Geographic Access Markets and Investments

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Abstract

We analyze geographic regulation of vertically-integrated operators who build infrastructures and provide access in different areas. We compare duplication-based remedies, where the regulator sets access prices that depend on the local degree of infrastructure competition, to competition-based remedies, where access is deregulated in competitive areas. We find that the latter regime leads to more regulatory uncertainty and lower welfare, as it leads to multiple and inefficient equilibria at the wholesale level, with either too little or too much investment.

Keywords: Infrastructure investment; Wholesale competition; Vertical integration; Geographical access regulation.

JEL codes: L51; L96.

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1 Introduction

Investment in broadband infrastructures is drawing extraordinary attention from governments and policy makers all over the world, due to the significant impact of high-speed access networks on economic growth (Czernich et al., 2011). The relative availability and quality of broadband are expected to have a significant impact on employment and economic growth not only at the national level but also at local level: areas with poor broadband infrastructure are likely to lag behind areas with better connectivity. To encourage the deployment of these new infrastructures within all areas in a country, incumbent operators lobby policy makers to lift regulatory burdens; however, policy makers at the same time attempt to prevent the monopolization of the market for advanced IT services. The latter objective calls for some form of regulated access to infrastructures, while the former implies that it should be done with care.

The need to provide incentives to create new network infrastructures calls for a careful revision of the existing regulatory framework, which was created for legacy networks. An added complication is that infrastructure competition is likely to emerge only in specific regions of a country, mostly in very dense metropolitan areas where investment costs are lower, while in the rest of the country it will probably not materialize.\(^1\) For the least densely populated areas, only government subsidies will make private investment viable. But even in areas covered without the need for public subsidies, the number of operators rolling out their network will differ. Large swaths of the country will most likely be left with only one high-speed network, while urban areas might be covered by two or more. From a regulatory point of view, this might call for \textit{ex-ante} access rules to vary across regions characterized by different degrees of infrastructure competition. While this is plausible from the point of view of competition law, there is a lack of theoretical research on this type of

\(^1\)Empirical evidence for the US points out the presence of substantial spatial disparities in infrastructure access across States and areas (urban vs. suburban) within a State (Grubesic and Murray, 2002).
geographically differentiated regime and its impact on firms' investment decisions. The aim of this paper is to fill this gap.

Our paper is also motivated by recent decisions by the European Commission that forcefully push for the adoption of geographically differentiated remedies, or "geographical access rules" as they are referred to by policy makers (e.g., see ERG, 2008).\(^2\) The 2009/140/EC Directive ("Better Regulation Directive") explicitly considers the possibility of defining different geographical markets and remedies according to prevailing competitive conditions.\(^3\) The European legislator thus invites national regulatory authorities (NRAs) to examine differences in the degree of infrastructure competition across geographical areas, in order to determine whether the definition of subnational geographical markets or the imposition of differentiated remedies are warranted.\(^4\)

This main focus of our paper is on how regulators should account for geographical differences in their access pricing policies. We therefore study the impact of the geographical structure of regulation on firms' investment incentives and welfare.

Our model is structured as follows. In a country composed of a continuum of areas with an increasing cost of coverage, two incumbent operators decide to deploy their own networks where investment can be recouped by retail profits. Two types of areas can emerge: Single infrastructure areas where only one incumbent has invested, and duplicate infrastructure areas where both in-

\(^2\) The association of European Telecom Regulators (ERG, 2008) provided a list of criteria to assess the homogeneity of competitive conditions in different geographical markets and to define geographical access remedies. Its successor BEREC launched a consultation on a new common position on geographical aspects of market analysis in December 2013, available at http://berec.europa.eu.

\(^3\) 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 subnational basis and to lift regulatory obligations in markets and/or geographic areas where there is effective infrastructure competition." This approach was recently confirmed in the EU Recommendation C(2010) 6223 on "Regulated Access to Next Generation Access Networks (NGANs)" (September 2010), with Recital 10 stating 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 [...]" (emphasis added).

\(^4\) For current broadband services, national regulators in the UK (Ofcom, 2007) and Portugal (Anacom, 2009) have already made the decision to divide the wholesale broadband market into different sub-markets according to differences in competitive conditions, and have proposed the adoption of differentiated wholesale remedies in different (competitive and non-competitive) areas. Similar decisions were recently taken by the Finnish, Dutch and Hungarian NRAs (see the EC decision FI/2009/900 for Finland; NL/2009/0868 for the Netherlands and HU/2007/0662-0663 for Hungary).
The incumbent operators must provide access to a third operator and to each other. However, access regimes can differ between areas depending on the differing degrees of infrastructure competition.

We compare two different access regimes, taking investment incentives into account. First, we consider duplication-based remedies, that is, differentiated access prices in both the single and the duplicate infrastructure areas. Setting one access charge everywhere is shown to be sub-optimal while setting two different access charges increases welfare. Alternatively, regulators can differentiate regulation according to the availability of multiple facilities by setting the access price in single infrastructure areas, and "leaving it to the market" in duplicate infrastructure areas. In this regulatory framework, contrary to what one might hope, market outcomes turn out to be neither easily predictable nor efficient. First, the wholesale game between access providers has a natural tendency towards multiple equilibria. Second, none of the resulting equilibria is efficient when investment incentives are factored in: Either wholesale competition results in very low access prices which destroy investment incentives, or wholesale competition does not take off, and access and retail prices remain high. Thus, partial deregulation of access tends to lead to less regulatory certainty and lower welfare. Our conclusion is that regulators should weigh very carefully the advantages and disadvantages of either regulatory regime.

Literature Review. Our paper merges three different strands of the literature. The first one studies the interaction between access regulation and investment, the second one analyzes competition at the wholesale level between vertically integrated firms, and the third one deals with universal service obligations (USOs), uniform pricing constraints and geographical service coverage.

The first strand of literature analyzes the impact of access regulation on firms’ investment.\(^5\)

\(^5\)Cambini and Jiang (2009) provide a recent and comprehensive review of both theoretical and empirical papers on broadband investment and regulation.
Some studies analyze the incumbent’s investment incentives (Foros, 2004; Nitsche and Wiethaus, 2011; Mizuno and Yoshino, 2012) or the alternative operators’ (Bourreau and Doğan, 2005 and 2006) as a function of the access regime. Several other papers (Gans, 2001; Hori and Mizuno, 2006; Vareda and Hoernig, 2010) study the impact of access charges in a dynamic investment race between the incumbent and the entrants. Finally, recent papers have focused on the interplay between access regulation and the migration from the old legacy network to an NGAN infrastructure (Brito, Pereira and Vareda, 2012; Inderst and Peitz, 2012; Bourreau, Cambini and Doğan, 2012). All these papers address the problem of investment in broadband infrastructures and access regulation in different ways. However, none of them specifically looks at the introduction of geographically differentiated access rules and the impact of geographically-based access remedies on market competition and firms’ investment, which is the topic of this paper.\footnote{Our paper also touches on the impact of the regulator’s commitment power on investment. Most papers assume either full commitment from the regulator (e.g., Vareda and Hoernig, 2010; Nitsche and Wiethaus, 2011) or no commitment (e.g., Foros, 2004). One exception is Brito, Pereira and Vareda (2010), who analyze the two polar cases of no commitment and full commitment.}

Our paper is also related to the literature on wholesale competition between vertically integrated firms (e.g., see Ordover and Shaffer, 2007; Brito and Pereira, 2009 and 2010; Bourreau et al., 2011). These authors study whether a competitive wholesale market can emerge, that is, whether there is partial or complete foreclosure in equilibrium. We contribute to this literature by studying two additional issues: first, how the interactions on the wholesale market affect integrated firms’ investment; second, the presence of multiple (geographically differentiated) input prices. We also introduce a specific regulatory tool - the dispute resolution mechanism - to avoid foreclosure, and show that it generates additional equilibria in the wholesale market.

Finally, the third stream of literature is related to the role of uniform pricing constraints and their impact on infrastructure coverage and market competition. 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. Similar results for the strategic links created through pricing restrictions have been found by Anton et al. (1998) 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 the 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 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 and firms’ investment, which is the focus of our paper.

The rest of the paper is organized as follows. In Section 2 we present the model setup and consider the social optimum in an extreme form of geographical regulation. In Section 3 we analyze the regulator’s choice of geographically differentiated access prices. In Section 4 we analyze the impact of competition-based access charges on investment incentives. Section 5 concludes the paper. All longer proofs can be found in the Appendix.

2 Model Setup

Two incumbent operators (firms 1 and 2) invest in coverage of new network infrastructures (e.g., next generation access networks), and an entrant (firm e) can ask for access but does not invest. The incumbent operators build infrastructures in different areas \([0, \bar{z}]\) of a country, where \(\bar{z}\) is large enough so that some areas remain uncovered in equilibrium. They can also request access to each other’s infrastructure.
Cost structure. In our model we want to capture the typical cost structure of new network infrastructures. Whereas the marginal cost of running the network is independent of a customer’s location, the fixed cost of deploying the network depends on it. To be more precise, it is cheapest to connect a customer in densely populated areas such as urban centres, and most costly in outlying rural areas. We therefore assume that the fixed cost of coverage $c(z)$, which is the same for both incumbent firms, is strictly increasing and differentiable in the area $z$, from $c(0) = 0$. Furthermore, we assume that firm $i = 1, 2$ builds a network that covers the contiguous areas $[0, z_i]$, with $z_i \leq \bar{z}$, and therefore its total investment cost is

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

We have $C'(z_i) = c(z_i)$ and $C''(z_i) = c'(z_i) > 0$. Finally, all firms have the same marginal (wholesale and retail) costs in all areas, which we normalize to zero.\(^7\)

Access and retail competition. According to the incumbents’ investment decisions, two types of areas can emerge: single infrastructure areas (SIAs), where only one incumbent has invested, and duplicate infrastructure areas (DIAs), where both incumbents have rolled out a network.\(^8\) Contrary to papers like Valletti et al. (2002) and Hoernig (2006), we assume that firms can set a different retail price in each area, depending on competitive conditions. Hence, they obtain different profits in DIAs and SIAs.\(^9\)

\(^7\)Our modeling assumptions for the cost structure are in line with Valletti et al. (2002), for example, who assume zero marginal production costs, and that the fixed investment cost increases over areas. By contrast, Choné et al. (2002), Foros and Kind (2003) and Hoernig (2006) assume an increasing marginal cost and a constant (or zero) fixed investment cost. Assuming increasing marginal costs in our setting would complexify the analysis. However, since the profitability of investing in a given area would decrease over areas, we would still obtain duplicate and single infrastructure areas, and the rest of our analysis would be qualitatively similar.

\(^8\)There are also, of course, areas with no infrastructure.

\(^9\)In some countries (e.g., Portugal), broadband operators offer discounts on 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.
We also assume that the regulator imposes an access obligation on incumbent firms’ infrastructures, which allows firm $e$ to enter the market and network owners to use each others’ networks. We denote by $a$ and $\tilde{a}$ the access charges in DIAs and SIAs, respectively.\textsuperscript{10,11} The possibility of access affects the outcome as follows. First, in DIAs only one network provides access, introducing an additional source of asymmetry between incumbents. Second, in SIAs, the incumbent provides access to both the entrant and the rival incumbent. Note that there may be a different wholesale provider in DIAs and SIAs.

We denote by $\pi_i^{(j)}(a)$ and $\tilde{\pi}_i^{(j)}(\tilde{a})$ 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). In SIAs, the access provider makes more profit than access seekers if $\tilde{a} > 0$, due to the higher perceived marginal cost of its competitors. In DIAs, if both incumbents make access offers, the entrant chooses the cheaper one. If they offer the same access price $a$, he chooses randomly his access provider,\textsuperscript{12} hence the (ex ante) expected per-DIA profit of infrastructure owner $i = 1, 2$ is 
\[ \pi^d(a) = (\pi_i^{(i)}(a) + \pi_i^{(j)}(a))/2, \]
where $j = 1, 2$ and $j \neq i$. All profits are continuous functions of access charges, and in the following we drop the arguments for clarity whenever possible.

We make the following assumptions on the relation between profits and access charges. First, we assume that access seekers’ profits are strictly decreasing in the access charges, and that there are unique access charge levels $a^e$, $\tilde{a}^e > 0$ such that $\pi_e^{(j)}(a^e) = \pi_e^{(j)}(\tilde{a}^e) = 0$, that is, the entrant just breaks even.

Second, the access provider’s (ex post) profits in DIAs and SIAs are maximized, subject to the constraint that the entrant is viable, at $a^m = \arg\max_{a \leq a^e} \pi_i^{(i)}(a)$ and $\tilde{a}^m = \arg\max_{\tilde{a} \leq \tilde{a}^e} \tilde{\pi}_i^{(i)}(\tilde{a})$.

\textsuperscript{10} Throughout the paper, we use a tilde ($\tilde{\text{)}$) on a variable to indicate that it relates to SIAs.

\textsuperscript{11} Access charges can differ between DIAs and SIAs, but not between infrastructure operators within the same type of area. In other words, we do not discuss here the adoption of asymmetric rules across infrastructure operators.

\textsuperscript{12} If the entrant is indifferent between two access offers for a given regulated access price, we assume that it chooses only one access provider in each type of area, e.g., due to transaction costs. An alternative assumption would be that the access seeker commits ex ante to using a specific network when two are present. This will not change total coverage if duplication is partial.
respectively. No individual access provider would voluntarily set a higher access charge. On the other hand, we assume that in DIAs the rival infrastructure firm’s profits $\pi_i^{(j)}(a)$ are increasing in $a$, e.g., because retail prices are strategic complements. As a result, $a^d = \arg\max_{a \leq a^m} \pi^d(a)$ is at least as high as $a^m$, and $\pi^d(a)$ strictly increases in $a$ for $a \in [0, a^d]$.

Access charges higher than $a^d$ and $\bar{a}^m$ would simultaneously lead to lower expected profits for network owners and lower welfare. In other words, they would reduce coverage without any compensating welfare gains, as we will see later.\footnote{While entry is unprofitable if $a > a^e$ and $\bar{a} > \bar{a}^e$, unregulated networks would foreclose entry if and only if the maximal profit they can make under access is less than the profit they obtain without providing access. Depending on the demand-expanding effect of entry, this may or may not be the case in our model.} A benevolent regulator will therefore only select $a \leq a^d$ and $\bar{a} \leq \bar{a}^m$, which we will assume for the rest of the paper.

**Welfare.** Finally, we denote by $w(a)$ and $\bar{w}(\bar{a})$ the social welfare in DIAs and SIAs, respectively, gross of investment costs, where welfare is defined as the sum of consumer surplus and profits. In our general setting, duplication of infrastructure entails two potential social benefits. First, it may have a direct effect on welfare, by bringing about a higher variety or quality of service. Second, duplication has a competitive (indirect) effect: Because the perceived marginal cost of an incumbent firm that duplicates infrastructure decreases,\footnote{Its marginal cost goes down from $\bar{a}$—since it was leasing access to its rival in SIAs—to 0, since it now uses its own infrastructure at marginal cost (i.e. 0, due to our normalization).} competition becomes more intense, causing retail prices to decline. We therefore assume that $w(a) > \bar{w}(\bar{a})$ for all $a \geq 0$.

As a starting point, let us first consider quickly which access charges the regulator would choose if he could set a different one in each area. While this is not a feasible proposal in practice, due to its sheer complexity, it indicates some of the trade-offs that must be made with less fine-grained regulation.

We want to look for the socially optimal access charges, taken coverage as given. If area $z$ is optimally covered by a single infrastructure, its optimal access charge $\bar{a}_z$ is found by maximizing
welfare subject to the constraint that investment takes place, i.e.

$$\max_{\bar{a}_z} \bar{w}(\bar{a}_z) - c(z) \quad s.t. \quad \bar{\pi}^i(\bar{a}_z) - c(z) \geq 0.$$ 

As a result, in SIAs the optimal local access charge is $\bar{a}_z = 0$ if $c(z) < \bar{\pi}^t$, and is given by $\bar{\pi}^i(\bar{a}_z) = c(z)$ otherwise, where $\bar{\pi}^t = \bar{\pi}^i(0) = \bar{\pi}^j(0)$. That is, access charges change with the area if and only if investment cost is so high that without this adjustment investment would not take place.

If area $z$ is optimally covered by two infrastructures, then the regulator chooses the local access charges $a_z$ and $\bar{a}_z$ in order to maximize welfare subject to the constraint that each incumbent prefers duplication to asking for access, i.e.

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

It is certainly optimal in this case to set $\bar{a}_z = 0$ since this reduces the incumbents’ profits from asking for access. The socially optimal DIA access charge is then given by $\pi^d(a_z) = c(z) + \bar{\pi}^t$, which changes with every DIA area.

To sum up, we have found that, unless there is no duplication in the areas with the lowest investment costs, the socially optimal access charges are different in every area. This result is obtained because under this type of pure geographical regulation the optimal access charge is just high enough to make coverage feasible, while being as low as possible in order to maximize local welfare. The analysis thus reveals an extreme trade-off between static welfare and investment incentives. Below, we consider the more realistic case where at most two different access prices are set, and where trade-offs involving infra-marginal areas must be made.
An illustrative market model. Following Shubik and Levitan (1980), we introduce a representative consumer with the following quasi-linear preferences:

\[ U = m + \sum_{k \in \kappa} q_k - \frac{3}{2} \sum_{k \in \kappa} q_k^2 + \gamma \left( \frac{\sum_{k \in \kappa} q_k}{1 + \gamma} \right)^2, \]

where \( m \) represents the consumption of the numeraire good, \( q_k \) the consumption of the product of firm \( k \in \kappa = \{1, 2, e\} \), and \( \gamma \geq 0 \) the degree of substituability between the firms’ products—a lower \( \gamma \) corresponding to a higher degree of differentiation. The demand function for firm \( k \in \kappa \) is then

\[ D_k = \frac{1}{3} \left( 1 - p_k - \gamma \left( p_k - \frac{p_1 + p_2 + p_3}{3} \right) \right). \tag{1} \]

When one firm or two firms are out of the market, we derive the demand functions by setting the quantity purchased from the firms that are out of the market to zero in the representative consumer’s program. Finally, we assume that firms compete in prices. As shown in Appendix A, our assumptions on per-area profits are satisfied with this illustrative setting.

3 Duplication-Based Remedies

In this section we assume that the regulator anticipates that there will be areas with different degrees of infrastructure competition, and can set different access prices for single and duplicate infrastructure areas. In other words, the regulator can implement what we call duplication-based remedies. As compared to the full geographic differentiation mentioned above, welfare will necessarily be lower. On the other hand, setting many different access prices is hardly feasible, due to information and time constraints.

The timing of the game is as follows. First, the regulator sets the access charges \( a \) and \( \tilde{a} \) for
DIAs and SIAs, respectively. Second, firms 1 and 2 non-cooperatively decide on coverage. Third, all firms decide whether to ask for access in DIAs and SIAs. Fourth, firms compete for customers and profits are realized. We consider subgame-perfect Nash equilibria in pure strategies.

**Access and investment.** At Stage 3, firms can ask for access in areas where an infrastructure has been rolled out. In DIAs, firm $e$ randomly chooses an access provider, while firms $i = 1, 2$ are (at least weakly) better off using their own infrastructure than asking for access. In SIAs, where firm $i = 1$ or 2 has invested, firms $j \neq i$ ask for access; this is always optimal for them, since the assumption is that each access seeker obtains positive profits.

At Stage 2, each incumbent firm $i = 1, 2$ chooses a coverage $[0, z_i]$ so as to maximize its profit, given its rival’s coverage $[0, z_j]$, with $j = 1, 2, j \neq i$. If firm $i$ chooses $z_i > z_j$, it will be the access provider in the SIAs $(z_j, z_i)$. However, in the DIAs $[0, z_j]$ 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 is then

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

This profit function highlights the incumbent’s trade-offs with regard to the coverage decision. For small $z_j$, firm $i$ chooses its coverage trading off the marginal profits derived from being an access provider in SIAs, $\tilde{\pi}^{(i)}_i(a)$, and the cost of covering an additional marginal area alone. If $z_j$ is large, on the other hand, firm $i$ trades off the profit it obtains from remaining an access seeker in its marginal area, $\tilde{\pi}^{(j)}_i(a)$, with the gains derived from becoming an infrastructure owner, i.e., $\pi^d(a)$ less the investment cost. Thus, access creates an additional opportunity cost for investment, consisting of the profits obtained after asking for access.

The following result characterizes the coverage equilibrium at Stage 2 and shows how the DIA
and SIA coverage limits, $z^d$ and $\tilde{z}^s$, respectively, vary with the access charges.\footnote{Since we model coverage strategies as intervals of areas starting from zero, equilibria where both infrastructure firms act as monopoly providers in different areas cannot emerge. This type of equilibria would arise if firms could decide whether or not to deploy a network separately in each (infinitesimal) area. Since this leads to a multiplicity of equilibria and complexifies the analysis, without necessarily being more realistic (since in practice firms tend to cover contiguous areas), we restrict the game to simpler coverage strategies.}

**Lemma 1** Define the coverage limits $z^d$ and $\tilde{z}^s$ by $c(z^d) \equiv \pi^d(a) - \bar{\pi}^{(j)}(\bar{a})$ and $c(\tilde{z}^s) \equiv \bar{\pi}^{(i)}(\bar{a})$. The equilibria of the coverage subgame are as follows:

- If $a$ is small, then $z^d < \tilde{z}^s$ and there is **Partial Duplication**: one incumbent firm covers the areas $[0, \tilde{z}^s]$, while the other firm duplicates in the areas $[0, z^d]$. There is **No Duplication**, i.e. $z^d = 0$, if and only if $a = \bar{a} = 0$.

- Otherwise, if $a$ is large, there is **Full Duplication**: both incumbent firms cover the areas $[0, z^{fd}]$, where $z^{fd}$ can take any value in $[\tilde{z}^s, z^d]$.

The coverage limits $z^d$ and $\tilde{z}^s$ increase strictly in $a \in [0, a^d]$ and $\bar{a} \in [0, \bar{a}^m]$.

**Proof.** See Appendix B, where we also state the exact limits on $a$. □

While the coverage limits in DIAs and SIAs, $z^d$ and $\tilde{z}^s$, are functions of the access charges, in the rest of the paper we mostly drop these arguments for the sake of clarity.

We now provide intuitions regarding the different outcomes. No duplication occurs when becoming a potential access provider is highly unattractive, which happens precisely when both access charges are very low. A DIA or SIA access charge at cost reduces returns on investment, while a SIA access charge at cost also increases the opportunity cost of duplicating rather than being an access seeker. With regard to social welfare, while with cost-based access the competition-enhancing effect of network duplication disappears, there is still a welfare loss from the absence of duplication, in terms of lower variety and/or quality of service.
For small though positive values of the DIA access charge $a$, duplication occurs in the cheapest areas, while only one infrastructure is rolled out in the 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 too low to be an incentive for full duplication.

At the other extreme, with a very high DIA access charge, we obtain multiple equilibria which all involve full duplication, but with different coverage levels. The existence of multiple equilibria is due to a coordination failure between investors. Both firms would actually prefer full duplication up to $z^d$, but if one firm covers less, 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 in the access charges. Together with the fact that these equilibria are Pareto-ranked in the sense that among them a joint coverage of all areas up to $z^d$ leads to the highest welfare and profits, this suggests an additional potential role for the regulator. This role would consist in helping firms to coordinate on the "right" equilibrium, while ensuring that coverage responds to the announced access charges.

The above Lemma also implies that SIA and DIA 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 setting higher access charges to maximize (or duplicate) coverage.\footnote{Access provision can increase coverage if access charges are high enough and services are sufficiently differentiated, so that entry increases demand and joint profits.} There is another subtler 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 assumed so far) and the imposition of a cap. This distinction matters whenever the regulator wants to increase coverage through an access price above $a^m$, which is the maximum price that the access provider would like to charge.
If the regulator sets a cap \( a \) above \( a^m \), rather than setting the access price \( a \), the access provider will choose \emph{ex post} the access price \( a^m < a \), which satisfies the cap, and duopoly coverage will not increase beyond \( z^d(a^m, \tilde{a}) \). On the other hand, if an access price \( a > a^m \) is fixed before investments are made, then the possibility of \emph{not} being the access provider while benefiting from a high retail price level raises expected profits and increases coverage.

**The regulator’s trade-off.** Higher access charges inflate retail prices and reduce consumption, hence decreasing per-area welfare. Social benefits from higher coverage therefore need to be traded off against social costs in terms of lower welfare per area. Infrastructure competition moreover reduces one incumbent firm’s perceived marginal cost and contributes additional benefits in terms of variety or quality of service, meaning that a positive degree of duplication is optimal.

We now discuss the trade-offs involved when there is partial duplication in the coverage subgame. In this case, total welfare is given by \( W = z^d w + (\bar{z}^s - z^d) \tilde{w} - C(\bar{z}^s) - C(z^d) \). The social benefits of covering a marginal single or duplicated area are

\[
\Delta^s = \tilde{w} - c(\bar{z}^s) = \tilde{w} - \pi^{(i)}_i,
\]

and

\[
\Delta^d = w - \tilde{w} - c(z^d) = w - \pi^d - (\tilde{w} - \pi^{(j)}_i),
\]

respectively. Both expressions contain the net benefit of investment, i.e., the welfare gain less the investment cost, but \( \Delta^d \) also includes the social opportunity cost of duplication, which is the social welfare forgone in a SIA, \( \tilde{w} \). While \( \Delta^s \) is always positive, as it is equal to consumer surplus plus the profits of firms \( j \) and \( e \), \( \Delta^d \) may be negative for high \( a \) and low \( \tilde{a} \). On the other hand, \( \Delta^d \) is
positive at $a = 0$.\footnote{Indeed, we have $w(0) > \tilde{w}(0)$ from our assumptions, and $\pi^{d}(0) = \bar{\pi}^{(j)}(0)$.} Therefore, total coverage is always too low from a social point of view; this is because the incumbent firm that deploys the network in SIAs does not internalize (fully) the access seekers’ profits and the consumers’ surplus. By contrast, the level of duplication can be either too low or too high.

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

$$\frac{\partial W}{\partial a} = z^{d} \frac{d w}{da} + \Delta a \frac{\partial z^{d}}{\partial a}, \quad (2)$$

and

$$\frac{\partial W}{\partial \bar{a}} = \left( z^{s} - z^{d} \right) \frac{d \tilde{w}}{d \tilde{a}} + \Delta s \frac{d z^{s}}{d \tilde{a}} + \Delta d \frac{\partial z^{s}}{\partial \tilde{a}}. \quad (3)$$

The first terms in equations (2) and (3) 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, keeping net per-area welfare fixed (i.e., the benefits or costs in terms of dynamic efficiency). The second term in (3) is positive, indicating that the regulator would always want to expand total coverage further by increasing $\tilde{a}$. On the other hand, the last terms in (2) and (3) have an ambiguous sign. Since they translate the net gain from transforming a SIA into a DIA, they are positive only if the gain from increased competition and variety outweighs the investment cost and the opportunity cost of duplication. If not, then the regulator would set both lower $a$ and $\tilde{a}$ in order to limit duplication.

What is clear, however, is that different trade-offs underlie the optimal choice of access charges in DIAs and SIAs, respectively. Therefore, the resulting optimal access charges $a^{o}$ and $\tilde{a}^{o}$ can only be equal by chance.
**Proposition 1** If partial duplication arises in equilibrium, the optimal duplication-based access charges depend on the number of infrastructures in each area.

While the trade-offs discussed above do not allow us to make a clear-cut statement about the relative sizes of access charges, the fact that the access provision in SIAs limits the feasibility of duplication indicates that it should be optimal to set a relatively high access charge in SIAs and a relatively lower one in DIAs. Figure 1 below presents a simulation of the optimal duplication-based access charges for our illustrative setting. In this example, as expected, the regulator sets the access charge in DIAs ($a$) at a lower level than the access charge in SIAs ($\bar{a}$).

![Figure 1](image-url)  
*Figure 1: Socially optimal duplication-based access charges with $c(z) = \beta z$ (dots: $a$, line: $\bar{a}$).*

A slightly different way to implement differentiated remedies would be to define *ex ante* the areas with different access charges. That is, the regulator could divide the country in "urban" and "rural" areas ($z \leq \bar{z}$ and $z > \bar{z}$ for some threshold $\bar{z}$ set by the regulator) and then apply a different access charge to each group of areas.\(^{18}\) It can easily be seen that under the optimal access charge

\(^{18}\)The French NRA for telecoms, Arcep, implements such geography-based remedies for differentiating access to fiber between "very dense areas" and all the other areas.
for rural areas total coverage is the same as under the duplication-based approach since the decision is unaffected. On the other hand, duplicated coverage will be either somewhat higher or lower. The reason is that for almost all areas $z$ the access charge will not depend on whether investment has been duplicated or not, while under duplication-based remedies it does. Thus, qualitatively, the outcomes are similar.$^{19}$

One might question whether the regulator is able to set two different access prices. First, he might face informational constraints and be unable to gather enough information to differentiate the access charges according to geography and market structure. Second, he may be unable to commit to the access regime *ex ante*. For example, Foros (2004) and Brito et al. (2010) discuss this problem.$^{20}$

If the regulator is unable to commit at all, then once investments have been made, he sets the access charge to marginal cost in all areas. Based on Lemma 1, cost-based access pricing implies that no duplication takes place. Even though the regulator may be unable to implement a sophisticated access rule, he may be able to use a simpler rule, with a single (linear) access price, as is standard in regulatory practice. For example, for telecoms, ERG (2008) argues that defining different geographical markets does not imply the need to adopt differentiated remedies if this might generate excessively complex regulatory intervention. However, the above discussion clearly shows that setting the same access price in all areas leads to lower welfare than duplication-based access pricing. A different approach to implementing geographic regulation while setting only one access price is to deregulate access in "competitive" areas, which we discuss next.

$^{19}$The details of the analysis are available upon request from the authors.
$^{20}$See also Besanko and Spulber (1992), and Mizuno and Yoshino (2012).
4 Competition-Based Remedies

An alternative regulatory regime which has been proposed by some regulators (see for instance Ofcom, 2007), and which we call competition-based remedies, is the following: The regulator sets the access charge in the areas with a single infrastructure (the SIAs), but does not regulate the wholesale market in the "competitive" areas (i.e., the DIAs). In DIAs incumbents can therefore set the access charge to their networks on a commercial basis. However, without any regulatory intervention the presence of wholesale competition might lead to market foreclosure (Ordover and Shaffer, 2007; Bourreau et al., 2011). Consequently, the only restriction that we make is that the entrant should not be foreclosed; if that happens, the regulator will impose access at a dispute resolution price $a^{dr} \leq a^e$.

Competition-based remedies might seem to be a good alternative to regulating two different wholesale prices. In what follows we show, though, that the resulting outcomes are not straightforward due to a multiplicity of equilibria in the wholesale market and due to the fact that these equilibria tend to have unattractive properties if investment incentives are taken into account. A further complication is that since the regulator cannot anticipate the equilibrium that will emerge in competitive areas, he may set a SIA access charge that is sub-optimal \textit{ex post}. Thus, deregulating access in competitive infrastructure areas generates an additional source of inefficiency. We will come back to this point below.

We modify the timing of the game as follows. In the first stage, the regulator sets the SIA access price $\tilde{a}$ and the dispute resolution price $a^{dr}$. In the second stage, firms 1 and 2 decide on coverage. In the third stage, firms 1 and 2 make their DIA access offers $a_1, a_2 \in [0, \infty]$, and then the regulator imposes $a_i = a^{dr}$ if $\min\{a_1, a_2\} > a^e$. Firms subsequently decide whether to ask for

\[ \text{This is in line, for example, with the existing regulatory framework in the telecommunications sector (see Directive 2009/140/EC).} \]

\[ \text{Setting the access price to infinity is tantamount to not making an access offer.} \]
access in any given area. Finally, in the fourth stage they compete for customers.

Again, we proceed by backward induction. The equilibrium at the retail competition stage (Stage 4) is the same as above, given access prices \( \bar{a} \) and \( a \), where \( a = \min\{a_1, a_2\} \). We now consider access decisions at Stage 3. In SIAs, where only firm \( i \) has invested, firm \( j \neq i \) and firm \( e \) ask for access at the regulated access price \( \bar{a} \). In DIAs, on the other hand, the entrant chooses the incumbent with lower access price \( a_i \) or selects one firm randomly if \( a_1 = a_2 \).

We now determine the incumbent networks' equilibrium choice of the DIA access charges \( a_1 \) and \( a_2 \). As one might expect, competitive bidding for access could ensue, with a resulting equilibrium at marginal cost. On the other hand, access provision changes strategic behavior in the retail market: The access-providing incumbent becomes a less aggressive competitor, since a high access price makes it unattractive to compete for retail customers. This corresponds to a "fat-cat effect" (Fudenberg and Tirole, 1984) or "softening effect" (Bourreau et al., 2011). Thus, the access provider might set a high retail price and rely mostly on wholesale profits. As a result, the owner of the other infrastructure feels little retail pricing pressure and may obtain higher retail profits than the access provider himself. This outcome implies that the underbidding that leads to a competitive wholesale equilibrium may not take place after all.

More precisely, we assume that \( \pi_j^{(i)}(0) = \pi_i^{(i)}(0) \), and that there exists an access charge \( a^* > 0 \) such that \( \pi_j^{(i)}(a^*) = \pi_i^{(i)}(a^*) \) and \( \pi_j^{(i)}(a) > \pi_i^{(i)}(a) \) if and only if \( a > a^* \). For access charges above \( a^* \) each infrastructure firm prefers its rival to offer access. On the other hand, if access charges are below \( a^* \) then each firm prefers to be the access provider. The structure of the equilibria depends on whether \( a^* \) lies above or below the profit-maximizing access charge \( a^m \).

Furthermore, the regulator's dispute resolution procedure also has surprising effects on potential equilibria. Depending on the level of the dispute resolution price additional equilibria can arise, as

\[ ^{23} \text{In our illustrative model, } a^* \text{ lies below } a^m \text{ if services are sufficiently homogeneous. Furthermore, } a^* \text{ is always below the foreclosure access level, } a^e. \text{ In our discussion, we therefore assume that } a^* < a^e. \]
summed up in the following Lemma.

**Lemma 2** All wholesale pricing equilibria are given by the following:

1. a "competitive equilibrium", i.e., cost-based access at $a_1 = a_2 = 0$;
2. equal and high access prices, i.e., $a_1 = a_2 = a^*$, if $a^* \leq a^m$;
3. a "dispute-resolution equilibrium" without feasible access offers, if the dispute resolution price is high, i.e., $\pi^d(a^{dr}) \geq \pi^{(i)}(a^m)$;
4. only one feasible but high access offer, i.e., $a_i = a^m$ and $a_j \geq a^e$, if $a^* \leq a^m$ and the dispute resolution price is low (i.e., $\pi^d(a^{dr}) \leq \pi^{(i)}(a^m)$).

**Proof.** See Appendix C. ■

Before discussing the economic consequences of this bewildering set of equilibria, we explain why each equilibrium arises.

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" stops only when the profits of the access provider and its rival are equal, i.e., at $a = 0$. This equilibrium is unique when $a^* > a^m$ and the dispute-resolution price is low. On the other hand, when $a^* < a^m$, there is a second symmetric equilibrium at $a^*$. This equilibrium also follows from rent equalization: At this access charge, infrastructure owners are indifferent between being the access provider or not, and therefore have no reason to underbid or set a higher access price in order to avoid being chosen. These two equilibria have already been identified by Bourreau et al. (2011).

The effects of the dispute resolution access charge $a^{dr}$, which is the novel part of this result, may be the least expected. If it is high, then incumbents may not find it worthwhile to make feasible
access offers at all. Rather, they may wait for the regulator to impose access and hope that their rival will subsequently be chosen by the entrant. In this case, the equilibrium outcome is the same as if the DIA access price had been fixed at $a^{dr}$.

On the other hand, for low values of the dispute resolution price $a^{dr}$ (i.e., for $\pi^{d}(a^{dr}) \leq \pi_{i}^{(i)}(a^{m})$) and if $a^{*} < a^{m}$, an additional equilibrium arises where one firm offers the monopoly access charge and the other firm refrains from making any 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 a low access price. This is because the firm that does not serve the wholesale market benefits from the "softening effect," and makes higher profits than if it undercuts the existing access price and becomes the access provider. Meanwhile, the access provider’s profit is maximized at $a^{m}$, as not making a viable access offer is ruled out by the low dispute resolution price.

While the outcomes of the wholesale pricing game do not depend on the SIA access charge, investments at Stage 2 will depend both on the latter and on the value of the DIA access charge resulting from the wholesale market equilibrium. For each given outcome, investments will then follow from the analysis in the last section, with the additional complication that there may potentially be multiple equilibria in the wholesale market, and firms do not know which equilibrium will be played when they make their investment decisions. The latter adds an element of highly undesirable "Knightian uncertainty" to investment decisions.

Finally, we turn to the question of whether and how the regulator can achieve the optimal duplication-based outcome under wholesale competition in DIAs. In short, the answer is "yes" in some cases, but mostly "no" unless he uses further instruments. On the other hand, it never leads to an outcome with higher welfare.

The following regulatory measures are not meant as practical proposals. Rather, our intention is to highlight the kind of (potentially difficult) intervention that would be necessary to achieve an
outcome comparable to duplication-based remedies. The "competitive" and "dispute resolution" equilibria have in common that they can be achieved for a continuum of parameter combinations: the first one since it is a corner solution, and the second one because the regulator can adjust the dispute resolution price. Recall from Section 3 that $a^o$ is the optimal DIA access charge when the regulator sets differentiated access charges.

**Proposition 2** Apart from knife-edge outcomes, the equilibrium under light regulation may correspond to the optimal outcome under duplication-based remedies only if either i) $a^o = 0$, or ii) $\pi^d(a^o) \geq \pi_i^{(i)}(a^m)$ and the regulator sets $a^{dr} = a^o$.

**Proof.** The competitive equilibrium at $a = 0$ always exists, and $a^o = 0$ occurs for non-trivial set of parameters since it is a boundary solution. The dispute resolution equilibrium exists whenever $\pi^d(a^{dr}) \geq \pi_i^{(i)}(a^m)$, and the regulator can choose such a value for $a^{dr}$ whenever $\pi^d(a^o) \geq \pi_i^{(i)}(a^m)$. The other equilibria, if they exist, are only efficient if, by chance, either $a^o = a^*$ or $a^o = a^m$. ■

Evidently, the dispute resolution equilibrium at $a^{dr} = a^o$ involves the same information and commitment issues discussed earlier, and therefore may not be very feasible as a regulatory proposal. If, due to these or other issues, the regulator sets a dispute resolution price close to the upper limit $a^e$, then the resulting equilibrium will involve excessively high access charges.

On the other hand, if the optimal DIA access charge is above $a^*$, then curiously the duplication-based optimum can only be achieved in the equilibrium where first the firms refuse to grant access and then the regulator imposes the optimal access price. It cannot be achieved with wholesale prices chosen freely by the market. Note also that the latter equilibrium will always coexist with the competitive equilibrium, and that the regulator cannot rule wholesale competition driving the access charge far below $a^*$, destroying investment incentives.

As concerns the "competitive" equilibrium, in our example of Figure 1 we have shown that for sufficiently differentiated goods the optimal DIA access charge is indeed zero. Thus, in theory
the "competitive" equilibrium can be efficient. On the other hand, with less differentiated goods we have $a^o > 0$, and the outcome $a = 0$ leads to inefficiently low duplication incentives. In this case, the optimal outcome can be achieved only if the regulator has some means for stopping the competitive process at $a^o$, for example if he can impose a floor access price at this level.

To sum up, competition-based wholesale regulation cannot generally achieve the optimal outcome under duplication-based remedies. Whether and how it does, though, depends on the fine details of consumer demand and on how the (de)regulation is implemented. The informational requirements and commitment powers for such instruments are essentially the same as those for duplication-based remedies. It follows that allowing for wholesale competition does not secure the necessary incentives for network duplication nor leads to better market outcomes.

5 Conclusions

One of the most hotly debated issues under the EU regulatory framework for electronic communications—which aims, among other objectives, at fostering 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 local markets. In this paper we develop a general model of infrastructure investment in geographical areas to assess the impact of geographically differentiated access remedies on investment incentives.

We compare two alternative types of geographic regulation, taking investment incentives explicitly into account. First, the regulator could implement duplication-based remedies, that is, differentiated access charges in single and duplicate infrastructure areas. The resulting two access prices are designed to balance static welfare with the correct investment incentives at the margin, and lead to higher welfare than a uniform access price.
An alternative proposal is to regulate the access price in single infrastructure areas only, while leaving the access price in duplicate infrastructure areas "to the market". We analyze the resulting market outcomes and show that multiple equilibria are possible. Furthermore, the intricacies of wholesale competition with investments imply that equilibrium wholesale prices can be either too high or too low from a social point of view. In particular, if strong wholesale competition is expected to arise \textit{ex post}, then \textit{ex ante} incentives for duplication are destroyed. Thus, the main finding of our paper is that partial deregulation of this kind tends not to be optimal: Duplication-based remedies create more certainty both for firms and regulators, and lead to higher welfare.

Our framework may be fruitfully extended into different directions. Obviously, our setting is static, as each operator plays only once and investments are one-shot. A 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 involve additional administrative costs for the regulator due to the continuous adaptation of wholesale regimes as competitive conditions change over time. We leave these interesting potential extensions for future research.

\textbf{References}


Appendix

Appendix A: Illustrative model

Per-area profits and welfare in DIAs  With a given access charge $a$, we obtain the following Nash equilibrium profits:

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

for $j \neq i, e$,

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

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

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

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

$$
a^d = \min \left\{ \frac{3(6 + 5\gamma)(7\gamma^2 + 21\gamma + 18)}{2(7\gamma^4 + 117\gamma^3 + 450\gamma^2 + 648\gamma + 324)} a^e \right\}.
$$
where \(a^d = \alpha^e\) for \(\gamma > 8.93\). Thus, \(\pi^d(a)\) is strictly increasing on \([0, a^d]\) 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 \(\gamma^*\) is the unique positive (real) solution to \(a^* = a^m\).

Finally, if \(\tilde{a}\) is defined by \(\pi^d(\tilde{a}) = \pi_i^i(a^m)\), it exists if \(\gamma > 8.830\) with
\[
\tilde{a} = \frac{3(6 + 5\gamma)(7\gamma^2 + 21\gamma + 18 - (3 + \gamma)\sqrt{\frac{280\gamma^6 - 339\gamma^5 - 12231\gamma^4 - 47952\gamma^3 - 83268\gamma^2 - 69984\gamma - 23328}{909\gamma^2 + 249\gamma^3 + 1296\gamma^2 + 648 + 20\gamma^4}})}{2(7\gamma^4 + 117\gamma^3 + 450\gamma^2 + 648\gamma + 324)}.
\]

Local welfare in DIAs is
\[
w(a) = \frac{(2\gamma + 9)(2\gamma + 3)}{8(\gamma + 3)^2} - \frac{3(1 + \gamma)}{4(\gamma + 3)^2}a - \frac{(1 + \gamma)(8\gamma^4 + 147\gamma^3 + 495\gamma^2 + 648\gamma + 324)}{24(\gamma + 3)^2(6 + 5\gamma)^2}a^2,
\]
which is strictly decreasing in \(a \geq 0\).

**Per-area profits and welfare in SIAs** With a given access charge \(\tilde{a}\), we find that
\[
\pi_i^i(\tilde{a}) = \frac{3 + \frac{2\gamma(9 + 5\gamma - 6\tilde{a})}{6 + 5\gamma}}{12(\gamma + 3)^2} \left(3 + 2\gamma - \frac{6\gamma(1 + \gamma - 6\tilde{a})}{6 + 5\gamma}\right) + \frac{(3 + 2\gamma)\tilde{a}(1 - \frac{6(1 + \gamma - \tilde{a})}{6 + 5\gamma})}{3(\gamma + 3)},
\]
and for \(j \neq i\),
\[
\pi_j^i(\tilde{a}) = \frac{(3 + 2\gamma)(1 - \frac{6(1 + \gamma - \tilde{a})}{6 + 5\gamma})^2}{4(3 + \gamma)^2}.
\]

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while the term inside the square is non-negative for

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

Straight computations show that $\tilde{\pi}_i^1(\tilde{a}) > \tilde{\pi}^t > \tilde{\pi}_j^1(\tilde{a})$ for all $\gamma, \tilde{a} > 0$, where

$$\tilde{\pi}^t = \pi_j^1(0) = \tilde{\pi}_j^j(0) = \frac{3 + 2\gamma}{4(3 + \gamma)^2}.$$  

The access charge that maximizes $\tilde{\pi}_i^1(\tilde{a})$ is

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

Contrary to DIA profits, $\tilde{\pi}_i^1(\tilde{a}) + \tilde{\pi}_j^1(\tilde{a})$ is not strictly increasing on $[0, \tilde{a}^m]$, since it obtains its maximum below $\tilde{a}^m$.

Local welfare in SIAs is

$$\tilde{w}(\tilde{a}) = \frac{(2\gamma + 9)(2\gamma + 3)}{8(\gamma + 3)^2} - \frac{3(1 + \gamma)}{2(\gamma + 3)^2} \tilde{a} - \frac{(1 + \gamma)(25\gamma^3 + 87\gamma^2 + 108\gamma + 54)}{2(\gamma + 3)^2(6 + 5\gamma)^2} \tilde{a}^2,$$

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

**Some other comparisons.** It is easy to see that $\tilde{\pi}^m > \tilde{\pi}^d > \tilde{\pi}^t > 0$, where $\tilde{\pi}^m$ and $\tilde{\pi}^d$ denote the local per-area profits under monopoly and duopoly (with no access), respectively. Furthermore, $\tilde{\pi}^m > 2\tilde{\pi}^d$ holds if and only if $\gamma > \gamma^{md} \approx 4.73$, where $\gamma^{md}$ is the unique non-negative (real) solution of $\tilde{\pi}^m = 2\tilde{\pi}^d$. 


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Appendix B: Proof of Lemma 1

**Proof.** Assume that firm \( j \) has covered the areas \([0, z_j]\). Firm \( i \)'s profit is then

\[
\Pi_i(z_i, z_j) = \begin{cases} 
  z_i \pi^d(a) + (z_j - z_i) \pi_i^{(j)}(\tilde{a}) - C(z_i) & \text{if } z_i \leq z_j, \\
  z_j \pi^d(a) + (z_i - z_j) \pi_i^{(j)}(\tilde{a}) - C(z_i) & \text{if } z_i > z_j.
\end{cases}
\]

The interior maximum on the first branch is obtained when the first-order condition holds, that is, when \( \pi^d(a) - \tilde{\pi}_i^{(j)}(\tilde{a}) = c(z_i) \). Since \( \pi^d(0) = \tilde{\pi}_i^{(j)}(0) \) and \( \pi^d(a) \) increases with \( a \), while \( \tilde{\pi}_i^{(j)}(\tilde{a}) \) decreases with \( \tilde{a} \), we have \( \pi^d(a) \geq \tilde{\pi}_i^{(j)}(\tilde{a}) \) \( \forall a \in [0, a^m] \) and \( \tilde{a} \in [0, \tilde{a}^m] \). We therefore obtain that \( z_i = z^d \equiv c^{-1}(\pi^d(a) - \tilde{\pi}_i^{(j)}(\tilde{a})) \). Similarly, the interior maximum on the second branch is obtained at \( \tilde{\pi}_i^{(j)}(\tilde{a}) = c(z_i) \), or \( z_i = \tilde{z}^s \equiv c^{-1}(\tilde{\pi}_i^{(j)}(\tilde{a})) \). In both cases the necessary second-order conditions hold, since \( -c(z_i) \leq 0 \). Thus, firm \( i \)'s local best responses are \( \min \{z_j, z^d\} \) on the first branch, and \( \tilde{z}^s \) on the second branch.

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

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

The ranges indicated in the Lemma now follow from the fact that \( \pi^d \) is strictly increasing on \([0, a^m]\) and therefore has a strictly increasing inverse function, thus \( \tilde{z}^s > z^d \) if and only if \( \pi^d(a) < \tilde{\pi}_i^{(j)}(\tilde{a}) + \tilde{\pi}_i^{(j)}(\tilde{a}) \), i.e. if \( a \) is small enough. The comparative statics for coverage ranges follow directly from \( d\pi^d/da > 0 \) for all \( a \in [0, a^m] \), and \( d\tilde{\pi}_i^{(j)}/d\tilde{a} > 0 \) and \( d\tilde{\pi}_i^{(j)}/d\tilde{a} < 0 \) for all \( \tilde{a} \in [0, \tilde{a}^m] \).
Appendix C: Proof of Lemma 2

Proof. Let us first consider symmetric equilibrium candidates \( a \in [0, a^e] \), where both infrastructure firms earn \( \pi^d(a) \). Any deviation by firm \( i = 1, 2 \) to \( a' < a \) leads to profits \( \pi^{(i)}_i(a') \), while an upwards deviation to \( a'' > a \) yields \( \pi^{(j)}_j(a) \), since the access price that is charged in the latter case is still \( a \). If \( \pi^{(i)}_i(a) \neq \pi^{(j)}_j(a) \), then a profitable deviation exists, since \( \pi^d(a) \) is their average. On the other hand, they are equal if either \( a = 0 \) or \( a = a^* \). At \( a = 0 \), there are no profitable deviations, thus \( a_1 = a_2 = 0 \) (i.e., cost-based access) is an equilibrium. At \( a = a^* \), one firm will deviate to \( a^m \) if and only if \( a^* > a^m \). Thus, \( a_1 = a_2 = a^* \) is an equilibrium too if \( a^* \leq a^m \).

We now consider asymmetric equilibrium candidates \( 0 \leq a_i < a_j < a^e \), yielding profits \( \pi^{(i)}_i(a_i) \) and \( \pi^{(j)}_j(a_j) \). First, for \( a_i = 0 \) firm \( i \) increases its profits by deviating to some \( 0 < a < a_j \). Second, if \( 0 < a_i < a^* \), firm \( j \) can increase its profits by underbidding. Third, if \( a_i \geq a^* \), firm \( i \) can increase its profits to \( \pi^{(j)}_j(a_j) \) by increasing its access price just beyond \( a_j \). Thus, there is no asymmetric equilibrium with \( a_j < a^e \).

Now, consider asymmetric equilibrium candidates with \( a_i < a^e \leq a_j \), with profits \( \pi^{(i)}_i(a_i) \) and \( \pi^{(j)}_j(a_j) \). The best choice for firm \( i \), if \( a_i < a^e \), is then to set \( a_i = a^m \) and earn the 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 \( \pi^d(a^{dr}) \). Firms will not deviate from \( a_i = a^m \) and \( a_j \geq a^e \) if \( \pi^{(i)}_i(a^m) \geq \pi^d(a^{dr}) \) and \( a^* < a^m \).

Finally, firms not making feasible access offers, i.e. \( \min \{a_i, a_j\} \geq a^e \), leads to profits \( \pi^d(a^{dr}) \), from which networks will not deviate if and only if \( \pi^d(a^{dr}) \geq \pi^{(i)}_i(a^m) \). \( \blacksquare \)