Geographic Access Rules and Investments*

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Abstract

We analyze competition between vertically integrated infrastructure operators that provide access in different geographical areas. A regulator may impose a uniform access price, set local access rates, or deregulate access locally. We analyze the impact of these alternative regulatory regimes on network investments. While cost-based access leads to both suboptimal rollout and duplication, uniform access prices bring too much duplication. Deregulation in competitive areas can spur investment and lead to social optimum, or call for continued regulatory intervention, depending on the resulting wholesale equilibrium.

Keywords: Next generation networks, infrastructure investment, geographical access regulation.

JEL: L51, L96.

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1 Introduction

Investment in broadband infrastructure is receiving extraordinary attention both from governments and regulators all over the world, due to the significant impact of high-speed access on economic growth (Czernich et al. 2011). While considered essential for every modern economy, the roll-out of these infrastructures requires a large amount of financial resources: Cost estimates for providing 100Mbps broadband coverage to half of all households in EU member states by 2020 are in the range of €180 – €260 billion (Cullen International, 2011).

The development of ultra-fast broadband networks, the so called Next Generation Access Networks (NGANs), raises several regulatory concerns. Regulatory intervention must create conditions that encourage (or rather, do not discourage) infrastructure investment, but at the same time should avoid the monopolization of the market for high-speed broadband services. The latter calls for some kind of regulated access to NGAN infrastructures, while the former implies that this should be done with care.

A complicating feature is that competition among high-speed broadband networks is likely to emerge only in specific regions of a country, mostly in very dense metropolitan areas, while in the rest of a country infrastructure competition will probably not materialize. From a regulatory point of view, this calls for ex ante access rules to differ across areas characterized by different degrees of infrastructure competition. Indeed, regulatory practice has changed and a transition from country-wide uniform measures to more locally tailored regulation is ongoing. While this is plausible from the competition law point of view now popular in telecoms regulation, there is a lack of theoretical research about the type and the linkage –if any– of different access regimes in differentiated competitive areas and the impact of the differentiation of access rules on firms' investment decisions. The aim of this paper is to fill this gap.

Our paper is motivated by recent decisions of the European Commission that forcefully push for the adoption of geographically differentiated remedies. Directive 2009/140/EC ("Better Regulation Directive") explicitly considers the possibility of defining different geographical markets and remedies according to the prevailing competitive conditions.[1] This approach has also been recently confirmed in the new EU Recommendation C(2010) 6223 on "Regulated Access to NGANs" (September 2010).[2] The European Commission thus invites national regulatory authorities (NRAs) to examine differences in the degree of competition among geographical areas in order to determine whether the definition of sub-national geographical markets or the imposition of differentiated remedies are warranted.[3]

National regulators in the UK (Ofcom, 2007) and Portugal (Anacom, 2009) already took the decision to divide the wholesale broadband market in different sub-markets according to differences in competitive conditions, and proposed the adoption of differentiated wholesale remedies in different (competitive and non-competitive) areas. Similar decisions have recently been taken by the Finnish and Hungarian NRAs.[4] In these decisions, while the existing regulatory rules (such as transparency, nondiscrimination, price control) have been confirmed for "non-competitive" areas, in "competitive" areas all obligations have been lifted.[5] Other NRAs (in France, Germany, Italy and Spain), while recognizing the presence of different degrees of competition in specific areas of the wholesale broadband market, have not imposed differentiated remedies but introduced instead uniform access remedies at national level.[6]

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[1] Recital 7 of the Directive states: "In order to ensure a proportionate and adaptable approach to varying competitive conditions, national regulatory authorities should be able to define markets on a sub-national basis and to lift regulatory obligations in markets and/or geographic areas where there is effective infrastructure competition."

[2] Recital 10 states that "the transition from copper-based to fibre-based networks may change the conditions of competition in different geographic areas and may necessitate a review of the geographical scope of markets [...] and remedies in cases where such markets or remedies have been segmented on the basis of competition from local loop unbundling (LLU)."

[3] The association of European Telecom Regulators (ERG, 2008) provides a list of criteria to assess the homogeneity of competitive conditions in different geographical markets and to define differentiated remedies.

[4] See the EC notifications FI/2009/900 for Finland and HU/2007/0662-663 for Hungary.

[5] Interestingly, in February 2008, the Austrian telecoms regulator (TKK) decided to define a national market, but to geographically differentiate the remedies imposed on the SMP operator on the basis of the competition faced in different areas (see case AT/2008/0757).

[6] For more details, see de Streel (2010). Xavier and Ypsilanti (2011) analyze the implementation of geographical

In our model, we explicitly consider the presence of geographical access regulation and the possibility to impose differentiated remedies in different areas. In a country composed of a continuum of areas with increasing cost of coverage, two incumbent operators decide to deploy their own networks as long as the investments can be recovered. As a result, infrastructure competition emerges only in a fraction of the country, while in the rest a monopolistic infrastructure operates. Access regulation therefore needs to trade off static welfare with incentives in network rollout and duplication.

We assume that the incumbent operators must provide access to a third operator and to each other. However, access regimes can differ between geographic areas. More specifically, we analyze different alternative regulatory schemes ranging from the adoption of a uniform access price (where the regulator sets the same access price everywhere, of which cost-based access is a special case), to duplication-based and competition-based access, where the regulator sets two different access prices or even deregulates "competitive" sub-markets, respectively, to pure geographical remedies where the regulator sets a separate access charge in each local area. We analyze how these alternative regulatory access regimes affect the incentives to invest in network coverage and duplication.

Comparing the no-access benchmark with access regulation, similarly to the previous literature we find that in general access regulation is detrimental to investment, as lower access charges reduce both overall network coverage and duplication. Even so, we also show that if services are sufficiently differentiated and access prices are high enough, then coverage increases with access. Thus, even with investments a case can be made for access if it allows the resulting services to be sufficiently differentiated.

The traditionally applied cost-based access regulation deprives firms of investment incentives in new high-speed infrastructures. Under such a regime, both total network rollout and duplication

regulation in a few countries (including the UK, Australia, Austria, and Portugal), and highlight the practical complexity of geographically segmented regulation.

are smaller than socially optimal. Even uniform access charges above cost are suboptimal since they involve the wrong trade-off between rollout and duplication: The access price is too high where two infrastructures are present and too low where there is only one, leading simultaneously to too much duplication and too little network rollout. We also show that LRIC (long-run incremental cost) access charges, both in uniform or regionally differentiated versions, are not optimal unless they are set locally.

Deregulation in "competitive" areas is based on the idea that wholesale competition should increase efficiency. We show that indeed competition can achieve the social optimum if the optimal access price in competitive areas is equal to cost. The problem with deregulation is that in general there are multiple wholesale equilibria, some of which are far from cost-based, and that even if equilibrium results in cost-based access it may actually not be socially optimal. The regulator can try to nudge equilibrium outcomes in the right direction by using either caps or floors on wholesale prices, but letting firms set them freely is not optimal in general.

Literature Review. Our paper merges two different strands of literature. The first one deals with universal service obligations (USOs), uniform pricing constraints and coverage, while the second one deals with the interaction between access regulation and investment.

With respect to the USO literature, a majority of papers focuses on the role of uniform pricing constraints and their impact on network coverage and market competition.[7] Valletti, Hoernig, and Barros (2002) show that the introduction of uniform pricing and coverage constraints is not competitively neutral: Under uniform pricing, the equilibrium coverage may be lower than without any regulatory intervention. Moreover, the imposition of a minimum coverage for the incumbent in the presence of a uniform pricing constraint raises market prices. Similar results on the strategic

[7] Related to this literature, Faulhaber and Hogendorn (2000) develop a model of broadband coverage, but without considering uniform pricing or coverage constraints.

links created through pricing restrictions have been found by Anton et al. (2002), Choné et al. (2000, 2002) and Foros and Kind (2003). Hoernig (2006) concentrates his analysis on the imposition of uniform pricing constraints and shows that the opening of the market to competition in presence of uniform pricing constraints on all operators gives rise to a series of neighboring monopolies rather than competition for customers.

All these papers focus on the impact of uniform pricing constraints at the *retail* level on market coverage and competition. However, they do not address the possibility of geographical differentiation in broadband coverage, and they completely neglect the problem of uniform and non-uniform (i.e., geographically differentiated) *wholesale* rules on investment incentives and their impact on market competition, which is the focus of our paper.

The second strand of literature analyzes the impact of access regulation on firms' investment. Cambini and Jiang (2009) provide a recent and comprehensive review of both theoretical and empirical papers on broadband investment and regulation. Gans and Williams (1999), Gans (2001 and 2007), Hori and Mizuno (2006) and Vareda and Hoernig (2010) study the optimal dynamics of investment in a discrete setting; in our paper the model is not dynamic but the decision where to invest is continuous and depends on the net benefits operators are able to obtain in different areas.

Some recent papers specifically focus on NGAN investment and access regimes to new infrastructures. Brito et al. (2010) show that, in a duopoly model where a vertically integrated incumbent and a downstream entrant compete, the introduction of a two-part access tariff solves the problem of regulatory opportunism and therefore enhances the incentives to invest in NGAN infrastructures. Nitsche and Wiethaus (2010) study the impact of various forms of access regulation (LRIC, risk-sharing, regulatory holidays) on the incentives to invest in NGANs in a game with uncertain returns and subsequent quantity competition. They find that risk-sharing enhances consumer welfare with respect to the other regulatory tools, since it positively influences the intensity of competition at the retail level. Inderst and Peitz (2012a) consider cost-sharing agreements in NGAN deployment between an incumbent firm and an entrant, in the form of long-term contracts concluded before the investment is made, as opposed to contracting taking place after the network has been constructed. They conclude that the former type of agreement reduces the duplication of investments and may lead to more areas being covered.

Finally, other papers have recently focused on the interplay between access regulation and the migration from the old legacy network to an NGAN infrastructure.[8] All the above papers address the problem of investment in NGANs and access regulation in different ways, but none specifically looks at the introduction of geographically differentiated access rules and the impact of geographical access remedies on market competition and firms' investments, which is what we address in this paper.

The paper is organized as follows. Section 2 describes the investment model and presents the no-access benchmark. In Sections 3 and 4 we present geographically differentiated access regulation and determine the social optimum. In Section 5 we assess the impact of alternative regulatory regimes on investment incentives. Section 6 concludes the paper. All longer proofs can be found in the Appendix.

2 Network Investments without Access

Two network incumbent operators (firms 1 and 2) invest in coverage of next generation access infrastructures, and a potential entrant (firm e) might ask for access but does not invest. Incumbent operators build infrastructures in different areas $[0, \overline{z}]$ of a country, where $\overline{z}$ is large enough so that some areas remain uncovered in equilibrium.

More precisely, firm $i = 1, 2$ builds a network that covers the areas $[0, z_i]$, with $z_i \leq \overline{z}$. The

[8] On this issue, see Bourreau, Cambini and Dogan (2011), Brito et al. (2012) and Inderst and Peitz (2012b).

fixed cost of covering the area x is $c(x)$, with $c(x) > 0$ and $c'(x) > 0$. Therefore, the total cost of covering the areas $[0, z_i]$ is

$$C(z_i) = \int_0^{z_i} c(x)dx.$$

We have $C'(z_i) = c(z_i) > 0$ and $C''(z_i) = c'(z_i) > 0$ and assume that incumbent firms face the same investment cost function.

At the beginning of the game, firm e is outside the market. It can enter a given area only via buying access to an incumbent's infrastructure. Finally, contrary to papers like Valletti, Hoernig, and Barros (2002) and Hoernig (2006), we assume that firms can set a different retail price in each area.[9] While we will assume for simplicity that marginal costs are the same in all areas, firms will adjust their prices locally according to competitive conditions.

We first consider the case of no access to the incumbents' networks. Therefore, the entrant operator cannot enter the market, and similarly, incumbents cannot ask for access to their rival's network. This will serve as a benchmark to which we will compare the outcomes under various access regimes.

The timing of the game is as follows. In a first stage, the incumbents decide simultaneously on the coverage of their networks.[10] Then, in a second stage, they compete in prices and profits are realized. Our equilibrium concept is subgame-perfect Nash equilibrium in pure strategies.

We denote by $\bar{\pi}^m > \bar{\pi}^d$ the per area monopoly and (per firm) duopoly profits in the absence of access, respectively. At the investment stage, firm i chooses its coverage z_i so as to maximize its

[9] In some countries (e.g., Portugal), broadband operators offer discounts from the catalogue price which vary according to geographical areas. In many countries, operators also offer different qualities of service (e.g., bandwidth) according to geography, corresponding to different quality-adjusted prices.

[10] Our results would not change if one network were to invest first since we assume that retail prices are set locally. Therefore total coverage does not depend on the extent of duplication.

total profit Π_i, where

$$\Pi_i\left(z_i, z_j\right) = \begin{cases} z_i \bar{\pi}^d - C(z_i) & \text{if} \quad z_i \leq z_j \\ z_j \bar{\pi}^d + \left(z_i - z_j\right) \bar{\pi}^m - C(z_i) & \text{if} \quad z_i > z_j \end{cases}. \tag{1}$$

If $z_i \leq z_j$, firm i has less coverage than its rival, hence, it obtains the duopoly profit $\bar{\pi}^d$ from area 0 to area z_i. Otherwise, if $z_i > z_j$, firm i has more coverage than its rival; it then obtains the duopoly profit $\bar{\pi}^d$ in the areas covered by firm j (i.e., from 0 to z_j), and the monopoly profit $\bar{\pi}^m$ from z_j to z_i. In both cases, firm i incurs a total investment cost of $C(z_i)$.

We have the following result.

Lemma 1 *Assume that access is not available. In equilibrium, one incumbent firm covers areas* $[0, \bar{z}^m]$ *and the other incumbent firm covers areas* $\left[0, \bar{z}^d\right]$, *where* $\bar{z}^m = c^{-1}(\bar{\pi}^m) > \bar{z}^d = c^{-1}(\bar{\pi}^d)$.

Proof. See Appendix A. ■

Though the firms are ex-ante symmetric, in equilibrium they are asymmetric ex post. This occurs because in some areas the investment cost is so high that only one firm can profitably enter. In equilibrium, and in the absence of any form of ex ante intervention, we have therefore areas with two infrastructures (in the less costly areas), and areas with only one infrastructure (in the most costly areas).[11]

3 Geographically Differentiated Access Regulation

3.1 Assumptions

In this section, we assume that the regulator imposes an access obligation on the incumbent firms' infrastructures, which both allows entry of firm e and network owners to use each others' networks.

[11] There are also, of course, areas without infrastructure investment.

The possibility of access affects the outcome as follows. First, in the duplicate infrastructure areas (DIAs), access introduces a second source of asymmetry between incumbents. One gives access to the entrant in these areas and will earn either a lower or a higher profit than the rival, due to the "softening effect" discussed below (see also Bourreau et al., 2011). Second, in the single infrastructure areas (SIAs), the incumbent provides access to both the entrant and its rival.

First, we show how firms' investment will depend on the access charges chosen. Then, in a second step we consider socially optimal access charges, where welfare will be maximized taking into account that the sizes of DIAs and SIAs are endogenous. We refer to this case as the *socially optimal access regime*. Finally, we specifically analyze the following alternative access regimes:[12]

- *Cost-based access charges*: In each area, the regulator sets the access charge at marginal cost.
- *Uniform access charges*: The regulator does not differentiate the wholesale remedies locally and sets the same access charge everywhere.[13]
- *Pure geographical remedies*: The regulator sets separate access charges in each local area.
- *Duplication-based remedies:* The regulator sets different access charges in DIAs and SIAs.
- *Competition-based remedies*: The regulator fixes the SIA access charge and implements a light regulation approach in the "competitive" areas (i.e., DIAs), where incumbents can set the access charge to their networks on a commercial basis, subject to the constraint that the entrant should not be foreclosed.

Most of the paper is framed in terms of duplication-based remedies. Denote by a and $\widetilde{a}$ the access charges in DIAs and SIAs, respectively. Access charges can differ between areas, but they are

[12] In this paper we do not address risk-sharing (cooperation) in infrastructure investment. We focus on this issue in our companion paper, Bourreau, Cambini and Hoernig (2012).

[13] Since we assume identical marginal costs, cost-based access is a special case of this regime.

not differentiated between infrastructure operators within the same areas.[14] Let $\pi_i^j(a)$ and $\widetilde{\pi}_i^j(\widetilde{a})$ be the per-DIA and per-SIA profit of firm $i = 1, 2, e$ when firm $j = 1, 2$ is the wholesale provider, including all retail and wholesale revenues, but gross of investment cost. At access charges equal to wholesale marginal cost, i.e. $a = \widetilde{a} = 0$, profits of all firms are equal to the symmetric triopoly outcome, i.e., $\pi_i^j(0) = \widetilde{\pi}_i^j(0) \equiv \bar{\pi}^t > 0$ for $i = 1, 2, e$ and $j = 1, 2$.[15] In SIAs the access provider makes more profits than access seekers at $\widetilde{a} > 0$, i.e., $\widetilde{\pi}_j^j(\widetilde{a}) > \widetilde{\pi}_i^j(\widetilde{a})$ for $i \neq j$. Finally, we assume that in DIAs the entrant randomly chooses an access provider,[16] so that the (ex ante) expected per-DIA profit of an infrastructure owner is $\pi^d(a) = (\pi_i^i(a) + \pi_i^j(a))/2$. We assume all profits functions to be continuous in access charges.

Access seekers' profits are strictly decreasing in the access charges. Assume that there are unique access charge levels a^e, $\widetilde{a}^e > 0$ such that $\pi_e^j(a^e) = \widetilde{\pi}_e^j(\widetilde{a}^e) = 0$, i.e., the entrant just breaks even. Let $a^m = \arg\max_{a \leq a^e} \pi_i^i(a)$ and $\widetilde{a}^m = \arg\max_{\widetilde{a} \leq \widetilde{a}^e} \widetilde{\pi}_i^i(\widetilde{a})$ be the access charges that maximize the access provider's (ex post) profits subject to the restriction that the entrant is at least just viable. No individual access provider would voluntarily set a higher access charge. On the other hand, we assume that in DIAs the rival infrastructure's profits $\pi_i^j(a)$ are increasing in $a \geq 0$, e.g., due to retail prices being strategic complements. As a result, $a^d = \arg\max_{a \leq a^e} \pi^d(a)$ is higher than a^m if $a^m < a^e$, and π^d is strictly increasing on $\left[0, a^d\right]$ and has a strictly increasing inverse $(\pi^d)^{-1}$. Access charges higher than a^d and $\widetilde{a}^m$ would simultaneously lead to lower expected profits of network owners and lower welfare, i.e. reduce coverage without any compensating welfare gains, as we will see later.[17] Therefore a benevolent regulator will only select $a \leq a^d$ and $\widetilde{a} \leq \widetilde{a}^m$, which we will

[14] In other words, we do not discuss here the adoption of rules that are asymmetric between infrastructure operators.

[15] The demand model specified below satisfies all assumptions made here.

[16] Though for regulated access prices the entrant is indifferent we assume that it chooses only one access provider in each area, e.g., due to transaction costs. An alternative assumption at this point would be that the access seeker commits itself *ex ante* to using a specific network when two are present. This will not change total coverage if duplication is partial.

[17] While entry is unprofitable if $a > a^e$ and $\widetilde{a} > \widetilde{a}^e$, unregulated networks would foreclose entry if and only if the maximal profit they can make under access is less than the profit without giving access, i.e. in DIAs if $\pi_i^i(a^m) < \bar{\pi}^d$ and in SIAs if $\widetilde{\pi}_i^i(\widetilde{a}^m) < \bar{\pi}^m$. In our model, the latter never happens, while the former occurs if and only if $\gamma > 26.67$.

assume for the rest of the paper.

While mostly we let the regulator freely set both a and $\widetilde{a}$, below we also consider access charges based on LRIC (long-run incremental cost). In the present context where both networks are used to provide only one type of service, LRIC for the region $[z_1, z_2]$ are equal to projected average costs, i.e. $a^{LRIC}([z_1, z_2]) = [C(z_2) - C(z_1)] / [(z_2 - z_1) Q]$ with local quantity Q on the infrastructure including self-supply.

The timing of the game is as follows. First, the access charges are set by the regulator. Second, firms 1 and 2 non-cooperatively decide on coverage. Third, firms 1, 2, and e decide where to ask for access. Fourth, in all areas of the country, firms 1, 2, and e compete for consumers. Again, we consider subgame-perfect Nash equilibria in pure strategies.

We have to slightly modify the timing of the game for the competition-based remedies regime, as access is now partially deregulated. First, the regulator sets the access price for monopolistic infrastructures. Second, firm 1 and firm 2 non-cooperatively decide on coverage. Third, infrastructure owners non-cooperatively make take-it-or-leave-it access offers in DIAs and firm 1, 2, and e decide where to ask for access. Fourth, firms 1, 2, and e compete for consumers.

We start by considering the last stage of the game, which is common to all regulatory regimes and where firms compete in the retail market with access.

3.2 A Model of Retail Competition with Access

Most of our results will not depend on the specific modeling of the price competition stage. Even so, in order to obtain additional answers to some of the questions posed below, we define firms' profits in monopoly, duopoly, and triopoly configurations with access in a more specific market model. Following Shubik and Levitan (1980, p.132), we introduce a representative consumer with the following quasi-linear preferences:

$$U = m + q_1 + q_2 + q_e - \frac{3\left(q_1^2 + q_2^2 + q_e^2\right) + \gamma\left(q_1 + q_2 + q_e\right)^2}{2\left(1+\gamma\right)}.$$

Here m represents the consumption of the numeraire good, q_k the consumption of good k, and $\gamma \geq 0$ represents the degree of substitutability – a higher γ corresponds to more homogeneity and thus a higher intensity of competition. The resulting demand function for firm $k = 1, 2, e$ is

$$D_k\left(p_1, p_2, p_e\right) = \frac{1}{3}\left(1 - p_k - \gamma\left(p_k - \frac{p_1 + p_2 + p_e}{3}\right)\right). \tag{2}$$

When one firm or two firms are out of the market, we derive the corresponding demand functions by setting the quantity purchased from those firms to zero in the representative consumer's program. We normalize the constant marginal cost for the provision of the retail service c_r and the marginal wholesale cost of access c_w to zero.[18]

Since we allow firms to set different prices according to local competition, we determine the equilibrium of the price-setting game separately where the two incumbent firms have rolled out an infrastructure and where only one of them has done so.

In DIAs, assume that firm $i = 1, 2$ serves the wholesale market. Then, firms i, firm $j \neq i, e$, and firm e make the following profits per area (gross of investment costs):

$$\begin{aligned}
\pi_i^i\left(a, p_1, p_2, p_e\right) &= p_i D_i\left(p_1, p_2, p_e\right) + a D_e\left(p_1, p_2, p_e\right), \\
\pi_j^i\left(a, p_1, p_2, p_e\right) &= p_j D_j\left(p_1, p_2, p_e\right), \\
\pi_e^i\left(a, p_1, p_2, p_e\right) &= \left(p_e - a\right) D_e\left(p_1, p_2, p_e\right),
\end{aligned}$$

[18] This is without loss of generality for our results, as in the presence of positive marginal costs the generic access charge a can be rescaled to $a' = \left(1 - c_r\right) a + c_w$.

where demands are given by (2).[19] In SIAs, similarly, assume that firm $i = 1, 2$ owns the monopoly network, and hence, serves the wholesale market alone. Then, firm i, firm $j \neq i, e$ and firm e make the following profits, per area (gross of investment costs):

$$
\begin{aligned}
\pi_i^i(\widetilde{a}, p_1, p_2, p_e) &= p_i D_i(p_1, p_2, p_e) + \widetilde{a}\left(D_j(p_1, p_2, p_e) + D_e(p_1, p_2, p_e)\right), \\
\pi_j^i(\widetilde{a}, p_1, p_2, p_e) &= (p_j - \widetilde{a}) D_j(p_1, p_2, p_e), \\
\pi_e^i(\widetilde{a}, p_1, p_2, p_e) &= (p_e - \widetilde{a}) D_e(p_1, p_2, p_e).
\end{aligned}
$$

The equilibrium profits with $a \geq 0$ and $\widetilde{a} \geq 0$ are reported in Appendix B. There, we also show that for all $\gamma > 0$ we have $a^m < a^d \leq a^e$ and $\widetilde{a}^m < \widetilde{a}^e$. We have $\bar{\pi}^m > \bar{\pi}^d > \bar{\pi}^t$, and $\bar{\pi}^m \geq 2\bar{\pi}^d$ for $\gamma \geq \gamma^{md} \approx 4.73$ and $\bar{\pi}^m < 2\bar{\pi}^d$ otherwise. Thus, a higher number of competitors reduces each firm's profit, and if services are sufficiently differentiated (i.e., γ is low enough), entry is beneficial from an industry point of view, due to a demand expansion effect.

To complete the specification of our market model, we will also sometimes assume that $c(z) = \beta z^k$, i.e. $C(z) = \beta z^{k+1}/(k+1)$, with $\beta, k > 0$.

3.3 Investment with Regulated Access

In the previous section, we solved the market competition stage. In this section, we consider the investment and access stages, assuming that access prices have been set by the regulator (which excludes the case of competition-based remedies).

At stage 3, firms ask for access in areas where an infrastructure has been rolled out. In DIAs, firm e randomly chooses an access provider. In SIAs where firm i has invested, firms $j \neq i$ ask for access. This is always optimal since by assumption each access seeker obtains positive profits, thus

[19] Note that for any $a > 0$ an infrastructure firm is always better off using its own network than renting access from the rival infrastructure firm's network.

stage 3 is trivial.

At stage 2, each incumbent firm i decides on a coverage $[0, z_i]$ so as to maximize its profit, given its rival's coverage $[0, z_j]$. If firm i chooses $z_i > z_j$ it will be the access provider in the SIAs $(z_j, z_i]$. However, in the areas $[0, z_j]$ either firm i or firm j can be the access provider, with expected per-area profits $\pi^d(a)$. Firm i's expected total profit then becomes

$$\Pi_i(z_i, z_j) = \begin{cases} z_i \pi^d(a) + (z_j - z_i)\,\widetilde{\pi}_i^j(\widetilde{a}) - C(z_i) & \text{if} \quad z_i \leq z_j \\ z_j \pi^d(a) + (z_i - z_j)\,\widetilde{\pi}_i^i(\widetilde{a}) - C(z_i) & \text{if} \quad z_i > z_j \end{cases}.$$

First, we determine under which conditions there are duplicate and single infrastructure areas at the stage 2 equilibrium. For small z_j, firm i chooses its coverage trading off the marginal profits from being an access provider $\widetilde{\pi}_i^i(\widetilde{a})$ and the cost of covering an additional marginal area alone. If z_j is large, on the other hand, firm i trades off remaining an access seeker in its marginal area to the gain from becoming an infrastructure owner minus investment cost. Its net profit gain in this case is the difference between an infrastructure owner's expected profits $\pi^d(a)$ and those of an access seeker, $\widetilde{\pi}_i^j(\widetilde{a})$.

Proposition 1 *Let* $a_f(\widetilde{a}) = (\pi^d)^{-1}(\widetilde{\pi}_i^i(\widetilde{a}) + \widetilde{\pi}_i^j(\widetilde{a}))$, $z^d(a, \widetilde{a}) \equiv c^{-1}\left(\pi^d(a) - \widetilde{\pi}_i^j(\widetilde{a})\right)$, *and* $\widetilde{z}(\widetilde{a}) \equiv c^{-1}(\widetilde{\pi}_i^i(\widetilde{a}))$. *The equilibria of the coverage subgames are as follows:*

- ***Partial Duplication (PD):*** *If* $a < a_f(\widetilde{a})$ *then* $z^d(a, \widetilde{a}) < \widetilde{z}(\widetilde{a})$ *and one incumbent firm covers the areas* $[0, \widetilde{z}(\widetilde{a})]$, *while the other firm duplicates in the areas* $\left[0, z^d(a, \widetilde{a})\right]$. *We have* $z^d(a, \widetilde{a}) = 0$, *i.e.* ***no duplication (ND)***, *if and only if* $a = \widetilde{a} = 0$.

- ***Full Duplication (FD):*** *If* $a \geq a_f(\widetilde{a})$, *both incumbent firms cover the areas* $\left[0, z^{fd}\right]$ *where* $z^{fd} \in \left[\widetilde{z}(\widetilde{a}), z^d(a, \widetilde{a})\right]$.

Coverage limits $z^d(a, \widetilde{a})$ *and* $\widetilde{z}(\widetilde{a})$ *strictly increase in* $a \in \left[0, a^d\right]$ *and* $\widetilde{a} \in [0, \widetilde{a}^m]$.

Proof. See Appendix C. ■

This general result does not use our market model, and we will now give some intuition for the different outcomes. No duplication occurs when investing in becoming a potential access provider is very unattractive, which happens exactly when both access charges are very low. A DIA access charge a at cost reduces the returns from duplication, while a SIA access charge at cost increases the opportunity cost of duplicating instead of being an access seeker.

For intermediate level of the DIA access charge a, or if the SIA access charge $\widetilde{a}$ is high enough, we see that duplication occurs in the cheapest areas to cover, while only one infrastructure will cover more costly areas. In this case, the SIA and DIA access charges are high enough so that being an access provider is attractive, while at the same time the DIA access charge is also low enough to avoid full duplication.

At the other extreme of a very high DIA access charge, i.e. $a \geq a_f(\widetilde{a})$, we obtain multiple equilibria which all involve full duplication but different coverage levels. The existence of these equilibria is due to a coordination failure between investors: All firms would actually prefer full duplication up to $z^d(a, \widetilde{a})$, but if one firm covers less then the other investor will not find it profitable to extend coverage any further on its own.

The case of full duplication involves an interesting additional issue: While the boundaries of the equilibrium region change with access charges, any interior equilibrium point remains unaffected by small changes of the latter. Together with the fact that these equilibria are Pareto-ranked in the sense that among them a joint coverage of all areas up to $z^d(a, \widetilde{a})$ leads to the highest welfare and profits, this points to an additional potential role to the regulator. This role would be to help firms coordinate on the "right" equilibrium while ensuring that coverage responds announced access charges.

The above Proposition also implies that total and duplicated coverage increase in both access charges. This implies that the regulator faces the usual dilemma between setting lower access charges to maximize per-area welfare and higher access charges to maximize or duplicate coverage. There is an additional subtle issue, however, which is that in DIAs it is necessary to distinguish between the imposition of a specific value for the access charge (as we have implicitly assumed in the statement of the proposition) or the imposition of a price cap. This distinction matters whenever the regulator would want to increase coverage through an access price above a^m, which is the maximum price that the access provider would like to have. If the regulator sets a cap a above a^m, rather than imposing the access price a, the access provider will ex post choose the access price $a^m < a$ and duopoly coverage will not increase beyond $z^d(a^m, \widetilde{a})$. On the other hand, if an access price $a > a^m$ is fixed before investments are made then the possibility of *not* being the access provider while benefiting from a high retail price level raises expected profits and increases coverage.

With our market model, full duplication cannot arise if $\gamma < 5.973$ since then $a^d < a_f(0)$. For larger values of γ, full duplication still arises only for sufficiently low values of $\widetilde{a}$ such that $a^d \geq a_f(\widetilde{a})$. Higher $\widetilde{a}$ makes full duplication less likely since $\widetilde{\pi}_i^i(\widetilde{a}) + \widetilde{\pi}_i^j(\widetilde{a})$ and thus $a_f(\widetilde{a})$ are increasing in this range. Thus, for full duplication it is both necessary that services are sufficiently homogeneous and that the SIA access price is close to cost. The latter implies that investing in an additional single coverage area has very low returns. Figure 1 depicts the equilibrium regions for $\gamma = 10$.

In order to obtain a more complete picture of the effects of the access obligation on coverage, we now compare for our market model the above outcomes to the ones under the no-access benchmark in Lemma 1.

Proposition 2 *Under our market model (2), the following holds for equilibrium coverage under access as compared to no access:*

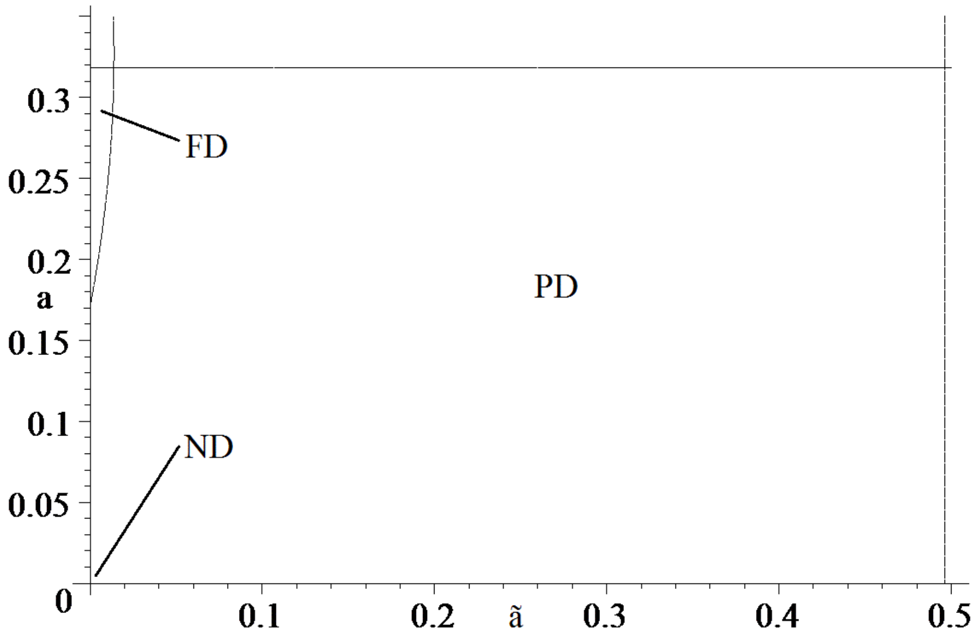

Figure 1: The equilibrium regions for the market model and $\gamma = 10$.

1. *The single infrastructure coverage limit is lower unless $\widetilde{a}$ is high enough.*

2. *Duplicated coverage under access is lower unless γ, a and $\widetilde{a}$ are high enough.*

Proof. See Appendix D, which also states precise conditions. ■

Low access charges reduce investment incentives and coverage. Still, contrary to what might be expected, coverage can increase if access charges are high enough. The reason for this outcome is that services are differentiated, so there is a demand expansion effect of entry which makes it profitable to provide access at sufficiently high access prices. The proof of Proposition 2 shows that SIA coverage under access is higher if and only if $\widetilde{\pi}_i^i(\widetilde{a}) > \bar{\pi}^m$. As mentioned above, this is exactly the condition that an unregulated single infrastructure owner would not want to foreclose the access seekers. Therefore, we can restate the above result as: SIA coverage increases under access if and only if the infrastructure owner would not want to foreclose entrants. This equivalence arises because both conditions hinge on comparing the access provider's profit to the monopoly profit.

Concerning duplication, the implications of access are similar, but with a twist. First of all, if the regulator imposes a price cap and thus firms will not choose an access price above a^m, duplicated coverage will always be smaller than without access. Thus the only way to increase coverage is force an access price above a^m. Even then, services must be sufficiently homogenous, so that high access charges can sufficiently soften competition in DIAs and reduce access seekers' profits in SIAs. The former then leads to higher gains from duplication, while the latter makes asking for access less attractive.

4 Socially Optimal Access Charges

We now turn to the regulator's preferred outcomes. First, we will consider very flexible schemes where access prices vary with location. Then, we will turn to duplication-based access charges.

4.1 Pure Geographical Remedies

With pure geographical differentiation, each local area z has a corresponding DIA access charge a_z and a SIA access charge $\widetilde{a}_z$. Whichever is applied will depend on whether the area will be covered by one or two infrastructures. While this case offers maximum flexibility to the regulator, and therefore leads to maximal welfare given that firms choose coverage given access charges, in practice such a scheme would be hard to implement. Informational requirements would be very large, and the process of setting a large number of different access charges should be even more contentious than setting just one or two. Therefore, we present this case principally as a theoretical benchmark, rather than as a practical proposal.

The analysis is straightforward since the optimal access rates for each area can be determined recursively and separately from those for other areas. If area z is a SIA, the regulator will maximize welfare while making sure that investment takes place:

$$\max_{\widetilde{a}_z} \widetilde{w}(\widetilde{a}_z) - c(z) \quad s.t.\ \widetilde{\pi}_i^i(\widetilde{a}_z) \geq c(z).$$

On the other hand, if z is a DIA the problem is to maximize welfare while making sure that duplication takes place, i.e., given $\widetilde{a}_z$ the regulator solves

$$\max_{a_z} w(a_z) - 2c(z) \quad s.t.\ \pi^d(a_z) - \widetilde{\pi}_i^j(\widetilde{a}_z) \geq c(z).$$

We find the following:

Proposition 3 *Under pure geographical differentiation,*

1. *In SIAs the optimal local access charge is $\widetilde{a}_z = 0$ if $c(z) < \bar{\pi}^t$, and is given by $\widetilde{\pi}_i^i(\widetilde{a}_z) = c(z)$ otherwise.*

2. *The socially optimal coverage is given by $z^{so} = c^{-1}(\widetilde{\pi}_i^i(\widetilde{a}^m))$.*

3. *It is socially optimal to have no duplication in area z if $w(a_z) - c(z) < \widetilde{w}(\widetilde{a}_z)$, where a_z is the optimal local access charge for DIAs. In particular, duplication is never optimal if $0 < c(z) < \bar{\pi}^t$.*

4. *LRIC access charges are higher than the socially optimal ones.*

Proof. 1. Since $\widetilde{w}(.)$ decreases and $\widetilde{\pi}_i^i(.)$ increases in the access charge up to $\widetilde{a}^m$, in area z it is optimal to choose the smallest access charge $\widetilde{a}_z \geq 0$ such that $\widetilde{\pi}_i^i(\widetilde{a}_z) \geq c(z)$ still holds. For $c(z) < \bar{\pi}^t$ this implies $\widetilde{a}_z = 0$, while for larger z the condition holds with equality.

2. Since the zero-profit condition will hold at the marginal covered area, the latter is defined by the maximal profit that the network owner can earn, i.e. $\widetilde{\pi}_i^i(\widetilde{a}^m)$.

3. The optimal a_z is the smallest access charge for area z such that duplication at least breaks even, i.e. that $\pi^d(a_z) - \widetilde{\pi}_i^j(\widetilde{a}_z) \geq c(z)$. Thus either $a_z = 0$ if $\bar{\pi}^t > \widetilde{\pi}_i^j(\widetilde{a}_z) + c(z)$, or the condition holds with equality. Welfare without duplication is higher if $w(a_z) - 2c(z) < \widetilde{w}(\widetilde{a}_z) - c(z)$. This is true whenever $c(z) < \bar{\pi}^t$ because then $\widetilde{a}_z = 0$ and maximal static welfare is achieved. That is, duplication brings no additional benefits but involves cost of duplication.

4. The LRIC access charge $\widetilde{a}_z^L$ in SIA z is given by $(\widetilde{q}_i^i(\widetilde{a}_z^L) + \widetilde{q}_j^i(\widetilde{a}_z^L) + \widetilde{q}_e^i(\widetilde{a}_z^L))\widetilde{a}_z^L = c(z)$, where $\widetilde{q}_k^i(.)$ is firm k's quantity, so that the incumbent's profits become

$$\widetilde{\pi}_i^i(\widetilde{a}_z^L) - c(z) = \widetilde{p}_i^i \widetilde{q}_i^i + (\widetilde{q}_j^i + \widetilde{q}_e^i)\widetilde{a}_z^L - c(z) = \left(\widetilde{p}_i^i - \widetilde{a}_z^L\right)\widetilde{q}_i^i.$$

These profits are strictly positive since $\widetilde{p}_i^i > \widetilde{p}_i^j$ due to the softening effect and since access seekers are not foreclosed. Thus the LRIC access charge is higher than the socially optimal access charge.

■

Essentially, under pure geographical differentiation the optimal access charge is just high enough to make coverage feasible while being as low as possible in order to maximize local welfare. Coverage can be achieved as long as the incumbent firm can make enough profits, i.e., profits at the monopoly access charge provide the coverage limit.

Duplication of infrastructure brings no social benefits when the optimal local access price in SIAs is very low. In this case the cost of duplication far outweigh the potential gains from a more competitive product market. While for higher SIA access charges generically it might be possible that duplication pays off if the latter leads to much higher welfare at equal access prices, for our market model we verified that duplication is indeed never optimal in any area z if the local SIA access prices are set optimally.

Finally, LRIC access charges by design leave a positive rent to the investing firm, so that their level needs to be higher than the socially optimal ones which again by design lead to zero profits.

Thus the analysis reveals an extreme trade-off between static welfare and investment incentives. Under duplication-based access charges the same trade-offs are present, but they are averaged out over regions subject to the same access charge.

4.2 Duplication-Based Remedies

Absent transaction costs, duplication-based remedies will lead to lower social surplus than pure geographical remedies, for the simple reason that the former provide less flexibility and therefore fewer instruments than the latter. Thus, in theory access prices should optimally vary with location. Still, the informational requirements and procedural complications seem daunting. For this reason, what has been implemented in practice is a style of regulation where the distinction between access charges is not based directly on location, but rather on the number of infrastructures at each location. This has the advantage of being a transparent and more easily implementable criterion.

For both single and duplicated investment, social benefits from higher coverage need to be traded off against social costs in terms of higher market prices. Before considering the regulatory regimes mentioned above, we clarify these trade-offs.

Welfare in a given area is the sum of consumer surplus and industry profits gross of investment costs, which we denote $w(a)$ in DIAs and $\widetilde{w}(\widetilde{a})$ in SIAs. Higher access charges push up the price level and reduce consumption, and therefore reduce per-area welfare.

We discuss the trade-offs involved for partial duplication. Since $\widetilde{z}(\widetilde{a}) > z^d(a, \widetilde{a})$, total welfare is given by

$$W(a, \widetilde{a}) = z^d(a, \widetilde{a})w(a) + \left(\widetilde{z}(\widetilde{a}) - z^d(a, \widetilde{a})\right) \widetilde{w}(\widetilde{a}) - C(\widetilde{z}(\widetilde{a})) - C(z^d(a, \widetilde{a})). \tag{3}$$

The social benefits of covering marginal single or duplicated areas are

$$\begin{aligned}\Delta^m(\widetilde{a}) &= \widetilde{w}(\widetilde{a}) - c(\widetilde{z}(\widetilde{a})) = \widetilde{w}(\widetilde{a}) - \widetilde{\pi}_i^i(\widetilde{a}), \\ \Delta^d(a,\widetilde{a}) &= w(a) - \widetilde{w}(\widetilde{a}) - c(z^d(a,\widetilde{a})) = w(a) - \pi^d(a) - \widetilde{w}(\widetilde{a}) + \widetilde{\pi}_i^j(\widetilde{a}),\end{aligned}$$

respectively. Both contain the net benefit of investment, i.e. welfare minus investment cost, while the latter also includes the social opportunity cost of duplication, which is the foregone social welfare under a monopoly infrastructure, $\widetilde{w}(\widetilde{a})$. While $\Delta^m(\widetilde{a})$ is always positive, $\Delta^d(a,\widetilde{a})$ may be negative for high a and low $\widetilde{a}$.

With these definitions, the effect of the access charges on welfare is given by

$$\frac{\partial W}{\partial a} = \underbrace{z^d(a,\widetilde{a})w'(a)}_{\text{(-)}} + \underbrace{\Delta^d(a,\widetilde{a})\frac{\partial z^d(a,\widetilde{a})}{\partial a}}_{\text{(+) or (-)}}, \tag{4}$$

and

$$\frac{\partial W}{\partial \widetilde{a}} = \underbrace{\left(\widetilde{z}(\widetilde{a}) - z^d(a,\widetilde{a})\right)\widetilde{w}'(\widetilde{a})}_{\text{(-)}} + \underbrace{\Delta^m(\widetilde{a})\widetilde{z}'(\widetilde{a})}_{\text{(+)}} + \underbrace{\Delta^d(a,\widetilde{a})\frac{\partial z^d(a,\widetilde{a})}{\partial \widetilde{a}}}_{\text{(+) or (-)}}. \tag{5}$$

The first terms in equations (4) and (5) are negative and represent the loss in "static efficiency" due to higher access charges. The other terms represent the variation in welfare due the change in coverage, holding net per-area welfare fixed (i.e., the benefits or costs in terms of "dynamic efficiency"). The second term in (5) is positive, indicating that the regulator would always want to expand total coverage further by increasing $\widetilde{a}$. On the other hand, the last term in both expressions is ambiguous. Since it translates the net gain from transforming a single into a duplicate infrastructure area, it is positive only if under the given access charges increased competition outweighs the cost of additional investment. If not, then the regulator set both lower a and $\widetilde{a}$ in order to limit duplication.

With our market model, the welfare maximum is always achieved in the partial duplication case, and never under full or no duplication.[20] ND is never optimal because at $a = \widetilde{a} = 0$ it pays off to increase single infrastructure coverage by raising $\widetilde{a}$ (as shown below for the general case, we also have $\Delta^d(0,0) = 0$, so a marginal increase in duplication does not change welfare). FD is never optimal, either. Remember that this case only occurs if a is high and $\widetilde{a}$ is low, which leads to low welfare in duplicated areas and a low total coverage.

Under partial duplication, we find that the single infrastructure access charge $\widetilde{a}$ is always optimally set above cost, while this is true for the duplicate infrastructure access charge a if and only if $\gamma > 1.225$ (see Figure 2). For smaller values of γ, i.e., less differentiation, market power limits the gains from facility-based competition, which then do not outweigh the costs of duplication. As a result, the regulator chooses $a = 0$ in order to reduce duplication for $\gamma < 1.225$.

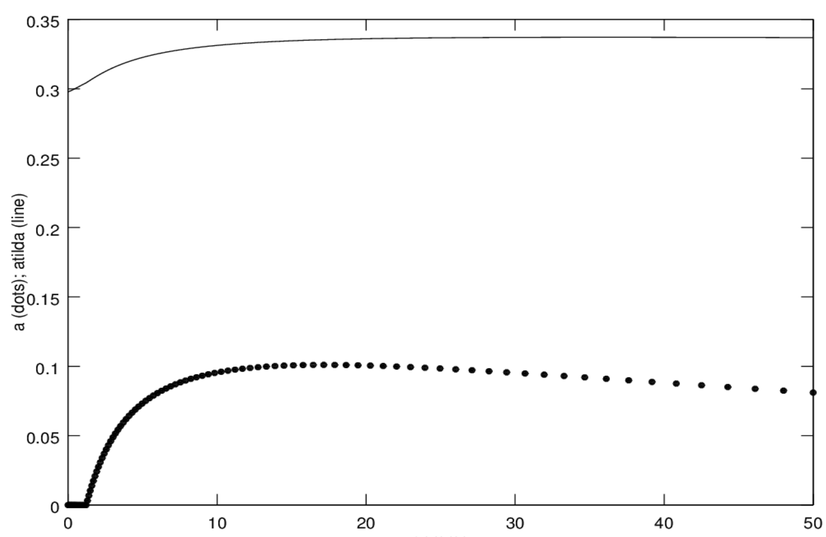

Figure 2: Socially optimal duplication-based access charges with $c(z) = \beta z$ (dots: a, line: $\widetilde{a}$).

The welfare derivatives (4) and (5) also show that duplication-based LRIC, i.e., $a = a^{LRIC}([0, z^d])$

[20] Details are available from the authors.

and $\widetilde{a} = a^{LRIC}([z^d, \widetilde{z}])$ will (almost) never be optimal. The reason is that the conditions that defines the access charges as being equal to (endogenously determined) average cost do not coincide with the first-order conditions for optimal access charges. Indeed, for the optimal access charges in Figure 2, we find that in SIAs aggregate access profits (including self-provision) significantly exceed investment cost, while in DIAs aggregate access profits exceed investment cost unless services are very differentiated. That is, duplication-based LRIC access charges, which would equate access profits and investment costs, tend to be lower than the optimal access charges.

5 Alternative Access Regimes and their Impact on Investment

In this section, we compare alternative access regimes–cost-based access pricing, uniform access pricing, and competition-based remedies–and their relative impact on coverage and welfare.

5.1 Cost-Based and Uniform Access Pricing

To begin with, we consider the standard regulatory practice of setting the same access charge everywhere, i.e., a uniform charge $a = \widetilde{a}$. This corresponds to the observation that some NRAs (e.g., in France, Germany, Italy and Spain) recognize the existence of geographical markets with different competitive pressure, but do not envision imposing differentiated remedies. ERG (2008) argues explicitly that having defined different geographical markets does not imply the need to adopt differentiated remedies if this might generate excessive complexity in the regulatory intervention.

Since we have assumed that marginal costs are the same everywhere, as opposed to the cost of investment, cost-based access charges ($a = \widetilde{a} = 0$) are a special case of uniform access pricing in our setup. As noted above, cost-based access will lead to no infrastructure duplication, since the second incumbent can obtain the same gross retail profits by asking for access and without having to invest. The first question we will ask is whether cost-based access can be the social optimum.

Let $k(z) = zc'(z)/c(z)$ be the elasticity of the local investment cost; for example, for $c(z) = z^{\kappa}$, one obtains $k(z) = \kappa$.

Proposition 4 *We have the following results: Cost-based access pricing*

1. *leads to no duplication of infrastructure.*

2. *is not socially optimal if*

$$k(z) < k^* \equiv \frac{\widetilde{w}(0) - \overline{\pi}^t}{\overline{\pi}^t} \frac{(\widetilde{\pi}_i^i)'(0)}{-\widetilde{w}'(0)} \tag{6}$$

3. *can be, simultaneously, optimal if duplication is not (technically) feasible and not optimal if duplication is possible.*

Proof. See Appendix E. ■

Cost-based access pricing implies that no duplication takes place when the other potential investor can ask for access. As pointed out above, doing the latter it can obtain the same retail profits without having to invest into a network.

For this reason, it is rather unlikely that cost-based access pricing can be optimal, and our sufficient conditions for its non-optimality are quite weak. If we complement our market model with the investment cost function $c(z) = \beta z^{\kappa}$, β, $\kappa > 0$, we obtain

$$k^* = \frac{(2\gamma + 7)\left(5\gamma^2 + 18\gamma + 18\right)}{3(6 + 5\gamma)} \geq 7.$$

Thus, cost-based access can be optimal only if $\kappa > 7$, which excludes linear and quadratic marginal cost specifications. Even then it tends not to be optimal, for the reason outlined in the proof of statement 3. At $a = \widetilde{a} = 0$ the last term in (5) is either zero or positive, and thus welfare under duplication increases at least as much at $\widetilde{a} = 0$ as when duplication was not feasible. The possibility of duplication changes the trade-off between loss in static welfare and coverage of additional areas that defines the optimal SIA access charge: When $\widetilde{a}$ is increased above cost, duplication starts to substitute SIA areas by DIA areas to which the access charge $\widetilde{a}$ is not applied. The loss in static welfare is reduced, which makes higher $\widetilde{a}$ optimal. Thus, partial duplication tends to dominate no duplication, implying that cost-based access is not optimal.

In contrast to the cost-based access regime, infrastructure competition can emerge in the uniform access regime when the access charge $\widetilde{a} = a$ is above cost. We now consider whether the uniform access regime can achieve the social optimum in this case.

Proposition 5 *Uniform access pricing is not socially optimal if* $\pi^d(a) - \widetilde{\pi}_i^j(a) > w(a) - \widetilde{w}(a)$ *for all* $a > 0$.

Proof. The result follows from $\Delta^d(a, a) < 0$ and thus $\partial W(a, \widetilde{a})/\partial a|_{\widetilde{a}=a} < 0$ from (4). ■

A sufficient condition for the non-optimality of uniform access pricing, even when marginal costs are identical in different areas, is that the gross private gain from transforming a single-infrastructure into a marginal duplicated infrastructure area exceeds the gross social gain from doing so. The intuition behind this result is that the private gains in marginal DIAs are equal to the investment cost, which therefore exceed the resulting benefits. In this case, the regulator would rather lower the DIA access charge a in order to reduce duplication. This conclusion also applies to uniform LRIC access charges on $[0, \widetilde{z}]$, since they are not structurally different from other uniform charges.

In our market model, independently of how investment cost is specified, $\Delta^d(a, a) < 0$ for all $0 < a \leq a^m$, and thus uniform access pricing is never socially optimal.[21] Thus, society is better off if the regulator adopts geographically differentiated access charges, as illustrated in Figure 2.

[21] However, total welfare tends to be higher under uniform access prices than under cost-based ones, because under our setting, the cost-based regime is a special case of the uniform regime where the uniform access price is set to zero.

In this case, the SIA access charge $\widetilde{a}$ is kept above the DIA access charge a in order to provide investment incentives while keeping the static welfare losses in DIAs low.

5.2 Competition-Based Remedies

An alternative to maintaining uniform or different access price regulation in regions with facility-based competition is to relax access obligations. This should not be done, though, without taking into account how this relaxation affects incentives for both duplication and total coverage, and how dispute resolution procedures are implemented.

More precisely, we consider differentiated remedies where the regulator implements a light regulatory approach in DIAs.

Infrastructure owners can make freely private access offers to the entrant. Only if the entrant does not receive any offer that allows it to make a positive profit, i.e. if either it receives no access offer or if the best offer is a^e or higher, will the regulator take action. In this case we assume that the regulator imposes a "dispute resolution access price" $a^{dr} < a^e$ to both incumbents. In this way, the regulator allows network owners to compete in access while guaranteeing positive profits for the entrant.[22] Foreseeing the resulting market outcome, the regulator also sets the SIA access charge in order to maximize total welfare.

As we already mentioned, we slightly modify the timing of the game in this section. In the first stage, the regulator sets the SIA access price. In the second stage, firms 1 and 2 decide on coverage. In the third stage, firms 1 and 2 set their DIA access charges $a_1, a_2 \in [0, \infty]$,[23] and the regulator imposes $a_i = a^{dr}$ if $\min\{a_1, a_2\} \geq a^e$. Then, firms decide whether to ask for access in any given area. Finally, in the fourth stage firms compete for consumers.

[22] See Bourreau et al. (2011) for the foreclosure case. We do not analyze it here since we consider an environment where a minimal regulation is present to prevent this outcome.

[23] We equate an access price of infinity to not making an access offer.

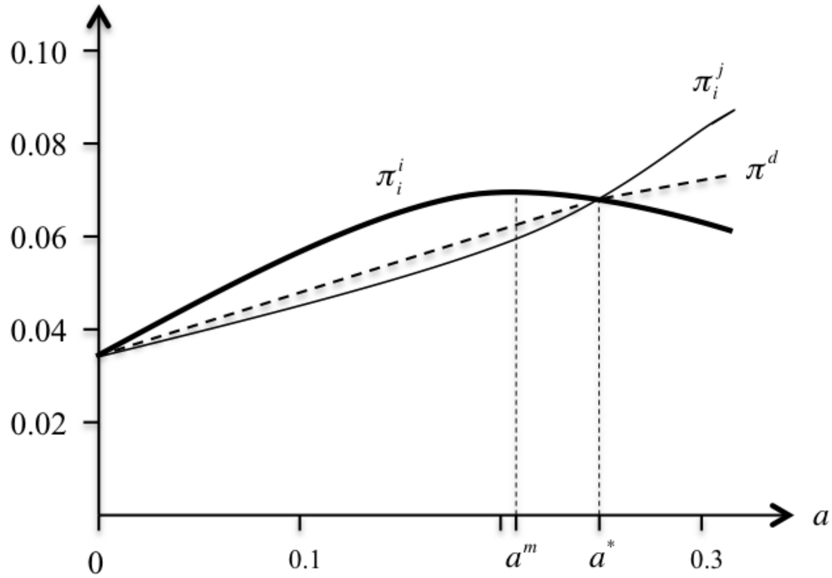

Figure 3: Profits in duplicated infrastructure areas for $a^* > a^m$

Again, we proceed by backward induction. The equilibrium in Stage 4 is the same as in Section 3.2. We now proceed with Stage 3 where firms ask for access. In SIAs, where only firm i has invested, firm $j \neq i$ and firm e ask for access at the regulated access price $\widetilde{a} \leq \widetilde{a}^m$. In DIAs, on the other hand, the entrant chooses the incumbent with lower access price a_i or selects one firm randomly if $a_1 = a_2$.

Now, we need to determine the incumbent networks' equilibrium choice of the DIA access charges a_i. As shown in Bourreau et al. (2011), more than one equilibrium outcome may exist. The reason is that the access-providing incumbent becomes a less aggressive competitor, which is due to the "fat-cat effect" (Fudenberg and Tirole, 1984) or "softening effect" (Bourreau et al., 2011). While for a low access charge the access provider's profits are higher than those of the other infrastructure owner, for a high access charge the opposite tends to hold. That is, there may be $a^* \in (0, a^e)$ such that $\pi_i^i(a) > (<)\ \pi_j^i(a)$ for $a < (>)\ a^*$. As we will see, this implies that firms may prefer to step back instead of competing to be the access provider.

Furthermore, the regulator's dispute resolution procedure also has surprising effects on potential

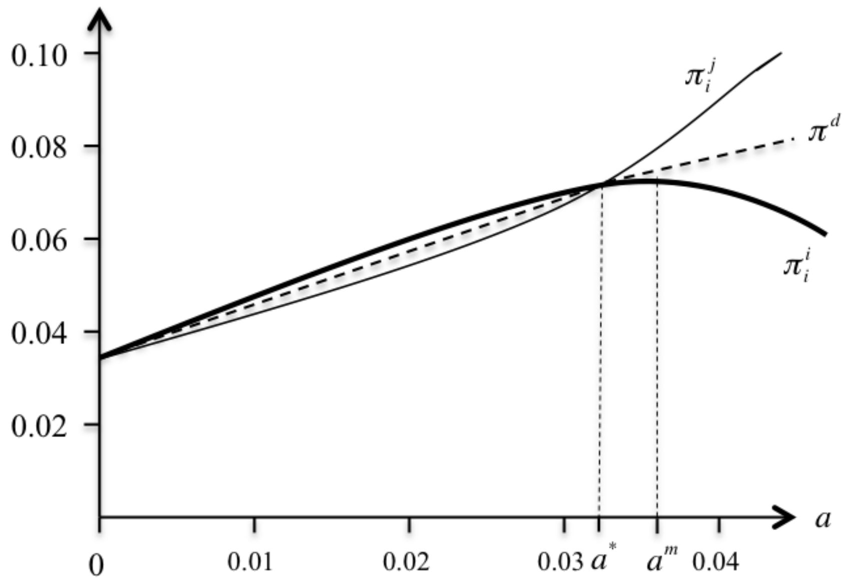

Figure 4: Profits in duplicated infrastructure areas for $a^* < a^m$

equilibria: Depending on the level of a^{dr} additional equilibria can arise. For the purpose of this discussion, define $\hat{a}$ by $\pi^d(\hat{a}) = \pi_i^i(a^m)$, and note that either $a^m < a^* < \hat{a}$, $a^* = a^m = \hat{a}$ or $a^* < \hat{a} < a^m$. Thus, in all cases we have $\hat{a} \geq a^*$. For our market model, $\hat{a}$ is given in Appendix B and is always very close to a^*.

Proposition 6 *All wholesale pricing equilibria are given by the following:*

1. *Cost-based access, $a_1 = a_2 = 0$, is always an equilibrium.*

2. *If $a^{dr} \geq \hat{a}$, then all $a_1, a_2 \geq a^e$, i.e., firms not making feasible access offers, are equilibria.*

3. *If $a^* \leq a^m$, then there is an equilibrium at $a_1 = a_2 = a^*$, and if also $a^{dr} \leq \hat{a}$ then $a_i = a^m$ and $a_j \geq a^e$ are equilibria.*

Proof. See Appendix F. ■

The intuitive explanation for the cost-based equilibrium is the rent equalization result of Fudenberg and Tirole (1985). Any access price below a^* can be profitably underbid, and the ensuing "race to the bottom" only stops when the profits of the access provider and its rival are equal, i.e. at $a = 0$ (see Figures 3 and 4). This equilibrium is unique if $a^* > a^m$ and $\pi^d(a^{dr}) < \pi_i^i(a^m)$. In our market model, we always have $a^* < a^e$, but $a^* < a^m$ happens if and only if $\gamma > \gamma^* \approx 41.0$ (see Appendix B), i.e., if services are sufficiently homogeneous. Thus, with enough homogeneity we obtain the second symmetric equilibrium at a^*. This is an equilibrium outcome because neither underbidding to be the definite provider, nor overbidding to not be the provider, increase expected profits.

The effects of the dispute resolution access charge a^{dr} may be most unexpected. If $a^{dr} \geq \hat{a}$, incumbents may not find it worthwhile to make feasible access offers. Rather, they can wait for the regulator to impose access and hope that afterwards their rival will be chosen by the entrant. In this case a^{dr} functions as if it was a cap on access prices to which equilibrium prices will stick. On the other hand, if $a^{dr} < \hat{a}$ then if services are sufficiently differentiated ($a^m < a^*$), it guarantees that the only equilibrium is at access prices equal to cost. With sufficient homogeneity, though, a new equilibrium arises where one firm offers the monopoly access charge and the other firm refrains from making a feasible offer. Thus, a low dispute resolution price can lead to an access market outcome at the monopoly price a^m, rather than inducing firms to necessarily settle for an equally low access price.

The outcomes of the wholesale pricing game do not depend on the SIA access charge $\widetilde{a}$, but investments at stage 2 will depend on both $\widetilde{a}$ and the value of the DIA access charge a resulting from the wholesale market equilibrium. For each given outcome, investments will then follow from the analysis in the last section.

Finally, we turn to the question whether and how the regulator can achieve the socially optimal outcome under wholesale competition. In short, the answer is "yes" in some cases, but mostly "no" unless it uses at least one further instrument.

We will first consider two broad cases, of whether the socially optimal DIA access charge is smaller or larger than a^*. Let us consider the former case first.

Proposition 7 *If $a^{so} < a^*$ then the regulator can only achieve the social optimum without further instruments if $a^{so} = 0$. Otherwise, imposing a price floor at $a = a^{so}$ restores the social optimum.*

Proof. The only wholesale equilibrium below a^* is at $a = 0$. A price floor at $a^{so} > 0$ avoids further underbidding and pegs the outcome at the socially optimal level. In either case, the regulator then chooses $\widetilde{a}$ at its optimal value. ■

In our market model, we find that $a^{so} < a^*$ if $\gamma < 33.30$, and $a^{so} = 0$ for $\gamma < 1.225$ (see Figure 2). Thus, for $1.225 < \gamma < 33.30$ the social optimum cannot be reached unless a price floor at a^{so} is introduced. On the other hand, since $\gamma < \gamma^* = 41.0$, we have $a^m < a^*$ and the only other equilibrium can be excluded if $a^{dr} \leq a^*$. Furthermore, if $a^{so} = a^*$ in our market model we still have $a^m < a^*$, so that a^* is not an equilibrium price unless the regulator sets a floor at this value.

Now, we consider the case $a^{so} > a^*$. In this case, we find the following outcomes:

Proposition 8 *If $a^{so} > a^*$ then $a^{dr} = a^{so}$ achieves the social optimum if $a^{so} \geq \hat{a}$. If $a^{so} < \hat{a}$ then the social optimum cannot be obtained without further instruments.*

Proof. For $a^{dr} = a^{so} \geq \hat{a}$ the equilibria with $a_i \geq a^e$ result in the social optimum after the dispute resolution price a^{dr} is imposed. On the other hand, if $a^{so} < \hat{a}$ these equilibria do not exist. ■

If the socially optimal access charge is above a^*, then curiously the social optimum is achieved in an equilibrium where first firms refuse to give access and where the regulator then imposes the socially optimal access price. It cannot be achieved at wholesale prices that are freely chosen by the market. Nor have we yet ruled out other equilibria.

For our market model, we have $a^{so} > \hat{a} > a^*$ when $\gamma > 33.32$, thus setting $a^{dr} = a^{so}$ results in an equilibrium at the socially optimal values.[24] Of course, the cost-based access equilibrium continues to exist, as much as the equilibrium at a^* for $\gamma > 41.0$. These can be avoided with a price floor above a^*.

Summing up, competition-based wholesale regulation can achieve the socially optimal outcome. Whether and how it does, though, depends on the fine details of how the "light regulation" is implemented. We will leave the investigation of other variants to further research.

6 Conclusions

One of the recent and hotly debated issues under the new EU regulatory framework – which aims to foster investment in new high-speed broadband networks – is the introduction of geographically differentiated remedies, that is, differentiated wholesale access schemes that vary according to the degree of infrastructure competition. In this paper we focus on this policy issue and explicitly consider the possibility for a regulator to impose differentiated access remedies and assess the impact of alternative regulatory access regimes on investment incentives.

Our results show that higher NGAN access charges lead to larger overall NGAN coverage and more duplication. This result implies that the regulator will face a dilemma between setting a lower access charge to maximize per-area welfare by maintaining lower retail prices, and setting a high access charge to maximize coverage. This trade-off is analyzed under different regulatory scenarios. In the presence of cost-based regulation, total coverage turns out to be lower than in the benchmark case where access is left unregulated. Hence, standard cost-based regulation, which has been traditionally applied to the legacy copper network, reduces investment incentives for new high-speed infrastructures.

[24] Only for γ between 33.30 and 33.32 do we obtain $a^* < a^{so} < \hat{a}$ and the social optimum cannot be achieved in this manner.

In presence of a uniform access price, total welfare is higher than under the cost-based regime. However, uniform access pricing never achieves the social optimum because it involves an excessive access charge for "competitive" areas and therefore too much duplication. Finally, with differentiated remedies where access is regulated in non-competitive areas, while access is privately negotiated in competitive areas, the socially optimal outcome may be achieved whenever the optimal access charge in competitive areas is equal to cost. The intricacies of wholesale competition imply, though, in general that equilibrium wholesale prices can be either too high or too low from a social point of view, and that the regulator would have to intervene with price floors or caps in order to improve on market outcomes.

Our framework is suitable to be extended in different directions. Obviously, our setting is static, hence each operator plays only once and investments are one-shot. One natural extension might be to introduce some dynamics in investment decisions. This would imply that the size of competitive and non-competitive areas change over time, calling for a dynamic adjustment of access remedies. A second, more practical, issue is the implementation of geographical remedies that might require additional administrative costs for the regulator due to the continuous adaptation of wholesale regimes as long as competitive conditions changes over time. Though interesting, we leave these potential extensions for future research.

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Appendix

Appendix A: Proof of Lemma 1

Let $\bar{z}^m = c^{-1}(\bar{\pi}^m)$ and $\bar{z}^d = c^{-1}(\bar{\pi}^d)$. Since $c' > 0$, we know that c^{-1} is a strictly increasing function, and thus $\bar{\pi}^m > \bar{\pi}^d$ implies $\bar{z}^m > \bar{z}^d$. Consider

$$\frac{\partial \Pi_i(z_i, z_j)}{\partial z_i} = \begin{cases} \bar{\pi}^d - c(z_i) & \text{if} \quad z_i \leq z_j \\ \bar{\pi}^m - c(z_i) & \text{if} \quad z_i > z_j \end{cases}.$$

We can see that if $z_j \geq \bar{z}^m$ then firm i's best response is $z_i = \bar{z}^d$; while it is $z_i = \bar{z}^m$ if $z_j \leq z^d$. For any equilibrium candidate $z_j \in (\bar{z}^d, \bar{z}^m)$, we see that firm i's profits are decreasing on $(\bar{z}^d, z_j)$ and increasing on $(z_j, \bar{z}^m)$, so that firm i's best response again is either $\bar{z}^d$ or $\bar{z}^m$, which together with the previous finding implies that z_j was no equilibrium candidate after all. Thus, the only (pure strategy) Nash equilibria are asymmetric with firms choosing either $\bar{z}^d$ or $\bar{z}^m$.

Appendix B: Expressions for the Shubik-Levitan Price Competition Model

No access. Without access, we find the following monopoly and duopoly profits:

$$\bar{\pi}^m = \frac{1+\gamma}{4(3+\gamma)}, \; \bar{\pi}^d = \frac{3(1+\gamma)(3+\gamma)}{(6+\gamma)^2(3+2\gamma)}.$$

Duplicate infrastructure areas (DIAs). With a given access charge a, we obtain the following Nash equilibrium profits:

$$\pi_i^i(a) = \frac{\left(3 + \frac{\gamma(9+5\gamma)}{6+5\gamma}a\right)\left(3 + 2\gamma - 3\frac{\gamma(1+\gamma)}{6+5\gamma}a\right)}{12(3+\gamma)^2} + \frac{a(3+2\gamma)\left(1 - \frac{(6+\gamma)(1+\gamma)}{6+5\gamma}a\right)}{6(3+\gamma)},$$

for $j \neq i, e$,

$$\pi_j^i(a) = \frac{(3+2\gamma)\left(1+\frac{\gamma(1+\gamma)}{6+5\gamma}a\right)^2}{4(3+\gamma)^2},$$

and

$$\pi_e^i(a) = \frac{(3+2\gamma)\left(1-\frac{(1+\gamma)(6+\gamma)}{6+5\gamma}a\right)^2}{4(3+\gamma)^2},$$

while the term inside the square is non-negative for

$$a \leq a^e = \frac{6+5\gamma}{(6+\gamma)(1+\gamma)}.$$

The access provider's (ex post) profits $\pi_i^i(a)$ are maximized at

$$a^m = \frac{3(6+5\gamma)\left(5\gamma^2+18\gamma+18\right)}{909\gamma^2+249\gamma^3+648+1296\gamma+20\gamma^4} < a^e,$$

while its ex-ante expected profits $\pi^d(a)$ over $[0, a^e]$ are maximized at

$$a^d = \min\left\{\frac{3(6+5\gamma)\left(7\gamma^2+21\gamma+18\right)}{2\left(7\gamma^4+117\gamma^3+450\gamma^2+648\gamma+324\right)}, a^e\right\},$$

where $a^d = a^e$ for $\gamma > 8.93$. Thus, $\pi^d(a)$ is strictly increasing on $\left[0, a^d\right]$ and has a strictly increasing inverse function $(\pi^d)^{-1}$.

We find that $\pi_i^i(a) \geq \pi_j^i(a)$ for $j \neq i, e$ (i.e., incumbents would prefer to give access rather than not) if and only if

$$a \leq a^* = \frac{9(\gamma+2)(6+5\gamma)}{13\gamma^3+93\gamma^2+180\gamma+108}.$$

It can be shown that $a^* < a^e$ for all $\gamma > 0$, but $a^* < a^m$ if and only if $\gamma > \gamma^* \approx 40.974$, where γ^* is the unique positive (real) solution to $a^* = a^m$.

Finally, if $\hat{a}$ is defined by $\pi^d(\hat{a}) = \pi_i^i(a^m)$, it exists if $\gamma > 8.830$ with

$$\hat{a} = \frac{3\,(6+5\gamma)\left(7\gamma^2+21\gamma+18-(3+\gamma)\sqrt{\frac{280\gamma^6-339\gamma^5-12\,231\gamma^4-47\,952\gamma^3-83\,268\gamma^2-69\,984\gamma-23\,328}{909\gamma^2+249\gamma^3+1296\gamma+648+20\gamma^4}}\right)}{2\,(7\gamma^4+117\gamma^3+450\gamma^2+648\gamma+324)}$$

Local welfare in DIAs is

$$\begin{aligned} w\,(a) \;&=\; \frac{(2\gamma+9)\,(2\gamma+3)}{8\,(\gamma+3)^2} - \frac{3\,(1+\gamma)}{4\,(\gamma+3)^2}a \\ &\quad - \frac{(1+\gamma)\left(8\gamma^4+147\gamma^3+495\gamma^2+648\gamma+324\right)}{24\,(\gamma+3)^2\,(6+5\gamma)^2}a^2, \end{aligned}$$

which is strictly decreasing in $a \geq 0$.

Single infrastructure areas (SIAs). With a given access charge $\widetilde{a}$, we find

$$\widetilde{\pi}_i^i(\widetilde{a}) = \frac{\left(3+\frac{2\gamma(9+5\gamma)}{6+5\gamma}\widetilde{a}\right)\left(3+2\gamma-\frac{6\gamma(1+\gamma)}{6+5\gamma}\widetilde{a}\right)}{12\,(\gamma+3)^2} + \frac{(3+2\gamma)\,\widetilde{a}\left(1-\frac{6(1+\gamma)}{6+5\gamma}\widetilde{a}\right)}{3\,(\gamma+3)},$$

and for $j \neq i$,

$$\widetilde{\pi}_j^i(\widetilde{a}) = \frac{(3+2\gamma)\left(1-\frac{6(1+\gamma)}{6+5\gamma}\widetilde{a}\right)^2}{4(3+\gamma)^2}$$

while the term inside the square is non-negative for

$$\widetilde{a} \leq \widetilde{a}^e = \frac{6+5\gamma}{6\,(1+\gamma)}.$$

Straight computations show that $\widetilde{\pi}_i^i(\widetilde{a}) > \bar{\pi}^t > \widetilde{\pi}_j^i(\widetilde{a})$ for all $\gamma, \widetilde{a} > 0$.

The access charge that maximizes $\widetilde{\pi}_i^i(\widetilde{a})$ is

$$\widetilde{a}^m = \frac{(6+5\gamma)\left(18+18\gamma+5\gamma^2\right)}{2\,(108+198\gamma+123\gamma^2+25\gamma^3)} < \widetilde{a}^e.$$

Contrary to DIA profits, $\widetilde{\pi}_i^i(\widetilde{a}) + \widetilde{\pi}_j^i(\widetilde{a})$ is not strictly increasing on $[0, \widetilde{a}^m]$, since it obtains its maximum below $\widetilde{a}^m$.

Local welfare in SIAs is

$$\begin{aligned}\widetilde{w}\left(\widetilde{a}\right) &= \frac{\left(2\gamma+9\right)\left(2\gamma+3\right)}{8\left(\gamma+3\right)^2} - \frac{3\left(1+\gamma\right)}{2\left(\gamma+3\right)^2}\widetilde{a} \\ &\quad - \frac{\left(1+\gamma\right)\left(25\gamma^3+87\gamma^2+108\gamma+54\right)}{2\left(\gamma+3\right)^2\left(6+5\gamma\right)^2}\widetilde{a}^2,\end{aligned}$$

which is strictly decreasing in $\widetilde{a} \geq 0$.

Some other comparisons. For $a = \widetilde{a} = 0$ we obtain for all $j = 1, 2, e$ that

$$\pi_j^i(0) = \widetilde{\pi}_j^i(0) = \bar{\pi}^t \equiv \frac{3+2\gamma}{4\left(3+\gamma\right)^2}.$$

It is easy to see that $\bar{\pi}^m > \bar{\pi}^d > \bar{\pi}^t > 0$. Furthermore, $\bar{\pi}^m > 2\bar{\pi}^d$ holds if and only if $\gamma > \gamma^{md} \approx 4.73$, where γ^{md} is the unique non-negative (real) solution of $\bar{\pi}^m = 2\bar{\pi}^d$.

Appendix C: Proof of Proposition 1

Proof. Assume that firm j has covered the areas $[0, z_j]$. Firm i's profit is

$$\Pi_i\left(z_i, z_j\right) = \begin{cases} z_i\pi^d(a) + \left(z_j - z_i\right)\widetilde{\pi}_i^j(\widetilde{a}) - C(z_i) & \text{if} \quad z_i \leq z_j \\ z_j\pi^d(a) + \left(z_i - z_j\right)\widetilde{\pi}_i^i(\widetilde{a}) - C(z_i) & \text{if} \quad z_i > z_j \end{cases}.$$

The interior maximum on the first branch is obtained when the first-order condition holds, that is, when $\pi^d(a) - \widetilde{\pi}_i^j(\widetilde{a}) = c\left(z_i\right)$. Since we have $\pi^d(a) \geq \bar{\pi}^t \geq \widetilde{\pi}_i^j(\widetilde{a})$ for all $a \in [0, a^m]$ and $\widetilde{a} \in [0, \widetilde{a}^m]$, we obtain $z_i = z^d(a, \widetilde{a}) \equiv c^{-1}\left(\pi^d(a) - \widetilde{\pi}_i^j(\widetilde{a})\right)$. Similarly, the interior maximum on the second branch is obtained at $\widetilde{\pi}_i^i(\widetilde{a}) = c(z_i)$, or $z_i = \widetilde{z}(\widetilde{a}) \equiv c^{-1}(\widetilde{\pi}_i^i(\widetilde{a}))$. In both cases the necessary second-order conditions hold since $-c(z_i) \leq 0$. Thus, firm i's local best responses are $\min\left\{z_j, z^d(a,\widetilde{a})\right\}$ on the first branch and $\widetilde{z}(\widetilde{a})$ on the second branch.

For $\pi^d(a) < \widetilde{\pi}_i^i(\widetilde{a}) + \widetilde{\pi}_i^j(\widetilde{a})$, which implies $0 \leq z^d(a,\widetilde{a}) < \widetilde{z}(\widetilde{a})$, the global best response to $z_j \leq z^d(a,\widetilde{a})$ is $z_i = \widetilde{z}(\widetilde{a})$, while the best response to $z_j \geq \widetilde{z}(\widetilde{a})$ is $z_i = z^d(a,\widetilde{a})$. Symmetry then implies that the only equilibria are $\left(z^d(a,\widetilde{a}), \widetilde{z}(\widetilde{a})\right)$ and $\left(\widetilde{z}(\widetilde{a}), z^d(a,\widetilde{a})\right)$. For $a = \widetilde{a} = 0$, we obtain $z^d(a,\widetilde{a}) = 0$ and thus no duplication (case ND), while for $a > 0$ or $\widetilde{a} > 0$ we have $\pi^d(a) > \widetilde{\pi}_i^j(\widetilde{a})$ and thus partial duplication (case PD).

On the other hand, for $\pi^d(a) \geq \widetilde{\pi}_i^i(\widetilde{a}) + \widetilde{\pi}_i^j(\widetilde{a})$ we have $0 < \widetilde{z}(\widetilde{a}) \leq z^d(a,\widetilde{a})$. The global best response is $\widetilde{z}(\widetilde{a})$ for $z_j \leq \widetilde{z}(\widetilde{a})$ and $\min\left\{z_j, z^d(a,\widetilde{a})\right\}$ for $z_j > \widetilde{z}(\widetilde{a})$. Thus by symmetry all equilibria are given by any $\left(z^{fd}, z^{fd}\right)$ with $z^{fd} \in \left[\widetilde{z}(\widetilde{a}), z^d(a,\widetilde{a})\right]$, i.e., full duplication (case FD).

The ranges indicated in the Proposition now follow from the fact that π^d is strictly increasing on $[0, a^m]$ and therefore has a strictly increasing inverse function, thus $\widetilde{z}(\widetilde{a}) > z^d(a,\widetilde{a})$ if and only if $a < a_f(\widetilde{a}) = (\pi^d)^{-1}(\widetilde{\pi}_i^i(\widetilde{a}) + \widetilde{\pi}_i^j(\widetilde{a}))$. The comparative statics for coverage ranges follow directly from $d\pi^d/da > 0$ for all $a \in [0, a^m)$, and $d\widetilde{\pi}_i^i/d\widetilde{a} > 0$ and $d\widetilde{\pi}_i^j/d\widetilde{a} < 0$ for all $\widetilde{a} \in [0, \widetilde{a}^m)$. ■

Appendix D: Proof of Proposition 2

Proof. 1. The SIA coverage limit is larger without access if $\bar{z}^m > \widetilde{z}(\widetilde{a})$, or $\bar{\pi}^m > \widetilde{\pi}_i^i(\widetilde{a})$. On the one hand, we have at $\widetilde{a} = 0$ that $\bar{\pi}^m > \widetilde{\pi}_i^i(0) = \bar{\pi}^t$ if $\gamma > 0$ (and $\bar{\pi}^m = \widetilde{\pi}_i^i(0)$ at $\gamma = 0$). On the other, at $\widetilde{a} = \widetilde{a}^m$ we find $\widetilde{\pi}_i^i(\widetilde{a}^m) > \bar{\pi}^m$. Since $\widetilde{\pi}_i^i(\widetilde{a})$ is strictly increasing in $\widetilde{a}$, there is a unique $\widetilde{a}^c \in [0, \widetilde{a}^m]$ such that $\widetilde{\pi}_i^i(\widetilde{a}^c) = \bar{\pi}^m$, which since $\widetilde{\pi}_i^i$ is concave and quadratic is the lower root of this equation:

$$\widetilde{a}^c = (6+5\gamma)\,\frac{5\gamma^2/2 + 9\gamma + 9 - \sqrt{(\gamma+3)\,(3+2\gamma)^3\,/\,(\gamma+1)}}{123\gamma^2 + 25\gamma^3 + 198\gamma + 108}.$$

2. The DIA coverage limit is larger without access if $\bar{z}^d > z^d(a,\widetilde{a})$, i.e., $\bar{\pi}^d > \pi^d(a) - \widetilde{\pi}_i^j(\widetilde{a})$. The right-hand side is increasing in a and $\widetilde{a}$ because π^d is increasing in a and $\widetilde{\pi}_i^j$ is decreasing in $\widetilde{a}$, with

$\pi^d(0) - \widetilde{\pi}_i^j(0) = 0 < \bar{\pi}^d$. We have

$$\begin{aligned}
\pi^d\left(a^m\right) &= \frac{\left(25\gamma^2+66\gamma+45\right)\left(95\gamma^5+1185\gamma^4+5238\gamma^3+10\,692\gamma^2+10\,368\gamma+3888\right)}{4\left(909\gamma^2+249\gamma^3+1296\gamma+648+20\gamma^4\right)^2}, \\
\pi^d\left(a^d\right) &= \begin{cases} \frac{203\gamma^3+831\gamma^2+1152\gamma+540}{16(450\gamma^2+117\gamma^3+648\gamma+324+7\gamma^4)} & if \quad \gamma \leq 8.927 \\ \pi^d\left(a^e\right) = \frac{1}{3}\frac{5\gamma^2+15\gamma+9}{(1+\gamma)(6+\gamma)^2} & if \quad \gamma \geq 8.927 \end{cases}, \\
\widetilde{\pi}_i^j\left(\widetilde{a}^m\right) &= \frac{(3+2\gamma)\left(5\gamma^2+12\gamma+9\right)^2}{\left(123\gamma^2+25\gamma^3+198\gamma+108\right)^2}.
\end{aligned}$$

We find that $\bar{\pi}^d > \pi^d(a^m) - \widetilde{\pi}_i^j(\widetilde{a}^m)$ for all $\gamma > 0$. Also, $\bar{\pi}^d > \pi^d(a^d) - \widetilde{\pi}_i^j(\widetilde{a}^m)$ for all $\gamma < 12.213$, while $\bar{\pi}^d < \pi^d(a^d) - \widetilde{\pi}_i^j(\widetilde{a}^m)$ for $\gamma > 12.213$ (where $a^d = a^e$). In the latter case there are pairs of $(a, \widetilde{a})$ such that $\pi^d(a) - \widetilde{\pi}_i^j(\widetilde{a}) = \bar{\pi}^d$ with $d\widetilde{a}/da = \left(\partial\pi^d(a)/\partial a\right) / \left(\partial\widetilde{\pi}_i^j(\widetilde{a})/\partial\widetilde{a}\right) < 0$. For any higher pair $(a, \widetilde{a})$, coverage increases under access. Note that for this argument we continue to assume that regulator imposes the exact access price levels, i.e. a and $\widetilde{a}$ are not price caps. ■

Appendix E: Proof of Proposition 4

Proof. 1. This follows directly from Proposition 1.

2. The first-order condition for welfare maximization with respect to the SIA access charge $\widetilde{a}$ at $a = \widetilde{a} = 0$ is

$$\frac{\partial W\left(0,0\right)}{\partial \widetilde{a}} = \left(\widetilde{z}(0) - z^d(0,0)\right)\widetilde{w}'\left(0\right) + \left(\widetilde{w}(0) - c(\widetilde{z}(0))\right)\widetilde{z}'(0) + \lim_{\widetilde{a}\to 0}\left(\Delta^d(0,\widetilde{a})\frac{\partial z^d(0,\widetilde{a})}{\partial \widetilde{a}}\right).$$

At $a = \widetilde{a} = 0$, we have $\pi^d(0) = \widetilde{\pi}_i^i(0) = \pi^t$ and

$$z^d(0,0) = c^{-1}\left(\bar{\pi}^t - \bar{\pi}^t\right) = 0, \quad \Delta^d\left(0,0\right) = w(0) - \bar{\pi}^t - \widetilde{w}(0) + \bar{\pi}^t = 0.$$

Thus, if $\partial z^d/\partial \widetilde{a}$ is finite, the last term disappears. Defining $k(z) = zc'(z)/c(z)$, we have

$$\begin{aligned} \frac{\partial W(0,0)}{\partial \widetilde{a}} &= \widetilde{z}(0)\widetilde{w}'(0) + (\widetilde{w}(0) - \bar{\pi}^t)\widetilde{z}'(0) \\ &= \widetilde{z}(0)\widetilde{w}'(0) + (\widetilde{w}(0) - \bar{\pi}^t)\frac{(\widetilde{\pi}_i^i)'(0)}{c'(\widetilde{z}(0))} \\ &= \widetilde{z}(0)\left(\widetilde{w}'(0) + \frac{\widetilde{w}(0) - \bar{\pi}^t}{\bar{\pi}^t}\frac{(\widetilde{\pi}_i^i)'(0)}{k(\widetilde{z}(0))}\right). \end{aligned}$$

A sufficient condition for $\partial W(0,0)/\partial \widetilde{a} > 0$ is

$$k(\widetilde{z}(0)) < k^* \equiv \frac{\widetilde{w}(0) - \bar{\pi}^t}{\bar{\pi}^t}\frac{(\widetilde{\pi}_i^i)'(0)}{-\widetilde{w}'(0)}.$$

Finally, if $\partial z^d/\partial \widetilde{a}$ is infinite, then $k(\widetilde{z}(0)) < k^*$ continues to be sufficient for $\partial W(0,0)/\partial \widetilde{a} > 0$.

3. The proof of the second statement is by way of an example. Let $\gamma = 1$ and $c(z) = z^\kappa$ with $\kappa = 12$. The welfare for the scenario where duplication is not feasible for some exogenous reason is $W^{ND}(\widetilde{a}) = \widetilde{w}(\widetilde{a})\widetilde{z}(\widetilde{a}) - C(\widetilde{z}(\widetilde{a}))$, which in this case has a global maximum at $\widetilde{a} = 0$. On the other hand, while $W(0, \widetilde{a})$ is locally decreasing at $\widetilde{a} = 0$ due to $\kappa > k^* \approx 11.2$, it takes on higher values for $\widetilde{a}$ high enough. Thus, welfare under duplication is not maximized at $a = \widetilde{a} = 0$. ■

6.1 Appendix F: Proof of Proposition 6

Proof. Let us first consider symmetric equilibrium candidates $a \in [0, a^e)$, where both firms earn $\pi^d(a)$. Any deviation to $a' < a$ leads to profits $\pi_i^i(a')$, while an upwards deviation to $a'' > a$ yields $\pi_j^i(a)$ since the access price charged in the latter case is still a. Now, since $\pi^d(a)$ is the unweighted average of $\pi_i^i(a)$ and $\pi_j^i(a)$, either one of the latter is strictly higher than $\pi^d(a)$ unless $a = 0$ or $a = a^*$ (where they are equal, see Figures 3 and 4 in the text), and due to continuity profitable deviations exist. At $a = a^*$, one firm will deviate to a^m if and only $a^m < a^*$, while at $a = 0$ there are never profitable deviations. Thus, $a_1 = a_2 = 0$ is an equilibrium, and $a_1 = a_2 = a^*$ is an equilibrium too if and only if $a^* \leq a^m$.

Now, consider asymmetric equilibrium candidates $0 \leq a_i < a_j < a^e$, with profits $\pi_i^i(a_i)$ and $\pi_j^i(a_i)$. First, for $a_i = 0$ firm i increases its profits by deviating to some $a < a_j$. Second, for $0 < a_i < a^*$ firm j can increase its profits by underbidding. Third, for $a_i \geq a^*$ firm i can increase its profits to $\pi_i^j(a_j)$ by increasing its access price just beyond a_j. Thus, there are no asymmetric equilibria with $a_j < a^e$.

Now, consider asymmetric candidates with $a_i < a^e \leq a_j$, with profits $\pi_i^i(a_i)$ and $\pi_j^i(a_i)$. Then, the best choice $a_i < a^e$ is $a_i = a^m$ with profits $\pi_i^i(a^m)$, while for $a_i \geq a^e$ the dispute resolution procedure is triggered which leaves firm i with profits $\pi^d\left(a^{dr}\right)$. Firms will not deviate from $a_i = a^m$ and $a_j \geq a^e$ if both $\pi_i^i(a^m) \geq \pi^d\left(a^{dr}\right)$ and $a^* < a^m$.

Finally, any candidate $a^e \leq a_i \leq a_j$ leads to profits $\pi^d\left(a^{dr}\right)$, from which networks will not deviate if and only if $\pi^d\left(a^{dr}\right) \geq \pi_i^i(a^m)$. ■