of demand is realised; or it can wait and see what the true state of demand is, before deciding which network to use; and, at any time, the OLO has always the option to switch back the other (copper) network. Notwithstanding this, the regulator may decide to set access conditions under which the OLO chooses to use the NGN after the investment is deployed and it does not change its decision even if the investment turns out to be a failure. This assumption is plausible for two reasons. First, given the difficulties in the take-off of NGN networks, it is of greater social interest to analyse the circumstances under which more industry actors would actually decide to initially join and stick with the NGN. Second, in a dynamic setting, restricting our attention to such circumstances allows us to avoid the issue of multiple equilibria (which would not however add much insights, but rather make the model's implications less clearcut) and makes the whole analysis more tractable by a great extent. In an extension of the model, we will also analyse the implications of a compulsory switch to the NGN for the OLO.

Demand Side

Consumers have unit demand. Their valuation of a firm's service is divided into two parts: one is for the basic broadband services and the other is for the value-added services running on NGN. Following Foros (2004), we assume the former is heterogeneous but the latter is homogeneous. Therefore a representative consumer's valuation of firm i's service is given by:

$$\begin{cases} v + \beta_i & \text{with probability } \gamma\text{, case of success} \\ v & \text{with probability } (1-\gamma)\text{, case of failure} \end{cases}$$

Subscripts $i = 1, 2$ indicates incumbent and OLO, respectively. Here v is interpreted as the consumer's willingness to pay for the basic service without new technology and is assumed to be uniformly distributed in $(-\infty, a]$. Following Foros (2004), we allow for negative values of v in order to avoid corner solutions where all consumers enter the market. β_i describes firm i's ability to offer value-added services after a successful investment and is assumed to belong to the interval $(0, g)$ with $g = a - c > 0$, where c is the marginal cost for the provision of value-added services. Unlike Nitsche and Wiethaus (2011) and similarly to Foros (2004), firms' abilities are differentiated. Notice also that there is no chance here for an overall "drastic" or "non-drastic" investment, as in Brito et al. (2010b), since the market is never covered[7]. As in Nitsche and Wiethaus (2011), market success is uncertain: with probability γ the investment increases consumers' willingness to pay by β_i; with probability $(1-\gamma)$, consumers' willingness to pay does not increase at all, even though NGN enhances the quality of services.

The subscription fee charged by firm i is p_i. A representative consumer buys from firm i other than firm j ($j = 1, 2$ and $j \neq i$) if the following conditions are satisfied:

$$\begin{cases} v + \beta_i - p_i > v + \beta_j - p_j & \text{with probability } \gamma \text{, case of success} \\ v - p_i > v - p_j & \text{with probability } (1-\gamma) \text{, case of failure} \end{cases}$$

Therefore the firms' quality-adjusted prices P should be equal if both firms are active in the market:

$$\begin{cases} p_i - \beta_i = p_j - \beta_j = P & \text{with probability } \gamma \text{, case of success} \\ p_i = p_j = P & \text{with probability } (1-\gamma) \text{, case of failure} \end{cases}$$

Consumers whose willingness to pay for the basic service v is no less than the quality-adjusted price P enter the market, so there are $a-P$ active consumers. The total quantity provided by firms is $Q = q_1+q_2$, so we have $Q = a-P$. Thus the inverse demand functions faced by firms are:

- case of success

$$\begin{cases} p_1^s = a + \beta_1 - q_1^s - q_2^s \\ p_2^s = a + \beta_2 - q_1^s - q_2^s \end{cases}$$

- case of failure

$$\begin{cases} p_1^f = a - q_1^f - q_2^f \\ p_2^f = a - q_1^f - q_2^f \end{cases}$$

With the superscript s, f we denote the case of investment's success and failure, respectively. Note that p_i^s here is a quality-adjusted Cournot price, which captures firm i's ability to provide value-added services. Since such abilities are differentiated between the two firms, the quality-adjusted prices differ between the incumbent and the OLO, in case of success. The demand for basic services running on the copper network, p_i^C is the same as the demand in case of failure, so we have that

$$\begin{cases} p_1^C = a - q_1^C - q_2^C \\ p_2^C = a - q_1^C - q_2^C \end{cases}$$

[7]In Brito et al. (2010b) instead, Hotelling framework for demand implies the possibility of all consumers preferring one firm to the other.

Although we assume linear demand here, Foros (2004) has shown that the qualitative results hold with a more general demand function $P_i(Q, \lambda_i)$ with $\lambda_i = \beta_i$ as long as $\partial P_i(Q, \lambda_i)/\partial \lambda_i > 0$ and $\partial^2 P_i(Q, \lambda_i)/\partial \lambda_i^2 \leq 0$.

Supply side

A local connection to an end user is composed of two main elements, namely, a local line and a line card. The first cost is borne by the network owner for maintaining the daily operation of the essential input and is normalised to 0 in our model without loss of generality. The second cost, incurred to provide services to end users at retail level, is assumed to be constant and equal to $c > 0$. Further, we assume that a market for the broadband access service exists, i.e. $a > c$. The access charge to the copper network and to the NGN are denoted with r^C and r^l, respectively, where the superscript $l = P, F$ corresponds to the cases of partial regulation and full regulation, respectively. The level of access charge is decided by the incumbent, in case of partial regulation, or by the regulator, in case of full regulation.

We assume that the regulator sets access charges after the investment is deployed, being aware of the presence of demand uncertainty. Hence, the access charge to the NGN becomes r^{lf} in case of failure and r^{ls} in case of success[8].

The investment in NGN entails a quadratic adoption cost given by $C_i(m, \Delta) = m^2\Delta^2\phi/2$. $\Delta \in [0, 1]$ is the discount factor determined by the new-technology adoption date. Here we use the same notation and interpretation as Bourreau and Dogan (2005) that $\Delta = exp(-\delta t)$ where δ is the discount rate normalised to 1 and t denotes time. Δ reflects the investment timing: a higher Δ corresponds to an earlier investment. The extent of network updating is represented by $m \in [0, 1]$. In our setting, the incumbent chooses Δ optimally and invests in the whole network, i.e. $m = 1$, so $C_i(\Delta) = \Delta^2\phi/2$. ϕ is a positive cost parameter. We assume the following: $\frac{d}{d\Delta}C \geq 0$ and $\frac{d^2}{d\Delta^2}C > 0$. Notice that since the investment cost decreases with time, there is no case in which there is no investment in this setting, unlike in Brito et al. (2010b).

The *ex-ante* profits of the two firms are the following:

$$\begin{cases} \pi_1^l = (1-\Delta)\pi_1^C + \Delta(\gamma\pi_1^{ls} + (1-\gamma)\pi_1^{lf}) \\ \pi_2^l = (1-\Delta)\pi_2^C + \Delta(\gamma\pi_2^{ls} + (1-\gamma)\pi_2^{lf}) \end{cases}$$

Here, firms' profits before the investment, denoted by the superscript C in the equa-

[8] We also solved the case where the regulator sets a single access charge for the NGN, independent of demand. We discuss the solution of this case in footnote 12.

tions above to represent the use of the copper network, are equal to:

$$\begin{cases} \pi_1^C = (p_1^C - c)q_1^C + r^C q_2^C \\ \pi_2^C = (p_2^C - c)q_2^C - r^C q_2^C \end{cases}$$

Firms' profits after investing in NGN, provided that the OLO also decides to use the new infrastructure, are different depending on the true state of demand.

- case of success

$$\begin{cases} \pi_1^{ls} = (p_1^{ls} - c)q_1^{ls} + r^{ls} q_2^{ls} - \alpha^l \Delta\phi/2 \\ \pi_2^{ls} = (p_2^{ls} - c)q_2^{ls} - r^{ls} q_2^{ls} - (1 - \alpha^l)\Delta\phi/2 \end{cases}$$

- case of failure:

$$\begin{cases} \pi_1^{lf} = (p_1^{lf} - c)q_1^{lf} + r^{lf} q_2^{lf} - \alpha^l \Delta\phi/2 \\ \pi_2^{lf} = (p_2^{lf} - c)q_2^{lf} - r^{lf} q_2^{lf} - (1 - \alpha^l)\Delta\phi/2 \end{cases}$$

The parameter $\alpha \in [0, 1]$ represents the way the investment's cost is shared between the two firms. So we have that $\alpha^P = \alpha^F = 1$, because in the cases of partial regulation and full regulation the investment is undertaken by the incumbent alone, while in case of risk sharing $\alpha^{RS} \in (0, 1)$.

The following assumption is made for the model.

Assumption 2.1. $r^F \geq 0$ *and* $r^C = 0$

This constraint imposes a lower bound limit to the NGN access price set by the regulator, r^F, which cannot be lower than the network operation marginal cost, as in Foros (2004). In other words, the incumbent must have a non-negative price cost margin on its sale to the OLO if the NGN access market is regulated. In the second part of Assumption 2.1, we assume that the access fee to the copper network, r^C, is regulated at marginal cost, restricting our attention to the problem of access price setting in the NGN market. In our model, indeed, we want to focus on those situations in which the OLO's participation to the NGN depends on the relative firms' abilities in offering value-added services and on the state of demand, therefore we consider a situation in which the OLO's outside option is positive to start with.

Social Welfare

The social welfare function faced by the regulator at the moment of the access fee setting is composed of a pre-investment part and a post-investment part, with $l = P, F, RS$, in the following way:

$$E(W) = (1-\Delta)W^C + \Delta E(W^l)$$

with

$$W^C = \left(\frac{a+\beta_1-p_1^C}{2}q_1^C + \frac{a+\beta_2-p_2^C}{2}q_2^C + \pi_1^C + \pi_2^C\right)$$

$$E(W^l) = \gamma\left(\frac{a+\beta_1-p_1^{ls}}{2}q_1^{ls} + \frac{a+\beta_2-p_2^{ls}}{2}q_2^{ls} + \pi_1^{ls} + \pi_2^{ls} - \Delta\phi/2\right)$$
$$+(1-\gamma)\left(\frac{a+\beta_1-p_1^{lf}}{2}q_1^{lf} + \frac{a+\beta_2-p_2^{lf}}{2}q_2^{lf} + \pi_1^{lf} + \pi_2^{lf} - \Delta\phi/2\right)$$

Stage 2: Retail Market Competition

Firms compete under Cournot competition in the retail market. The resulting equilibrium quantities in this segment are:

- Before investment

$$q_1^{C*} = \frac{a-c}{3}\ ,\ q_2^{C*} = \frac{a-c}{3}$$

- After successful investment

$$q_1^{ls*} = \frac{a-c+r^{ls}+2\beta_1-\beta_2}{3}\ ,\ q_2^{ls*} = \frac{a-c-2r^{ls}+2\beta_2-\beta_1}{3}$$

- After unsuccessful investment

$$q_1^{lf*} = \frac{a-c+r^{lf}}{3}\ ,\ q_2^{lf*} = \frac{a-c-2r^{lf}}{3}$$

with $l = P, F, RS$ denoting the different regulatory regimes.

We now make the following assumption.

Assumption 2.2. *$2\beta_i \geq \beta_j$, $\forall i, j = 1, 2$ with $i \neq j$*

The above inequality implies that the difference in ability to provide value-added services between firms is not too large. Therefore with any given access price r^l, each firm's quantity is a non decreasing function with respect to the investment. Under this assumption, the incumbent cannot use the investment in NGN as a foreclosure tool (Foros (2004)).

Stage 2: the OLO chooses whether to use the NGN

Ex-ante, the OLO decides to ask access to NGN only if the expected profits from doing so are not lower than the profits obtainable by staying with the copper network, whose access price is regulated at cost:

$$E(\pi_2^l) = \gamma\pi_2^{ls} + (1-\gamma)\pi_2^{lf} \geq \pi_2^C$$

with $l = P, F, RS$.

Once we insert the equilibrium quantities, this inequality implies that:

$$\gamma\left(\frac{a-c-2r^{ls}+2\beta_2-\beta_1}{3}\right)^2 + (1-\gamma)\left(\frac{a-c-2r^{lf}}{3}\right)^2 \geq \left(\frac{a-c}{3}\right)^2 \tag{2.1}$$

If the above condition is satisfied, the OLO will switch to NGN once the incumbent's investment is deployed, but its success is still uncertain.

In this paper, we establish the conditions under which the OLO finds it convenient to stay with the NGN *ex-post*, whatever the true state of demand turns out to be [9]. The after investment profits arising when the OLO stays with copper network, or switches back to copper network - outside option profits, denoted by the superscript o - in case of success and failure, respectively, are the following:

$$\pi_1^{os} = \left(\frac{a-c+2\beta_1}{3}\right)^2, \; \pi_2^{os} = \left(\frac{a-c-\beta_1}{3}\right)^2$$

$$\pi_1^{of} = \left(\frac{a-c}{3}\right)^2, \; \pi_2^{of} = \left(\frac{a-c}{3}\right)^2$$

We will only consider access conditions for which the *ex-post* OLO's profits from using NGN are not lower than the outside option profits:

[9] This restriction is required in order to be able to analyse a stable equilibrium. Otherwise, in a dynamic context, the analysis would become much more complicated and less insightful, due to multiplicity of potential equilibria. This hypothesis is also empirically supported by the analysis of Alleman and Rappoport (2004) who show that the degree of substitutability between DSL services and traditional dial-up connections is asymmetric: the cross-elasticity of dial-up services with respect to DSL access prices is 0.423 while the cross-elasticity of DSL access services with respect to dial-up prices is only 0.04. This means that data supports our assumption that once a consumer switch to a new high-quality broadband service he/she is less likely to turn back to use the "old" one.

- in case of success

$$\left(\frac{a-c-2r^{ls}+2\beta_2-\beta_1}{3}\right)^2 \geq \left(\frac{a-c-\beta_1}{3}\right)^2 \tag{2.2}$$

- in case of failure

$$\left(\frac{a-c-2r^{lf}}{3}\right)^2 \geq \left(\frac{a-c}{3}\right)^2 \tag{2.3}$$

Following from the assumption that the copper network access price is regulated at marginal cost level, Condition 2.3 requires that:

$$r^{lf} = r^C = 0 \text{ with } l = P, F, RS \tag{2.4}$$

By charging an access fee higher than zero in case of failure, the incumbent would earn zero profits from the upstream segment in any case, because the OLO would switch back to the regulated copper network. Therefore, the access fee in case of failure will respect Condition (2.4) and profits will be the same as with the copper network under all regulatory regimes:

$$\pi_1^{lf*} = \left(\frac{a-c}{3}\right)^2, \pi_2^{lf*} = \left(\frac{a-c}{3}\right)^2$$

After substituting the expression for π_2^{lf*}, we can simplify the OLO's *ex-ante* constraint 2.1 in the following way:

$$\left(\frac{a-c-2r^{ls}+2\beta_2-\beta_1}{3}\right)^2 \geq \left(\frac{a-c}{3}\right)^2 \tag{2.5}$$

As we can see, when the above condition is satisfied, Condition 2.2 is automatically fulfilled. We will therefore consider only Conditions 2.5 and 2.4 in the rest of the analysis. Notice that, since we are focusing on access rules which do not distort competition no matter what the true state of demand is, Condition 2.5 does not depend on the probability of success γ.

2.2 Partial Regulation

Stage 1: the incumbent chooses the access price to the NGN

The incumbent's profit function after investment is:

$$E(\pi_1^P) = \gamma((q_1^{Ps*})^2 + r^{Ps}q_2^{Ps*}) + (1-\gamma)(q_1^{Pf*})^2 - \Delta\phi/2$$

Remind that $r^{Pf*} = 0$, by Condition 2.4. We analyse the situation in which the incumbent makes a take-it-or-leave-it offer to the OLO, differently from Nitsche and Wiethaus (2011) who model the partial regulation case as a Nash bargaining. Considering Condition 2.5, incumbent's profit maximisation gives three parameters range that determine different values for the access price chosen by the firm, as shown in Figure 1:

$$r^{Ps*} = \begin{cases} \frac{a-c}{2} + \frac{\beta_1+4\beta_2}{10} & \text{if } 2(\beta_2-\beta_1)/5 \geq (a-c)/3 \text{ and } 6\beta_2 < 5\beta_1 \\ \frac{2\beta_2-\beta_1}{2} & \text{if } 6\beta_2 \geq 5\beta_1 \end{cases}$$

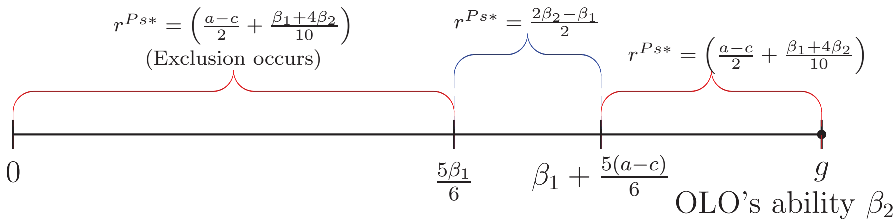

Figure 1: Partial Regulation

When β_2 is higher than β_1 by a considerable extent, i.e. $2(\beta_2 - \beta_1)/5 \geq (a-c)/3$, the OLO earns higher profits in the NGN market, paying the unregulated access charge, than in the outside option. Therefore, the incumbent charges the access price that maximises its profits and allows the greatest rent extraction from the OLO in the upstream market. The parameter threshold $2(\beta_2-\beta_1)/5 \geq (a-c)/3$ derives from Condition 2.5, once inserted the expression for the unregulated access price into the equilibrium quantities.

If $2(\beta_2 - \beta_1)/5 \geq (a-c)/3$, the corresponding expected equilibrium quantities are the following:

$$\begin{cases} E(q_1^{P*}) = \gamma\left(\frac{a-c}{2} + \frac{7\beta_1-2\beta_2}{10}\right) + (1-\gamma)\left(\frac{a-c}{3}\right) \\ E(q_2^{P*}) = \gamma\left(\frac{2(\beta_2-\beta_1)}{5}\right) + (1-\gamma)\left(\frac{a-c}{3}\right) \end{cases}$$

For intermediate values of the quality parameters, the incumbent will lower the access price to verify Condition 2.5 with equality, once considered the equilibrium quantities. When β_1 is not considerably higher than β_2 - as defined by the second parameter threshold $6\beta_2 \geq 5\beta_1$ (see Appendix A.1) -, in particular, the incumbent's profit from charging the constrained access price to NGN is higher than the profit from exclusion.

In this case, we have an intermediate parameters range such that $2(\beta_2 - \beta_1)/5 < (a-c)/3$ and $6\beta_2 \geq 5\beta_1$ (see Figure 1), that yields the following expected equilibrium quantities:

$$\begin{cases} E(q_1^{P*}) = \gamma\left(\frac{a-c}{3} + \frac{\beta_1}{2}\right) + (1-\gamma)\left(\frac{a-c}{3}\right) \\ E(q_2^{P*}) = \frac{a-c}{3} \end{cases}$$

Finally, when the incumbent is considerably better in offering value-added services, it prefers to exclude the OLO from the NGN market.

Hence, for $6\beta_2 < 5\beta_1$, we obtain:

$$\begin{cases} E(q_1^{P*}) = \gamma\left(\frac{a-c}{3} + \frac{2\beta_1}{3}\right) + (1-\gamma)\left(\frac{a-c}{3}\right) \\ E(q_2^{P*}) = \frac{a-c}{3} \end{cases}$$

Notice that since the OLO's outside option is copper network rather than leaving the market entirely, unlike in Foros (2004), the OLO gets better wholesale access conditions. In Foros (2004), the incumbent always charges the unconstrained access price, which excludes the entrant whenever the entrant's ability is not higher than the incumbent's ability. In this setting, for the parameters range $\beta_1 + 5(a-c)/6 > \beta_2 > \beta_1$, the OLO is better than the incumbent but this latter cannot charge the unconstrained access price or the OLO will find it more convenient to switch to the outside option. Furthermore, for the parameters range $\beta_1 > \beta_2 \geq 5\beta_1/6$, the incumbent is better than the OLO in offering value-added services, but it gains more profits by charging an access price that ensures the OLO positive profits in the NGN market. Only for values of the parameters such that $5\beta_1/6 > \beta_2$ there is exclusion.

Proposition 2.1. *Under the assumptions $r^C = 0$ and $2\beta_i \geq \beta_j$ $(i, j = 1, 2$ with $i \neq j)$, when the OLO has as an outside option the possibility to use the regulated copper network rather than leaving the market entirely, there is a range of parameters for which there is no exclusion in the provision of higher value-added services without ex ante intervention, even if the incumbent's ability is higher than the OLO.*

Proof. See Appendix A.1. □

Stage 0: the incumbent chooses the investment timing Δ

After inserting r^{Ps*}, q_1^{P*} and q_2^{P*} into the incumbent's profit function, the first-order condition with respect to Δ returns the following investment timings:

$$\Delta^{P*} = \begin{cases} \frac{(25(a-c)^2 + 9(10\beta_1(a-c) + (3\beta_1 - 2\beta_2)^2 + 4\beta_1\beta_2))\gamma}{180\phi} & \text{if } 2(\beta_2 - \beta_1)/5 \geq (a-c)/3 \\ \frac{(3\beta_1^2 + 2(a-c)(\beta_1 + 2\beta_2))\gamma}{12\phi} & \text{if } 6\beta_2 \geq 5\beta_1 \\ \frac{(4\beta_1(a-c+\beta_1))\gamma}{9\phi} & \text{if } 6\beta_2 < 5\beta_1 \end{cases}$$

These are the optimal investment timings chosen by the incumbent as long as the conditions $((25(a-c)^2 + 9(10\beta_1(a-c) + (3\beta_1 - 2\beta_2)^2 + 4\beta_1\beta_2))\gamma)/(180\phi) \leq 1$, $((3\beta_1^2 + 2(a-c)(\beta_1 + 2\beta_2))\gamma)/(12\phi) \leq 1$ and $((4\beta_1(a-c+\beta_1))\gamma)/(9\phi) \leq 1$ are satisfied.

Here we find that, when the OLO participates into the NGN market, investment timing is positively correlated with its ability to provide value-added services, $\frac{d}{d\beta_2}\Delta^{P*} > 0$. Since the incumbent seeks to capture some rent from the OLO, the higher the OLO's ability is, the earlier the incumbent invests hoping to earn from access rents in the upstream market, in case of successful investment. This effect is stronger, the higher is the probability of success, $\frac{d^2}{d\beta_2 d\gamma}\Delta^{P*} > 0$. Also, unsurprisingly, the investment is made earlier in time the higher the probabilty of success, $\frac{d}{d\gamma}\Delta^{P*} > 0$.

The socially optimal investment timing

As a benchmark for comparison, we now evaluate the socially optimal investment timing. The social welfare function can be written as:

$$E(W^P) = (1-\Delta)W^C + \Delta E(W^{NP})$$

where $E(W^{NP})$ is the post-investment expected welfare with partial regulation - the superscript N stands for NGN -, and it is given by:

$$\begin{aligned} E(W^N P) =& \gamma \left(\frac{(q_1^{Ps*} + q_2^{Ps*})^2}{2} + (q_1^{Ps*})^2 + r^{Ps*} q_2^{Ps*} - (\Delta)\phi/2 + (q_2^{Ps*})^2 \right) \\ &+ (1-\gamma) \left(\frac{(q_1^{Pf*} + q_2^{Pf*})^2}{2} + (q_1^{Pf*})^2 - (\Delta)\phi/2 + (q_2^{Pf*})^2 \right) \end{aligned}$$

The first term inside the brackets represents the consumer surplus, the last term is the OLO's profit and the remaining ones are the profit earned by the incumbent. Now we put all equilibrium solutions into $E(W^P)$ and the first-order conditions with respect to Δ^{P*} yields the following results in the different cases:

$$\Delta^{PW*} = \begin{cases} \frac{(-5(a-c)^2)\gamma}{72\phi} + \frac{(76(\beta_2-\beta_1)^2 + \beta_1(55\beta_1+20\beta_2) + (130\beta_1+20\beta_2)(a-c))\gamma}{200\phi} & \text{if } 2(\beta_2 - \beta_1)/5 \geq (a-c)/3 \\ \frac{(9\beta_1^2 + 4(a-c)(3\beta_1+2\beta_2))\gamma}{24\phi} & \text{if } 6\beta_2 \geq 5\beta_1 \\ \frac{(11(\beta_1-\beta_2)^2 + 8(a-c)(\beta_1+\beta_2) + 8\beta_1\beta_2)\gamma}{18\phi} & \text{if } 6\beta_2 < 5\beta_1 \end{cases}$$

The superscript W stands for the welfare maximising result. This solution will represent the socially optimal investment timings as long as the conditions $((-5(a-c)^2/72\phi) + (76(\beta_2 - \beta_1)^2 + \beta_1(55\beta_1 + 20\beta_2) + (130\beta_1 + 20\beta_2)(a-c))\gamma/(200\phi)) \leq 1$, $(9\beta_1^2 + 4(a -$

$c)(3\beta_1 + 2\beta_2))\gamma)/(48\phi) \leq 1$ and $((11(\beta_1 - \beta_2)^2 + 8(a - c)(\beta_1 + \beta_2) + 8\beta_1\beta_2)\gamma)/(18\phi) \leq 1$ are satisfied.

2.2.1 Extension: Compulsory switch to NGN

In this extension we show what happens to the incumbent's access price decisions when there is compulsory switch to the NGN once the investment is deployed[10]. In this case, the OLO's outside option would be zero, as in Foros (2004). When the OLO's alternative is leaving the market entirely, the only circumstance under which the OLO makes positive profits in the NGN is when it has more ability than the incumbent. When $\beta_2 < \beta_1$, indeed, the incumbent is indifferent between charging an access price that extracts OLO's profits entirely, or one that excludes the OLO from the NGN market *tout court*.

Stage 2

Equilibrium quantities in stage 2 are unchanged.

The *ex-post* participation conditions are different, since the copper network option is not available anymore once the NGN investment is deployed. The outside option scenario consists in the OLO exiting the market and the incumbent being monopolist:

$$\pi_1^{os} = \left(\frac{a - c + \beta_1}{2}\right)^2, \ \pi_2^{os} = 0$$

$$\pi_1^{of} = \left(\frac{a - c}{2}\right)^2, \ \pi_2^{of} = 0$$

The *ex-post* OLO's participation conditions are the following:

- in case of success
$$\left(\frac{a - c - 2r^{ls} + 2\beta_2 - \beta_1}{3}\right)^2 \geq 0$$
- in case of failure
$$\left(\frac{a - c - 2r^{lf}}{3}\right)^2 \geq 0$$

[10] Consider that, at present, mandatory switch of the legacy network is not included in the EU regulatory framework.

The above conditions require that:

$$r^{ls} \leq \frac{a-c+2\beta_2-\beta_1}{2}$$
$$r^{lf} \leq \frac{a-c}{2}$$

with $l = P, F, RS$.

Stage 1: the incumbent chooses the access price to the NGN

The incumbent's profit function after investment is unchanged:

$$E(\pi_1^P) = \gamma((q_1^{Ps*})^2 + r^{Ps}q_2^{Ps*}) + (1-\gamma)(q_1^{Pf*})^2 - \Delta\phi/2$$

The expected access price chosen by the firm is the following:

$$r^{P*} = \begin{cases} \frac{a-c}{2} + \frac{\beta_1+4\beta_2}{10} & \text{in case of success} \\ \frac{a-c}{2} & \text{in case of failure} \end{cases}$$

The corresponding expected equilibrium quantities are the following:

$$\begin{cases} E(q_1^{P*}) = \gamma\left(\frac{a-c}{2} + \frac{7\beta_1-2\beta_2}{10}\right) + (1-\gamma)\left(\frac{a-c}{2}\right) \\ E(q_2^{P*}) = \gamma\left(\frac{2(\beta_2-\beta_1)}{5}\right) \end{cases}$$

As we can see, the incumbent always has positive quantities, but the OLO has non negative quantities only if $\beta_2 > \beta_1$: with this access price level, whenever the OLO is not at least as good as the incumbent in offering value-added services, it will be excluded from the market. Alternatively, the incumbent can charge the constrained access price that verifies the OLO's *ex-post* access condition with equality.

In the following we prove that, when $\beta_2 \leq \beta_1$, the incumbent is indifferent between charging the unconstrained access price that excludes the OLO and charging the constrained access price that verifies the OLO's *ex-post* participation constraints with equality, $r^{Pconst*}$, which is:

$$r^{Pconst*} = \begin{cases} \frac{a-c+2\beta_2-\beta_1}{2} & \text{in case of success} \\ \frac{a-c}{2} & \text{in case of failure} \end{cases}$$

The constrained access price level above yields the following expected equilibrium quantities:

$$\begin{cases} E(q_1^{P*}) = \gamma\left(\frac{a-c+\beta_1}{2}\right) + (1-\gamma)\left(\frac{a-c}{2}\right) \\ E(q_2^{P*}) = 0 \end{cases}$$

Therefore, the incumbent's profits from exclusion, $\pi_1^o = \gamma\pi_1^{os} + (1-\gamma)\pi_1^{of}$, or from market sharing with the constrained access price, $\pi_1^{Ps}[_{r^P = r^{Pconst*}}]$, are the same:

$$\pi_1^o = \gamma\left(\frac{a-c+\beta_1}{2}\right)^2 + (1-\gamma)\left(\frac{a-c}{2}\right)^2$$
$$\pi_1^{Ps}[_{r^P = r^{Pconst*}}] = \gamma\left(\frac{a-c+\beta_1}{2}\right)^2 + (1-\gamma)\left(\frac{a-c}{2}\right)^2$$

When the OLO's outside option is exiting the market entirely, if we assume that when indifferent the incumbent favors market sharing, there is no case for exclusion with partial regulation.

The access conditions though are less favorable to the OLO. Whenever the OLO is not at least as good as the incumbent in offering value-added services, its profits are driven down to zero. In our basic model instead, we find that there is a case in which the OLO is worse than the incumbent but it earns positive profits and remains active in the market with partial regulation.

2.3 Full Regulation

We consider this case as a benchmark for cost-based regulation, where the regulator chooses the access charge by maximising a standard welfare function. In our case, cost-based regulation translates in marginal cost pricing, so the regulator only ensures to cover the incumbent's operating costs.

Stage 1: the regulator sets the access price to the NGN

In this case, the regulator sets the access rule to the NGN in order to maximise social welfare. Its objective function after investment is the following:

$$E(W^{NF}) = \gamma\left(\frac{(q_1^{Fs*} + q_2^{Fs*})^2}{2} + (q_1^{Fs*})^2 + r^{Fs}q_2^{Fs*} - \Delta\phi/2 + (q_2^{Fs*})^2\right)$$
$$(1-\gamma)\left(\frac{(q_1^{Ff*} + q_2^{Ff*})^2}{2} + (q_1^{Ff*})^2 - \Delta\phi/2 + (q_2^{Ff*})^2\right)$$

We remind that $r^{Ff} = 0$ by Condition 2.4[11]. The first-order condition with respect to

[11] In case of failure, the regulated access charge is set to the marginal cost level to prompt the OLO's use of NGN anyways. In this case, from a policy point of view, it is more suitable and less distorsive to use other instruments rather than the access charge to help covering investment's costs, i.e. public subsidies.

r^{Fs} gives the access price as:

$$r^{Fs*} = c - a + 4\beta_1 - 5\beta_2$$

$c - a < 0$ is a necessary condition for a broadband market to exist. If $\beta_1 > \beta_2$ so much that $4\beta_1 - 5\beta_2 > a - c$, then the solution to the first-order condition given by the expression above is positive, $r^{Fs*} > 0$, implying that the regulator set an above cost access charge[12].

If, otherwise, the incumbent is worse than the OLO in offering value-added services, $\beta_1 \leq \beta_2$, or if it is better in offering value-added services but not by a great extent, $\beta_1 > \beta_2$ but $4\beta_1 - 5\beta_2 < a - c$, the solution to the first-order condition is lower than the incumbent's marginal cost of network operations, i.e. $r^{Fs*} < 0$. The regulator, indeed, not only values the fact that the OLO is able to increase demand through β_2, as also the incumbent does through β_1, but it also values that the OLO's presence increases competition downstream. This is the reason why, in order to encourage the OLO's participation into the NGN market, the regulator may set a below-cost access charge. However, $r^{Fs*} < 0$ contradicts Assumption 2.1, according to which $r^{Fs*} \geq 0$, so in this case we will impose $r^{Fs*} = 0$, such that optimal regulated access price will be set equal to the marginal cost.

The access price in case of full regulation is as following:

$$r^{F*} = \begin{cases} 0 & \text{if } 4\beta_1 - 5\beta_2 \leq a - c \\ c - a + 4\beta_1 - 5\beta_2 & \text{otherwise} \end{cases}$$

By substituting the values for r^{F*} into the expressions for the equilibrium quantities, we obtain the following expected quantities:

$$E(q_1^{F*}) = \begin{cases} \gamma\left(\frac{a-c+2\beta_1-\beta_2}{3}\right) + (1-\gamma)\left(\frac{a-c}{3}\right) & \text{if } 4\beta_1 - 5\beta_2 \leq a - c \\ \gamma 2(\beta_1 - \beta_2) + (1-\gamma)\left(\frac{a-c}{3}\right) & \text{otherwise} \end{cases}$$

[12] In an unreported document, available from authors upon request, we analyse the case where the regulator chooses a single access charge independent of demand, $\hat{r}$. The socially optimal access charge becomes equal to $c - a + \hat{\gamma}(4\beta_1 - 5\beta_2)$, where $\hat{\gamma}$ is the perceived probability of success. We can observe that the solution remains exactly the same as in the basic model, unless β_1 is so high that $\hat{r}$ becomes positive. In those cases, we observe that the range of parameters for which the regulated access price is positive shrinks, meaning that the chance for the incumbent to be awarded of its higher ability in offering services is lower. Moreover, the main difference to our basic model is that, in case of failure, the OLO would be forced out of the NGN market, due to an above cost access price, switching back to the legacy network. Finally, in case of success, the access charge $\hat{r}$ would be lower than in our basic model, depriving the incumbent's incentives to invest in NGN.

$$E(q_2^{F*}) = \begin{cases} \gamma\left(\frac{a-c+2\beta_2-\beta_1}{3}\right) + (1-\gamma)\left(\frac{a-c}{3}\right) & \text{if } 4\beta_1 - 5\beta_2 \leq a-c \\ \gamma(a-c+4\beta_2-3\beta_1) + (1-\gamma)\left(\frac{a-c}{3}\right) & \text{otherwise} \end{cases}$$

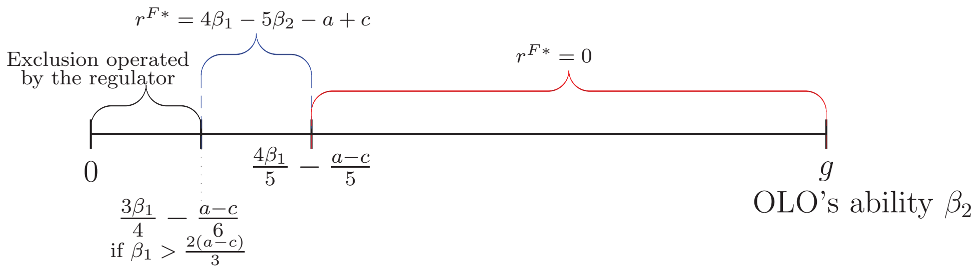

Figure 2: Full Regulation

From the above equations we can see that: when $4\beta_1 - 5\beta_2 \leq a - c$, the expected equilibrium quantities are positive, given $a - c > 0$ and Assumption 2.2; when $4\beta_1 - 5\beta_2 > a - c$, on one side, the incumbent's expected quantity is unambiguously positive - because $a - c > 0$ and $\beta_1 > \beta_2$ in this case -, and on the other side, the positive sign for the OLO's quantity is guaranteed by Condition 2.5[13].

Notice that Condition 2.5 here implies that the regulator sets access conditions in such a way not to exclude the OLO from the market, when the OLO has a lower ability in offering value-added services with respect to the incumbent, although it is equally efficient on the cost side. This case appears to be more realistic and in line with the institutional framework in Europe [14].

Simple algebra identifies the range for β_2 where it is possible to have a positive regulated access price together with the OLO active in the NGN market. Such range of parameters is:

$$3\beta_1/4 - (a-c)/6 \leq \beta_2 < 4\beta_1/5 - (a-c)/5$$

where the right hand side corresponds to the condition for an above cost access price, while the left hand side corresponds to the condition for non exclusion of the OLO. This

[13]Recall that Condition 2.5 ensures the *ex-post* convenience for the OLO to use NGN in any state of demand.

[14]The European Commission (2002, page 117−119), indeed, has adopted the standard of Equally Efficient Operator (EEO) in the context of access regulation and price test. Besides that, demand factors are less observable and much more volatile, so we would not expect the regulator to base its decisions on access price on demand factors so heavily as to exclude an EEO from the market, most of all in a situation where uncertainty plays a central role.

range of parameters exists only if $\beta_1 > 2(a-c)/3$. For all $\beta_1 \leq 2(a-c)/3$, the threshold value for β_2 to have non exclusion and positive access price is higher than the threshold necessary to have a positive regulated access price in the first place, as shown in Figure 2.

Intuitively, as long as the OLO's ability is higher than the incumbent's one, the regulator favours the OLO's participation into the market through a low access price, i.e. setting the access charge equal to the marginal cost. The regulator starts setting an above cost access charge when the incumbent's ability becomes considerably higher than the OLO's one[15]. In this case the OLO remains active in the market as long as its ability is above some minimum threshold, $3\beta_1/4 - (a-c)/6 \leq \beta_2$.

Stage 0: the incumbent chooses the investment timing

The incumbent will have different objective functions depending on the parameters. In particular, when $4\beta_1 - 5\beta_2 \leq a-c$ we have that $r^{F*} = 0$. Therefore the incumbent makes no profit in the upstream market and its objective function is:

$$\max_{\Delta^F} E(\pi_1^F) = (1-\Delta^F)\left(\frac{a-c}{3}\right)^2 + \Delta^F\left(\gamma\left(\frac{a-c+2\beta_1-\beta_2}{3}\right)^2 + (1-\gamma)\left(\frac{a-c}{3}\right)^2\right) - (\Delta^F)^2\phi/2$$

When $4\beta_1 - 5\beta_2 > a-c$, we have that $r^{F*} > 0$, then the incumbent's objective function is:

$$\begin{aligned}\max_{\Delta^F} E(\pi_1^F) =& (1-\Delta^F)\left(\frac{a-c}{3}\right)^2 + \\ & \Delta^F\Bigg(\gamma(2(\beta_1-\beta_2)^2 + (c-a+4\beta_1-5\beta_2)(a-c+4\beta_2-3\beta_1)) + \\ & (1-\gamma)\left(\frac{a-c}{3}\right)^2\Bigg) - (\Delta^F)^2\phi/2\end{aligned}$$

The two first-order conditions with respect to investment timing Δ^F give the following solution:

$$\Delta^{F*} = \begin{cases} \frac{(2(a-c)(2\beta_1-\beta_2)+(2\beta_1-\beta_2)^2)\gamma}{9\phi} & \text{if } 4\beta_1 - 5\beta_2 \leq a-c \\ \frac{(-72(\beta_1-\beta_2)^2+9(7\beta_1-9\beta_2)(a-c)+9\beta_2(7\beta_1-8\beta_2)-10(a-c)^2)\gamma}{9\phi} & \text{otherwise} \end{cases}$$

[15] This result is in line with Mizuno and Yoshino (2012) that also find that when the degree of spillover is small, i.e. that the OLO has a lower ability to offer value-added services, the incumbent has the incentive to overinvest in order to obtain from the regulator an above cost access charge

This is the incumbent optimal investment timing as long as the conditions $((2(a-c)(2\beta_1-\beta_2)+(2\beta_1-\beta_2)^2)\gamma)/(9\phi) \leq 1$ and $((-72(\beta_1-\beta_2)^2+9(7\beta_1-9\beta_2)(a-c)+9\beta_2(7\beta_2-8\beta_2)-10(a-c)^2)\gamma)/(9\phi) \leq 1$ are satisfied.

In line with Foros (2004), here we find that the optimal investment timing chosen by the incumbent is negatively correlated with the OLO's ability to provide value-added services, i.e. $\frac{d}{d\beta_2}\Delta^{F*} < 0$. When the regulated access price is set equal to the marginal cost, the incumbent has no profit by leasing lines to the OLO in the upstream market. Therefore the incumbent's investment is a pure spillover, increasing with the ability the OLO has to exploit the new technology. When the regulated access price is positive, the investment decreases with the OLO's ability. So in both cases, the better is the OLO, the later the incumbent tends to invest.

When the probability of success increases, the incumbent's incentive to invest in NGN decreases less rapidly with the OLO's ability, $\frac{d^2}{d\beta_2 d\gamma}\Delta^{F*} < 0$, but also the investment is made earlier $\frac{d}{d\gamma}\Delta^{F*} > 0$. This happens because, other things being equal, a higher probability of success gives the incumbent overall higher incentives to invest. Therefore, even if regulated access conditions are such that an increase in the OLO's ability determines a decrease in the incumbent's investment incentive, this effect becomes less strong if the probability of success is higher.

The socially optimal investment timing

If we substitute all equilibrium solutions into the welfare function, the first-order condition with respect to Δ^{FW} gives the following result:

$$\Delta^{FW*} = \begin{cases} \frac{(8(a-c)(\beta_1+\beta_2)+11(\beta_2-\beta_1)^2+8\beta_1\beta_2)\gamma}{18\phi} & \text{if } 4\beta_1 - 5\beta_2 < a-c \\ \frac{((a-c)^2+9(2\beta_2-\beta_1)^2+18\beta_1(\beta_1-\beta_2)+18\beta_2(a-c))\gamma}{18\phi} & \text{otherwise} \end{cases}$$

This solution will be the socially optimal investment timing as long as the conditions $(8(a-c)(\beta_1+\beta_2)+11(\beta_2-\beta_1)^2+8\beta_1\beta_2)\gamma/(18\phi) \leq 1$ and $(((a-c)^2+9(2\beta_2-\beta_1)^2+18\beta_1(\beta_1-\beta_2)+18\beta_2(a-c))\gamma)/(18\phi) \leq 1$ are satisfied.

2.4 Risk Sharing

We model the risk sharing agreement as an exogenous alternative, to highlight its potential improvements over social welfare outcomes. More specifically, following Nitsche and Wiethaus (2011), the risk sharing option is treated in a reduced form in which parties share the fixed cost of investment through some agreement and then they can use the NGN network without further side-payments. In this respect, risk sharing may be thought as a compulsory regime imposed on firms by the regulator.[16]

In this setting we do not have the choice of access price, because firms first compete on services using the copper network and then use the commonly built NGN, without further side-payments for the network usage. Therefore we can directly analyse the choice of investment timing.

Stage 0: Joint choice of investment timing

The expected equilibrium quantities in the last stage of the risk sharing game write as below:

$$\begin{cases} E(q_1^{RS*}) = \gamma\left(\frac{a-c+2\beta_1-\beta_2}{3}\right) + (1-\gamma)\left(\frac{a-c}{3}\right) \\ E(q_2^{RS*}) = \gamma\left(\frac{a-c+2\beta_2-\beta_1}{3}\right) + (1-\gamma)\left(\frac{a-c}{3}\right) \end{cases}$$

Assumption 2.2 ensures that both firms are active in the market, in every state of demand.

The two firms choose the investment timing by maximising over the sum of their expected profits, $E(\pi_{12}^{RS})$, considering the equilibrium quantities in the retail market:

$$\begin{aligned} \max_{\Delta^{RS}} E(\pi_{12}^{RS}) =& (1-\Delta^{RS})\frac{2(a-c)^2}{9} + \\ & \Delta^{RS}\left(\gamma\left(\frac{(a-c+2\beta_1-\beta_2)^2}{9} + \frac{(a-c+2\beta_2-\beta_1)^2}{9}\right) + \right. \\ & \left. (1-\gamma)\frac{2(a-c)^2}{9}\right) - (\Delta^{RS})^2\phi/2 \end{aligned}$$

Their choice yields the following timing for the investment in NGN:

$$\Delta^{RS*} = \frac{(2(a-c)(\beta_1+\beta_2) + 5(\beta_1-\beta_2)^2 + 2\beta_1\beta_2)\gamma}{9\phi}$$

Δ^{RS*} is the optimal timing of investment when incumbent and OLO enter in a cooperation agreement for the construction of the NGN infrastructure only if $((2(a-c)(\beta_1 +$

[16]We do not address in this paper the issue of the risk sharing contracts. Specifically on this point, Inderst and Peitz (2012) analyse cost-sharing agreements between an incumbent firm and an entrant, in the form of long-term contracts concluded before the investment is made, as opposed to contracting taking place after the network has been constructed. The authors show that the former type of agreement reduces the duplication of investment and may lead to more areas being covered. Coordination at the investment level may come at a price, though, which is reduced competition in the areas thus covered.

$\beta_2) + 5(\beta_1 - \beta_2)^2 + 2\beta_1\beta_2)\gamma)/(9\phi) \leq 1$. The second-order condition is always satisfied. Notice that the optimal Δ^{RS*} would be zero if there were no expected demand increase following the investment, i.e. $\beta_1 = \beta_2 = 0$. Of course, the two firms would have no interest in investing in NGN technology if they believed there would be no market for value-added services.

Furthermore, it is interesting to analyse how such choice changes with the difference in the ability to offer value-added services and therefore with the returns from the investment. Comparative statics shows that the sign of $\frac{d}{d\beta_i}\Delta^{RS*}$ depends on the term $5\beta_i - 4\beta_j + a - c$, with $i, j = 1, 2$ and $i \neq j$. Keeping β_1 fixed, an increase in the value of β_2 unambiguously yields to anticipating the joint construction of the NGN, i.e. $\frac{d}{d\beta_2}\Delta^{RS*} > 0$, when $5\beta_2 - 4\beta_1 + a - c \geq 0$, therefore, only when the OLO is better than the incumbent, or when the incumbent is better than the OLO but not too much. When $5\beta_2 - 4\beta_1 + a - c < 0$, the incumbent is considerably better than the OLO in offering value-added services and an increase in the ability of the OLO delays the construction of the NGN, i.e. $\frac{d}{d\beta_2}\Delta^{RS*} < 0$. This effect reflects the fact that, with risk sharing, the two firms internalise the profit externalities generated by Cournot competition. Notice, indeed, that we encountered the same conditions for the solution to the first-order condition in case of full regulation: $r^{F*} = 0$ if $5\beta_2 - 4\beta_1 + a - c \geq 0$ and $r^{F*} > 0$ if $5\beta_2 - 4\beta_1 + a - c < 0$.

The socially optimal investment timing

The socially optimal investment timing in case of risk sharing, obtained by inserting equilibrium quantities into the welfare function and maximising with respect to Δ^{RSW}, writes as below:

$$\Delta^{RSW*} = \frac{(8(a-c)(\beta_1 + \beta_2) + 11(\beta_1 - \beta_2)^2 + 8\beta_1\beta_2)\gamma}{18\phi}$$

The equation above represents the socially optimal investment timing in case of risk sharing as long as $((8(a-c)(\beta_1 + \beta_2) + 11(\beta_1 - \beta_2)^2 + 8\beta_1\beta_2)\gamma)/18\phi) \leq 1$.

2.5 Comparison of results under partial regulation, full regulation and risk sharing

We can derive the first insight from this model by comparing the results obtained in case of partial access regulation, full access regulation and risk sharing.

Proposition 2.2. *For a given timing of investment Δ and under the assumptions $r^F \geq 0$ and $2\beta_i \geq \beta_j$ $(i, j = 1, 2$ with $i \neq j)$, expected industry output $E(Q^l(\Delta))$ satisfies*

$$E(Q^{RS}(\Delta)) > E(Q^P(\Delta))$$
$$E(Q^{RS}(\Delta)) \geq E(Q^F(\Delta))$$

Proof. See Appendix A.1. □

In line with Nitsche and Wiethaus (2011), risk sharing is expected to induce more competition than partial regulation and full regulation regimes. The first inequality $E(Q^{RS}(\Delta)) > E(Q^P(\Delta))$ arises because risk sharing involves no wholesale transfers and a more symmetric market structure[17], whereas partial regulation implies transfer from the OLO to the incumbent and an asymmetric market structure, which reflects the lower level of competition. The second inequality $E(Q^{RS}(\Delta)) \geq E(Q^F(\Delta))$ arises because, when the regulated access price is constrained to zero by Assumption 2.1, risk sharing and full regulation yield the same outcome in terms of expected total quantities, but when the regulated access price is positive, full regulation involves a positive transfer which is higher than marginal cost of production, so the overall market efficiency is higher under risk sharing.

The equilibrium results in terms of NGN access conditions and, consequentially, investment incentives, change depending on the relative and absolute value of firms' abilities. In Table 1, we combine the various modes of regulation's equilibrium outcomes, identifying five different relevant parameters ranges. For ease of exposition, we name them as following: $P1F1RS$, $P2F1RS$, $P3F1RS$, $P3F2RS$, $P3F3RS$.

Case $P1F1RS$ describes the situation in which the OLO has considerably more ability than the incumbent in offering value-added services through the NGN. In this case, when the access price is not regulated, the incumbent chooses the monopoly price, whereas the regulator would choose a negative access price that we constrained to zero by Assumption 2.1. In the second case, $P2F1RS$, the values of the two firms' abilities are close to

[17] The possible difference in market shares reflects only the differences in abilities, not differences in market power. If the two firms are equal in abilities, market structure is symmetric under risk sharing.

each other, either favoring the incumbent or the OLO. Here, with partial regulation, the incumbent chooses to charge a constrained access price that makes it indifferent for the OLO to use the NGN or switch back to the copper network, while the full regulation outcome is unchanged compared to the previous situation. As the OLO's ability decreases with respect to the incumbent's one, the incumbent finds it more and more convenient to exclude the OLO from the NGN network and provide value-added services alone. Therefore in the range of values $P3F1RS$, we obtain exclusion with partial regulation, while the access price is zero with full regulation. When the incumbent becomes considerably better than the OLO in boosting the demand, the regulator favors its activity by imposing a positive regulated access price, but only insofar as that does not exclude the OLO from the market - case $P3F2RS$. A positive regulated access price together with non exclusion is not possible if the difference between the two firms' abilities is important but their absolute values are low. In that case, the OLO would prefer to use the regulated copper network if asked to pay for the NGN, as in case $P3F3RS$ where we have double exclusion, with full regulation and with partial regulation. We do not look into this case, as explained in section 2.3.

Parameters Range	Partial Regulation	Full Regulation	Risk Sharing
$g > \beta_2 \geq \beta_1 + \frac{5(a-c)}{6}$ $P1F1RS$	$P1$: $E(r^{P*})$ unconstrained, OLO in the NGN market	$F1$: $E(r^{F*}) = 0$	RS: no upstream transfers
$\beta_1 + \frac{5(a-c)}{6} > \beta_2 \geq \frac{5\beta_1}{6}$ $P2F1RS$	$P2$: $E(r^{P*})$ constrained, OLO in the NGN market	$F1$: $E(r^{F*}) = 0$	RS: no upstream transfers
$\frac{5\beta_1}{6} > \beta_2 \geq \frac{4\beta_1}{5} - \frac{a-c}{5}$ $P3F1RS$	$P3$: $E(r^{P*})$ unconstrained, OLO's EXCLUSION	$F1$: $E(r^{F*}) = 0$	RS: no upstream transfers
If $\beta_1 > \frac{2(a-c)}{3}$			
$\frac{4\beta_1}{5} - \frac{a-c}{5} > \beta_2 \geq \frac{3\beta_1}{4} - \frac{a-c}{6}$ $P3F2RS$	$P3$: $E(r^{P*})$ unconstrained, OLO's EXCLUSION	$F2$: $E(r^{F*}) > 0$, OLO in the NGN market	RS: no upstream transfers
$\frac{3\beta_1}{4} - \frac{a-c}{6} > \beta_2 > 0$ $P3F3RS$	$P3$: $E(r^{P*})$ unconstrained, OLO's EXCLUSION	$F3$: $E(r^{F*}) > 0$, OLO's EXCLUSION	RS: no upstream transfers
If $\beta_1 \leq \frac{2(a-c)}{3}$			
$\frac{4\beta_1}{5} - \frac{a-c}{5} > \beta_2 > 0$ $P3F3RS$	$P3$: $E(r^{P*})$ unconstrained, OLO's EXCLUSION	$F3$: $E(r^{F*}) > 0$, OLO's EXCLUSION	RS: no upstream transfers

Table 1: Relevant Parameters Thresholds

Proposition 2.3. *Under the assumptions $r^F \geq 0$, $2\beta_i \geq \beta_j$ ($i, j = 1, 2$ with $i \neq j$), and given the OLO's participation constraints (2.3) and (2.5), the following results hold:*

1. *Both firms are active in the market no matter what is the mode of regulation, for $\beta_2 \geq 5\beta_1/6$*

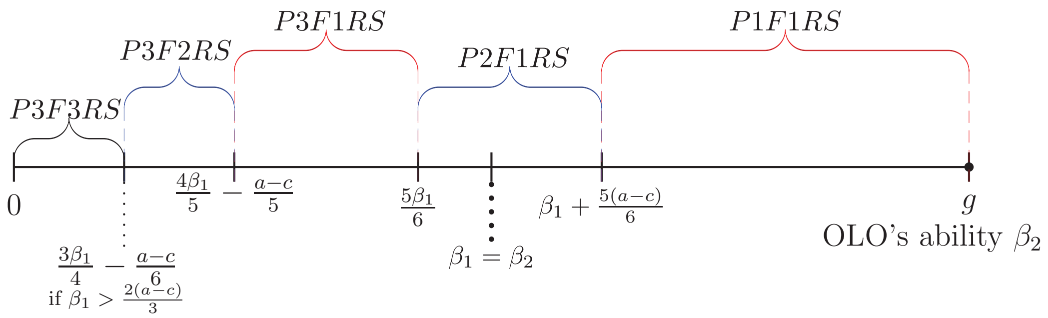

Figure 3: Relevant parameter thresholds

2. *The OLO is excluded from the NGN market with partial regulation, for* $\beta_2 < 5\beta_1/6$

3. *The chosen investment timing is always later with full regulation and risk sharing than with partial regulation:* $\Delta^{F*} < \Delta^{P*}$*;* $\Delta^{RS*} < \Delta^{P*}$

4. *The chosen investment timing is later with full regulation than with risk sharing when regulated access price is zero, and ambiguous when it is positive: for* $\beta_1 \leq 2(a-c)/3$, $\Delta^{F*} < \Delta^{RS*}$*;* $\Delta^{F*} \lesseqgtr \Delta^{RS*}$*, for* $\beta_1 > 2(a-c)/3$

5. *The OLO's ability to provide value-added services through the NGN affects the timing of investment. The effect is: positive with partial regulation,* $\frac{d}{d\beta_2}\Delta^{P*} > 0$*; negative with full regulation,* $\frac{d}{d\beta_2}\Delta^{F*} < 0$*; with risk sharing, this effect changes from positive to negative as* β_2*'s absolute value decreases with respect to* β_1*, or vice versa.*

6. *The chosen investment timing is always later than the socially optimal one, with partial regulation, full regulation, and risk sharing:* $\Delta^{P*} < \Delta^{PW*}$*;* $\Delta^{F*} < \Delta^{FW*}$*; and* $\Delta^{RS*} < \Delta^{RSW*}$*.*

Proof. See Appendix A.1. □

The OLO always benefits from a spillover effect from the construction of NGN done by the incumbent. Nevertheless, the incumbent can potentially capture some rent by leasing its infrastructure to the rival. Under full access price regulation though, when the OLO has more ability than the incumbent, the rent is set just equal to marginal cost by the regulator, so the incumbent earns nothing from the upstream market. In this case, its investment incentive is dampened since it cannot extract any benefit from the OLO's value-added services. Therefore, it chooses to invest later with respect to the case when the NGN is unregulated. This confirms the finding in the literature that access price regulation plays a disincentive role in the incumbent's investment decision (Kotakorpi (2006)). It is important to stress here that, although the firms earn positive profits in this model in case of full regulation with marginal cost pricing, because of the Cournot competition assumption, the same result is found in a setting with Hotelling competition by Kotakorpi (2006). Less uncertainty mitigates such effect: when the investment success becomes more likely, the speed at which the incumbent delays its investment plans when β_2 is higher decreases, $\frac{d^2}{d\beta_2 d\gamma}\Delta^{F*} < 0$.

When $\beta_1 > 2(a-c)/3$, there is a range of parameters, $3\beta_1/4 - (a-c)/6 \leq \beta_2 < 4\beta_1/5 - (a-c)/5$, for which the regulated access price is positive, the OLO is active in the NGN market with full regulation, but it is excluded with partial regulation. In this case, partial regulation gives the highest investment incentives, but the relationship between full regulation and risk sharing gives ambiguous results in terms of investment timing.

2.6 Welfare analysis

The previous analysis revealed that risk sharing induces the highest expected level of competition downstream for a given timing of investment, in line with Nitsche and Wiethaus (2011), while partial regulation gives the strongest investment incentives. In this section, we provide a comprehensive welfare ranking of the different modes of regulation, broken down according to the range of parameter values shown in Figure 3. In the Appendix $A.1.4$ we report a detailed overview of the results. From these results, we derive the following statement.

Proposition 2.4. *Under the assumptions $r^F \geq 0$, $2\beta_i \geq \beta_j$ $(i, j = 1, 2$ with $i \neq j)$, and given the OLO's participation constraints (2.3) and (2.5), the following results hold:*

1. *Expected consumer welfare is higher under risk sharing compared to partial regulation;*

2. *When the OLO is better than the incumbent in offering value-added services, expected total welfare is higher under risk sharing compared to partial regulation ;*

3. *When the OLO is better than the incumbent in offering value-added services or when the incumbent is better than the OLO by a great extent, expected consumer welfare and expected total welfare are higher under partial regulation compared to full regulation.Otherwise, the difference in total welfare and consumer welfare between partial and full regulation remains ambiguous.*

4. *When the access price to NGN is regulated at cost, expected consumer welfare and expected total welfare are higher under risk sharing compared to full regulation;*

Proof. See Appendix A.1. □

Once taken into account the equilibrium choice of investment timing, we find that risk sharing yields a higher expected consumer surplus than full regulation. When the regulated access price is zero, risk sharing also unambiguously yields a higher overall welfare than full regulation. However, when comparing partial regulation and risk sharing, investment incentives and intensity of competition go in opposite directions, therefore the results in terms of expected consumer welfare and expected total welfare change depending on the different parameter values.

When the OLO is better in offering value-added services, with partial regulation the incumbent always charges an access price that ensures the OLO‘s participation to the NGN, while with full regulation the access price is set to marginal cost, i.e. cases $P1F1RS$ and $P2F1RS$ with $\beta_2 \geq \beta_1$. Under these circumstances, risk sharing is unambiguously dominant, both from a total welfare and a consumer welfare viewpoint. Even though compared to partial regulation, risk sharing investment‘s incentives are lower, retail market higher competitive intensity more than compensates for the delay in NGN construction.

When the incumbent has more ability than the OLO, welfare analysis becomes less clearcut. In the range of parameters for which the incumbent charges a constrained access fee and both firms are active in the NGN market, i.e. $P2F2RS$ with $\beta_2 < \beta_1$, we find that full regulation still yields the least desirable outcome, but the relationship between partial regulation and risk sharing is ambiguous both from a consumer welfare and a total welfare viewpoint. The reason is that the trade-off between stronger investment‘s incentives under partial regulation and higher competitive intensity under risk sharing is less stark when the incumbent charges the access fee that makes the OLO indifferent between staying in the NGN or switching back to the regulated copper network. For this reason, indeed, depending on the parameters, total welfare can be higher or lower under risk sharing or partial regulation.

Finally, we analyse two cases in which the incumbent finds it more convenient to exclude the OLO from the NGN market because its own ability is considerably higher than the OLO's ability. In this case, the OLO offers broadband services through the copper network, earning positive profits thanks to the regulated access price. Under this circumstance, when the incumbent's ability is not too high, i.e. $\beta_1 \leq 2(a-c)/3$, there is exclusion with partial regulation and a zero access charge with full regulation, i.e. $P3F1RS$. Risk sharing is still unambiguously better than full regulation, both from a total welfare and a consumer welfare perspective. The relationship between partial regulation and risk sharing, though, is again ambiguous as of the total welfare outcome.

Under conditions for which there is exclusion with partial regulation, if the incumbent's ability is high enough, i.e. $\beta_1 > 2(a-c)/3$, there exists a range of parameters such that the regulator sets an above cost NGN access price and the OLO stays in the NGN market nonetheless, i.e. $P3F2RS$. In this case, partial regulation investment incentives are so high that total welfare turns out to be the highest compared to risk sharing and full regulation. The relationship between risk sharing and full regulation as of total welfare is ambiguous: investment's incentives can be higher or lower depending on parameters, but consumer welfare is always higher with risk sharing.

3 Summary and conclusion

In this paper we dynamically model the competition between a vertically-integrated incumbent firm and a facilities-free OLO in the broadband market, where the former has the option to invest in building a NGN that allows firms to drastically increase the quality and variety of their services. Market success of the NGN in terms of demand increase is uncertain. Different from other studies that assume demand uncertainty, the choice of investment with demand uncertainty here is analysed in a dynamic setting with differentiated firms. The analysis is conducted under three different possible modes of regulation: partial regulation (the NGN is unregulated), full regulation (the NGN is regulated) and risk sharing (there are no side payments between the firms for the use of the NGN).

Our analysis reveals that the investment is always undertaken later than the social optimum timing in all modes of regulation. The investment choice is affected by the OLO's ability to offer value-added services. Such effect is positive with partial regulation and negative with full regulation, while with risk sharing the effect is changing from positive for high values of β_2, to negative as β_1 gets considerably bigger than β_2, and vice versa. Partial regulation always yields the earliest investment compared to the other regulatory regimes, while risk sharing ensures the highest level of competition intensity.

Welfare outcomes reveal that risk sharing is the dominant regime in a consumer surplus perspective. Expected consumer surplus is always higher under risk sharing than under partial regulation, but also under full regulation for a large set of parameters. In particular, when both firms are active, full regulation's consumer surplus outcome is the least preferable; only when the incumbent's ability is so high that regulated access price to NGN is larger than the marginal cost, the comparison of consumer surplus between full regulation and risk sharing becomes ambiguous.

Furthermore, when the OLO's ability is higher, risk sharing is the dominant regime also from a total welfare perspective. When the incumbent's ability is higher, welfare comparisons between the three regulatory regimes become less clearcut.

Our analysis sheds some conceptual light on the debate about what is the preferable access regulation regime to prompt telecommunications network development, ensuring that the benefits of it will be enjoyed by final consumers eventually. The difference in firms' ability to provide value-added services is important in the context. It exerts influence on the investment choice and on the previous access pricing decisions, which in turn affect market competition and social welfare. Furthermore, we find that demand uncertainty requires a careful formulation of access regulation rules. A robust set of rules should take into account the potential for an investment failure and provide reasonable access conditions for the firms involved in all cases. Also, uncertainty plays the role of delaying the investment decision in all regimes. According to our analysis, risk sharing can be particularly beneficial for consumers and give fairly high investment incentives at the same time. At this stage, it would be interesting to go further in the research to study how risk sharing agreement can be robust to the inclusion of late entrants, to avoid that the construction of NGN could possibly become a new source of market power and thereof be unable to deploy all of its benefits. Moreover, it would be interesting to make the choice to engage in a risk sharing agreement endogenous. We leave these questions for future research.

A Appendix

A.1 Proof of Propositions

A.1.1 Proof of Proposition 2.1

When $2(\beta_2-\beta_1)/5 < (a-c)/3$, partial regulation unconstrained access price gives the OLO less profits than the outside option. The access price that verifies the OLO's participation constraint 2.5 with equality is:

$$\frac{a-c+r^{Ps}+2\beta_2-\beta_1}{3} = \frac{a-c}{3}$$
$$r^{Ps} = \frac{2\beta_2-\beta_1}{2}$$

The incumbent will prefer to charge the access price above rather than charge the unconstrained access price and exclude the OLO as long as the outside option profits - being the only provider of valued added services through NGN - are not higher than the market sharing profits:

$$\pi^{Ps}_{1[r^{Ps*}=\frac{(2\beta_2-\beta_1)}{2}]} \geq \pi^o_1$$
$$\left(\frac{a-c}{3}+\frac{\beta_1}{2}\right)^2 + \frac{(2\beta_2-\beta_1)}{2}\frac{(a-c)}{3} \geq \left(\frac{a-c}{3}+\frac{2\beta_1}{3}\right)^2$$

The above inequality is unambiguously satisfied only for values of β's such that the incumbent‘s advantage in ability to offer value-added services is not too large:

$$6\beta_2 \geq 5\beta_1$$

A.1.2 Proof of Proposition 2.2

Total expected quantities for a given investment timing, under the different modes of regulation are the following:

- Partial regulation

$$\begin{cases} E(Q^P) = (1-\Delta^P)\frac{a-c}{3} + \Delta^P\left(\frac{2(a-c)}{3} + \left(\frac{3\beta_1+2\beta_2}{10} - \frac{a-c}{6}\right)\gamma\right) & \text{if } 2(\beta_2-\beta_1)/5 \geq (a-c)/3 \\ E(Q^P) = (1-\Delta^P)\frac{a-c}{3} + \Delta^P\left(\frac{2(a-c)}{3} + \frac{\beta_1\gamma}{2}\right) & \text{if } 6\beta_2 \geq 5\beta_1 \\ E(Q^P) = (1-\Delta^P)\frac{a-c}{3} + \Delta^P\left(\frac{2(a-c)}{3} + \frac{\beta_1\gamma}{3}\right) & \text{if } 6\beta_2 < 5\beta_1 \end{cases}$$

- Full regulation

$$\begin{cases} E(Q^F) = (1-\Delta^F)\frac{a-c}{3} + \Delta^F\left(\frac{2(a-c)}{3} + \frac{(\beta_1+\beta_2)\gamma}{3}\right) & \text{if } 4\beta_1 - 5\beta_2 \leq a-c \\ E(Q^F) = (1-\Delta^F)\frac{a-c}{3} + \Delta^F\left((2\beta_2-\beta_1)\gamma + \frac{(a-c)(2+\gamma)}{3}\right) & \text{otherwise} \end{cases}$$

- Risk sharing

$$E(Q^{RS}) = (1-\Delta^{RS})\frac{a-c}{3} + \Delta^{RS}\left(\frac{2(a-c)}{3} + \frac{(\beta_1+\beta_2)\gamma}{3}\right)$$

We now compare partial regulation and full regulation with risk sharing, considering the specific conditions under each relevant parameter threshold, as defined in Table 1, and Assumption 2.2:

- if $P1RS$:

$$\frac{E(Q^{RS})}{E(Q^P)} = \frac{10(2(a-c)+(\beta_1+\beta_2)\gamma)}{20(a-c)+(3(3\beta_1+2\beta_2)-5(a-c))\gamma}$$

$$10(2(a-c)+(\beta_1+\beta_2)\gamma) - (20(a-c)+(3(3\beta_1+2\beta_2)-5(a-c))\gamma) = (\beta_2 - \frac{\beta_1}{2})\gamma > 0$$

- if $P2RS$:

$$\frac{E(Q^{RS})}{E(Q^P)} = \frac{2(2(a-c)+(\beta_1+\beta_2)\gamma)}{4(a-c)+3\beta_1\gamma}$$

$$2(2(a-c)+(\beta_1+\beta_2)\gamma) - (4(a-c)+3\beta_1\gamma) = (2\beta_2-\beta_1)\gamma > 0$$

- if $P3RS$:

$$\frac{E(Q^{RS})}{E(Q^P)} = \frac{2(a-c)+(\beta_1+\beta_2)\gamma}{2(a-c)+\beta_1\gamma}$$

$$2(a-c)+(\beta_1+\beta_2)\gamma - (2(a-c)+\beta_1\gamma) = \beta_2\gamma > 0$$

- if $F1RS$:

$$\frac{E(Q^{RS})}{E(Q^P)} = 1$$

- if $F2RS$:

$$\frac{E(Q^{RS})}{E(Q^P)} = \frac{2(a-c)+(\beta_1+\beta_2)\gamma}{2(a-c)+(3(2\beta_2-\beta_1)+(a-c))\gamma}$$

$$2(a-c)+(\beta_1+\beta_2)\gamma - (2(a-c)+(3(2\beta_2-\beta_1)+(a-c))\gamma) = (4\beta_1-5\beta_2-(a-c))\gamma > 0$$

Therefore, $E(Q^{RS}) > E(Q^P)$; and $E(Q^{RS}) \geq E(Q^F)$.

A.1.3 Proof of Proposition 2.3

(1) and (2) Proof of these statements derives directly from Proposition 2.1.

(3) *Investment timing: partial regulation vs full regulation and risk sharing*

In order to compare investment timings we do the following computations, considering each time the specific conditions under each relevant parameter threshold, as defined in Table 1, and Assumption 2.2:

- if $P1F1$

$$\frac{\Delta^P}{\Delta^F} = \frac{25(a-c)^2 + 90\beta_1(a-c) + 81\beta_1^2 - 72\beta_1\beta_2 + 36\beta_2^2}{20(2\beta_1 - \beta_2)(2(a-c)(2\beta_1 - \beta_2))}$$

$$25(a-c)^2 + 90\beta_1(a-c) + 81\beta_1^2 - 72\beta_1\beta_2 + 36\beta_2^2 - (20(2\beta_1 - \beta_2)(2(a-c)(2\beta_1 - \beta_2))) = (5(a-c) + \beta_1 + 4\beta_2)^2 > 0$$

- if $P2F1$

$$\frac{\Delta^P}{\Delta^F} = \frac{3(3\beta_1^2 + 2(\beta_1 + 2\beta_2)(a-c))}{4(2\beta_1 - \beta_2)(2(a-c) + 2\beta_1 - \beta_2)}$$

$$3(3\beta_1^2 + 2(\beta_1 + 2\beta_2)(a-c)) - (4(2\beta_1 - \beta_2)(2(a-c) + 2\beta_1 - \beta_2)) = 4(2\beta_2 - \beta_1)(10(a-c) + 7\beta_1 - 2\beta_2) > 0$$

- if $P3F1$

$$\frac{\Delta^P}{\Delta^F} = \frac{4(a - c + \beta_1^2}{(2\beta_1 - \beta_2)(2(a-c) + 2\beta_1 - \beta_2)}$$

$$4(a - c + \beta_1^2) - (2\beta_1 - \beta_2)(2(a-c) + 2\beta_1 - \beta_2) = \beta_2(a - c + 4\beta_1 - \beta_2) > 0$$

- if $P3F2$

$$\frac{\Delta^P}{\Delta^F} = \frac{4\beta_1(a - c + \beta_1^2)}{-72(\beta_1 - \beta_2)^2 + 9(7\beta_1 - 8\beta_2)\beta_2 + 9(7\beta_1 - 9\beta_2)(a-c) - 10(a-c)^2}$$

$$4\beta_1(a - c + \beta_1^2) - (-72(\beta_1 - \beta_2)^2 + 9(7\beta_1 - 8\beta_2)\beta_2 + 9(7\beta_1 - 9\beta_2)(a-c) - 10(a-c)^2) = 10(a-c)^2 + 76(\beta_1 - \beta_2)^2 + \beta_2(-55\beta_1 + 68\beta_2) + (a-c)(-59\beta_1 + 81\beta_2) > 0$$

- if $P1RS$

$$\frac{\Delta^P}{\Delta^{RS}} = \frac{25(a-c)^2 + 90\beta_1(a-c) + 81\beta_1^2 - 72\beta_1\beta_2 + 36\beta_2^2}{20(5(\beta_1 - \beta_2)^2 + 2(a-c)(\beta_1 + \beta_2) + 2\beta_1\beta_2)}$$

$$25(a-c)^2 + 90\beta_1(a-c) + 81\beta_1^2 - 72\beta_1\beta_2 + 36\beta_2^2 - (20(5(\beta_1 - \beta_2)^2 + 2(a-c)(\beta_1 + \beta_2) + 2\beta_1\beta_2)) = 25(a-c)^2 + 10(5\beta_1 - 4\beta_2)(a-c) - 4(5\beta_1 - 4\beta_2)^2 + 9\beta_1(9\beta_1 - 8\beta_2) > 0$$

- if $P2RS$

$$\frac{\Delta^P}{\Delta^{RS}} = \frac{3(3\beta_1^2 + 2(\beta_1 + 2\beta_2)(a-c))}{4(5(\beta_1 - \beta_2)^2 + 2(a-c)(\beta_1 + \beta_2) + 2\beta_1\beta_2)}$$

$$\begin{aligned}&3(3\beta_1^2 + 2(\beta_1 + 2\beta_2)(a-c)) - (4(5(\beta_1 - \beta_2)^2 + 2(a-c)(\beta_1 + \beta_2) + 2\beta_1\beta_2)) = \\ &(2\beta_2 - \beta_1)(2(a-c) + 11\beta_1 - 10\beta_2) > 0\end{aligned}$$

- if $P3RS$

$$\frac{\Delta^P}{\Delta^{RS}} = \frac{4\beta_1(a - c + \beta_1^2)}{5(\beta_1 - \beta_2)^2 + 2(a-c)(\beta_1 + \beta_2) + 2\beta_1\beta_2}$$

$$\begin{aligned}&4\beta_1(a - c + \beta_1^2) - (5(\beta_1 - \beta_2)^2 + 2(a-c)(\beta_1 + \beta_2) + 2\beta_1\beta_2) = \\ &-\beta_1^2 + 2(a-c)(\beta_1 - \beta_2) + 8\beta_1\beta_2 - 5\beta_2^2 > 0\end{aligned}$$

Therefore, $\Delta^{F*} < \Delta^{P*}$; and $\Delta^{RS*} < \Delta^{P*}$.

(4) *Investment timing: risk sharing vs full regulation*

In order to compare investment timings we do the following computations, considering each time the specific conditions under each relevant parameter threshold, as defined in Table 1, and Assumption 2.2:

- if $F1RS$

$$\frac{\Delta^{RS}}{\Delta^F} = \frac{5(\beta_1 - \beta_2)^2 + 2(a-c)(\beta_1 + \beta_2) + 2\beta_1\beta_2}{(2\beta_1 - \beta_2)(2(a-c)(2\beta_1 - \beta_2))}$$

$$\begin{aligned}&5(\beta_1 - \beta_2)^2 + 2(a-c)(\beta_1 + \beta_2) + 2\beta_1\beta_2 - ((2\beta_1 - \beta_2)(2(a-c)(2\beta_1 - \beta_2))) = \\ &2(2\beta_2 - \beta_1)(a-c) + (2\beta_2 - \beta_1)^2 > 0\end{aligned}$$

- if $F2RS$

$$\frac{\Delta^{RS}}{\Delta^F} = \frac{5(\beta_1 - \beta_2)^2 + 2(a-c)(\beta_1 + \beta_2) + 2\beta_1\beta_2}{-72(\beta_1 - \beta_2)^2 + 9(7\beta_1 - 8\beta_2)\beta_2 + 9(7\beta_1 - 9\beta_2)(a-c) - 10(a-c)^2}$$

$$\begin{aligned}&5(\beta_1 - \beta_2)^2 + 2(a-c)(\beta_1 + \beta_2) + 2\beta_1\beta_2 - \\ &(-72(\beta_1 - \beta_2)^2 + 9(7\beta_1 - 8\beta_2)\beta_2 + 9(7\beta_1 - 9\beta_2)(a-c) - 10(a-c)^2) = \\ &10(a-c)^2 + (83\beta_2 - 61\beta_1)(a-c) + 77(\beta_1 - \beta_2)^2 + \beta_2(72\beta_2 - 61\beta_1) \lesseqgtr 0\end{aligned}$$

Therefore, for $\beta_1 \leq 2(a-c)/3$, $\Delta^{F*} < \Delta^{RS*}$; for $\beta_1 > 2(a-c)/3$ (only occasion in which there is no exclusion with a positive regulated access price), $\Delta^{F*} \lesseqgtr \Delta^{RS*}$.

(5) *Comparative statics*
Our comparative statics results, considering the specific conditions under each relevant parameter threshold, as defined in Table 1, and Assumption 2.2, are shown below:

- if $P1$
$$\frac{\delta(\Delta^P)}{\delta(\beta_2)} = \frac{2(\beta_2 - \beta_1)\gamma}{5\phi} > 0$$
- if $P2$
$$\frac{\delta(\Delta^P)}{\delta(\beta_2)} = \frac{(a-c)\gamma}{3\phi} > 0$$
- if $P3$, the OLO is not in the NGN market.
- if $F1$
$$\frac{\delta(\Delta^F)}{\delta(\beta_2)} = \frac{-(2(a-c+2\beta_1 - \beta_2)\gamma}{9\phi} < 0$$
- if $F2$
$$\frac{\delta(\Delta^F)}{\delta(\beta_2)} = \frac{(-9(a-c) + 23\beta_1 - 32\beta_2)\gamma}{phi} < 0$$
- RS
$$\frac{\delta(\Delta^{RS})}{\delta(\beta_2)} = \frac{2(a-c-4\beta_1 + 5\beta_2)\gamma}{9\phi}$$

$$\frac{2(a-c-4\beta_1 + 5\beta_2)\gamma}{9\phi} > 0 \text{ if } \beta_2 > 4\beta_1/5 - (a-c)/5$$
$$\frac{2(a-c-4\beta_1 + 5\beta_2)\gamma}{9\phi} \leq 0 \text{ if } \beta_2 \leq 4\beta_1/5 - (a-c)/5$$

Therefore, $\frac{d}{d\beta_2}\Delta^{P*} > 0$; $\frac{d}{d\beta_2}\Delta^{F*} < 0$; and $\frac{d}{d\beta_2}\Delta^{RS*}$ changing as shown above.

(6) *Comparison of equilibrium investment timing and socially optimal investment timing*
The comparison of equilibrium investment timing and socially optimal investment timing in the different regulatory regimes give the following results, considering conditions for each parameter range as defined in Table 1 and all other assumptions:

- if $P1$

$$\frac{\Delta^{PW}}{\Delta^{P}} = -3((125(a-c)^2)-30(3\beta_1+2\beta_2)(a-c)-15\beta_1(\beta_1+4\beta_2)-108(\beta_1-\beta_2)^2) > 0$$

- if $P2$

$$\frac{\Delta^{PW}}{\Delta^{P}} = -6\beta_1^2 - 4(a-c)(\beta_1+2\beta_2) + (4(a-c)(3\beta_1+2\beta_2) + 9\beta_1^2) > 0$$

- if $P3$

$$\frac{\Delta^{PW}}{\Delta^{P}} = 11(\beta_1-\beta_2)^2 + 8\beta_1(\beta_2-\beta_1) + 8\beta_2(a-c) > 0$$

- if $F1$

$$\frac{\Delta^{FW}}{\Delta^{F}} = 3(\beta_1^2 + 4\beta_2(a-c) + \beta_2(3\beta_2 - 2\beta_1)) > 0$$

- if $F2$

$$\frac{\Delta^{FW}}{\Delta^{F}} = 21(a-c)^2 + (180\beta_2 - 126\beta_1)(a-c) + 171(\beta_1-\beta_2)^2 + \beta_2(153\beta_2 - 126\beta_1) > 0$$

- RS

$$\frac{\Delta^{RSW}}{\Delta^{RS}} = (\beta_1+2\beta_2)(4(a-c)+\beta_1+2\beta_2) > 0$$

Therefore, $\Delta^{P*} < \Delta^{PW*}$; $\Delta^{F*} < \Delta^{FW*}$; and $\Delta^{RS*} < \Delta^{RSW*}$.

A.1.4 Proof of Proposition 2.4

Expected consumer welfare is defined as:

$$\begin{aligned} E(CS^l) =& \Delta^{l*}(CS^C) + (1-\Delta^{l*})E(CS^l) \\ =& \Delta^{l*}\left(\frac{(Q^{C*})^2}{2}\right) + (1-\Delta^{l*})\left(\gamma\left(\frac{(Q^{ls*})^2}{2}\right) + (1-\gamma)\left(\frac{(Q^{lf*})^2}{2}\right)\right) \end{aligned}$$

with $Q^l = q_1^l + q_2^l$.

Expected total welfare is defined as:

$$\begin{aligned} &E(W^l) = \Delta^{l*}\left(\frac{(Q^{C*})^2}{2} + (q_1^{C*})^2 + (q_2^{C*})^2\right) + \\ &(1-\Delta^{l*})\left(\gamma\left(\frac{(Q^{ls*})^2}{2} + (q_1^{ls*})^2 + r^{ls}q_2^{ls*} - \Delta^{l*}\phi/2 + (q_2^{ls*})^2\right) + \right. \\ &\left.(1-\gamma)\left(\frac{(Q^{lf*})^2}{2} + (q_1^{lf*})^2 - \Delta^{l*}\phi/2 + (q_2^{lf*})^2\right)\right) \end{aligned}$$

Our analysis reveal the following ranking of expected total welfare and expected consumer welfare, respectively. Notice that the results are broken down according to the relevant parameter thresholds defined in Table 1[18].

$$\begin{cases} E(W^{RS}) > E(W^P) > E(W^F) & \text{if } \beta_2,\beta_1 \text{ s.t. } P1/P2F1RS\text{, with } \beta_2 \geq \beta_1 \\ E(W^{RS}) \lesseqgtr E(W^P) > E(W^F) & \text{if } \beta_2,\beta_1 \text{ s.t. } P2F1RS\text{, with } \beta_2 < \beta_1 \\ E(W^{RS}) > E(W^F)\ ;\ E(W^{RS}) \lesseqgtr E(W^P)\ ;\ E(W^P) \lesseqgtr E(W^F) & \text{if } \beta_2,\beta_1 \text{ s.t. } P3F1RS \\ E(W^P) > E(W^{RS}) \lesseqgtr E(W^F)] & \text{if } \beta_2,\beta_1 \text{ s.t. } P3F2RS \end{cases}$$

$$\begin{cases} E(CS^{RS}) > E(CS^P) > E(CS^F) & \text{if } \beta_2,\beta_1 \text{ s.t. } P1/P2F1RS \\ E(CS^{RS}) > E(CS^P) \lesseqgtr E(CS^F) & \text{if } \beta_2,\beta_1 \text{ s.t. } P3F1RS \\ E(CS^{RS}) > E(CS^P) \lesseqgtr E(CS^F) & \text{if } \beta_2,\beta_1 \text{ s.t. } P3F2RS \end{cases}$$

We now proceed by analysing each single statement contained in Proposition 2.4.

(1) *Consumer welfare: risk sharing vs partial regulation*
In order to compare consumer welfare outcomes it is sufficient to compare total quantities. So we check under each of the specific parameter thresholds, defined in Table 1 and find:

$$\begin{cases} \frac{Q^P}{Q^{RS}} < 0 & \text{if } P1RS \\ \frac{Q^P}{Q^{RS}} < 0 & \text{if } P2RS \\ \frac{Q^P}{Q^{RS}} < 0 & \text{if } P3RS \end{cases}$$

Therefore, $E(CS^{RS}) > E(CS^P)$.

(2) *Total welfare: risk sharing vs partial regulation* and (3) *Total welfare and consumer welfare: partial regulation vs full regulation*
From the results above, we derive that, in all cases in which $\beta_2 \geq \beta_1$, namely $P1F1RS$ and $P2F1RS$ (only for the part in which $\beta_2 \geq \beta_1$): $W^{RS} > W^P > W^F$. Furthermore, when the incumbent is better than the OLO by a great extent and the regulated access price is positive, case $P3F2$, we have: $W^P > W^F$.

(4) *Total welfare and consumer welfare: risk sharing vs full regulation* In order to compare consumer welfare outcomes it is sufficient to compare total quantities. So we check under each of the specific parameter thresholds, defined in Table 1 and find:

$$\begin{cases} \frac{Q^F}{Q^{RS}} < 0 & \text{if } F1RS \\ \frac{Q^F}{Q^{RS}} \lesseqgtr 0 & \text{if } F2RS \text{ (happening without exclusion only if } \beta_1 > 2(a-c)/3) \end{cases}$$

[18] Since expressions are cumbersome, Detailed equations are available upon request.

Therefore, $E(CS^{RS}) > E(CS^{F})$ when the access price is regulated at cost, and the relationship is ambiguous when the access price is positive. Also, from the results above we obtain that only in case $F1$: $W^{RS} > W^{F}$.

(5) *Total welfare and consumer welfare: full regulation ranking* From the results above, we can conclude that, in all cases in which there is no exclusion of the OLO from the NGN market, namely $P1F1RS$ and $P2F1RS$: $W^{RS} > W^{F}$ and $W^{P} > W^{F}$; $CS^{RS} > CS^{F}$ and $CS^{P} > CS^{F}$.

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