Access Pricing, Competition, and Incentives to Migrate From "Old" to "New" Technology*

Marc Bourreau†, Carlo Cambini‡, Pınar Doğan§

June 26, 2011

Abstract

We analyze the incentives of an incumbent and an entrant to migrate from an "old" technology to a "new" technology, and how wholesale access conditions affect this migration. Our analysis fits with the transition in the telecommunications industry, from ("old") legacy networks to ("new") high-speed broadband infrastructures. We show that a higher access charge on the legacy network pushes an entrant to invest more, but has an ambiguous effect on an incumbent's investments, due to two conflicting effects: the wholesale revenue effect, and the business migration effect. If both the old and the new infrastructure are subject to ex ante access regulation, we also find that the two access charges are positively related.

Keywords: Access pricing; Investment; Next generation networks.

JEL Codes: L96; L51.

---

*We thank Tommaso Valletti, Martin Peitz, Steffen Hoernig and Marc Lebourges for useful remarks. We also thank audiences at the Workshop on Telecommunications Economics (Barcelona, 2011) and the Florence School of Regulation Communications & Media Conference (Florence, 2011).

†Telecom ParisTech, Department of Economics and Social Sciences, and CREST-LEI, Paris. Email: marc.bourreau@telecom-paristech.fr.

‡Politecnico di Torino. Email: carlo.cambini@polito.it

§Harvard Kennedy School of Government, Harvard University. E-mail: pinar_dogan@hks.harvard.edu.

1 Introduction

Infrastructure investments are crucial in network industries for the provision of final services in adequate quantity and quality. In these industries, such investments are highly influenced by regulatory interventions that might undermine or enhance companies' incentives to invest.[1] The typical regulatory instrument adopted to sustain market competition at the retail level is to mandate access to existing infrastructures - operated and maintained by incumbent operators - for alternative operators. Access regulation thus plays a fundamental role in vertically integrated markets, where the network is the essential facility for the provision of final services and network access is vital to encourage and sustain entry in the competitive segment of the market.

Modern telecommunications provide an interesting case to study because investment in new communication infrastructures – the so called Next Generation Networks (NGNs), which in the near future will provide very high-speed connections to the Internet as well as broadband and ultra broadband services– calls for a large amount of capital expenditure, attracting regulatory concerns on third party access to these networks. National regulatory authorities are in fact adopting new regulatory frameworks on network access rules that, on one side, should avoid market re-monopolization by incumbents, and, on the other side, provide enough incentives to invest in the high speed infrastructures by telecoms (both incumbent and entrants) operators. Moreover, this investment is also considered to be a significant contributor to economic growth.[2]

The recent literature on this topic mainly focuses on the impact of access rules on new in-

[1] For a general overview of the relationship between regulation and investment, see Guthrie (2006).

[2] Investments in broadband networks are supposed to contribute significantly to economic growth. Röller and Waverman (2001), using data from 21 OECD countries over a 20-year period, show that an increase of 10% in the broadband adoption rate leads on average to an increase of 2.8% of GDP growth. Koutroumpis (2009) shows that the average impact of broadband infrastructure on GDP is 0.63% (for the EU-15, in the period 2002-2007), that is, 16.92% of total growth in this period. Greenstein and McDevitt (2009) show that broadband accounted for $28 billion of US GDP in 2006, and they estimate that $20 to $22 billion was associated with household use. Czernich et al. (2011) find that, in OECD countries, a 10 percentage point increase in broadband penetration raises annual per-capita growth by 0.9 to 1.5 percentage points.

frastructures or on investment to upgrade existing networks. Although this focus is appropriate when these investments immediately replace the old technology or network, the evidence suggests that the transition from old infrastructures to new infrastructures will go slowly. This implies that, during the transition phase, two different infrastructures will operate, and presumably each networks would be regulated with different set of rules. Coexistence of new and old technologies in this phase implies that incentives to invest in new infrastructures can be influenced not only by the terms of access set for those high-tech infrastructures, but also by the terms of access set for the existing networks. The interplay between the (potentially different) access regulations on the existing "old" network and on the "new" network in the context of new infrastructure investments, which has been largely overlooked in the literature, is the focus of this paper.

The recent EU Recommendation C(2010) 6223 on "Regulated Access to NGANs" (September 2010) clearly states how regulatory policies during the migration phase can be fundamental in determining the incentives to invest in new infrastructures. The new legislation states that "existing obligations [..] should continue and should not be undone by changes to the existing network architecture and technology, unless agreement is reached on an appropriate migration path between the SMP operator and operators currently enjoying access to the SMP operator's network" (Article 39). Regulators play a distinctive role in this process. In Article 40, the document states that "NRAs should put in place a transparent framework for the *migration from copper to fibre-based networks.* NRAs should ensure that the systems and procedures put in place by the SMP operator [...] are designed so as to facilitate the switching of alternative providers to NGA-based access products". In this respect, the recommendation not only stresses that existing regulatory tools in the legacy ("old") network should be maintained in the medium term, but also that a new set of rules should be introduced to facilitate the migration from old to new infrastructures. However, the legislation is completely silent on the potential interplay between the access remedies in both old and new networks, and also seems to neglect the potential impact of the access regulation on the existing infrastructure on the incentives to invest in new infrastructures (for both alternative and incumbents operators).

The migration issue has recently received considerable attention also by market specialists, whose proposals however appear in sharp contrast one with each other. In a recent report for the European Competitive Telecommunication Association (ECTA), WIK (2011) proposes to decrease the access charge to legacy network to encourage entrants to invest in NGNs and to allow a rapid switch-off of the copper networks where the fibre is already installed. On the other hand, the report by Plum (2011) for the European (incumbent) Telecommunications Network Operators (ETNO) states that a lower copper price would discourage NGA investment by encouraging customers to stay on copper, thereby negatively impacting on the fibre business case; moreover, the Plum's study proposes to set a direct link between the regulated access charge on the legacy network and the regulated access charge on the NGN. In sum, both documents show that not only the access charges to the high-tech infrastructure have an impact on the incentive to invest in the new network, but it is also the access charge to the old (legacy) network which has a major influence on the transition to the NGN. However, the direction of this link is still unclear and not theoretically based.

The research questions we address in this paper are as follows: (1) How do the terms of access to the existing networks affect investments in new (NGNs) infrastructures? (2) Does this effect differ for entrant and incumbent firms? (3) Which type of access rule is socially optimal to i) spur new investment in upgraded broadband services, but ii) not to distort allocative efficiency in the provision of old services? The aim of this paper is to contribute to the recent stream of literature on the impact of access regulation on investments developing a theory of incentives to migrate from an old to a new technology, pointing out how these incentives are affected by access regulation.

Our paper contributes to the stream of literature that analyzes the impact of access regulation on infrastructure investment.[3] Bourreau and Doğan (2005) analyze the impact of access regulation (in the form of local loop unbundling) on entrants' incentive to invest. They have shown that the access charge may influence the facility-based entry date of the entrant. Therefore, when the regulator sets the access charge, it faces a trade-off: on the one hand, a high (low) access charge speeds up (slows down) facility-based entry, but it also reduces (increases) the consumer surplus in the phase of service-based competition. In a companion paper, Bourreau and Doğan (2006) propose a formal model to analyze the effect of service-based competition on facility-based entry, and show that an access charge increasing over time can resolve this trade-off. In a similar vein Avenali et al. (2010) show that an access charge that increases over time can be critical to entrants' incentives to invest in alternative infrastructures. All these papers, however, focus only on entrants' investment and do not consider the impact of access regulation on the incentive to adopt an old or new technology for the provision of final services.

Another set of studies focuses on the impact of access regulation on incumbents' incentives to invest without considering the migration issue. Gans and Williams (1999), Gans (2001 and 2007), Hori and Mizuno (2006) and Vareda and Hoernig (2010) study the impact of access charges in a dynamic investment race between two operators and focus on the effect of specific access pricing regimes (e.g., regulatory holidays). The regulator's capability of credible commitment is subtle to firms' investment decisions. If such commitment is ensured, Kotakorpi (2006) finds that the incumbent's investment is negatively affected by investment spillovers and it is not only below the socially optimal level but also less than the amount in the absence of regulation. If this commitment ability is absent, the relative comparison of firms' ability to offer value-added services – that enhances the consumers' willingness to pay and so their demand – plays a substantial role in

[3] Valletti (2003) reviews the theoretical literature of access pricing and points out that the linkage between access pricing and incentives to invest does not provide clear cut solutions to the policy makers. For a more recent comprehensive survey, see also Cambini and Jiang (2009).

the incumbent's investment incentives (Foros, 2004). In all these papers the aim is to explore the optimal time of investment mainly by incumbent operators, but the decision to invest is a zero-one (discrete) decision only, while our setting is not dynamic but the decision to invest is a continuous function.

More recently, Brito et al. (2010a) show that in a duopoly model where a vertically integrated incumbent and a downstream entrant compete, the introduction of a two-part tariff access charge solve the regulatory opportunism and therefore enhance the incentives to invest in NGN infrastructures. Klumpp and Su (2010) analyze the link between investment and access regulation, showing that a revenue-neutral access scheme – that is, a price that lets firms share the investment costs in proportion to the infrastructure used – enhances dynamic efficiency without negatively affecting static efficiency. Finally, Nitsche and Wiethaus (2010) study the impact of various form of access regulation (LRIC, risk sharing, regulatory holidays) on the incentive to invest in NGNs in a game with uncertain returns and quantity competition. They find that risk-sharing enhances consumer welfare with respect to the other regulatory tools since it positively influences the intensity of competition at retail level. All these papers address in a different vein the problem of investment and access regulation, but none of them specifically looks at the effect of migration from old to new infrastructures and how access regulation affects the decision to enter in one segment of the market. Moreover, none of these papers focuses on the relationship between access rules to *both* old and new infrastructures.

The closest study to ours is that of Brito et al. (2010b), which analyzes the incentives of a vertically integrated firm (regulated at wholesale level) to invest in and to give access to a new (upgraded) wholesale technology. Brito et al. assume that the new technology is not subject to regulation, and focus on the type of investment. In particular, they consider two types of innovations (i.e., investments), a drastic and a non-drastic, and show that equilibrium may largely differ according to the nature of the innovation. In the presence of a non-drastic innovation, monopolization of the industry is not a concern, and hence, the regulator can increase the entrants' competitiveness by setting a low access charge on the old technology and let them compete fiercely vis-a-vis the incumbent. On the contrary, if innovation is drastic in nature, the incumbent can monopolize the market and therefore the regulator should introduce specific incentives for entrant operators to invest in alternative infrastructures.

Our paper differs from the previous studies in several directions. We consider a model where access to existing old technology (in the form of local loop unbundling, ULL) is available everywhere in a country, and an incumbent and an entrant compete for providing retail (broadband) services to consumers. In our setting, the country is composed of a continuum of areas, for which the fixed cost of a new technology network varies. We first analyze the firms' (both entrant and incumbent) incentives to invest in new technology (e.g., in the so-called next generation networks) in different areas of the country, as a function of the rental price for ULL. Then, we also consider the case in which the incumbent is also obliged to grant access to the new technology, which enables us to analyze the interplay between different access charges to different (old versus new) infrastructures.

Three conflicting effects emerge in this setting: (i) when the access charge for the existing infrastructure is high (i.e., when the entrant's opportunity cost of investment is low) it kicks in the so-called "replacement effect"[4] and promotes infrastructure investment by alternative operators; (ii) in the presence of a positive spillover in new investments, a higher access charge increases the incumbent's opportunity cost of investment due to the *wholesale revenue effect*: if the incumbent invests in a higher quality network, the entrant will invest in reaction, and the incumbent will then lose some wholesale profits; and finally (iii) when the access charge on the legacy network is low, the

[4] This effect implies that, everything else constant, a monopoly firm is argued to have lower incentives to invest in drastic innovations than a competitive firm, as it involves "replacing itself." See Bourreau et al. (2010) for a general description of this effect in the telecom industry.

prices for the services which rely on this network are low, hence, in order to encourage customers to switch from the legacy "old" network to the "new" network, operators should also offer low prices. This effect, which we refer to as the *business migration effect*, reduces the profitability of the new technology infrastructure, and hence the incentives to invest in it. Coexistence of these multiple effects creates a non-monotonic relation between the access price and investments in the new technology (i.e., in the coverage of the NGNs). Finally, we find that the socially optimal access charge on the NGN increases with the access charge on the legacy network, when the incumbent is leader in NGN investments, whereas the reverse can be true if the entrant is the leader in NGN investments.

The rest of the paper is organized as it follows. In Section 2, we describe our setting. The model is then solved in Section 3. In Section 4, we discuss the interplay between regulation of the old network and regulation of the new network. Finally, in Section 5, we provide some concluding remarks.

2 The Setting

There are two firms, an incumbent, firm 1, and an entrant, firm 2. At the beginning of the game, both firms compete in the market for retail (broadband) services based on the "old" network technology (copper). The incumbent owns the local copper network, with which it provides its retail (broadband) services. The entrant relies on access to the incumbent's local network (possibly through a local loop unbundling offer) at a regulated price, $a \geq 0$. Then, firms sequentially decide on their investments in a new and more advanced infrastructure (the so-called next generation access fibre network –NGN) which we refer to as the "new" technology. We consider the incumbent firm as the first-mover, due to its control over the legacy (copper) network and over other essential facilities, like civil works, etc.

Investment costs. We assume that the incumbent and the entrant operate in different "areas" of the country. We consider a country composed of a continuum of areas, with a total size of $\overline{z}$. We also assume that the fixed cost of a new technology network varies in different areas of the country. We order the areas from 0 to $\overline{z}$ according to the NGN investment cost (from low cost to high cost) in each area.

For each firm, $i = 1, 2$, the decision to invest in the NGN involves setting the area, $z_i \in [0, \overline{z}]$, for which the fibre network will be rolled-out.

The fixed cost of covering an area at a given location, $x \in [0, \overline{z}]$, for firm 1, is denoted by $c_1(x)$, with $c_1(x) > 0$ and $c_1'(x) > 0$. That is, the areas in the country are ordered according to the investment cost. The total cost of covering the areas $[0, z_1]$ for firm 1 is then

$$C_1(z_1) = \int_0^{z_1} c_1(x)\,dx,$$

and we have $C_1'(z_1) = c_1(z_1) > 0$ and $C_1''(z_1) = c_1'(z_1) > 0$.

We assume that, provided that firm 1 has not rolled-out its NGN in a given location, the fixed cost of covering that area with an NGN for firm 2 is either the same as firm 1, or higher. We also consider the possibility of positive "spillovers" from the incumbent's NGN investments; the entrant's fixed cost of investing in NGN may be lower in the areas where the incumbent has already rolled-out its NGN than in those areas where an NGN is absent.[5] We define the cost of covering

[5] For example, when the incumbent builds an NGN in a given area, it may have to obtain administrative authorizations, to gather information on existing civil works or paths of way, etc., which generates some administrative and contractual costs. When the entrant decides to roll-out its own NGN network in the same area, its investment costs can be lower if it can benefit from these incumbent's earlier efforts. One could also consider informational spillovers, as well as direct cost savings due to infrastructure sharing.

an area x for firm 2 as

$$c_2(x, z_1) = \begin{cases} \beta c_1(x) & \text{if} \quad x > z_1 \\ \beta c_1(x) / (1+\gamma) & \text{if} \quad x \le z_1 \end{cases},$$

where $\beta \geq 1$ represents firm 2's cost disadvantage, and $\gamma \in [0, +\infty)$ represents the degree of spillovers from firm 1's investment. With this formulation, a higher γ represents a higher degree of spillovers, whereas $\gamma = 0$ corresponds to the case with no spillovers. The total cost of covering the areas $[0, z_2]$ for firm 2 is then

$$C_2(z_2, z_1) = \begin{cases} \beta C_1(z_2) / (1+\gamma) & \text{if} \quad z_2 \le z_1 \\ \beta C_1(z_2) - \beta\gamma / (1+\gamma) C_1(z_1) & \text{if} \quad z_2 > z_1 \end{cases}.$$

We have $\partial C_2 / \partial z_2 > 0$ and $\partial^2 C_2 / \partial (z_2)^2 > 0$, that is, the entrant's total investment is strictly convex with respect to the size of the areas covered. We also have $\partial C_2 / \partial z_1 \leq 0$; due to the spillover effect, the higher the coverage of firm 1's NGN, the lower the total cost of rolling out an NGN for firm 2.

Profits. We denote by $\pi_i^{k,l}$ the profit of firm $i = 1, 2$ in a given area, where $k = O, N$ refers to firm 1's network technology in the area (Old or New) and $l = O, N$ refers to firm 2's network technology in the same area (Old or New). We assume that the firms' profits in a given area depend only on their respective network technologies, and not on the coverage of the new technology networks.[6] Finally, we normalize the marginal cost of access to 0.

We introduce the following assumptions on profits.

[6] We might consider indirect effects between the market for broadband access (which we model in this paper) and the market for content. A larger coverage for the NGN might stimulate innovation in contents suited to NGNs only, which in turn would increase the demand for NGNs.

Assumption 1. For $k = O, N$, we have (i) $d\pi_2^{k,O}(a)/da \leq 0$; (ii) for $k = O, N$, there exists $\widehat{a}^k > 0$ such that, for all $a \leq \widehat{a}^k$, $d\pi_1^{k,O}(a)/da \geq 0$, and $d\pi_1^{k,O}(a)/da \leq 0$ otherwise.

Assumption 1(i) states that when the entrant leases access to the legacy network, its profit decreases with the access charge, a. Assumption 1(ii) means that, the incumbent's profit increases with the access charge, but only up to a certain point. The threshold $\widehat{a}^k$ corresponds to the monopoly access charge for the incumbent when it operates a network of technology $k = O, N$.

Assumption 2. For $k = O, N$ and all $a \leq \widehat{a}^k$, $\pi_1^{k,O}(a) \geq \pi_1^{k,N}$.

Assumption 2 implies that, given its network technology, firm 1 makes more profit when firm 2 uses the old network than when firm 2 has rolled-out an NGN.

Finally, we assume that the investment in the new technology is non-drastic, so that there is no monopolization at the retail level after investment; therefore, we have $\pi_2^{N,O}(a) \geq 0$ and $\pi_1^{O,N} \geq 0$. In Appendix A, we provide an example of a competitive setting à la Katz and Shapiro (1985), with quality differentiation and quantity competition, that satisfies the assumptions of the general model.

In the benchmark setting, we focus on the effect of regulation of access on the old network on investment incentives in NGNs, and hence, ignore any possibilities of access to the NGNs.[7]

Timing of the game. The timing of the game is as follows: The regulator sets the access charge on the old network, $a \geq 0$. Then, firm 1 decides on the areas to cover with an NGN, z_1. Finally, observing firm 1's decision, firm 2 decides on its NGN coverage, z_2.[8]

We look for the subgame perfect equilibrium of this game.[9]

[7] In Section 4, we study the interplay between access to the legacy network and access to the incumbent's NGN.

[8] See Bourreau, Cambini and Hoernig (2011), for a "coverage game," where the investment decisions are made simultaneously.

[9] In some European countries, some new entrants seem to move first for the investments in next generation networks. Our setting does not preclude this possibility. After observing the incumbent's investment, the entrant can decide to invest in areas where its rival has not rolled out an infrastructure. Therefore, in equilibrium, the entrant may be the

3 The Equilibrium

In this Section, we solve the game backwards, starting with the last stage.

3.1 Stage 3: the entrant's investment decision

Assume that firm 1 has covered the areas $[0, z_1]$. Firm 2's profit writes

$$\Pi_2 (z_1, z_2) = z_2 \pi_2^{N,N} + (z_1 - z_2) \pi_2^{N,O} (a) + (\overline{z} - z_1) \pi_2^{O,O} (a) - C_2 (z_2, z_1) , \tag{1}$$

if $z_2 \leq z_1$ and

$$\Pi_2 (z_1, z_2) = z_1 \pi_2^{N,N} + (z_2 - z_1) \pi_2^{O,N} + (\overline{z} - z_2) \pi_2^{O,O} (a) - C_2 (z_2, z_1) , \tag{2}$$

otherwise. Equation (1) reads as follows. From area 0 to area z_2, both firms have rolled out NGNs, and there is infrastructure competition. From area z_2 to area z_1, only firm 1 has installed an NGN, whereas firm 2 relies on access to the legacy network. Finally, from area z_1 to area $\overline{z}$, both firms use the legacy network to provide broadband services. Similarly, in equation (2), there are two competing NGN infrastructures in areas $[0, z_1]$, a monopoly NGN infrastructure owned by firm 2 in areas $[z_1, z_2]$, and finally no NGN infrastructure in areas $[z_2, \overline{z}]$.

To determine firm 2's optimal investment, we therefore distinguish two cases that depend on whether firm 2 decides to cover a smaller *or* a larger geographical area than firm 1.

First, consider the case where firm 2 installs an NGN in areas where firm 1 has already invested, i.e., we have $z_2 \leq z_1$. For firm 2, it is profitable to invest in an area $z_2 \in [0, z_1]$ if the extra profit

first mover for the deployment of NGN in large parts of the country. As our analysis in Section 3, there are indeed equilibrium outcomes where the entrant invests more than the incumbent, and hence, can be viewed *ex post* as the "first mover".

it earns by investing in an NGN is higher than the investment cost in this area, that is, if

$$\pi_2^{N,N} - \pi_2^{N,O}(a) \geq c_2(z_2, z_1) = \beta c_1(z_2) / (1+\gamma). \tag{3}$$

The term on the left-hand side represents firm 2's profit incentive, which is equal to the difference between its profit when the two firms operate an NGN, and its profit when only firm 1 operates an NGN. We define $z_2^c(a) = (c_1)^{-1}\left((1+\gamma)\left(\pi_2^{N,N} - \pi_2^{N,O}(a)\right)\Big/\beta\right)$ as the highest z_2 which satisfies inequality (3); z_2^c represents the largest area in which firm 2 will invest, provided that firm 1 has already invested.

Now consider the case where firm 2 decides to invest in an area z_2, where firm 1 has not invested in an NGN, i.e., we have $z_2 > z_1$. It is profitable for firm 2 to invest if

$$\pi_2^{O,N} - \pi_2^{O,O}(a) \geq c_2(z_2, z_1) = \beta c_1(z_2). \tag{4}$$

That is, firm 2 compares its gross profit gain when it operates an NGN (provided that firm 1 operates the old network) and its investment cost in the area. Similarly as above, we define $z_2^m(a) = (c_1)^{-1}\left(\left(\pi_2^{O,N} - \pi_2^{O,O}(a)\right)\Big/\beta\right)$ as the highest z_2 which satisfies inequality (4); z_2^m represents the largest area in which firm 2 will invest, provided that firm 1 has not already invested.

In sum, for any given z_1, we have the following equilibrium candidates

i. If $z_2^c > z_2^m$, firm 2 has more incentives to invest in an NGN in a given area, if firm 1 has already invested in this area than if firm 1 has not invested, and

ii. if $z_2^c \leq z_2^m$, firm 2 has more incentives to invest in an NGN in a given area, if firm 1 has not invested in this area than if firm 1 has already invested.

As the following Lemma shows, whether we have (i) or (ii) depends on the degree of spillovers and on the level of access charge to the legacy network.

Lemma 1 *For any given a, there exists $\overline{\gamma}(a) \in [0, +\infty)$ such that we have $z_2^c(a) > z_2^m(a)$ for all $\gamma > \overline{\gamma}(a)$.*

Proof. See Appendix B. ■

Intuitively, if the degree of spillovers is sufficiently large, then in any given area, firm 2 will have a higher incentive to invest in an NGN, when the incumbent has its NGN in that area than when it has not. We will refer to this effect as the "spillover effect." Note that, since $\pi_2^{O,O}(a)$ and $\pi_2^{N,O}(a)$ are both decreasing with a, the variations of $\overline{\gamma}(a)$ with respect to a are indeterminate in general.

With the model of quantity competition with quality differentiation (à la Katz and Shapiro, 1985) that we will use as an example, we have $\pi_2^{O,N} - \pi_2^{O,O}(a) > \pi_2^{N,N} - \pi_2^{N,O}(a)$, for all a, and therefore in this case, we have $z_2^c > z_2^m$ only if $\gamma > 0$, that is, if there are spillovers in NGN investments.[10] In this example, we also find that $\partial\overline{\gamma}(a)/\partial a > 0$; a higher access charge therefore makes the "spillover effect" less likely to occur.

To determine firm 2's coverage decision, we now distinguish two cases, depending on whether $\gamma > \overline{\gamma}(a)$, or the reverse.

High degrees of spillovers. We start by studying the case where the degree of spillovers is sufficiently high so that we have $z_2^c > z_2^m$. Since $z_2^c > z_2^m$, firm 2 is not willing to cover areas that firm 1 has not already covered. The following Lemma gives the best-response of the entrant.

[10] Note that, in most competition models, a strictly positive degree of spillover (i.e., $\gamma > \overline{\gamma} > 0$) is required to have $z^c > z^m$. Apart from the Katz and Shapiro model, this is also true for the Hotelling model and the Mussa-Rosen model of competition (see Lestage and Flacher, 2010, for the computations for the Mussa-Rosen model).

Lemma 2 *If $\gamma > \overline{\gamma}(a)$, the best-response of the entrant writes:*

$$z_2^{BR}(z_1) = \begin{cases} z_2^m & \text{if} \quad z_1 \leq z_2^m \\ z_1 & \text{if} \quad z_2^m < z_1 \leq z_2^c \\ z_2^c & \text{if} \quad z_1 > z_2^c \end{cases}. \tag{5}$$

Proof. Appendix C. ■

The entrant's optimal coverage reads as follows. If firm 1 covers a small part of the country with an NGN (i.e., $z_1 \leq z_2^m$), firm 2 rolls out its NGN as if it had a monopoly over NGNs. Therefore, firm 2 covers $z_2 = z_2^m$. For larger coverage from the incumbent, the entrant's best decision is to mimic its rival investment (i.e., $z_2 = z_1$). Finally, if firm 1 covers a very large share of the country (i.e., $z_1 > z_2^c$), firm 2 covers less than its rival. Note that, if firm 1 covers a larger part of the country (that is, z_1 increases), then firm 2 also invests more.

Low degrees of spillovers. Now, assume that $\gamma \leq \overline{\gamma}(a)$, which implies that $z_2^c \leq z_2^m$. We have the following result.

Lemma 3 *If $\gamma \leq \overline{\gamma}(a)$, the best-response of the entrant writes:*

$$z_2^{BR}(z_1) = \begin{cases} z_2^m & \text{if} \quad z_1 \leq \widehat{z}_1(a) \\ z_2^c & \text{if} \quad z_1 > \widehat{z}_1(a) \end{cases}, \tag{6}$$

where $\widehat{z}_1(a) \in [z_2^c, z_2^m]$.

Proof. See Appendix D. ■

The threshold $\widehat{z}_1(a)$ is defined as the lowest z_1 such that $\Pi_2(z_1, z_2^c) \geq \Pi_2(z_1, z_2^m)$. The variations of $\widehat{z}_1(a)$ are indeterminate, and in our Katz and Shapiro example, we find that $\widehat{z}_1(a)$ varies non-monotically with a.

The entrant's best-response (6) is similar than in the case with high spillovers, except that $z_2^{\mathrm{BR}}(z_1)$ decreases with z_1 when $\gamma \leq \overline{\gamma}(a)$, as $z_2^c \leq z_2^m$.. Firm 2 acts as a monopoly for the NGN investment if firm 1's coverage is low. Otherwise, firm 2's coverage choice depends on its incentive to duplicate firm 1's network. Note that firm 2 never mimics firm 1's decision in this situation with a low degree of spillovers.

In contrast with the case with high spillovers, we find here that the entrant invests (weakly) less when firm 1 covers a larger share of the country. Indeed, assume that firm 1 increases its coverage from $z_1 \leq \widehat{z}_1$ to $z_1' > \widehat{z}_1$. Then, firm 2's coverage is reduced from z_2^m to $z_2^c \leq z_2^m$.

Impact of the access charge on z_2^m and z_2^c. We can determine the impact of a change of the access charge when the coverage of the incumbent, z_1, is given. We have

$$\frac{dz_2^c}{da} = \frac{1+\gamma}{\beta\left(c_1\right)'\left(\left(c_1\right)^{-1}\left((1+\gamma)(\pi_2^{N,N} - \pi_2^{N,O}(a))\right)\right)}\left(-\frac{d\pi_2^{N,O}(a)}{da}\right).$$

Since $d\pi_2^{N,O}(a)/da \leq 0$ (due to Assumption 1), then $dz_2^c/da \geq 0$. Similarly, since $d\pi_2^{O,O}(a)/da \leq 0$, we have

$$\frac{dz_2^m}{da} = \frac{1}{\beta\left(c_1\right)'\left(\left(c_1\right)^{-1}\left(\pi_2^{O,N} - \pi_2^{O,O}(a)\right)\right)}\left(-\frac{d\pi_2^{O,O}(a)}{da}\right) \geq 0.$$

Therefore, a higher access charge, a, shifts firm 2's best-response (which is given by (5) and (6)) upwards, which implies that for a given z_1, firm 2 invests *more*. This highlights a first effect in our setting, the so-called "replacement effect"[11]: a higher a implies a lower opportunity cost ($\pi_2^{k,O}(a)$, for $k = O, N$) of investing in an NGN, which increases firm 2's investment incentives.

[11] The replacement effect has been introduced by Arrow (1962) in the innovation literature. Arrow shows that an incumbent has less incentives to invest than an entrant, as it "replaces" itself.

3.2 Stage 2: the incumbent's investment decision

We now turn to firm 1's investment decision, at stage 2 of the game. Firm 1 decides to cover the areas $[0, z_1]$, taking into account firm 2's best-response in the next stage of the game, $z_2^{\mathrm{BR}}(z_1)$, which is given by (5) if $\gamma > \overline{\gamma}(a)$, and by (6) otherwise.

3.2.1 High degrees of spillovers

To determine the incumbent's optimal coverage decision, we begin by writing its profit function when it anticipates the entrant's best-response. Since $z_2^{\mathrm{BR}}(\cdot)$ has three parts, we have to consider three possible cases, according to the value of z_1.

If $z_1 \in [0, z_2^m]$, firm 2's best-response is to cover $z_2^m \geq z_1$, and hence, firm 1's profit is given by

$$\Pi_1(z_1, z_2^{\mathrm{BR}}(z_1)) = z_1 \pi_1^{N,N} + (z_2^m(a) - z_1)\, \pi_1^{O,N} + (\overline{z} - z_2^m(a))\, \pi_1^{O,O}(a) - C_1(z_1). \tag{7}$$

This expression reads as follows. For $z \in [0, z_1]$, both firm 1 and firm 2 have invested in an NGN, hence, firm 1 obtains a profit $\pi_1^{N,N}$ in these areas. For $z \in [z_1, z_2^m]$, only the entrant has invested in an NGN, and therefore, firm 1 earns the profit $\pi_1^{O,N}$ from its legacy network. Finally, for $z \in [z_2^m, \overline{z}]$, neither of the two firms have invested, and the incumbent obtains $\pi_1^{O,O}(a)$.

If $z_1 \in [z_2^m, z_2^c]$, firm 2's best-response will be to cover the same areas as firm 1 (i.e., $z_2 = z_1$). Firm 1's profit then writes

$$\Pi_1(z_1, z_2^{\mathrm{BR}}(z_1)) = z_1 \pi_1^{N,N} + (\overline{z} - z_1)\, \pi_1^{O,O}(a) - C_1(z_1). \tag{8}$$

If $z \in [0, z_1]$, both firm 1 and firm 2 have invested in an NGN, and firm 1 therefore obtains a profit of $\pi_1^{N,N}$ from area 0 to area z_1. Then, for $z \in [z_1, \overline{z}]$, neither of the two firms have invested, and the incumbent earns $\pi_1^{O,O}(a)$.

Finally, if $z_1 \in [z_2^c, \overline{z}]$, firm 2 will cover $z_2^c \leq z_1$, and firm 1's profit is then given by

$$\Pi_1(z_1, z_2^{\mathrm{BR}}(z_1)) = z_2^c(a)\,\pi_1^{N,N} + (z_1 - z_2^c(a))\,\pi_1^{N,O}(a) + (\overline{z} - z_1)\,\pi_1^{O,O}(a) - C_1(z_1)\,. \tag{9}$$

For any $z \in [0, z_2^c]$, both firm 1 and firm 2 have invested in an NGN, and hence, firm 1 obtains a profit $\pi_1^{N,N}$. For $z \in [z_2^c, z_1]$, only the incumbent has invested, and therefore, firm 1 earns the profit $\pi_1^{N,O}$ from its NGN. Finally, for $z \in [z_1, \overline{z}]$, neither of the two firms have invested, and the incumbent obtains $\pi_1^{O,O}(a)$.

The incumbent's optimal decision. The incumbent chooses a coverage z_1 so as to maximize its profit, and hence, in equilibrium firm 1 and firm 2's coverage are given by

$$z_1^* = \arg\max_{z_1 \in [0,\overline{z}]} \Pi_1(z_1, z_2^{\mathrm{BR}}(z_1)),$$

and

$$z_2^* = z_2^{\mathrm{BR}}(z_1^*)\,.$$

Given that Π_1 has three parts, we have three potential interior optima, which correspond to the maxima of (7), (8), and (9), as well as two potential corner optima, at z_2^m and z_2^c. We define z_1^c, z_1^d and z_1^m as the maxima with respect to z_1 of equations (7), (8), and (9), respectively. We have

$$z_1^c = (c_1)^{-1}\left(\pi_1^{N,N} - \pi_1^{O,N}\right), \tag{10}$$

$$z_1^d = (c_1)^{-1}\left(\pi_1^{N,N} - \pi_1^{O,O}(a)\right), \tag{11}$$

and

$$z_1^m = (c_1)^{-1}\left(\pi_1^{N,O}(a) - \pi_1^{O,O}(a)\right). \tag{12}$$

Note that under Assumption 2, we have $\pi_1^{O,N} \leq \pi_1^{O,O}(a)$ and $\pi_1^{N,O}(a) \geq \pi_1^{N,N}$, which implies that $z_1^d \leq z_1^c$ and $z_1^m \geq z_1^d$.[12]

We have $dz_1^c/da = 0$. This means that, if in equilibrium the incumbent invests strictly less than the entrant, its NGN coverage does not depend on the access charge on the legacy network.

As for the second case, we have $dz_1^d/da < 0$, for all $a \leq \widehat{a}^O$ (due to Assumption 1). In this case, if the access charge is not too high (i.e., if it is not above the monopoly access charge), increasing the access charge makes the incumbent invest *less*. This is due to our second effect, the "wholesale revenue effect." Indeed, when the entrant does not invest in an NGN, the incumbent enjoys wholesale revenues from its legacy network, and its profit ($\pi_1^{O,O}(a)$) is an increasing function of the access charge. To the extent that the incumbent's investment favors the entrant's investment through the spillover effect, the incumbent faces an opportunity cost of investing in an NGN, namely, the foregone wholesale revenues.[13]

Finally, we have

$$\frac{dz_1^m}{da} = 1/(c_1)'\left((c_1)^{-1}\left(\pi_1^{N,O}(a) - \pi_1^{O,O}(a)\right)\right)\left(\frac{d\pi_1^{N,O}(a)}{da} - \frac{d\pi_1^{O,O}(a)}{da}\right).$$

Since $(c_1)'(\cdot) \geq 0$, the sign of dz_1^m/da is the same as the sign of $d\pi_1^{N,O}(a)/da - d\pi_1^{O,O}(a)/da$. Under our assumptions, we have $d\pi_1^{N,O}(a)/da \geq 0$ for all $a \leq \widehat{a}^N$, and $d\pi_1^{O,O}(a)/da \geq 0$ for all $a \leq \widehat{a}^O$. Therefore, if a is not too high (i.e., $a \leq \min\{\widehat{a}^O, \widehat{a}^N\}$), the sign of dz_1^m/da is indeterminate and can be either positive or negative. This reflects the presence of two opposite effects. First of all, the "wholesale revenue effect," which we explained above, is at work. Due to this effect, a higher a implies a higher opportunity cost of investing in an NGN. Second, we have a different (and third) effect which works in the opposite direction: the "business migration effect." When the

[12] Therefore, there is a local optimum either at z_1^d or at z_1^c.

[13] In other words, the incumbent, like the entrant, faces a "replacement effect."

access charge on the legacy network is low, the prices for the retail (broadband) services which rely on this network are low. Therefore, to encourage customers to switch from the legacy network to the new NGN, any operator has to offer its retail services through the new and high-tech NGN at low prices too. This reduces the profitability of the NGN, and hence the incentives to invest in such a network.

According to our analysis, we have five potential equilibria.[14] Table 1 presents each equilibrium, and gives the impact of the access charge on equilibrium investments. Each candidate equilibrium is characterized by one of the five potential incumbent's equilibrium coverage (z_1^c, z_2^m, z_1^d, z_2^c and z_1^m) and the entrant's best-response to the incumbent's coverage, which is given by (5).

Table 1: Candidate equilibria (high degrees of spillovers)

	$\partial z_1^*/\partial a$	$\partial z_2^*/\partial a$	comparison	total coverage
$\{z_1^c, z_2^m\}$	$\emptyset$	$+$	$z_1^* < z_2^*$	z_2^m
$\{z_2^m, z_2^m\}$	$+$	$+$	$z_1^* = z_2^*$	z_2^m
$\{z_1^d, z_1^d\}$	$-$	$-$	$z_1^* = z_2^*$	z_1^d
$\{z_2^c, z_2^c\}$	$+$	$+$	$z_1^* = z_2^*$	z_2^c
$\{z_1^m, z_2^c\}$	$+$ or $-$	$+$	$z_1^* > z_2^*$	z_1^m

Note that in Table 1, the candidate equilibria are ordered according to total coverage. Besides, we find that there both symmetric equilibria (where the incumbent and the entrant have the same equilibrium coverage) and asymmetric equilibria (where either of the two firms covers more than its rival). As long as the incumbent invests less than the entrant in equilibrium, the entrant invests as if it were deploying a monopolistic NGN infrastructure (i.e., we have $z_2^* = z_2^m$). If the incumbent invests more, the entrant mimics the incumbent's coverage if it is not too large. Finally, if the

[14] Note that the equilibrium is unique, but that it can be either of our five candidate equilibria.

incumbent rolls out its NGN infrastructure massively, the entrant invests less than the incumbent.

3.2.2 Low degrees of spillovers

Now, consider the case where $\gamma \leq \overline{\gamma}(a)$. Given that $z_2^{\mathrm{BR}}(\cdot)$ has two parts, we have two possible cases, according to the value of z_1.

If $z_1 \in [0, \widehat{z}_1]$, firm 1's profit is given by (7), whereas if $z_1 \in [\widehat{z}_1, \overline{z}]$, firm 1's profit is given by (8). Since the incumbent's profit function has two different parts, we have two potential interior optima, which corresponds to the maxima of (7) and (8), that is, z_1^c and z_1^m, respectively, as well as a potential corner optimum at $\widehat{z}_1$.

We then have three candidate equilibria, that we characterize in Table 2 below.

Table 2: Candidate equilibria (low degrees of spillovers)

	$\partial z_1^*/\partial a$	$\partial z_2^*/\partial a$	comparison	total coverage
$\{z_1^c, z_2^m\}$	$\emptyset$	$+$	$z_1^* < z_2^*$	z_2^m
$\{\widehat{z}_1, z_2^m\}$	$+$ or $-$	$+$	$z_1^* < z_2^*$	z_2^m
$\{z_1^m, z_2^c\}$	$+$ or $-$	$+$	$z_1^* > z_2^*$	z_1^m

Note that, contrary to the previous case, all candidate equilibria are asymmetric.

3.2.3 An application

We use the competitive setting of quantity competition with quality differentiation of Katz and Shapiro (1985). The indirect utility function of a consumer of type τ is $U = \tau + s_i - p_i$, where s_i and p_i denote the quality and price of firm i, with $i = 1, 2$. Consumers' types are uniformly distributed over $[0, 1]$. Firms set quantities, and we normalize marginal costs to zero. The quality of the "old" network is denoted by s^O, and the quality of the "new" network is denoted by s^N. Therefore, we have $s_i = s^O$ or s^N, for $i = 1, 2$. Finally, we assume that $s^N > s^O$ and that

$s^N < 1 + 2s^O$. The latter assumption ensures that a firm using the old network is not evicted by a firm using the new network.[15]

Figure 1 below shows the equilibrium coverage levels, according to the degree of spillovers γ and the investment cost disadvantage of firm 2, β. We use the following values for our model parameters: $\overline{z} = 10$, $s^O = 1$, $s^N = 2$, $a = 0$,[16] and $c_1(x) = x^2/2$.

The figure shows that for low values of β ($\beta \in [1, 1.65]$), the equilibrium is asymmetric. If the degree of spillovers is low (below the solid line), firm 1 covers more than firm 2 (i.e., we have $z_1^* > z_2^*$). In this area, increasing the access charge has an ambiguous effect on firm 1's investment, whereas it increases firm 2's investment. If the degree of spillovers is high (above the solid line), firm 2 invests more than firm 1. In this case, increasing the access charge enhances the entrant's investment incentives but it does not affect the incumbent's investment incentives. For higher values of β ($\beta > 1.65$) and high degrees of spillovers, the equilibrium is symmetric. In this equilibrium area, increasing the access charge enhances both firm 1's and firm 2's investment incentives. Finally, note that increasing the access charge shifts the solid line upwards, and hence, makes the equilibrium where the incumbent invests in more areas than the entrant more likely to occur.

[15] See Appendix A for a detailed analysis.

[16] That is, the access charge is equal to marginal cost.

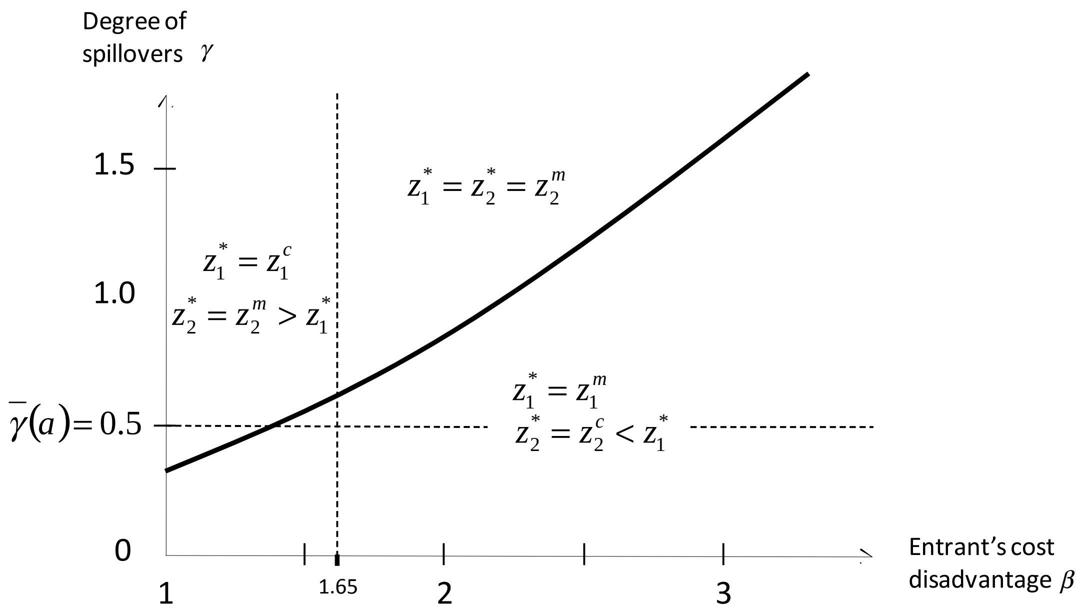

Figure 1: Equilibrium outcomes

3.3 Stage 1: the regulator's decision

The regulator chooses the access charge on the old network, a, so as to maximize social welfare, which is defined as the sum of consumer surplus and industry profits. We denote by $w^{k,l}$ the gross welfare in an area where firm 1 uses technology $k = O(\text{ld}), N(\text{ew})$ and firm 2 uses technology $l = O(\text{ld}), N(\text{ew})$. We also assume that $dw^{O,O}(a)/da \leq 0$. The idea is that, when both firms use the old technology, a higher access charge inflates retail prices and reduces the total quantity consumed.[17]

As shown above, in our general setting, we have both symmetric and asymmetric candidate equilibria at the investment subgame. We express below the social welfare for each type of equilibrium, and discuss how welfare varies with the access charge. Finally, we provide an application to our Katz and Shapiro setting.

[17] In Appendix E, we provide the welfare analysis for our example setting, and show that this assumption holds.

3.3.1 Symmetric equilibria

We denote by $z_1^* = z_2^* = z^*$ the generic optimal coverage of the two firms in a symmetric equilibrium at the investment subgame. Social welfare then writes

$$W = z^*(a)\, w^{N,N} + (\overline{z} - z^*(a))\, w^{O,O}(a) - C_1(z^*(a)) - C_2(z^*(a), z^*(a)).$$

The variation of welfare with respect to the access charge is given by[18]

$$\frac{dW}{da} = \frac{dz^*(a)}{da}\left[\left(w^{N,N} - w^{O,O}(a)\right) - c_1(z^*(a)) - c_2(z^*(a), z^*(a))\right] + (\overline{z} - z^*(a))\frac{dw^{O,O}(a)}{da}. \quad (13)$$

Equation (13) highlights the regulator's potential trade-off between static efficiency and investment incentives. On the one hand, setting a higher access charge lowers welfare in the uncovered areas, as $dw^{O,O}(a)/da \leq 0$. On the other hand, provided that investment in new infrastructures is socially efficient (i.e., if $\left(w^{N,N} - w^{O,O}(a)\right) - c_1(z^*(a)) - c_2(z^*(a), z^*(a)) > 0$[19]), a higher access charge increases investment incentives if $dz^*(a)/da \geq 0$. As shown in Table 1, in the two candidate symmetric equilibria $z_1^* = z_2^* = z_2^m$ and $z_1^* = z_2^* = z_2^c$, we have $dz^*(a)/da \geq 0$. In this case, the regulator faces a standard trade-off between investment incentives and static efficiency in the uncovered areas.

However, this trade-off is absent when we consider the symmetric candidate equilibrium $z_1^* = z_2^* = z_1^d$, where the entrant mimics the incumbent's investment decision. In this equilibrium configuration, in contrast with the two previous cases, the objectives to provide strong investment incentives and to maximize static efficiency in the uncovered areas are aligned. Setting a low access charge indeed stimulates investment as, from Table 1, we have $dz^*(a)/da = dz_1^d/da \leq 0$, and it

[18] Note that, as the access charge a varies, the actual equilibrium (which is always unique) can move from one of our potential equilibrium (symmetric or asymmetric) to another (symmetric or asymmetric).

[19] This is always true in our application setting (see Appendix E).

also increases welfare in the uncovered areas, as $dw^{O,O}(a)/da \leq 0$. In this case, since $dW/da \leq 0$, the regulator has incentives to set a low access charge.[20]

3.3.2 Asymmetric equilibria

We have two candidate asymmetric equilibria, one in which the incumbent invests more than the entrant, and one in which it is the reverse.

(i) $z_1^* > z_2^*$: Consider first the case where the incumbent invests more than the entrant (i.e., the equilibrium coverage levels are z_1^m and z_2^c). Social welfare writes

$$W = z_2^c(a)\, w^{N,N} + (z_1^m - z_2^c(a))\, w^{N,O}(a) + (\overline{z} - z_1^m)\, w^{O,O}(a) - C_1(z_1^m) - C_2(z_2^c(a), z_1^m).$$

We have

$$\begin{aligned}\frac{dW}{da} &= \underbrace{\frac{dz_2^c}{da}}_{+}\underbrace{\left(w^{N,N} - w^{N,O}(a) - c_2(z_2^c(a), z_1^m)\right)}_{\text{+ or -}} + \underbrace{\frac{dz_1^m}{da}}_{\text{+ or -}}\underbrace{\left(w^{N,O}(a) - w^{O,O}(a) - c_1(z_1^m)\right)}_{\text{+ or -}} \\ &\quad \underbrace{+(z_1^m - z_2^c)\frac{dw^{N,O}}{da}}_{\text{-}} + \underbrace{(\overline{z} - z_1^m)\frac{dw^{O,O}}{da}}_{\text{-}}.\end{aligned}$$

When determining the access charge, the regulator has to take into account three different objectives. First, it aims at maximizing static efficiency, which requires setting a low access charge. This corresponds to the two last (negative) terms in the equation above. Second, the regulator is concerned about dynamic efficiency, that is, firms' incentives to invest in the new technology. Whereas raising the access charge always increases the entrant's investment incentives (as $dz_2^c/da > 0$), it has an ambiguous effect on the incumbent's investment incentives (we can have either $dz_1^m(a)/da > 0$

[20] When a decreases, the equilibrium can switch from this symmetric equilibrium where $z_1^* = z_2^* = z_1^d$ to another (symmetric or asymmetric) equilibrium. Therefore, we cannot infer that $a^w = 0$.

or the reverse –see Table 1).

Finally, third, the regulator aims at avoiding excessive duplication of infrastructure costs. With our application setting, we find that $w^{N,O}(a) - w^{O,O}(a) - c_1(z_1^m) > 0$, whereas $w^{N,N} - w^{N,O}(a) - c_2(z_2^c(a), z_1^m) < 0$.[21] That is, the coverage of the incumbent (in the areas with a single infrastructure) is too low from a social point view, whereas the coverage of the entrant (in the areas with two competing infrastructures) is too large. The intuition is that, while firms do not internalize all consumer surplus (and hence, might *under*-invest), their investment incentives also involve a business-stealing effect (and, hence, they might *over*-invest). Therefore, in our application, the regulator is willing to extend the incumbent's coverage by setting a lower or higher access (depending on whether $dz_1^m(a)/da > 0$ or the reverse) and to reduce the entrant's coverage by setting a lower access charge (as $dz_2^c/da > 0$).

(ii) $z_1^* < z_2^*$: Conversely, consider the case where the entrant has a larger coverage than the incumbent. We begin by considering the asymmetric equilibrium $z_1^* = z_1^c$, $z_2^* = z_2^m$. In this equilibrium, social welfare writes

$$W = z_1^c w^{N,N} + \left(z_2^m(a) - z_1^c\right) w^{O,N} + \left(\overline{z} - z_2^m(a)\right) w^{O,O}(a) - C_1(z_1^c) - C_2\left(z_2^m(a), z_1^c\right).$$

We have

$$\frac{dW}{da} = \underbrace{\frac{dz_2^m(a)}{da}}_{+}\underbrace{\left(w^{O,N} - w^{O,O}(a) - c_2\left(z_2^m(a), z_1^c\right)\right)}_{+\text{ or }-} + \underbrace{\left(\overline{z} - z_2^m(a)\right)\frac{dw^{O,O}(a)}{da}}_{-}. \tag{14}$$

Note that in this asymmetric equilibrium, the regulator does not take into account the incumbent's investment incentives in its choice of an access charge as $dz_1^c/da = 0$.

[21] See Appendix E for the proof.

If $w^{O,N} - w^{O,O}(a) - c_2(z_2^m(a), z_1^c) > 0$,[22] if the entrant's coverage is too large from a social point of view, the regulator faces a trade-off between investment incentives and static efficiency in the uncovered areas. On the one hand, setting a higher access charge increases coverage as $dz_2^m(a)/da > 0$. On the other hand, it lowers welfare in the uncovered areas, as $dw^{O,O}(a)/da < 0$.

If $w^{O,N} - w^{O,O}(a) - c_2(z_2^m(a), z_1^c) \leq 0$, then $dW/da \leq 0$. Therefore, when the entrant is going to invest too much from a social point of view, the regulator has incentives to set the lowest access charge as possible to reduce both investment incentives and static inefficiency.

Finally, we consider the asymmetric equilibrium $z_1^* = \widehat{z}_1$, $z_2^* = z_2^m$ in the low spillovers case (see Table 2). Social welfare writes

$$W = \widehat{z}_1 w^{N,N} + (z_2^m(a) - \widehat{z}_1) w^{O,N} + (\overline{z} - z_2^m(a)) w^{O,O}(a) - C_1(\widehat{z}_1) - C_2(z_2^m(a), \widehat{z}_1),$$

and hence, dW/da is given by (14). Therefore, the analysis is similar to the above case.

3.3.3 Application

Since we cannot characterize the socially optimal access charge, we revert to a numerical application, using the Katz and Shapiro, that we introduced in Section 3.2.3. We use the same parameter values, $\overline{z} = 10$, $s^O = 1$, $s^N = 2$, and we assume that $c_1(x) = x^2/5$. Figure 2

[22] In our application setting, we find that $w^{O,N} - w^{O,O}(a) - c_2(z_2^m(a), z_1^c)$ can be either positive or negative (see Appendix E).

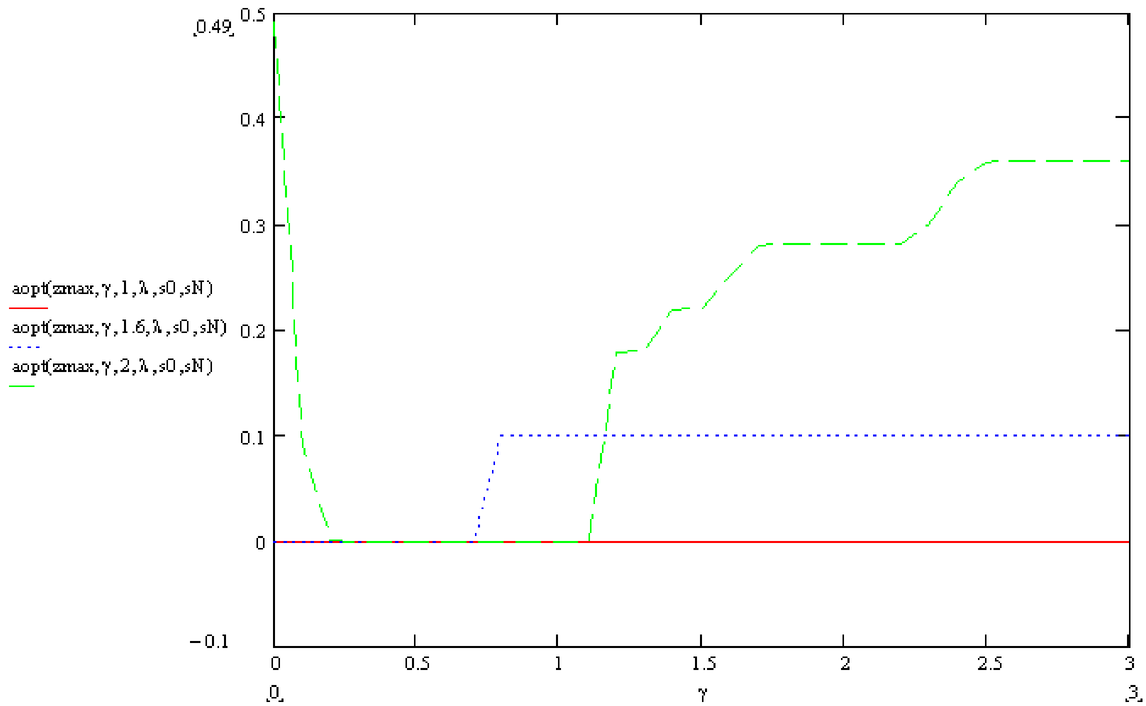

Figure 2: Optimal access charge as a function of the degree of spillovers (γ), for different values of the cost disadvantage (β)

If the entrant has no cost disadvantage (i.e., $\beta = 1$), the regulator sets the access charge at marginal cost for all values of the degree of spillovers. This is because, though the incumbent tends to invest less as the degree of spillovers increases, the entrant invests massively in NGN infrastructure. Therefore, the regulator does not harm investment by setting a low access charge to increase static efficiency.

However, if the entrant a cost disadvantage (i.e., $\beta = 1.6$ or $\beta = 2$), if the incumbent reduces its investment for high degrees of spillovers, the entrant does not invest much either, as it faces high investment costs. This is why the regulator increases the access charge on the "old" network to provide the firms (both the incumbent and the entrant) with stronger investment incentives and counter balance the spillover effect.

4 Interplay Between Regulation of the Old Network and Regulation of the New Network

In this section, we discuss the interplay between the regulation of the old network and the regulation of the new network. We assume that regulation obliges an operator with a monopoly NGN infrastructure (in some areas) to provide access to its competitor at a regulated price of $\widetilde{a}$. We denote by $\widetilde{\pi}_i^{N,N}(\widetilde{a})$ firm i's profit when it provides access to its NGN to firm $j \neq i$, and by $\pi_j^{N,N}(\widetilde{a})$ firm j's profit when it leases access to the NGN of firm i. We assume that $\partial\widetilde{\pi}_i^{N,N}(\widetilde{a})/\partial\widetilde{a} \geq 0$ for $\widetilde{a}$ not too high, and that $\partial\pi_j^{N,N}(\widetilde{a})/\partial\widetilde{a} \leq 0$.

Before determining the entrant's and the incumbent's investment decisions, we discuss under which condition migration occurs at the wholesale level.

Migration at the wholesale level. To begin with, consider that the incumbent has invested more than the entrant, and hence, that it has to provide access to its NGN. When an NGN wholesale offer is available in a given area, the entrant trades off between leasing access to the old technology network and leasing access to the NGN. The entrant prefers the NGN wholesale offer to the old network wholesale offer if and only if $\pi_2^{N,N}(\widetilde{a}) \geq \pi_2^{N,O}(a)$. Since $\pi_2^{N,N}(\widetilde{a})$ is a decreasing function, this condition can be rewritten as $\widetilde{a} \leq \widetilde{a}_2^{\max}(a)$, where $\partial\widetilde{a}_2^{\max}(a)/\partial a \geq 0$ (as $\pi_2^{N,O}(a)$ is decreasing with a).

This simple and general result suggests a positive relation between the access price on the old network and the access price on the new network. This wholesale migration condition is a constraint that the regulator has to take into account when setting the access prices on the old network and the new network: if the access price for the legacy network is low, the regulator has to set a low access price too on the incumbent's NGN to make the entrant switch from the legacy to the new network at the *wholesale* level.

Now, consider that the entrant has invested more than the incumbent. In a given area where the entrant owns an NGN infrastructure whereas the incumbent does not own such an infrastructure, the incumbent leases access to the entrant's NGN if and only if $\pi_1^{N,N}(\widetilde{a}) \geq \pi_1^{O,N}$, that is, $\widetilde{a} \leq \widetilde{a}_1^{\max}$ (as $\pi_1^{N,N}(\widetilde{a})$ is decreasing with $\widetilde{a}$). Note that $\widetilde{a}_1^{\max}$ does not depend on a, since the incumbent provides access to the legacy network to itself at marginal cost.

For the rest of the analysis, we assume that $\widetilde{a} \leq \min\{\widetilde{a}_1^{\max}, \widetilde{a}_2^{\max}(a)\}$, so that there is access to the monopoly NGN infrastructures.

The entrant's investment decision. Given firm 1's coverage z_1, firm 2's profit writes

$$\widetilde{\Pi}_2(z_1, z_2) = z_2\pi_2^{N,N} + (z_1 - z_2)\pi_2^{N,N}(\widetilde{a}) + (\overline{z} - z_1)\pi_2^{O,O}(a) - C_2(z_2, z_1), \tag{15}$$

if $z_2 \leq z_1$, and

$$\widetilde{\Pi}_2(z_1, z_2) = z_1\pi_2^{N,N} + (z_2 - z_1)\widetilde{\pi}_2^{N,N}(\widetilde{a}) + (\overline{z} - z_2)\pi_2^{O,O}(a) - C_2(z_2, z_1), \tag{16}$$

otherwise. As in Section 3, we define $\widetilde{z}_2^c$ and $\widetilde{z}_2^m$ as the values of z_2 that maximize (15) and (16), respectively. We have

$$\widetilde{z}_2^c(\widetilde{a}) = (c_1)^{-1}\left((1+\gamma)\left(\pi_2^{N,N} - \pi_2^{N,N}(\widetilde{a})\right)\Big/\beta\right).$$

and

$$\widetilde{z}_2^m(a, \widetilde{a}) = (c_1)^{-1}\left(\left(\widetilde{\pi}_2^{N,N}(\widetilde{a}) - \pi_2^{O,O}(a)\right)\Big/\beta\right).$$

Since $\pi_2^{N,N}(\widetilde{a}) \geq \pi_2^{N,O}(a)$ (from the wholesale migration condition), then we have $\widetilde{z}_2^c(\widetilde{a}) \leq z_2^c(a)$. In other words, introducing an access offer on the monopoly NGNs increases the replacement effect for the entrant, which in turn decreases its investment incentives. Besides, we have $\widetilde{z}_2^m(a,\widetilde{a}) \leq z_2^m(a)$ if $\widetilde{\pi}_2^{N,N}(\widetilde{a}) \leq \pi_2^{O,N}$, and $\widetilde{z}_2^m(a,\widetilde{a}) \leq z_2^m(a)$ otherwise. Note that in our application we have $\widetilde{\pi}_2^{N,N}(\widetilde{a}) \leq \pi_2^{O,N}$ for all $\widetilde{a} \leq \widetilde{a}_1^{\max}$, and therefore $\widetilde{z}_2^m(a,\widetilde{a}) \leq z_2^m(a)$. In the rest of the analysis, we will assume that this is the case, and hence, the introduction of an NGN wholesale offer reduces investment incentives, because it lowers the profit of the firm which invests in an NGN. Finally, we have $\partial \widetilde{z}_2^c(\widetilde{a})/\partial\widetilde{a} \geq 0$, $\partial \widetilde{z}_2^m(a,\widetilde{a})/\partial\widetilde{a} \geq 0$ and $\partial \widetilde{z}_2^m(a,\widetilde{a})/\partial a \geq 0$. That is, increasing the access charge on the legacy network or on the new network increases coverage.

The entrant's optimal investment decision then writes

$$\widetilde{z}_2^{\mathrm{BR}}(z_1) = \begin{cases} \widetilde{z}_2^m & \text{if} \quad z_1 \leq \widetilde{z}_2^m(a,\widetilde{a}) \\ z_1 & \text{if} \quad \widetilde{z}_2^m(a,\widetilde{a}) < z_1 \leq \widetilde{z}_2^c(\widetilde{a}) \\ \widetilde{z}_2^c & \text{if} \quad z_1 > \widetilde{z}_2^c(\widetilde{a}) \end{cases}$$

if $\widetilde{z}_2^c > \widetilde{z}_2^m$, and

$$\widetilde{z}_2^{\mathrm{BR}}(z_1) = \begin{cases} \widetilde{z}_2^m & \text{if} \quad z_1 \leq \widetilde{z}_1(a,\widetilde{a}) \\ \widetilde{z}_2^c & \text{if} \quad z_1 > \widetilde{z}_1(a,\widetilde{a}) \end{cases},$$

otherwise, where $\widetilde{z}_1(a,\widetilde{a})$ is the lowest z_1 such that $\widetilde{\Pi}_2(z_1,\widetilde{z}_2^c(\widetilde{a})) \geq \widetilde{\Pi}_2(z_1,\widetilde{z}_2^m(a,\widetilde{a}))$.

The incumbent's investment decision. The analysis is similar to that in Section 3. To begin with, we assume that $\widetilde{z}_2^c > \widetilde{z}_2^m$. If $z_1 \in [0,\widetilde{z}_2^m]$, firm 1's profit writes

$$\widetilde{\Pi}_1(z_1,\widetilde{z}_2^{\mathrm{BR}}(z_1)) = z_1\pi_1^{N,N} + (\widetilde{z}_2^m(a,\widetilde{a}) - z_1)\,\pi_1^{N,N}(\widetilde{a}) + (\overline{z} - \widetilde{z}_2^m(a,\widetilde{a}))\,\pi_1^{O,O}(a) - C_1(z_1). \quad (17)$$

If $z_1 \in [\widetilde{z}_2^m,\widetilde{z}_2^c]$, firm 1's profit is given by

$$\widetilde{\Pi}_1(z_1,\widetilde{z}_2^{\mathrm{BR}}(z_1)) = z_1\pi_1^{N,N} + (\overline{z} - z_1)\,\pi_1^{O,O}(a) - C_1(z_1), \quad (18)$$

and finally, if $z_1 \in [\widetilde{z}_2^c, \overline{z}]$, firm 1's profit writes

$$\widetilde{\Pi}_1(z_1, \widetilde{z}_2^{\mathrm{BR}}(z_1)) = \widetilde{z}_2^c(\widetilde{a})\,\pi_1^{N,N} + (z_1 - \widetilde{z}_2^c(\widetilde{a}))\,\widetilde{\pi}_1^{N,N}(\widetilde{a}) + (\overline{z} - z_1)\,\pi_1^{O,O}(a) - C_1(z_1)\,. \tag{19}$$

We define $\widetilde{z}_1^c$, $\widetilde{z}_1^d$ and $\widetilde{z}_1^m$ as the maxima with respect to z_1 of equations (17), (18), and (19), respectively. We have

$$\widetilde{z}_1^c(\widetilde{a}) = (c_1)^{-1}\left(\pi_1^{N,N} - \pi_1^{N,N}(\widetilde{a})\right),$$

$$\widetilde{z}_1^d(a) = (c_1)^{-1}\left(\pi_1^{N,N} - \pi_1^{O,O}(a)\right),$$

and

$$\widetilde{z}_1^m(a, \widetilde{a}) = (c_1)^{-1}\left(\widetilde{\pi}_1^{N,N}(\widetilde{a}) - \pi_1^{O,O}(a)\right).$$

We have $\widetilde{z}_1^c \leq z_1^c$ as $\pi_1^{N,N}(\widetilde{a}) \geq \pi_1^{O,N}$ (since $a \leq \widetilde{a}_1^{\max}$), $\widetilde{z}_1^d = z_1^d$, and $\widetilde{z}_1^m \leq z_1^m$ if $\widetilde{\pi}_1^{N,N}(\widetilde{a}) \leq \pi_1^{N,O}(a)$, and $\widetilde{z}_1^m > z_1^m$ otherwise. Since $\widetilde{\pi}_1^{N,N}(\widetilde{a})$ is increasing with $\widetilde{a}$, we have $\widetilde{\pi}_1^{N,N}(\widetilde{a}) \leq \pi_1^{N,O}(a)$ if $\widetilde{a}$ is sufficiently low, and $\widetilde{\pi}_1^{N,N}(\widetilde{a}) > \pi_1^{N,O}(a)$ otherwise.

Finally, note that with the introduction of the NGN access offer, the business migration effect –which was present in z_1^m– disappears. Indeed, migration now takes place at the wholesale level (through the entrant's switch to the NGN access offer), which automatically triggers the migration at the retail level.

The following table shows how the candidate equilibria that we determined in Section 3 are modified with the introduction of an NGN wholesale offer. As the table shows, the introduction of a wholesale offer on monopoly NGNs affects total coverage negatively, except in two cases: (i) when the equilibrium corresponds to the optimal "mimicking" equilibrium $\left\{\widetilde{z}_1^d, \widetilde{z}_1^d\right\}$, in which case the equilibrium does not depend on the access charge on the NGN; (ii) in the large coverage equilibrium

$\{\widetilde{z}_1^m, \widetilde{z}_2^c\}$, where total coverage can increase if $\widetilde{a}$ is sufficiently high.

Table 3: Effect of an NGN wholesale offer on total coverage (case $\widetilde{z}_2^c > \widetilde{z}_2^m$)

Without wholesale offer	With wholesale offer	Effect on total coverage
$\{z_1^c, z_2^m\}$	$\{\widetilde{z}_1^c, \widetilde{z}_2^m\}$	$-$
$\{z_2^m, z_2^m\}$	$\{\widetilde{z}_2^m, \widetilde{z}_2^m\}$	$-$
$\{z_1^d, z_1^d\}$	$\{\widetilde{z}_1^d, \widetilde{z}_1^d\}$	$=$
$\{z_2^c, z_2^c\}$	$\{\widetilde{z}_2^c, \widetilde{z}_2^c\}$	$-$
$\{z_1^m, z_2^c\}$	$\{\widetilde{z}_1^m, \widetilde{z}_2^c\}$	$-$ if $\widetilde{a}$ low, $+$ otherwise

The analysis is similar for the case where $\widetilde{z}_2^c < \widetilde{z}_2^m$. In the two first candidate equilibria, $\{z_1^c, z_2^m\}$ and $\{\widehat{z}_1, z_2^m\}$, total coverage is reduced upon the introduction of a wholesale NGN offer. However, in the third candidate equilibrium, $\{z_1^m, z_2^c\}$, total coverage decreases if $\widetilde{a}$ is sufficiently low, and can increase otherwise.

The regulator's decision. We finally analyze the regulator's choice of the access charge on the new technology network, $\widetilde{a}$, and the relation between the socially optimal access charge on the NGN, $\widetilde{a}^w$, and a.

If the equilibrium is symmetric, no firm has a monopolistic NGN infrastructure, and therefore, the choice of $\widetilde{a}$ is irrelevant (since there is no access to NGNs).

Now, consider that the equilibrium is asymmetric. If the incumbent invests more than the entrant, we find that, if the marginal investment cost is convex, there is a positive relation between the socially optimal $\widetilde{a}$ and the access charge on the legacy network, i.e., $d\widetilde{a}^\omega/da \geq 0$.[23] On the other hand, if the entrant invests more than the incumbent (and marginal investment costs are still

[23] If the marginal investment cost is concave, this result does not always hold.

convex), the relation between $\widetilde{a}^{\omega}$ and a can be reversed, that is, we can have $d\widetilde{a}^{\omega}/da \leq 0$.[24]

The intuition is as follows. When the regulator sets the access charge on the new technology network at the optimal level, the marginal benefit of increasing the access charge in terms of dynamic efficiency (i.e., larger coverage of the NGN and higher welfare in covered areas) equals the marginal cost in terms of static inefficiency that an access charge above marginal cost yields in the areas where there is access on NGN. When the access price on the legacy network changes, the marginal benefit and marginal cost of increasing of access charge on the NGN are affected in different ways, depending on whether the incumbent or the entrant owns the monopoly NGN infrastructure.

When the incumbent owns the monopoly NGN infrastructure, it happens that a higher access charge on the legacy network reduces the size of the region with a monopoly NGN infrastructure as it intensifies the wholesale revenue effect, and hence, reduces the incumbent's investment incentives. This, in turn, reduces the marginal cost (in terms of static inefficiency) of an access charge on the monopoly NGN set above cost. At the same time, a higher access charge on the legacy network increases the sensitivity of the incumbent's investment with respect to the access charge on the NGN, and it increases the net gains in welfare of having a monopoly NGN compared to no NGN. This increases the marginal benefit associated to an increase of the access charge on the NGN in terms of dynamic efficiency. All in all, as an increase of the access charge on the legacy network leads to an increase of the marginal benefit of increasing the access charge on the NGN (in terms of dynamic efficiency), and to a decrease of the marginal cost (in terms of static inefficiency), and therefore, the regulator has incentives to raise the access charge on the NGN.

On the other hand, if the monopoly NGN infrastructure is owned by the entrant, a higher access charge on the legacy network increases the marginal cost of an access charge above cost for the NGN (in terms of static inefficiency), as it increases the entrant's investment in the NGN

[24] See Appendix F for the formal proofs.

through a softer replacement effect. It also decreases the marginal benefit of a higher access charge on the NGN (in terms of dynamic efficiency), since a higher access charge on the legacy network reduces the sensitivity of the entrant's investment with respect to the access charge on the NGN and decreases the net gains in welfare of having a monopoly NGN compared to no NGN. In contrast with the case where the incumbent is the leader in NGN investments, the regulator should here lower the access charge on the NGN if the access charge on the legacy network is increased.

5 Conclusion

This paper analyzes the incentives to migrate from an "old" technology to a "new" one, and how this migration process is affected by the interplay between wholesale conditions imposed to grant access to third parties to one or both of these technologies. Our application is related to the transition that we observe in the telecommunications industry, from the use of the ("old") legacy network to a ("new") high-speed broadband infrastructure, but the framework we develop is general and can be applied to every regulated market where infrastructure investment in new technology should be associated with a transitory period of coexistence of different technologies whose access is subject to different types of ex-ante intervention.

Developing a general model of transition from an "old" to a "new" infrastructure, we first analyze the firms' (both entrant and incumbent) incentives to invest in a new technology (e.g., in the so-called next generation networks) in different areas of the country, as a function of the wholesale price set by a regulator on the old network. Then, we consider the case in which a firm with a monopolistic new infrastructure is also obliged to grant access to its new infrastructure, which enables us to analyze the interplay between different access charges to different (old versus new) infrastructures.

The analysis highlights the presence of three conflicting effects that affect investment incentives negatively: (i) a replacement effect, i.e., if the access charge to the old network is too low, investment incentives by alternative operators are deprived; (ii) in the presence of a positive investment spillover, a higher access charge increases the incumbent's opportunity cost of investment due to a wholesale revenue effect: if the incumbent invests in a higher quality network, the entrant will invest in reaction, and the incumbent will then lose some wholesale profits; and finally (iii) when the access charge on the legacy network is low, the prices for the services which rely on this network are low, hence, in order to encourage customers to switch from the "old" legacy network to the "new" network, operators should also offer low prices. This effect, which we refer to as the business migration effect, reduces the profitability of the new technology infrastructure, and hence, the incentives to invest in it. To provide incentives, the regulator should then increase the access charge. The coexistence of these multiple effects creates a non-monotonic relation between the access price and investments in the new technology (i.e., in the coverage of the NGNs).

From a social point of view, we show that, when it sets the access charge on the legacy network, the regulator has to take into account potential conflicts between investment incentives, static efficiency in uncovered areas, and excessive duplication of infrastructure costs. We also point out that if the access charges to both the old and new infrastructures are subject to ex ante intervention, in order to favor the migration from the old to the new technology at wholesale level, the regulator has to set an access charge for the new infrastructure that is sufficiently low relative to the access charge on the legacy network. However, extending regulation to the new technology negatively affects investments.

Finally, we find that the socially optimal access charge on the NGN increases with the access charge on the legacy network, when the incumbent is leader in NGN investments. Whereas the reverse can be true if the entrant is the leader in NGN investments. On a policy ground, our result suggests that, because the legacy network is an essential facility controlled by the incumbent, to extent that the access charge on the legacy network affects investments in NGN, the regulation of access to NGNs should be asymmetric, that is, access prices to incumbents' and entrants' NGNs should be set at different levels.

Our general framework is suitable to be extended in different directions. First, it might be interesting to analyze the impact of demand and/or cost uncertainty on the incentives to migrate. We expect that if the demand uncertainty on the new technology is large, then the access conditions to the legacy and the NGA networks should take into account such an effect, leading to an increase in the wholesale charges. Second, in our setting each operator plays only once, whereas in reality this interaction is more dynamic. Migration per se is also a time-dependent process. Finally, access conditions to the new technology may differ across areas: in some areas the entrant might be interested to invest whatever the incumbent does, while in other areas the entrant might be more in favour of renting the incumbent's network. Regulatory rules, as well as the relation with the economic conditions for accessing the old technology network, might therefore be different across areas. We leave all these potential extensions to future research.

References

Arrow, K. (1962). "Economic Welfare and the Allocation of Resources for Invention," in NBER Conference, *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Princeton University Press, Princeton.

Avenali, A., Matteucci, G., and Reverberi, P. (2010). "Dynamic Access Pricing and Investment in Alternative Infrastructures." *International Journal of Industrial Organization*, 28(2), 167-175.

Bourreau, M. and Doğan, P. (2005). "Unbundling the Local Loop." *European Economic Review*, 49, 173-199.

Bourreau, M. and Doğan, P. (2006). "“Build-or-Buy” Strategies in the Local Loop." *American Economic Review*, 96, 72-76.

Bourreau, M., Doğan, P. and Manant, M. (2010). "A Critical Review of the “Ladder of Investment” Approach." *Telecommunications Policy,* 34(11), 683-696.

Bourreau, M., Cambini, C. and Hoernig, S. (2011). "Geographical Access Markets and Investment in Next Generation Networks." *Mimeo.*

Brito, D., Pereira, P., and J. Vareda (2010a). "Can Two-Part Tariffs Promote Efficient Investment on Next Generation Networks?" *International Journal of Industrial Organization*, 28(3), 323-33.

Brito, D., Pereira, P., and J. Vareda (2010b). "Incentives to Invest and to Give Access to New Technologies." *Mimeo.*

Cambini, C. and Jiang, Y. (2009). "Broadband Investment and Regulation. A Literature Review." *Telecommunications Policy*, 33, 559-574.

Czernich, N., Falck, O., Kretschmer, T. and Woessmann, L. (2011). "Broadband Infrastructure and Economic Growth." *The Economic Journal*, 121, 505–532.

Foros, Ø. (2004). "Strategic Investments with Spillovers, Vertical Integration and Foreclosure in the Broadband Access Market." *International Journal of Industrial Organization*, 22, 1-24.

Gans, J. and Williams, P. (1999). "Access Regulation and the Timing of Infrastructure Investment." *The Economic Record*, 75(229), 127-137.

Gans, J. (2001). "Regulating Private Infrastructure Investment: Optimal Pricing for Access to Essential Facilities." *Journal of Regulatory Economics*, 20(2), 167-189.

Gans, J. (2007). "Access Pricing and Infrastructure Investment," in *Access Pricing: Theory and Practice*, Haucap J. and R. Dewenter (eds.), Elsevier B.V.

Greenstein, S., and McDevitt, P. (2009). "The Broadband Bonus: Accounting for Broadband Internet's Impact on US GDP." *NBER Working Paper* no. 14758, Cambridge, MA.

Guthrie, G. (2006). "Regulating Infrastructure: The Impact on Risk and Investment." *Journal of Economic Literature*, 44(4), 925-972.

Hori, K. and Mizuno, K. (2006). "Access Pricing and Investment with Stochastically Growing Demand." *International Journal of Industrial Organization*, 24, 705-808.

Katz, M., and Shapiro, C. (1985). "Network Externalities, Competition, and Compatibility." *American Economic Review*, 75, 424–440.

Kotakorpi, K. (2006). "Access Price Regulation, Investment and Entry in Telecommunications." *International Journal of Industrial Organization*, 24, 1013-1020.

Klumpp, T. and Su, X. (2010). "Open Access and Dynamic Efficiency." *American Economic Journal: Microeconomics,* 2, 64–96.

Koutroumpis, P. (2009). "The Economic Impact of Broadband on Growth: A Simultaneous Approach." *Telecommunication Policy*, 9, 471-485.

Nitsche, R., and Wiethaus, L. (2011). "Access Regulation and Investment in Next Generation Networks — A Ranking of Regulatory Regimes." *International Journal of Industrial Organization*, 29(2), 263-272.

Plum (2011). *Costing Methodology and the Transition to Next Generation Access.* Report for ETNO, March, London, UK.

Röller, L.H., and Waverman, L. (2001). "Telecommunications Infrastructure and Economic Development: a Simultaneous Approach." *American Economic Review*, 91(4), 909-923.

Valletti, T. (2003). "The Theory of Access Pricing and Its Linkage with Investment Incentives." *Telecommunications Policy*, 27, 549-675.

Vareda, J. and Hoernig, S. (2010). "Racing for Investment under Mandatory Access." *The BE Journal of Economic Analysis & Policy*, 10(1), Article 67.

WIK (2011). *Wholesale Pricing, NGA Take-Up and Competition.* Report for ECTA, April, Bad Honnef, Germany.

Appendix

Appendix A: A competitive setting

We use the competitive setting in Katz and Shapiro (1985). The indirect utility function of a consumer of type τ is

$$U = \tau + s_i - p_i,$$

where s_i and p_i denote the quality and price of firm i, with $i = 1, 2$. Consumers' types are uniformly distributed over $(-\infty, 1]$.[25] Firms set quantities, and we normalize marginal costs to zero. The quality of the "old" network is denoted by s^O, and the quality of the "new" network is denoted by s^N. Therefore, we have $s_i = s^O$ or s^N, for $i = 1, 2$. Finally, we assume that $s^N > s^O$ and that $s^N < 1 + 2s^O$. The latter assumption ensures that a firm using the old network is not evicted by a firm using the new network.

If both firm 1 and firm 2 are active in equilibrium, their quality-adjusted prices are the same, that is, we have $p_1 - s_1 = p_2 - s_2 = \widehat{p}$. The marginal consumer has valuation $\tau = \widehat{p}$, and hence, from the uniform distribution assumption, the total demand is given by $Q = q_1 + q_2 = 1 - \widehat{p}$. Firm 1's profit writes

$$\pi_1 = p_1 q_1 + a q_2,$$

whereas firm 2's profit writes

$$\pi_1 = (p_2 - a)\, q_2,$$

where $a = 0$ if firm 2 operates a "new" network. Each firm $i = 1, 2$ maximizes its profit π_i with respect to q_i. We look for the perfect equilibrium of this quantity-setting game. We give below the

[25] Allowing for negative values of τ avoids corner solutions where all consumers purchase one of the two firms' goods.

equilibrium profits in each possible configuration.

Both firms use the "old" network. We have

$$\pi_1^{O,O}(a) = \frac{1}{9}\left((1+s^O)^2 + 5a(1-a) + 5as^O\right),$$

and

$$\pi_2^{O,O}(a) = \frac{(1+s^O-2a)^2}{9}.$$

Note that $\pi_2^{O,O}(a) \geq 0$ if and only if $a \leq \overline{a}^O = \left(1+s^O\right)/2$. Besides, we have $\widehat{a}^O = \arg\max \pi_1^{O,O}(a) = \left(1+s^O\right)/2 = \overline{a}^O$.

Firm 1 operates a "new" network, firm 2 uses the "old" network. We have

$$\pi_1^{N,O}(a) = \frac{(1+2s^N-s^O)^2 + 5a(1-a) + a(s^N+4s^O)}{9},$$

and

$$\pi_2^{N,O}(a) = \frac{(1+2s^O-s^N-2a)^2}{9}.$$

Note that $\pi_2^{N,O}(a) \geq 0$ if and only if $a \leq \overline{a}^N = \left(1+2s^O-s^N\right)/2$, and that $\overline{a}^N < \overline{a}^O$ as $s^N > s^O$. We have $\widehat{a}^N = \arg\max \pi_1^{N,O}(a) = (5+s^N+4s^O)/10$, and $\widehat{a}^N > \overline{a}^N$.

Firm 1 uses the "old" network, firm 2 operates a "new" network. We have

$$\pi_1^{O,N} = \frac{(1+2s^O-s^N)^2}{9},$$

and

$$\pi_2^{O,N} = \frac{(1+2s^N-s^O)^2}{9}.$$

Both firms operate a "new" network. We have

$$\pi_1^{N,N} = \frac{(1+s^N)^2}{9},$$

and

$$\pi_2^{N,N} = \frac{(1+s^N)^2}{9}.$$

This competitive model satisfies the assumptions of our general setting.

Assumption 1. From the expressions of profits, Assumption 1(i) is satisfied, as we have $\partial\pi_2^{k,O}(a)/\partial a \leq 0$, for $k = O, N$. Assumption 1(ii) is also satisfied. Indeed, $\pi_1^{O,O}(a)$ is increasing with a, for all $a \leq \widehat{a}^O = \overline{a}^O$. Similarly, $\pi_1^{N,O}(a)$ is increasing with a, for all $a \leq \overline{a}^N$. Indeed, we have $\partial^2\pi_1^{N,O}(a)/\partial a^2 < 0$ and $\partial\pi_1^{N,O}(a)/\partial a\left(a = \overline{a}^N\right) = 2\left(s^N - s^O\right)/3 > 0$.

Assumption 2. First, since $\pi_1^{O,O}(a)$ is increasing in a, we have

$$\pi_1^{O,O}(a) \geq \pi_1^{O,O}(0) = \frac{\left(1+s^O\right)^2}{9}.$$

Since $s^O < s^N$, we have also $\pi_1^{O,N} < \left(1+s^O\right)^2/9$, and hence, $\pi_1^{O,O}(a) > \pi_1^{O,N}$.

Second, since $\pi_1^{N,O}(a)$ is increasing with a for all $a \leq \overline{a}^N$, we have $\pi_1^{N,O}(a) \geq \pi_1^{N,O}(0) = (1+2s^N - s^O)^2/9$. As $s^N > s^O$, we have then $\pi_1^{N,O}(a) > (1+s^N)^2/9 = \pi_1^{N,N}$.

Finally, with this setting, we find that $\overline{\gamma}(a) = \left(s^N - s^O\right)/\left(1+s^O - a\right)$, and therefore, $\overline{\gamma}$ is increasing with a and s^N, and decreasing with s^O.

Appendix B: Proof of Lemma 1

For a given a, if $\pi_2^{N,N} - \pi_2^{N,O}(a) > \pi_2^{O,N} - \pi_2^{O,O}(a)$, then $z_2^c > z_2^m$ is true for all $\beta \geq 1$ and $\gamma \geq 0$, hence, we have $\overline{\gamma} = 0$. Now, note that $(c_1)^{-1}$ is an increasing function, as $c_1(\cdot)$ is also an increasing function. Therefore, if $\pi_2^{N,N} - \pi_2^{N,O}(a) \leq \pi_2^{O,N} - \pi_2^{O,O}(a)$, we have $z_2^c > z_2^m$ if and only if $\gamma > \overline{\gamma}(a)$, where $\overline{\gamma}(a)$ is defined by

$$\overline{\gamma}(a) = \frac{\pi_2^{O,N} - \pi_2^{O,O}(a)}{\pi_2^{N,N} - \pi_2^{N,O}(a)} - 1 \geq 0.$$

Appendix C: Proof of Lemma 2

To begin with, assume that $z_1 \leq z_2^m$. If $z_2 \geq z_1$, firm 2's profit is maximized for $z_2 = z_2^m$ (since $z_1 \leq z_2^m$). If $z_2 \leq z_1$, since $z_2^c > z_2^m \geq z_1$, then firm 2's profit is maximum at $z_2 = z_1$. By continuity, the global maximum is therefore $z_2 = z_2^m$. Similarly, if $z_1 > z_2^c$, firm 2's profit is maximized at $z_2 = z_2^c$. Finally, consider the case where $z_1 \in (z_2^m, z_2^c]$. Since $z_1 \leq z_2^c$, then firm 2's profit is increasing with z_2 for all $z_2 \leq z_1$. Besides, since $z_2^c > z_2^m$, then firm 2's profit is decreasing with z_2 for all $z_2 > z_1$. Therefore, firm 2's profit is maximized at $z_2 = z_1$.

Appendix D: Proof of Lemma 3

If $z_1 \leq z_2^c$, the entrant is willing to mimic the incumbent's investment in the areas $[0, z_1]$ and to invest in a monopoly NGN infrastructure in the areas between z_2^c and z_2^m. Hence, we have $z_2^{\mathrm{BR}}(z_1) = z_2^m$. On the other hand, if $z_1 > z_2^m$, since $z_2^c \leq z_2^m$, the entrant is willing to mimic the incumbent's investment only in the areas between 0 and z_2^c, and hence, we have $z_2^{\mathrm{BR}}(z_1) = z_2^c$.

If $z_1 \in (z_2^c, z_2^m)$, firm 2's best-response is necessarily a coverage z_2 such that $z_2 \in [z_2^c, z_2^m]$, as firm 2 is willing to cover at least z_2^c and at most z_2^m. Firm 2's profit then writes

$$\Pi_2 = z_2 \pi_2^{N,N} + (z_1 - z_2)\, \pi_2^{N,O}(a) + (\overline{z} - z_1)\, \pi_2^{O,O}(a) - C_2(z_2, z_1), \tag{20}$$

if $z_2 \in [z_2^c, z_1]$ and

$$\Pi_2 = z_1 \pi_2^{N,N} + (z_2 - z_1)\, \pi_2^{O,N} + (\overline{z} - z_2)\, \pi_2^{O,O}(a) - C_2(z_2, z_1), \tag{21}$$

if $z_2 \in [z_1, z_2^m]$.

If $z_2 \leq z_1$, (20) is maximized at $z_2 = z_2^c$, by the definition of z_2^c. Similarly, by the definition of z_2^m, (21) is maximized at $z_2 = z_2^m$. Therefore, the entrant trades off between setting z_2^c and z_2^m. It sets $z_2 = z_2^c$ if and only if $\Pi_2(z_2^c) \geq \Pi_2(z_2^m)$, where

$$\Pi_2(z_1, z_2^c) = z_2^c \pi_2^{N,N} + (z_1 - z_2^c)\, \pi_2^{N,O}(a) + (\overline{z} - z_1)\, \pi_2^{O,O}(a) - \frac{\beta}{1+\gamma} C_1(z_2^c),$$

and

$$\Pi_2(z_1, z_2^m) = z_1 \pi_2^{N,N} + (z_2^m - z_1)\, \pi_2^{O,N} + (\overline{z} - z_2^m)\, \pi_2^{O,O}(a) - \frac{\beta}{1+\gamma} C_1(z_2^c) - \beta\left(C_1(z_2^m) - C_1(z_2^c)\right).$$

Rearranging these expressions, we have $\Pi_2(z_1, z_2^c) \geq \Pi_2(z_1, z_2^m)$, that is, firm 2's best-response is to set $z_2 = z_2^c$, if and only if

$$\left(\pi_2^{N,N} - \pi_2^{O,N} + \pi_2^{O,O} - \pi_2^{N,O}\right) z_1 \leq \beta\left(C_1(z_2^m) - C_1(z_2^c)\right) + z_2^c\left(\pi_2^{N,N} - \pi_2^{N,O}\right) - z_2^m\left(\pi_2^{O,N} - \pi_2^{O,O}\right).$$

Now, note that for $z_1 = z_2^c$, firm 2's best-response is z_2^m, whereas for $z_1 = z_2^m$, firm 2's best-response is z_2^c. Therefore, the condition holds for $z_1 = z_2^m$ and does not hold for $z_1 = z_2^c$. Besides, the left-hand side in the above inequality is continuous and increasing with z_1 as $\pi_2^{N,N} - \pi_2^{O,N} - \left(\pi_2^{N,O} - \pi_2^{O,O}\right) \geq 0$, since $z_2^c \leq z_2^m$. This shows that there exists $\widehat{z}_1 \in [z_2^c, z_2^m]$ such that $z_2^{\mathrm{BR}}(z_1) = z_2^m$ if $z_1 \leq \widehat{z}_1$, and $z_2^{\mathrm{BR}}(z_1) = z_2^c$ otherwise.

Appendix E: Welfare analysis for the application setting

Computation of social welfare. We denote by s_1 and s_2 the qualities offered by firm 1 and firm 2, respectively, and we assume that firm 2 pays an access charge a to firm 1 (possibly 0). Consumer surplus then writes

$$CS = \int_{\widetilde{\tau}}^{1} (\tau - \widehat{p}^*) \, d\tau,$$

where $\widehat{p}^* = p_1^* - s_1 = p_2^* - s_2$ is the quality-adjusted price at the equilibrium of the quantity-setting subgame and $\widetilde{\tau} = \widehat{p}^*$ is the marginal consumer. We find that

$$CS = \frac{(2 + s_1 + s_2 - a)^2}{18}.$$

The social welfare is then defined by $w = CS + \pi_1 + \pi_2$, and we have

$$w = \frac{(4 + 4s_2 + a)(2 + 2s_2 - a)}{18} + \frac{11}{18}(s_1 - s_2)^2 + \frac{4}{9}(a + 1 + s_2)(s_1 - s_2).$$

The social welfare decreases with the access charge when both firms use the old technology. When firm 1 and firm 2 both use the old technology, we have $s_1 = s_2 = s^O$, and we find that

$$\frac{\partial w^{O,O}}{\partial a} = -\frac{a + \left(1 + s^O\right)}{9} < 0.$$

Private versus social investment incentives.

(i) $w^{N,N} - w^{O,O}(a) - c_1(z^*(a)) - c_2(z^*(a), z^*(a)) > 0$**.** Note that $w^{N,N} - w^{O,O}(a) - c_1(z^*(a)) - c_2(z^*(a), z^*(a))$ becomes lower if z^* becomes higher. Therefore, it suffices to show that $w^{N,N} - w^{O,O}(a) - c_1(z^*(a)) - c_2(z^*(a), z^*(a)) > 0$ is true for the highest value of z^*, that is, $z^* = z_2^c$. From the definition of z_2^c, we have $c_2(z_2^c, z_2^c) = \pi_2^{N,N} - \pi_2^{N,O}(a)$. Besides, since $\{z_2^c, z_2^c\}$ is a corner equilibrium, we have $c_1(z_2^c) \leq \pi_1^{N,N} - \pi_1^{O,O}$ (since the incumbent's profit is increasing for $z_1 \leq z_2^c$). Therefore, $w^{N,N} - w^{O,O}(a) - c_1(z^*(a)) - c_2(z^*(a), z^*(a)) \geq w^{N,N} - w^{O,O}(a) - \left(\pi_2^{N,N} - \pi_2^{N,O}(a)\right) - \left(\pi_1^{N,N} - \pi_1^{O,O}\right) \equiv \Delta_1$. We find that

$$\Delta_1 = \frac{1}{18}\left(-a^2 + a(4 + 8s^N - 4s^O) + 2(s^N - s^O)(2 + 3s^N - s^O)\right).$$

Since $\partial \Delta_1 / \partial a|_{a=0} > 0$ and $\partial \Delta_1 / \partial a|_{a=\overline{a}^N} > 0$, and $\Delta_1(a = 0) > 0$, then $\Delta_1 > 0$ is true for all a.

(ii) $w^{N,O}(a) - w^{O,O}(a) - c_1(z_1^m) > 0$**.** From the definition of z_1^m,we have $c_1(z_1^m) = \pi_1^{N,O}(a) - \pi_1^{O,O}(a)$. We find that

$$w^{N,O}(a) - w^{O,O}(a) - \left(\pi_1^{N,O}(a) - \pi_1^{O,O}(a)\right) = \frac{1}{6}\left(s^N - s^O\right)\left(s^N - s^O + 2a\right) > 0.$$

(iii) $w^{N,N} - w^{N,O}(a) - c_2(z_2^c(a), z_1^m) < 0$**.** From the definition of z_2^c, we have $c_2(z_2^c(a), z_1^m) = \pi_2^{N,N} - \pi_2^{N,O}(a)$. We find that

$$w^{N,N} - w^{N,O}(a) - \left(\pi_2^{N,N} - \pi_2^{N,O}(a)\right) = \frac{1}{6}\left(3a^2 - 2a\left(1 + s^O\right) - \left(s^N - s^O\right)^2\right) \equiv \Delta_2.$$

X is a second-degree polynomial with inverted bell-shape, and we have $\partial \Delta_2 / \partial a|_{a=0} < 0$ and $\Delta_2(a = 0) < 0$. Besides, we have $\Delta_2\left(a = \overline{a}^N\right) < 0$. Therefore, $\Delta_2 < 0$ always holds, and hence, $w^{N,N} - w^{N,O}(a) - c_2(z_2^c(a), z_1^m) < 0$.

(iv) $w^{O,N} - w^{O,O}(a) - c_2(z_2^m(a), z_1^c)$ **can be either positive or negative.** From the definition of z_2^m, we have $c_2(z_2^m(a), z_1^c) = \pi_2^{O,N} - \pi_2^{O,O}(a)$. We find that

$$w^{O,N} - w^{O,O}(a) - \left(\pi_2^{O,N} - \pi_2^{O,O}(a)\right) = \frac{1}{6}\left(3a^2 + \left(s^N - s^O\right)^2 - 2a\left(1 + s^O\right)\right) \equiv \Delta_3.$$

If a is close to 0, then $w^{O,N} - w^{O,O}(a) - \left(\pi_2^{O,N} - \pi_2^{O,O}(a)\right) > 0$. On the other hand, assume that $s^N \simeq s^O$. Then $w^{O,N} - w^{O,O}(a) - \left(\pi_2^{O,N} - \pi_2^{O,O}(a)\right) \simeq a\left(3a - 2\left(1+s^O\right)\right)/6 < 0$ as $a < \left(1+s^O\right)/2$.

Appendix F: Regulator's choice of the access charge on the NGN

To begin with, we consider that the incumbent invests more than the entrant; the equilibrium coverage are $z_1^* = \widetilde{z}_1^m(a,\widetilde{a})$ and $z_2^* = \widetilde{z}_2^c(\widetilde{a})$. The social welfare writes

$$W = \widetilde{z}_2^c(\widetilde{a})\, w^{N,N} + \left(\widetilde{z}_1^m(a,\widetilde{a}) - \widetilde{z}_2^c(\widetilde{a})\right) w^{N,N}(\widetilde{a}) + \left(\overline{z} - \widetilde{z}_1^m(a,\widetilde{a})\right) w^{O,O}(a) - C_1\left(\widetilde{z}_1^m\right) - C_2\left(\widetilde{z}_2^c, \widetilde{z}_1^m\right),$$

and assuming an interior solution, the socially optimal access charge for the NGN solves

$$\begin{aligned}\frac{\partial W}{\partial \widetilde{a}} &= \frac{d\widetilde{z}_2^c(\widetilde{a})}{d\widetilde{a}}\left(w^{N,N} - w^{N,N}(\widetilde{a}) - c_2\left(\widetilde{z}_2^c, \widetilde{z}_1^m\right)\right) + \frac{\partial \widetilde{z}_1^m(a,\widetilde{a})}{\partial \widetilde{a}}\left(w^{N,N}(\widetilde{a}) - w^{O,O}(a) - c_1\left(\widetilde{z}_1^m\right)\right) \\ &\quad + \left(\widetilde{z}_1^m - \widetilde{z}_2^c\right)\frac{dw^{N,N}(\widetilde{a})}{d\widetilde{a}} \equiv G(a,\widetilde{a}) = 0.\end{aligned}$$

Let $\widetilde{a}^w$ denote the solution of $G(a,\widetilde{a}^w) = 0$. From the implicit function theorem, provided that the second-order condition holds, the sign of $\partial\widetilde{a}^w/\partial a$ has the same sign as $\partial^2 W/\partial\widetilde{a}\partial a$. We find that

$$\begin{aligned}\text{sign}\left[\frac{\partial \widetilde{a}^w}{\partial a}\right] &= \text{sign}\left[\frac{\partial^2 W}{\partial\widetilde{a}\partial a}\right] = \text{sign}\left[\frac{\partial^2 \widetilde{z}_1^m(a,\widetilde{a})}{\partial\widetilde{a}\partial a}\left(w^{N,N}(\widetilde{a}) - w^{O,O}(a) - c_1\left(\widetilde{z}_1^m\right)\right)\right. \\ &\quad -\frac{\partial \widetilde{z}_1^m(a,\widetilde{a})}{\partial\widetilde{a}}\left(\frac{dw^{O,O}(a)}{da} + \frac{\partial\widetilde{z}_1^m}{\partial a}(c_1)'\left(\widetilde{z}_1^m\right)\right) + \\ &\quad \left. + \frac{\partial\widetilde{z}_1^m}{\partial a}\frac{dw^{N,N}(\widetilde{a})}{d\widetilde{a}}\right].\end{aligned}$$

The second term is positive as $\partial\widetilde{z}_1^m/\partial\widetilde{a} \geq 0$, $dw^{O,O}(a)/da \leq 0$, $\partial\widetilde{z}_1^m/\partial a \leq 0$ and $(c_1)'(z) \geq 0$. The third term is also positive as $\partial\widetilde{z}_1^m/\partial a \leq 0$ and $dw^{N,N}(\widetilde{a})/d\widetilde{a} \leq 0$. Assuming that $w^{N,N}(\widetilde{a}) -$

$w^{O,O}(a) - c_1(\widetilde{z}_1^m) \geq 0$, the first term is positive if $\partial^2 \widetilde{z}_1^m(a, \widetilde{a}) / \partial\widetilde{a}\partial a \geq 0$. We find that

$$\frac{\partial^2 \widetilde{z}_1^m(a,\widetilde{a})}{\partial\widetilde{a}\partial a} = \frac{\frac{\partial\widetilde{\pi}_1^{N,N}}{\partial\widetilde{a}} \frac{\partial\pi_1^{O,O}}{\partial a} (c_1)'' \left[(c_1)^{-1}\left(\widetilde{\pi}_1^{N,N} - \pi_1^{O,O}\right)\right]}{\left((c_1)'\left[(c_1)^{-1}\left(\widetilde{\pi}_1^{N,N} - \pi_1^{O,O}\right)\right]\right)^3} \geq 0,$$

as $\partial\widetilde{\pi}_1^{N,N}/\partial\widetilde{a} \geq 0$, $\partial\pi_1^{O,O}/\partial a \geq 0$ and $(c_1)'' \geq 0$. It follows that $\partial\widetilde{a}^w/\partial a \geq 0$.

Now, we consider that the entrant invests more than the incumbent; the equilibrium coverage are $z_1^* = \widetilde{z}_1^c(\widetilde{a})$ and $z_2^* = \widetilde{z}_2^m(a, \widetilde{a})$. The social welfare writes

$$W = \widetilde{z}_1^c w^{N,N} + (\widetilde{z}_2^m - \widetilde{z}_1^c) w^{N,N}(\widetilde{a}) + (\overline{z} - \widetilde{z}_2^m) w^{O,O}(a) - C_1(\widetilde{z}_1^c) - C_2(\widetilde{z}_2^m, \widetilde{z}_1^c).$$

Assuming an interior solution, the socially optimal access charge for the NGN solves the first-order condition

$$\begin{aligned}\frac{\partial W}{\partial\widetilde{a}} &= \frac{d\widetilde{z}_1^c(\widetilde{a})}{d\widetilde{a}}\left(w^{N,N} - w^{N,N}(\widetilde{a}) - C_1(\widetilde{z}_1^c(\widetilde{a}))\right) + \frac{\partial\widetilde{z}_2^m(a,\widetilde{a})}{\partial\widetilde{a}}\left(w^{N,N}(\widetilde{a}) - w^{O,O}(a) - c_2(\widetilde{z}_2^m, \widetilde{z}_1^c)\right) \\ &\quad + (\widetilde{z}_2^m - \widetilde{z}_1^c)\frac{dw^{N,N}(\widetilde{a})}{d\widetilde{a}} \equiv H(a, \widetilde{a}) = 0.\end{aligned}$$

Let $\widetilde{a}^w$ denote the solution of $H(a, \widetilde{a}^w) = 0$. From the implicit function theorem, provided that the second-order condition holds, the sign of $\partial\widetilde{a}^w/\partial a$ has the same sign as $\partial^2 W/\partial\widetilde{a}\partial a$. We find that

$$\begin{aligned}\text{sign}\left[\frac{\partial\widetilde{a}^w}{\partial a}\right] &= \text{sign}\left[\frac{\partial^2 W}{\partial\widetilde{a}\partial a}\right] = \text{sign}\left[\frac{\partial^2\widetilde{z}_2^m(a,\widetilde{a})}{\partial\widetilde{a}\partial a}\left(w^{N,N}(\widetilde{a}) - w^{O,O}(a) - c_2(\widetilde{z}_2^m)\right)\right. \\ &\quad -\frac{\partial\widetilde{z}_2^m(a,\widetilde{a})}{\partial\widetilde{a}}\left(\frac{dw^{O,O}(a)}{da} + \frac{\partial\widetilde{z}_2^m}{\partial a}(c_2)'(\widetilde{z}_2^m)\right) + \\ &\quad \left. + \frac{\partial\widetilde{z}_2^m}{\partial a}\frac{dw^{N,N}(\widetilde{a})}{d\widetilde{a}}\right].\end{aligned}$$

As $\partial\widetilde{z}_1^m/\partial\widetilde{a} \geq 0$, the second term is negative if $dw^{O,O}(a)/da +$ $\partial\widetilde{z}_2^m/\partial a \times (c_2)'(\widetilde{z}_2^m) \geq 0$, and we assume that this is the case. The third term is always negative as $\partial\widetilde{z}_2^m/\partial a \geq 0$ and $dw^{N,N}(\widetilde{a})/d\widetilde{a} \leq$

0. Finally, assuming that $w^{N,N}(\widetilde{a}) - w^{O,O}(a) - c_2(\widetilde{z}_2^m) \geq 0$, the first term is negative as

$$\frac{\partial^2 \widetilde{z}_2^m(a,\widetilde{a})}{\partial \widetilde{a} \partial a} = \frac{\frac{\partial \widetilde{\pi}_2^{N,N}}{\partial \widetilde{a}} \frac{\partial \pi_2^{O,O}}{\partial a} (c_2)'' \left[(c_2)^{-1}\left(\widetilde{\pi}_2^{N,N} - \pi_2^{O,O}\right)\right]}{\left((c_2)' \left[(c_2)^{-1}\left(\widetilde{\pi}_2^{N,N} - \pi_2^{O,O}\right)\right]\right)^3} \leq 0,$$

since $\partial \widetilde{\pi}_2^{N,N}/\partial \widetilde{a} \geq 0$, $\partial \pi_2^{O,O}/\partial a \leq 0$ and $(c_2)'' \geq 0$. It follows that $\partial \widetilde{a}^w/\partial a \leq 0$ when the entrant is the leader in NGN investments (provided that $dw^{O,O}(a)/da + \partial \widetilde{z}_2^m/\partial a \times (c_2)'(\widetilde{z}_2^m) \geq 0$).