HARVARD Kennedy School
JOHN F. KENNEDY SCHOOL OF GOVERNMENT

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

Faculty Research Working Paper Series

Marc Bourreau

Telecom ParisTech and CREST-LEI

Carlo Cambini

Politecnico di Torino and EUI

Pinar Dogan

Harvard Kennedy School

July 2011
RWP11-029

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

Marc Bourreau[†], Carlo Cambini[‡], Pınar Doğan[§]

July 22, 2011

Abstract

In this paper, we analyze the incentives of an incumbent and an entrant to migrate from an "old" technology to a "new" technology, and discuss how the terms of wholesale access affect this migration. We show that a higher access charge on the legacy network pushes the entrant firm to invest more, but has an ambiguous effect on the incumbent's investments, due to two conflicting effects: the wholesale revenue effect, and the business migration effect. If both the old and the new infrastructures are subject to ex-ante access regulation, we also find that the two access charges are positively correlated.

Keywords: Access pricing; Investment; Next generation networks.

JEL Codes: L96; L51.

*We thank Steffen Hoernig, Marc Lebourges, Martin Peitz, Yossi Spiegel, and Tommaso Valletti for their useful remarks. We also thank participants at the Workshop on Telecommunications Economics (Barcelona, 2011), the EUI-Florence School of Regulation Conference on Communications & Media (Florence, 2011), the ZEW Conference on Economics of Information and Communication Technologies (Mannheim, 2011) and the CRESSE Conference on Competition Policy and Regulation (Rhodes, 2011). We also thank Katie Naeve for her editorial assistance. Marc Bourreau acknowledges financial support from France Telecom/Orange. Carlo Cambini acknowledges financial support from the Italian Ministry of Education (No. 20089PYFHY_004).

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

[‡]Politecnico di Torino and EUI. 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 of 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 (essential) infrastructures, mainly operated and maintained by incumbent firms. While access regulation plays a fundamental role in promoting competition in the short-run, it can also have a significant impact on an incumbent's incentives to upgrade its infrastructure. It can also impact all firms' incentives to invest in new alternative infrastructures,[2] and hence, impact the transition from old technology infrastructures to new ones

The transition from "old" to "new" infrastructures often does not happen instantaneously. In the broadband telecoms industry, for example, the evidence suggests a rather slow transition from the old (copper) to the new (fiber) generation networks. In such instances, the transition phase is characterized by the co-existence of different generation infrastructures, where the investment incentives are shaped not only by the terms of access to the existing infrastructure, but also by those to the new infrastructure. Such an interplay between–potentially different sets of–terms of access to the existing network and to the new network has been overlooked in the recent literature, where the main focus has been on the impact of access regulation (of *either* old *or* of new infrastructures) on the investments. While the settings with a such focus are most appropriate for the industries where the new technologies replace the old technology instantaneously, they are not suitable for addressing interesting research questions in industries where different generations of technologies remain in co-existence–at least during the transition phase. The main question we address in this paper is as

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

[2] See Valletti (2003) for the review of the theoretical literature, and see Cambini and Jiang (2009) for a more recent and comprehensive survey.

follows: How does the presence of access requirements on both old and new infrastructures affect the incentives (of both the owner of the legacy network and the entrant firm) to invest in new infrastructures? In the policy context, the question is the characterization of the access rules that spur investments in new infrastructures while minimizing the distortion in allocative efficiency (in the provision of services with the old network).

In the stream of literature to which we aim to contribute, the majority of papers fall into either one of the two groups. One set of papers consider only the entrant firm as a potential investor, and therefore, study the impact of access regulation (to the incumbent's network) only on the entrant's incentives to invest.[3] Another set of papers considers both the entrant and the incumbent firms' incentives to invest, but nevertheless ignore the migration issue.[4] This latter set of papers mainly explore the optimal access scheme in terms of the timing of investments, where the investment decisions are "zero-one" in nature. Various recent studies, namely, Klumpp and Su (2010), Nitsche and Wiethaus (2010), and Brito et al. (2010a), also address the problem of investment and access regulation in a different vein, and yet, neglect the effect of migration from old to new infrastructures and how access regulation affects the decision to enter into one segment of the market. Brito et al. (2010b), which is the most similar paper to ours, focuses on the nature of innovation (which can be either drastic or non-drastic) and considers a new technology that is not subject to access regulation.

Our paper differs from the previous studies in several directions. We consider a setting where

[3]See for example, Bourreau and Doğan (2005), (2006) and Avenali et al. (2010). The latter two papers suggest that access pricing that increases over time would give the entrants the proper incentives to invest in alternative technologies in a timely manner.

[4]See Gans and Williams (1999), Gans (2001), (2007), Hori and Mizuno (2006) and Vareda and Hoernig (2010) for the impact of access prices in a dynamic investment race between two operators. These studies show that the regulator's capacity to make credible commitments is important for firms' investment decisions. When the regulator lacks credibility, Foros (2004) shows that the difference in firms' abilities to provide value added services can be the major determinant in investment incentives. When there is no credibility issue, Kotakorpi (2006) shows that the presence of spillovers reduces the incumbent's incentives, which leads to a level of investment, which is not only below the socially optimal level, but also less than the amount in the absence of regulation.

access to an existing old technology is available everywhere within 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, in which the fixed cost of rolling-out the new technology network varies. We first analyze the firms' (both entrant and incumbent) incentives to invest in new technology in different areas of the country, as a function of the access price of the existing network. Then, we consider the case in which access obligation also applies to the new network (possibly with different terms).

Three conflicting effects emerge in this setting: (i) when the access price for the existing infrastructure is low (i.e., when the entrant's opportunity cost of investment is high) it kicks in the so-called *replacement effect*[5] and hinders infrastructure investment by alternative operators; (ii) in the presence of a positive spillover of new investments, a higher access price 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 price of 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 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. The coexistence of these multiple effects creates a non-monotonic relationship between the access price and investments in the new technology (i.e., in the coverage of the new network).

We also study the effects that emerge when both the old and new infrastructures are subject to ex-ante intervention. Our analysis shows that extending regulation to the new infrastructure

[5] 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.

negatively affects investments. More interestingly, our results highlight that regulators must not treat the decisions regarding the two access prices (to the old and to the new infrastructures) independently. We find that the socially optimal access price of the new network increases with the access price of the legacy network when the incumbent has a larger NGN coverage than the entrant, whereas the opposite can be true if the entrant has a larger NGN coverage than the incumbent.

While overlooked in the theoretical literature, the migration issue has recently received considerable attention in the policy arena, where the proposals made by the market specialists appear to be in sharp contrast to one another. For example, in a recent report prepared by WIK (2011) for the European Competitive Telecommunication Association (ECTA), WIK proposes to decrease the access price to legacy (copper) networks to encourage entrants to invest in new (fiber) networks, and to allow a rapid switch-off of the copper networks where the fiber is already installed. In contrast to WIK (2011), the report prepared by Plum (2011) for the European (incumbent) Telecommunications Network Operators (ETNO) states that a lower copper price would discourage investments to next-generation access networks by encouraging customers to stay on copper, thereby negatively impacting the fiber business case. Moreover, Plum proposes to set a direct link between the regulated access price of the legacy network and the regulated access price on the new network. Both documents show that not only do the access prices of the high-tech infrastructure have an impact on the incentive to invest in the new network, but also the access price to the old (legacy) network has a major influence on the transition to the new networks. However, the direction of this link is still unclear and not theoretically based.[6]

The rest of the paper is organized as follows. In Section 2, we describe our benchmark model (with no access obligations on the new network). We solve the model in Section 3. In Section 4,

[6]See also the recent EU Recommendation C(2010) 6223 on "Regulated Access to NGANs" (September 2010), which states that the regulatory policies during the migration phase can be fundamental in determining the incentives to invest in new infrastructures. However, the legislation is completely silent on the potential interplay between the access remedies in both old and new networks.

we extend our analysis to consider the interplay between access regulation of both old and new networks. Finally, Section 5 concludes.

2 The Setting

There are two firms, an incumbent (firm 1) and an entrant (firm 2). At the beginning of the game, both firms rely on the incumbent's old generation network (OGN) to provide their services. The entrant's access to the OGN is regulated with the per-unit access price a.[7] Then, both firms sequentially decide on their investments in the next generation network (NGN).[8] In our benchmark model, we consider the case where the incumbent moves first. This assumption reflects the fact that the incumbent firm typically faces some specific advantages due to its control over the existing infrastructure and ducts that facilitate the deployment of the new infrastructure.[9] When a firm invests in the NGN, it no longer employs the OGN to provide its services (i.e., the NGN technology replaces that of the OGN).

Investment costs We consider a country, composed of a continuum of areas, with a total size of $\overline{z}$. We assume that the fixed cost of rolling out the NGN varies in different areas of the country, and we order the areas (from 0 to $\overline{z}$) so that the ranking reflects the order of the magnitude of NGN investment costs (from low to high) .

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

[7] In the broadband telecommunications market, OGN would be the copper network, whereas NGN would be the fiber network. Prior to investing in NGNs, the entrant firms often rely on the incumbents' local copper networks (possibly through a local loop unbundling offer) to provide their services.

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

[9] Note that, the incumbent moves first in terms of deciding which areas of the country it invests in the NGN. The entrant may end up investing "first" in the NGN in a given geographical area if the incumbent decides not to invest in that area. We also verified that our the qualitative nature of our results remain unchanged when the entrant moves first. unchanged (the computations for this extension are available upon request). Since the "spillover effect" is an important feature of our model, we consider a sequential game rather than a simultaneous one.

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 $c_1'(x) > 0$. The total cost of covering the area $[0, z_1]$ 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 $C_1''(z_1) = c_1'(z_1) > 0$.

The fixed cost of covering an area at a given location, $x \in [0, \overline{z}]$, for firm 2 is

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

with $\beta \geq 1$ and $\gamma \in [0, +\infty)$.

The parameter β represents any cost-disadvantage the entrant might have.[10] The parameter γ allows for spillovers from the incumbent's investments; the entrant's fixed cost of investing in the NGN may be lower in the areas where the incumbent has already rolled-out its NGN than in those where an NGN is absent.[11] A higher γ represents a higher degree of (positive) spillovers, whereas $\gamma = 0$ corresponds to the case with no spillovers. The total cost of covering the area $[0, z_2]$ for firm 2 is then

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

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).

[10] In the broadband setting, the incumbent firms may have lower investment costs than the entrant firms due to their control over the legacy (copper) network infrastructure and other essential inputs (e.g., civil works).

[11] For example, when the incumbent builds an NGN in a given zone, 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 in the same area, its investment costs can be lower if it can benefit from the incumbent's earlier efforts. One could also consider informational spillovers, as well as direct cost savings due to infrastructure sharing.

Profits We denote the profit of firm $i = 1,2$ in a given area by $\pi_i^{k,l}$, where $k,l = O,N$ refer to the network technology (OGN or NGN) of firms 1 and 2, respectively. We assume that the firms' profits in a given area depend on their respective network technologies, and not on their total coverage of the NGN in the country.[12] In particular, we consider that firms can set different prices in different areas according to their network technology and that of their rival.[13] Finally, we normalize the marginal cost of access to 0.

We introduce the following assumptions on profits.[14]

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 relies on the OGN to provide its services, its profit decreases with the access price, a. Assumption 1(ii) means that the incumbent's profit increases with the access price, but only up to a certain level of access price. The threshold $\widehat{a}^k$ corresponds to the monopoly access price when the incumbent 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 OGN than when firm 2 invests in the NGN.

Assumption 3 We have $\pi_1^{O,N}, \pi_2^{N,O}(a) > 0$, which implies that two technologies can co-exist.

In the benchmark setting, we ignore the possibility of access provision by the NGN owner, and

[12] Although it is not our focus in this paper, the size of the total coverage might indirectly affect the market demand in a given area. In the broadband context, for example, larger coverage of the NGN might stimulate innovation in contents that are suited for NGNs only, which would in turn increase the demand for NGNs in any given area.

[13] Assuming uniform pricing for the OGN services and the NGN services (of each firm) would complexify the analysis, as the firms' pricing strategies would then depend on their coverage decisions. Since we aim at providing an analysis with general profit functions, we ignore the possibility of uniform pricing.

[14] 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 we list below.

focus on the relationship between the OGN access regulation and investment incentives.[15]

Timing of the game The timing of the game is as follows: The regulator sets the access price on the OGN, a. Then, firm 1 decides on the areas in which to roll-out the NGN, z_1. Finally, observing firm 1's decision, firm 2 decides on its own NGN coverage, z_2.

We look for the subgame perfect equilibrium of this game.

3 The Equilibrium

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

3.1 The entrant's investment decision (Stage 3)

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

$$\Pi_2 = -C_2\left(z_2, z_1\right) + \begin{cases} z_2\pi_2^{N,N} + \left(z_1 - z_2\right)\pi_2^{N,O}\left(a\right) + \left(\overline{z} - z_1\right)\pi_2^{O,O}\left(a\right) & \text{if } z_2 \leq z_1 \\ z_1\pi_2^{N,N} + \left(z_2 - z_1\right)\pi_2^{O,N} + \left(\overline{z} - z_2\right)\pi_2^{O,O}\left(a\right) & \text{if } z_2 > z_1 \end{cases} \tag{1}$$

In order to determine firm 2's optimal investment, first, consider the case where firm 2 covers an area where firm 1 has already rolled out its NGN (i.e., $z_2 \leq z_1$). It is profitable for firm 2 to invest in an area $z_2 \in [0, z_1]$ if the extra gross profit it earns by investing in an NGN is higher than the investment cost in this area, that is, if

$$\pi_2^{N,N} - \pi_2^{N,O}\left(a\right) \geq c_2\left(z_2, z_1\right) = \beta c_1\left(z_2\right) / \left(1 + \gamma\right). \tag{2}$$

[15] In Section 4, we study the interplay between access to the OGN and access to the incumbent's NGN.

The same reasoning applies when firm 2 decides to cover an area z_2, where firm 1 has not rolled-out its NGN (i.e., $z_2 > z_1$). It is profitable for firm 2 to invest in this area if

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

Let $z_2^c(a)$ and $z_2^m(a)$ be defined as the highest value of z_2 that satisfy inequalities (2) and (3), respectively. In each respective case, $z_2^c(a)$ and $z_2^m(a)$ represent the largest area in which firm 2 invests. We have

$$z_2^c(a) = (c_1)^{-1}\left((1+\gamma)\left(\pi_2^{N,N} - \pi_2^{N,O}(a)\right) \Big/ \beta\right),$$

and

$$z_2^m(a) = (c_1)^{-1}\left(\left(\pi_2^{O,N} - \pi_2^{O,O}(a)\right) \Big/ \beta\right).$$

In the equilibrium of this stage, for any given a,[16] we either have $z_2^c > z_2^m$, or the reverse. In the former case, for a given area, firm 2 has a higher incentive to invest in an NGN if firm 1 has already invested in the given area than if it has not. The opposite is true for the latter case. As the following Lemma implies, whether the former or the latter case applies in equilibrium depends on the degree of spillovers, as well as the level of access price.

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

Proof. See Appendix B. ■

If the degree of spillovers is sufficiently large, then the "spillover effect" becomes operational, and (for a given area) it gives firm 2 a greater incentive to invest in an NGN if the incumbent's

[16] Note that both z_2^c and z_2^m are independent of z_1.

NGN is already rolled-out than when it is not.[17] The threshold degree of spillovers above which this effect is in force depends on the access price, a. However, since both $\pi_2^{O,O}(a)$ and $\pi_2^{N,O}(a)$ are decreasing with a, its variation with respect to a is indeterminate, in general. Our computations with quantity competition à la Katz and Shapiro (1985) show that $\partial\overline{\gamma}(a)/\partial a > 0$, i.e., a higher access price makes the spillover effect less likely to be operational.[18]

Firm 2's decision on its NGN investments are effected by whether the spillover effect is operational or not. Therefore, in studying firm 2's coverage decision, we distinguish between two cases: high degrees of spillovers (i.e., $\gamma > \overline{\gamma}(a)$), and low degrees of spillovers (i.e., $\gamma \leq \overline{\gamma}(a)$).

High degrees of spillovers ($\gamma > \overline{\gamma}(a)$)

In this case, the spillover effect is in force. That is, we have $z_2^c > z_2^m$, and hence, firm 2 is not willing to cover areas where firm 1 has not already rolled-out its NGN. The following Lemma describes the best-response of the entrant.

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

$$z_2^{BR}(z_1) = \begin{cases} z_2^m & \textit{if} \quad z_1 \leq z_2^m \\ z_1 & \textit{if} \quad z_2^m < z_1 \leq z_2^c \\ z_2^c & \textit{if} \quad z_1 > z_2^c \end{cases} \tag{4}$$

Proof. See Appendix C. ■

The entrant's optimal coverage reads as follows. If firm 1's NGN covers a relatively small part of the country (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 sets $z_2 = z_2^m$. The entrant's best response to greater coverage by the incumbent is to mimic

[17] With quantity competition à la Katz and Shapiro (1985), a strictly positive degree of spillover (i.e., $\gamma > \overline{\gamma} > 0$) is required to obtain $z_2^c > z_2^m$ .This is also true for competition à la Hotelling, as well as for the Mussa-Rosen model of competition. See Lestage and Flacher (2010) for the computations regarding the latter.

[18] See Subsection 3.4 for the analysis in the Katz and Shapiro (1985) setting.

the incumbent's investment (i.e., $z_2 = z_1$). If the incumbent maintains sufficiently large NGN coverage (i.e., $z_1 > z_2^c$), then firm 2 invests in less coverage than its rival. We also find that the entrant's best-response coverage increases with the incumbent's coverage (hence, the incumbent's and the entrant's coverage levels are strategic complements).

Low degrees of spillovers ($\gamma \leq \overline{\gamma}(a)$)

In this case the degree of spillovers is sufficiently small (i.e., $\gamma \leq \overline{\gamma}(a)$) so that the spillover effect is not in force. The following Lemma describes the best-response of the entrant in this case.

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

$$z_2^{BR}(z_1) = \begin{cases} z_2^m & \text{if } z_1 \leq \widehat{z}_1(a) \\ z_2^c & \text{if } z_1 > \widehat{z}_1(a) \end{cases}, \tag{5}$$

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-monotonically with a.

The entrant's best-response (5) is similar to the case with high spillovers, except that $z_2^{\text{BR}}(z_1)$ decreases (weakly) with z_1 when $\gamma \leq \overline{\gamma}(a)$, as $z_2^c \leq z_2^m$ (and hence, the incumbent's and the entrant's coverage levels are strategic substitutes).[19] Firm 2 acts as a monopoly for the NGN investments if firm 1's coverage is sufficiently low. Otherwise, firm 2's coverage choice depends on its incentive to duplicate firm 1's NGN. Different than the case with high degree of spillovers, in

[19] To see this, assume that firm 1 increases its coverage from z_1 with $z_1 \leq \widehat{z}_1$ to z_1' with $z_1' > \widehat{z}_1$. Then, firm 2's coverage is reduced from z_2^m to z_2^c.

deciding on its coverage, firm 2 never mimics firm 1's decision.

As the following Proposition states, for a given level of NGN coverage set by the incumbent, the access price set for the incumbent's legacy network affects the entrant's choice for coverage.

Proposition 1 *For a given level of NGN coverage, z_1, set by the incumbent, a higher access price implies a higher level of NGN coverage by the entrant.*

Proof. We have

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

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

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

Therefore, an increase in a shifts firm 2's best-response functions (given by equations (4) and (5)) upward, which implies that for a given z_1, firm 2 invests more. ■

This result highlights the first of the three effects we described earlier: the "replacement effect":[20] a higher a implies a lower opportunity cost (i.e., a lower $\pi_2^{k,O}\left(a\right)$, for $k = O, N$) of investing in an NGN, which increases firm 2's incentives to invest in NGN coverage.

3.2 The incumbent's investment decision (Stage 2)

We now turn to firm 1's investment decision, at stage 2 of the game. Since the best-response of firm 2 in the presence of a high degree of spillovers ($\gamma > \overline{\gamma}\left(a\right)$) is different than with a low degree of spillovers ($\gamma \leq \overline{\gamma}\left(a\right)$), we study firm 1's decision in these two cases separately.

[20] 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.

High degrees of spillovers ($\gamma > \overline{\gamma}(a)$)

To determine the incumbent's optimal coverage decision, we begin by writing its profit function when it anticipates the entrant's best-response. Since $z_2^{\text{BR}}(\cdot)$, defined in equation (4), has three parts, we have to consider three possible cases, according to the value of z_1. We have

$$\Pi_1(z_1, z_2^{\text{BR}}(z_1)) = -C_1(z_1) + \begin{cases} z_1\pi_1^{N,N} + (z_2^m(a) - z_1)\pi_1^{O,N} + (\overline{z} - z_2^m(a))\pi_1^{O,O}(a) & \text{if } z_1 \in [0, z_2^m] \\ z_1\pi_1^{N,N} + (\overline{z} - z_1)\pi_1^{O,O}(a) & \text{if } z_1 \in [z_2^m, z_2^c] \\ z_2^c(a)\pi_1^{N,N} + (z_1 - z_2^c(a))\pi_1^{N,O}(a) + (\overline{z} - z_1)\pi_1^{O,O}(a) & \text{if } z_1 \in [z_2^c, \overline{z}] \end{cases}$$

For example, assume that $z_1 \in [0, z_2^m]$. For $z \in [0, z_1]$, both firm 1 and firm 2 have their NGNs rolled-out, and hence, firm 1 obtains a profit $\pi_1^{N,N}$ in this area. For $z \in [z_1, z_2^m]$, only the entrant has its NGN rolled-out, and therefore, in this area 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 in the NGN, and hence, the incumbent obtains $\pi_1^{O,O}(a)$. The profit of firm 1 for the other ranges of z_1 can be read similarly.

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

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

respectively.

Let z_1^c, z_1^d and z_1^m be the (interior) maxima of $\Pi_1(z_1, z_2^{\text{BR}}(z_1))$ for $z_1 \in [0, z_2^m]$, $z_1 \in [z_2^m, z_2^c]$, and $z_1 \in [z_2^c, \overline{z}]$, respectively.[21] We have $z_1^c = (c_1)^{-1}\left(\pi_1^{N,N} - \pi_1^{O,N}\right)$, $z_1^d = (c_1)^{-1}\left(\pi_1^{N,N} - \pi_1^{O,O}(a)\right)$, and $z_1^m = (c_1)^{-1}\left(\pi_1^{N,O}(a) - \pi_1^{O,O}(a)\right)$.[22]

[21] In addition to these three potential interior optima, there are two potential corner optima, at z_2^m and z_2^c.

[22] 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 $z_1^m \geq z_1^d$. Therefore, there is a local optimum either at z_1^d or at z_1^c.

Access price and the equilibrium NGN coverage We now determine the relationship between the access price, a, and the equilibrium NGN coverage of the incumbent. Below, we describe the variation of the three potential interior optima, namely, z_1^c, z_1^d and z_1^m, with respect to a.

First, we have $dz_1^c/da = 0$, which implies that if the incumbent invests strictly less than the entrant in the equilibrium, its NGN coverage does not depend on the access price of the legacy network. This is because, in the areas where the incumbent is going to invest, the entrant does not rely on the legacy network, and does not pay the access charge.

Second, we have $dz_1^d/da < 0$, for all $a \leq \widehat{a}^O$.[23] In this case, if the access price is not too high (i.e., if it is not above the monopoly access price), increasing the access price makes the incumbent invest less. This is due to the "wholesale revenue effect;" 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 increasing with the access price. To the extent that the incumbent's investment favors the entrant's investment through the spillover effect, the incumbent faces an opportunity cost of rolling out its NGN, namely, the foregone wholesale revenues. In other words, just like the entrant, the incumbent faces a "replacement effect."

Third, 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., $a \leq \min\left\{\widehat{a}^O, \widehat{a}^N\right\}$), the sign of dz_1^m/da is indeterminate and can be either positive or negative. This is due to the presence of two opposite effects: the wholesale

[23] Note that this is due to Assumption 1.

revenue and business migration effects. First of all, due to the wholesale revenue effect, a higher a implies a higher opportunity cost of investing in an NGN. Second, we outline a new but important effect that we interpret as the "business migration effect," which works in the opposite direction. When the access price on the legacy network is low, the prices for the retail services which rely on this network are low. Therefore, to encourage customers to switch from the legacy network to the services provided with the NGN, firms need to offer lower prices for the NGN services. This, in turn, reduces the profitability of the NGN, and hence, the incentives to invest in the NGN. To our knowledge, this is the first time that this effect emerges due to the existence of two alternative ("Old" and "New") infrastructures, and this represents a key contribution of this paper.

According to our analysis, we have five potential equilibria: the three interior maxima and two corner solutions.[24] Table 1 presents each equilibrium, and summarizes the impact of the access price on equilibrium investments. Each candidate equilibrium is characterized by one of the five potential equilibrium NGN coverage of the incumbent (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 (4). We order the candidate equilibria according to the total NGN coverage (from low to high).

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

[24]Note that the equilibrium is unique, but that it can be either of the five equilibrium candidates.

We find that three out of five equilibria involve symmetry in NGN coverage. In the asymmetric equilibria, (i) if the incumbent invests less than the entrant, the entrant invests as if it were deploying a monopolistic NGN infrastructure (i.e., we have $z_2^* = z_2^m$), and (ii) if the incumbent invests more than the entrant, the entrant mimics the incumbent's coverage unless it is too large. Finally, if the incumbent rolls out its NGN infrastructure massively, the entrant invests less than the incumbent.

Low degrees of spillovers ($\gamma \leq \overline{\gamma}(a)$)

Given that $z_2^{\text{BR}}(\cdot)$ has two parts, we have two possible cases according to the value of z_1. Firm 1's profit is given by

$$\Pi_1(z_1, z_2^{\text{BR}}(z_1)) = -C_1(z_1) + \begin{cases} z_1 \pi_1^{N,N} + (z_2^m(a) - z_1)\,\pi_1^{O,N} + (\overline{z} - z_2^m(a))\,\pi_1^{O,O}(a) & \text{if } z_1 \in [0, \widehat{z}_1] \\ z_2^c(a)\,\pi_1^{N,N} + (z_1 - z_2^c(a))\,\pi_1^{N,O}(a) + (\overline{z} - z_1)\,\pi_1^{O,O}(a) & \text{if } z_1 \in [\widehat{z}_1, \overline{z}] \end{cases}$$

Since the incumbent's profit function has two different parts, we have two potential interior optima, z_1^c and z_1^m, that correspond to the maxima of $\Pi_1(z_1, z_2^{\text{BR}}(z_1))$ for $z_1 \in [0, \widehat{z}_1]$ and $z_1 \in [\widehat{z}_1, \overline{z}]$, respectively.[25]

Access price and the equilibrium NGN coverage We list the potential equilibria and summarize the relationship between the access price and the equilibrium coverage 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

[25] Note that there is also a potential corner optimum at $\widehat{z}_1$.

The first and the last equilibrium candidates are also present in the case with a high degree of spillovers. Differently, the equilibrium is never symmetric with a low degree of spillovers. This is due to the fact that the spillover effect is not operational, and therefore the entrant never mimics the incumbent coverage choice. Note however that all other effects (replacement, wholesale revenue, and business migration effects) are still operational.

In Section 3.4, we adopt the competition model of Katz and Shapiro (1985), and describe the equilibria for both cases.

3.3 The regulator's decision (Stage 1)

The regulator chooses the access price on the old network, a, so as to maximize social welfare, which is defined as the sum of consumer surplus and industry profits. Let $w^{k,l}$ denote the gross welfare in an area where firm 1 uses technology $k = O, N$ and firm 2 uses technology $l = O, N$. We assume that $dw^{O,O}(a)/da \leq 0$. The idea is that when both firms use the old technology to provide their services, a higher access price inflates the retail prices and reduces the total quantity consumed.[26]

Since we have both symmetric and asymmetric candidate equilibria at the investment subgame of our general setting, we first express the social welfare for each type of equilibrium. Then, we discuss how welfare varies with the access price.

Symmetric equilibria

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

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

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

The variation of welfare with respect to the access price is given by[27]

$$\frac{dW}{da} = \frac{dz^*(a)}{da}\left[\left(w^{N,N} - w^{O,O}(a)\right) - c_1(z^*(a)) - c_2(z^*(a), z^*(a))\right] + (\overline{z} - z^*(a))\frac{dw^{O,O}(a)}{da}. \quad (6)$$

Equation (6) highlights the regulator's potential trade-off between static efficiency and investment incentives. On the one hand, setting a higher access price lowers welfare in the uncovered areas, as $dw^{O,O}(a)/da \leq 0$. On the other hand, a higher access price increases investment incentives if $dz^*(a)/da \geq 0$, which is likely to be socially efficient.[28] As shown in Table 1, in two of the three symmetric equilibrium candidates, $z^* = z_2^m$ and $z^* = z_2^c$, we have $dz^*(a)/da \geq 0$. Therefore, in this case the regulator faces a standard trade-off between investment incentives and static efficiency in the uncovered areas.

This trade-off, however, is absent in the symmetric equilibrium candidate, with $z^* = z_1^d$, where the entrant mimics the incumbent's investment decision. In contrast with the two other symmetric equilibrium candidates, the objectives to provide strong investment incentives and to maximize static efficiency in the uncovered areas are aligned in this equilibrium configuration. Setting a low access price indeed stimulates investment (as it can be seen from Table 1, we have $dz^*(a)/da = dz_1^d/da \leq 0$), and it 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 price.[29]

[27] Note that, as the access charge a varies, the actual equilibrium, which is always unique, can move from symmetric equilibrium to asymmetric equilibrium, or vice versa.

[28] This is the case if $\left(w^{N,N} - w^{O,O}(a)\right) - c_1(z^*(a)) - c_2(z^*(a), z^*(a)) > 0$. In our example setting, we show that this inequality always holds, i.e., investment in NGN is always socially efficient (see Appendix E).

[29] When a decreases, the equilibrium can switch from this symmetric equilibrium with $z^* = z_1^d$ to another (symmetric or asymmetric) equilibrium. Therefore, we cannot conclude that $a^* = 0$ (that the access price is set at marginal cost).

Asymmetric equilibria

We have two candidate asymmetric equilibria, one in which the incumbent invests more than the entrant, and one in which the opposite is true. We begin with the study of the equilibrium in which the incumbent obtains larger NGN coverage than the entrant.

(i) $z_1^* > z_2^*$**:** The equilibrium NGN coverage for the incumbent and the entrant are z_1^m and z_2^c, respectively. Social welfare writes

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

We have

$$\begin{aligned} \frac{dW}{da} &= \underbrace{\frac{dz_2^c}{da}}_{(+)} \underbrace{\left(w^{N,N} - w^{N,O}(a) - c_2\left(z_2^c(a), z_1^m\right)\right)}_{(+)\text{ or }(-)} + \underbrace{\frac{dz_1^m}{da}}_{(+)\text{ or }(-)} \underbrace{\left(w^{N,O}(a) - w^{O,O}(a) - c_1\left(z_1^m\right)\right)}_{(+)\text{ or }(-)} \quad (7) \\ &\quad + \underbrace{\left(z_1^m - z_2^c\right) \frac{dw^{N,O}}{da}}_{(-)} + \underbrace{\left(\overline{z} - z_1^m\right) \frac{dw^{O,O}}{da}}_{(-)}. \end{aligned}$$

When determining the access price, the regulator must take into account three different objectives. First, it aims at maximizing static efficiency, which requires setting a low access price. This corresponds to the last two (negative) terms in equation (7). Second, the regulator is concerned about dynamic efficiency, that is, firms' incentives to invest in NGN coverage. While raising the access price always increases the entrant's investment incentives (as $dz_2^c(a)/da > 0$), it has an ambiguous effect on the incumbent's investment incentives (as it can be seen from Table 1, we can have either $dz_1^m(a)/da < 0$ or the opposite). Lastly, the regulator aims at avoiding excessive duplication of infrastructure costs.

In our example setting, we find that the NGN coverage of the incumbent (in the areas with a single infrastructure) is too low from a social point view, whereas the NGN coverage of the entrant (in the areas with two competing infrastructures) is too large.[30] 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 this setting, the regulator is willing to extend the incumbent's NGN coverage by setting a lower or higher access price (depending on whether we have $dz_1^m(a)/da > 0$ or the opposite), and to reduce the entrant's coverage by setting a lower access price.

(ii) $z_1^* < z_2^*$: Now, consider the equilibria in which the entrant has larger NGN coverage than the incumbent. We begin by studying the asymmetric equilibrium in which $z_1^* = z_1^c$ and $z_2^* = z_2^m(a)$. In this equilibrium, the social welfare writes

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

We have

$$\frac{dW}{da} = \underbrace{\frac{dz_2^m(a)}{da}}_{(+)} \underbrace{\left(w^{O,N} - w^{O,O}(a) - c_2(z_2^m(a), z_1^c)\right)}_{(+) \text{ or } (-)} + \underbrace{(\overline{z} - z_2^m(a)) \frac{dw^{O,O}(a)}{da}}_{(-)}. \quad (8)$$

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

If $w^{O,N} - w^{O,O}(a) - c_2(z_2^m(a), z_1^c) > 0$[31] (which implies that the entrant's NGN coverage is too small 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 price increases

[30] That is, we find that $w^{N,O}(a) - w^{O,O}(a) - c_1(z_1^m) > 0$, whereas $w^{N,N} - w^{N,O}(a) - c_2(z_2^c(a), z_1^m) < 0$. See Appendix E.

[31] In our example 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.

NGN 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 we have $dW/da \leq 0$. Therefore, as the entrant is going to invest too much from a social point of view, the regulator has incentives to set the lowest access price possible to reduce both investment incentives and static inefficiency.

A similar analysis applies for the other asymmetric equilibrium candidate, where $z_1^* = \widehat{z}_1$ and $z_2^* = z_2^m$ (in the low spillovers case). This is because in this case the 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 (8).

In the following section, we adopt the competitive setting of quantity competition with quality differentiation of Katz and Shapiro (1985) and demonstrate the trade-offs involved in the NGN investment decisions.

3.4 An example: competition à la 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. We denote the quality of the OGN by s^O, and the quality of the NGN 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 $s^N < 1 + 2s^O$.[32]

In order to illustrate how the equilibrium coverage is determined by the degree of spillovers and the investment cost disadvantage of the entrant, we adopt the following values for our model

[32] The latter assumption ensures that a firm using the old network is not evicted by a firm using the new network. See Appendix A for a detailed analysis.

parameters: $\overline{z} = 10$, $s^O = 1$, $s^N = 2$, $a = 0$,[33] and $c_1(x) = x^2/2$, and depict the relationship in Figure 1 below.

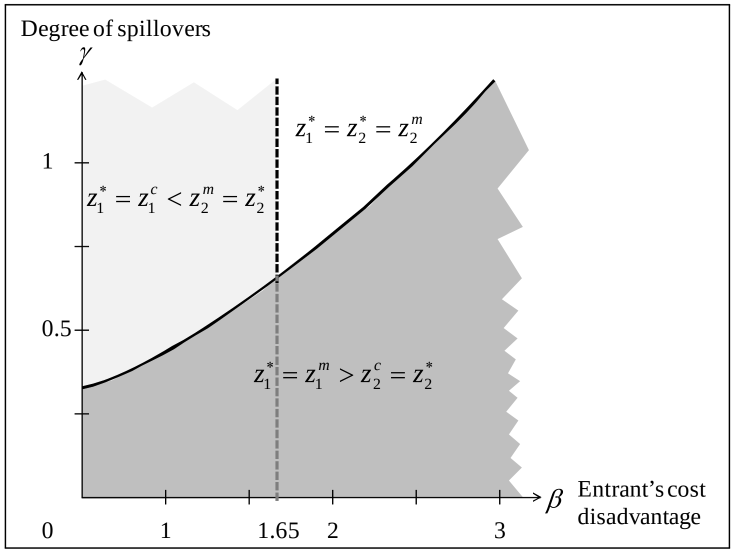

Figure 1: Equilibrium Outcomes

The figure shows that for sufficiently low values of β (in this example, for $\beta \in [1, 1.65]$), the equilibrium is asymmetric. If the degree of spillovers is sufficiently low (below the solid line), then the incumbent has larger NGN coverage than the entrant (i.e., we have $z_1^* > z_2^*$). In this area, increasing the access price has an ambiguous effect on the incumbent's investment, whereas it increases the entrant's investment. If the degree of spillovers is sufficiently high (above the solid line), the entrant has larger NGN coverage than the incumbent. In this case, increasing the access price enhances the entrant's incentives for investment but it does not affect that of the incumbent. For higher values of β (in this example, for $\beta > 1.65$) and high degrees of spillovers, the equilibrium can be either symmetric or asymmetric: while the entrant obtains less NGN coverage than the incumbent (and hence, an asymmetric equilibrium) if the degree of spillovers is low, it invests in the same areas as the incumbent (symmetric equilibrium) if the degree of spillovers is sufficiently large. The larger the cost disadvantage of the entrant, the higher the degree of spillovers

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

that is required to obtain a symmetric coverage equilibrium (as the presence of a substantial cost disadvantage plays against the entrant's coverage). In the symmetric equilibrium, increasing the access price enhances both firm 1's and firm 2's investment incentives.

Finally, increasing the access price shifts the solid line upwards, and hence, leads to the equilibrium in which the incumbent invests in a larger NGN coverage than the entrant for larger values of parameters γ and β.

Regulator's decision

If the entrant has no cost disadvantage (i.e., $\beta = 1$), the regulator sets the access price 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 coverage. Therefore, the regulator can increase static efficiency without sacrificing larger NGN coverage. As Figure 2, which depicts the optimal access price as a function of the degree of spillovers (for $\beta = 1$, 1.6, and 2), illustrates, this is no longer true when the entrant has a sufficiently high cost disadvantage.

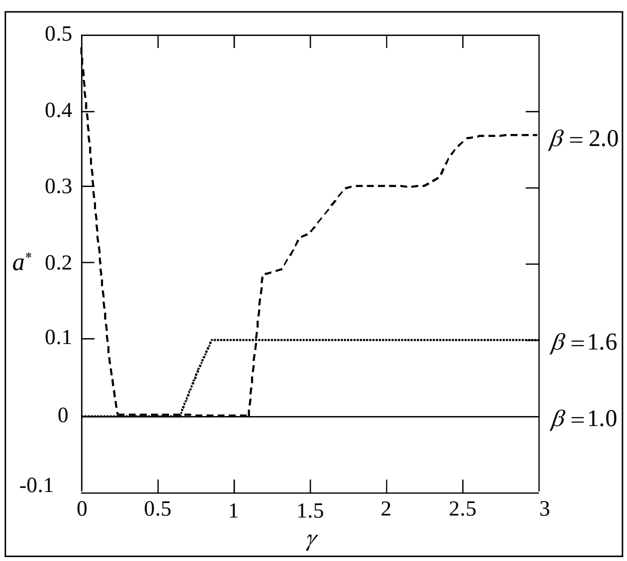

Figure 2: Socially optimal access charge

If the incumbent reduces its NGN investment in the presence of high degrees of spillovers, the entrant does not invest much either, as it faces high investment costs. This is why the regulator should increase the access price on the OGN in order to provide both firms with stronger investment incentives and counter-balance the spillover effect.

4 The interplay between the access regulations on the OGN and on the NGN

In this section, we study the case where the NGN infrastructure is also subject to access regulation and analyze the interplay between the regulation of the OGN and the NGN. We consider a symmetric regulation of the NGN, i.e., both the incumbent and the entrant are required to provide access to their NGN at a regulated price.[34] We denote this regulated price at which the firms are mandated to provide access to their NGN by $\widetilde{a}$.

Let $\widetilde{\pi}_i^{N,N}(\widetilde{a})$ and $\pi_j^{N,N}(\widetilde{a})$ denote firm i's profit when it provides access to its NGN to firm $j \neq i$ and firm j's profit when it leases access from firm i, respectively. We assume that $\partial\widetilde{\pi}_i^{N,N}(\widetilde{a})/\partial\widetilde{a} \geq 0$ for $\widetilde{a}$ that is not too high, and that $\partial\pi_j^{N,N}(\widetilde{a})/\partial\widetilde{a} \leq 0$. In words, provided that the access price to the NGN is not too high, the gross profits of the firm that owns the NGN is increasing with the access price, whereas the opposite is true for the firm that acquires access.

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

Migration at the wholesale level. First, consider the case where the incumbent has larger NGN coverage than the entrant, and hence, it must provide access to its NGN in the areas where

[34] Access is required in the areas where the firm holds a monopoly in the NGN. For example, for a given location where the incumbent has NGN coverage, the incumbent is required to provide to access to the entrant only if the entrant has no NGN coverage in that area.

the entrant has no coverage. 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 to acquire access to the NGN rather than the OGN if and only if $\pi_2^{N,N}(\widetilde{a}) \geq \pi_2^{N,O}(a)$. This condition, which we name the "wholesale migration condition," can be rewritten as $\widetilde{a} \leq \widetilde{a}_2^{\max}(a)$, where $\partial\widetilde{a}_2^{\max}(a)/\partial a \geq 0$.[35]

The wholesale migration condition is a constraint that the regulator has to take into account when setting the access prices both on the OGN and the NGN: if the access price for the OGN is low, the regulator must also set a low access price on the incumbent's NGN to make the entrant switch from the legacy to the new network at the wholesale level. This fairly general condition suggests that the regulator should seek a positive correlation between the access price of the OGN and the access price of the NGN.

Second, consider the case where the entrant has larger NGN coverage than the incumbent. In a given area where the entrant has NGN coverage but the incumbent does not, 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, $\widetilde{a} \leq \widetilde{a}_1^{\max}$.[36]

For the rest of the analysis, we assume that $\widetilde{a} \leq \min\{\widetilde{a}_1^{\max}, \widetilde{a}_2^{\max}(a)\}$, that is, the regulated access price of the NGN is not too high, 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

$$\widetilde{\Pi}_2(z_1, z_2) = -C_2(z_2, z_1) + \begin{cases} z_2\pi_2^{N,N} + (z_1 - z_2)\pi_2^{N,N}(\widetilde{a}) + (\overline{z} - z_1)\pi_2^{O,O}(a) & \text{if } z_2 \leq z_1 \\ z_1\pi_2^{N,N} + (z_2 - z_1)\widetilde{\pi}_2^{N,N}(\widetilde{a}) + (\overline{z} - z_2)\pi_2^{O,O}(a) & \text{if } z_2 > z_1 \end{cases}$$

[35]This is because $\pi_2^{N,N}(\widetilde{a})$ is a decreasing function and we also have $\pi_2^{N,O}(a)$ decreasing with a.

[36]Note that $\pi_1^{N,N}(\widetilde{a})$ is decreasing with $\widetilde{a}$. Note also that $\widetilde{a}_1^{\max}$ does not depend on a, since the incumbent's internal transfer price equals marginal cost (i.e., it provides access to its own legacy network at marginal cost).

As in Section 3, we define $\widetilde{z}_2^c$ and $\widetilde{z}_2^m$ as the values of z_2 that maximize $\widetilde{\Pi}_2(z_1, z_2)$ for $z_2 \leq z_1$ and $z_2 > z_1$, 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 $\widetilde{z}_2^m(a, \widetilde{a}) = (c_1)^{-1}\left(\left(\widetilde{\pi}_2^{N,N}(\widetilde{a}) - \pi_2^{O,O}(a)\right)\big/\beta\right)$.

Due to the wholesale migration condition, we have $\pi_2^{N,N}(\widetilde{a}) \geq \pi_2^{N,O}(a)$, which implies that $\widetilde{z}_2^c(\widetilde{a}) \leq z_2^c(a)$. In other words, introducing an access offer on the monopoly NGN increases the replacement effect for the entrant, which in turn decreases its investment incentives. Additionally, 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 the opposite otherwise. In our example setting, we have $\widetilde{\pi}_2^{N,N}(\widetilde{a}) \leq \pi_2^{O,N}$ for all $\widetilde{a} \leq \widetilde{a}_1^{\max}$, and hence $\widetilde{z}_2^m(a, \widetilde{a}) \leq z_2^m(a)$. In the remainder of the analysis, we focus on this case, where the introduction of an NGN wholesale offer reduces investment incentives, because it lowers the profit of the firm which invests in NGN.

Finally, we have $\partial\widetilde{z}_2^c(\widetilde{a})/\partial\widetilde{a}$, $\partial\widetilde{z}_2^m(a, \widetilde{a})/\partial\widetilde{a}$, $\partial\widetilde{z}_2^m(a, \widetilde{a})/\partial a \geq 0$. That is, increasing the access price of the OGN or of the NGN increases NGN coverage.

The entrant's optimal investment decision then writes

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

for $\widetilde{z}_2^c > \widetilde{z}_2^m$ and $\widetilde{z}_2^c \leq \widetilde{z}_2^m$, respectively, where $\widetilde{z}_1(a, \widetilde{a})$ is the lowest z_1 such that $\widetilde{\Pi}_2(z_1, \widetilde{z}_2^c(\widetilde{a})) \geq \widetilde{\Pi}_2(z_1, \widetilde{z}_2^m(a, \widetilde{a}))$ holds.

The incumbent's investment decision

The analysis is similar to that in Section 3. Consider the case where $\widetilde{z}_2^c > \widetilde{z}_2^m$. Firm 1's profit writes

$$\widetilde{\Pi}_1(z_1, \widetilde{z}_2^{\mathrm{BR}}(z_1)) = -C_1(z_1) + \begin{cases} z_1 \pi_1^{N,N} + (\widetilde{z}_2^m - z_1)\,\pi_1^{N,N}(\widetilde{a}) + (\overline{z} - \widetilde{z}_2^m)\,\pi_1^{O,O}(a) & \text{if } z_1 \in [0, \widetilde{z}_2^m] \\ z_1 \pi_1^{N,N} + (\overline{z} - z_1)\,\pi_1^{O,O}(a) & \text{if } z_1 \in [\widetilde{z}_2^m, \widetilde{z}_2^c] \\ \widetilde{z}_2^c \pi_1^{N,N} + (z_1 - \widetilde{z}_2^c)\,\widetilde{\pi}_1^{N,N}(\widetilde{a}) + (\overline{z} - z_1)\,\pi_1^{O,O}(a) & \text{if } z_1 \in [\widetilde{z}_2^c, \overline{z}] \end{cases}$$

Let $\widetilde{z}_1^c$, $\widetilde{z}_1^d$ and $\widetilde{z}_1^m$ denote the maxima of $\widetilde{\Pi}_1(z_1, \widetilde{z}_2^{\mathrm{BR}}(z_1))$ with respect to z_1 for $z_1 \in [0, \widetilde{z}_2^m]$, $z_1 \in [\widetilde{z}_2^m, \widetilde{z}_2^c]$, and $z_1 \in [\widetilde{z}_2^c, \overline{z}]$, respectively. The profit of firm 1 can be written in a similar way for $\widetilde{z}_2^c \leq \widetilde{z}_2^m$, that yields three maxima for different ranges of values for z_1.

Proposition 2 *If the regulated access price for the NGN is sufficiently low, the resulting NGN coverage of the incumbent is (weakly) less than when the NGN infrastructure is not subject to any access regulation.*

Proof. For $\widetilde{z}_2^c > \widetilde{z}_2^m$, 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 $a \leq \widetilde{a}_1^{\max}$) and $\widetilde{z}_1^d = z_1^d$. Furthermore, we have $\widetilde{z}_1^m \leq z_1^m$ if $\widetilde{\pi}_1^{N,N}(\widetilde{a}) \leq \pi_1^{N,O}(a)$, and the opposite 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). Similarly, for $\widetilde{z}_2^c \leq \widetilde{z}_2^m$, in two out of three equilibrium candidates the equilibrium coverage is less than if there were no NGN access offer, and in the third equilibrium candidate, it is less if $\widetilde{a}$ is sufficiently low. ■

Note that with the introduction of the NGN access offer, the business migration effect (which is present in determining z_1^m in the absence of NGN regulation) 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 compare in the presence of an NGN wholesale offer, for $\widetilde{z}_2^c > \widetilde{z}_2^m$.[37]

Table 3: The effect of an NGN wholesale offer on total coverage (case $\widetilde{z}_2^c > \widetilde{z}_2^m$)		
Without wholesale offer		With wholesale offer
$\{z_1^c, z_2^m\}$	$>$	$\{\widetilde{z}_1^c, \widetilde{z}_2^m\}$
$\{z_2^m, z_2^m\}$	$>$	$\{\widetilde{z}_2^m, \widetilde{z}_2^m\}$
$\{z_1^d, z_1^d\}$	$=$	$\{\widetilde{z}_1^d, \widetilde{z}_1^d\}$
$\{z_2^c, z_2^c\}$	$>$	$\{\widetilde{z}_2^c, \widetilde{z}_2^c\}$
$\{z_1^m, z_2^c\}$	$\gtrless$	$\{\widetilde{z}_1^m, \widetilde{z}_2^c\}$

As we summarize in Table 3, the introduction of a wholesale offer on monopoly NGNs leads to a lower total coverage, except in two cases: (i) when the equilibrium corresponds to the optimal "mimicking" equilibrium $\{\widetilde{z}_1^d, \widetilde{z}_1^d\}$, in which case the equilibrium does not depend on the access price of the NGN, and (ii) when the equilibrium coverage is large (i.e., $\{\widetilde{z}_1^m, \widetilde{z}_2^c\}$), if $\widetilde{a}$ is sufficiently high.

The regulator's decision

We finally analyze the regulator's choice of the access price on the new technology network, $\widetilde{a}$, and the relationship between the socially optimal access price on the NGN, $\widetilde{a}^*$, and a.

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

[37] 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.

If the equilibrium is asymmetric, and if the incumbent invests in larger NGN coverage than the entrant, we find that there is a positive relationship between the socially optimal $\widetilde{a}$ and the access price of the legacy network, i.e., $d\widetilde{a}^*/da \geq 0$.[38] On the other hand, if the entrant invests in larger NGN coverage than the incumbent, the relationship between $\widetilde{a}^*$ and a can be reversed, that is, we can have $d\widetilde{a}^*/da \leq 0$.[39]

The intuition is that the OGN access price affects the trade-off for the regulator between setting a high NGN access price, which increases marginally the NGN coverage, and setting a low NGN access price, which limits the deadweight loss in the areas with a monopoly NGN infrastructure. How the OGN access price affects the regulator's trade-off between a low and a high NGN access price depends also on whether the incumbent or the entrant owns the NGN infrastructure subject to access.

When the incumbent owns the monopoly NGN infrastructure, raising the access price of the legacy network has three effects, which all gives the incentive to the regulator to increase the NGN access price. First, a higher OGN access price reduces the size of the area with a monopoly NGN infrastructure, as it intensifies the wholesale revenue effect, hence reducing the incumbent's investment incentives. This, in turn, reduces the deadweight associated to a high NGN access price in the areas with the monopoly NGN. Second, a higher OGN access price reduces welfare in the areas not covered by an NGN. Hence, the regulator has an incentive to expand marginally the areas covered by an NGN and to reduce the uncovered areas where retail prices tend to increase. Third, the frontier between the uncovered areas and the areas with a monopoly NGN becomes more sensitive to the NGN access price; this also gives an incentive to the regulator to increase the NGN access price to encourage investment. All in all, when the incumbent is the "leader" in the

[38] Note that this result holds if the marginal investment cost is convex, and it does not always hold when the marginal investment cost is concave.

[39] This holds when the marginal investment cost is convex. See Appendix F for the formal proofs.

deployment of the NGN, the socially optimal NGN access price is positively related to the OGN access price.

When the entrant owns the monopoly NGN infrastructure, a higher OGN access price increases the entrant's investment incentives because the replacement effect is softened. Since the size of the areas with the monopoly NGN increases, the regulator has an incentive to lower the NGN access price to reduce the deadweight loss in these areas. At the same time, the marginal gain of rolling out an NGN in uncovered areas can either increase or decrease, which gives the incentive to the regulator to either increase or decrease the NGN access price. Finally, the frontier between the uncovered areas and the areas with a monopoly NGN becomes less sensitive to the NGN access price, which gives an incentive to the regulator to decrease the NGN access price. In sum, when the OGN access price increases, the regulator should either lower or increase the NGN access price. Hence, the relation between the socially optimal NGN access price and the OGN access price can be negative, when the entrant is the "leader" in NGN investments.

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 generation network (OGN, i.e., the legacy network) to a new generation network (NGN, i.e., a 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 the coexistence of different technologies whose access is subject to different types of ex-ante intervention.

In 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 as a function of the wholesale price set by a regulator on the old technology. Then, we consider the case in which a firm (the incumbent or the entrant) 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 prices of different (old versus new) infrastructures.

The analysis highlights the presence of three conflicting effects on investment incentives: (i) a replacement effect that reduces investment incentives of alternative operators when the access fee to existing infrastructure is low; (ii) a wholesale revenue effect that is related to the profitability of the access services on the "old" infrastructure and that in turn affects the incentive to invest in the new technology; and finally (iii) a new effect – that we refer to as the "business migration effect" – that creates a link between the wholesale and retail prices of the "old" infrastructure and in turn impacts retail prices on the new infrastructure: if the access price of the OGN is low, retail prices based on that network are also low and hence, in order to encourage customers to switch from the “old” legacy network to the “new” network, operators should also offer low prices for NGN services; this effect reduces the profitability of the new technology infrastructure, and hence, the incentives to invest in it. The coexistence of these multiple effects creates a non-monotonic relationship between the access price and investments in the new technology (i.e., in the coverage of the new infrastructure).

From a social point of view, we show that, when setting the access price on the legacy network, the regulator must take into account potential conflicts between investment incentives, static efficiency in uncovered areas, and excessive duplication of infrastructure costs. We also point out that the effects that emerge when both the old and new infrastructures are subject to ex ante intervention. The analysis shows that extending regulation to the new technology negatively affects investments. More interestingly, our results highlight that regulators cannot treat the two access prices to the two different technologies independently.

Our results show that, when the incumbent has larger NGN coverage than the entrant, the regulator has to set an access price for the new infrastructure that is positively correlated with the access price of the legacy network. Hence, if the regulator wants to keep the access prices of the “old” network relatively low, in order to favor migration at wholesale level (and in turn at the retail level), it also must set a relatively low access price on the new technology. Whereas the reverse can be true if the entrant has larger NGN coverage than the incumbent: given the relative advantage the incumbent enjoys due to its control over the old technology, it could be socially optimal for the regulator to set a low access price on the old network to “level” the playing field between the two competitors in the uncovered areas, but also to set a higher access price on the NGN infrastructure controlled by the entrant in order to incentivize investment by both the entrant and the incumbent.

In policy terms, our result suggests that, because the legacy network is an essential facility controlled by the incumbent, to the extent that the access price of the legacy network affects investments in NGN by both the incumbent and the entrant, the regulation of access to NGNs should be somehow asymmetric, that is, access prices of incumbents' and entrants' NGNs should be set following different principles according to the relative market position (in terms of NGN coverage) of each competitor.

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 new networks should take into account such an effect, leading to an increase in the wholesale prices. 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 in investing whatever the incumbent invests in, while in other areas the entrant might be more in favour of renting the incumbent's network. Regulatory rules, as well as the relationship to 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.

Lestage, R., and Flacher, D. (2010). "Telecommunications Infrastructure Investment: Access Regulation and Geographical Coverage." *Mimeo.*

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 $(-\infty, 1]$.[40] 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

[40] 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

$$\pi_1^{O,O}(a) = \frac{1}{9}\left((1+s^O)^2 + 5a(1-a) + 5as^O\right) \quad \text{and} \quad \pi_2^{O,O}(a) = \frac{(1+s^O-2a)^2}{9}.$$

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 $\widehat{a}^O = \arg\max_a \pi_1^{O,O}(a) = \left(1+s^O\right)/2 = \overline{a}^O$.

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

$$\pi_1^{N,O}(a) = \frac{(1+2s^N-s^O)^2 + 5a(1-a) + a(s^N+4s^O)}{9} \quad \text{and} \quad \pi_2^{N,O}(a) = \frac{(1+2s^O-s^N-2a)^2}{9}.$$

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 $\widehat{a}^N = \arg\max_a \pi_1^{N,O}(a) = (5+s^N+4s^O)/10$, and $\widehat{a}^N > \overline{a}^N$.

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

$$\pi_1^{O,N} = \frac{(1+2s^O-s^N)^2}{9} \quad \text{and} \quad \pi_2^{O,N} = \frac{(1+2s^N-s^O)^2}{9}.$$

Both firms operate a "new" network. We have

$$\pi_1^{N,N} = \frac{(1+s^N)^2}{9} \quad \text{and} \quad \pi_2^{N,N} = \frac{(1+s^N)^2}{9}.$$

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

$$\Pi_2 = z_2 \pi_2^{N,N} + (z_1 - z_2)\, \pi_2^{N,O}(a) + (\overline{z} - z_1)\, \pi_2^{O,O}(a) - C_2(z_2, z_1), \tag{9}$$

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

$$\Pi_2 = z_1 \pi_2^{N,N} + (z_2 - z_1)\, \pi_2^{O,N} + (\overline{z} - z_2)\, \pi_2^{O,O}(a) - C_2(z_2, z_1), \tag{10}$$

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

If $z_2 \leq z_1$, (9) is maximized at $z_2 = z_2^c$, by the definition of z_2^c. Similarly, by the definition of z_2^m, (10) 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

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

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

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

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 $\widehat{z}_1\in\left[z_2^c,z_2^m\right]$ such that $z_2^{\text{BR}}\left(z_1\right)=z_2^m$ if $z_1\leq\widehat{z}_1$, and $z_2^{\text{BR}}\left(z_1\right)=z_2^c$ otherwise.

Appendix E: Welfare analysis for the example 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 price a to firm 1 (possibly 0). Consumer surplus then writes

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

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

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

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 price 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 an 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 price 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 price 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 $w^{N,N}(\widetilde{a}) - w^{O,O}(a) - c_1\left(\widetilde{z}_1^m\right) \geq 0$, 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 $\partial\widetilde{\pi}_1^{N,N}/\partial\widetilde{a} \geq 0$ and $\partial\pi_1^{O,O}/\partial a \geq 0$, and provided that $(c_1)'' \geq 0$ (i.e., the investment cost is convex). 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 price 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 $\partial \widetilde{\pi}_2^{N,N} / \partial \widetilde{a} \geq 0$ and $\partial \pi_2^{O,O} / \partial a \leq 0$, and provided that $(c_2)'' \geq 0$. It follows that $\partial \widetilde{a}^w / \partial a \leq 0$ when the entrant is the leader in NGN investments (provided that $dw^{O,O}(a)/da +$ $\partial \widetilde{z}_2^m / \partial a \times (c_2)'(\widetilde{z}_2^m) \geq 0$ and that the investment cost is convex).