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ABSTRACT

Cooperative Investment, Uncertainty and Access*

We investigate cooperative investment for the deployment of a new infrastructure, and how it interacts with access obligations and demand uncertainty. Co-investment increases total coverage only if service differentiation and/or cost savings from joint investment, in particular due to high uncertainty, are high. Mandated access reduces incentives for co-investment not only through lower returns but also by the existence of the access option itself. Voluntary access provision increases infrastructure coverage but reduces social welfare by softening competition.

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1 Introduction

The Issues at Hand. In high-tech industries, continuous investment in innovation and physical assets is necessary for both competitive success and welfare-enhancing market outcomes. In these industries, strategic alliances and joint ventures have become an important form of business organization. Joint ventures in R&D are common for example in the automotive, electronic, and pharmaceutical industries. A similar trend also characterizes the energy and telecommunication industries. In the energy sector, several leading European operators have signed agreements for the joint deployment of new gas transmission pipelines across Europe, and other kinds of joint investment agreements have also emerged in the electricity markets in the EU and in Canada.[1]

In the telecoms industry, technological evolution has pushed operators to invest substantial resources in deploying new high-bandwidth networks or in acquiring new intangibles (e.g., spectrum rights in the mobile sector). However, the construction of high-bandwidth infrastructure is extraordinarily expensive.[2] For this reason, in the recent Directive 2009/140/EC ("Better Regulation Directive"), the European Commission invites network operators to reach cooperative agreements for the creation of new infrastructure. "Co-investment" agreements aim not only at sharing investment expenditures among different players, but also at ensuring rapid rollout of new infrastructure and avoiding excessive duplication of fixed costs. Indeed, especially for fixed connections, both in the US and in Europe, outside of urban centres the population is much more dispersed, which makes it unprofitable to construct multiple networks and in the limit even to build a single one.[3]

[1] For more details, see the analysis by Oxera (2011).

[2] Cost estimates for providing 100Mbps fixed-only broadband coverage to half of households in EU member states by 2020 are in the range of €180 – €260 billion (Cullen International, 2011).

[3] Examples of co-investment agreements among telecoms operators can be found in several European countries, both in the fixed broadband market (such as those between Telecom Italia and Fastweb in Italy, France Telecom-Orange and SFR in France, Vodafone Portugal and Sonaecom in Portugal, KPN and Riggefiber in the Netherlands, Swisscom and local utilities in Switzerland) and in the mobile market (between Vodafone UK and Telefonica, and between Orange and T Mobile, for co-siting of antennas in UK).

Our paper is concerned with the extent of the potential benefits of operators jointly investing in a new infrastructure.[4] Co-investment reduces the cost borne by each firm because the total cost is lower than when firms invest in separate networks. The rules for co-investment must specify at least the timing of decisions and how the costs will be shared among investors. However, although co-investment can be a positive mechanism for stimulating investment, depending on its implementation it can result in unexpected outcomes. The first objective of our paper is to see how effective co-investment is at furthering investment, as compared to simple duplication of investments.

While co-investment reduces the investment cost per operator, it may not be enough to make the market sufficiently competitive. Collaboration at the network and investment level may even lead operators to compete less fiercely downstream, that is, it creates scope for tacit collusion at the retail level.[5] In order to avoid the latter, access obligations are likely to be imposed even when networks co-invest. As a by-product of these access obligations, not only will the entry of additional operators change incentives for (co-)investment, but the availability of access itself also means that operators may ask for access instead of entering co-investment agreements. The second objective of this paper is to analyze this interaction between access provision and co-investment, including the possibility of providing access voluntarily.

A third issue related to co-investment is uncertainty about future demand, which is often hard to predict before new infrastructures are constructed and used. Co-investment itself is a means of spreading risk among investors, which makes it easier for them to finance their investments and therefore raises investment incentives. Furthermore, a co-investor must invest before final demand is known, while an access seeker can wait until enough information is available to decide whether entry will be profitable. Thus, access provides entrants with a cream-skimming option they can exercise, while co-investment involves a sunk

[4] This is especially true for fixed broadband investment, since the largest part is spent on digging ducts and not on fibre or electronic equipment.

[5] Collusion is a recurring concern in the literature on research joint ventures, see the literature review below. The issue is openly recognized as the most relevant problem in telecoms, too, e.g. by the association of European telecoms regulators (BEREC, 2012).

cost. The third question that we address below is how uncertainty affects the effectiveness of co-investment and the trade-off between different entry modes.

Contribution and Results. We model a game where two incumbents invest to cover areas which differ in terms of deployment costs. This permits us to have areas where infrastructure competition is feasible, either via duplication or co-investment, and also areas where only one network is economically viable and where retail competition is possible only through granting access to existing facilities. Before the investment phase, firms must announce the areas in which they plan to invest, and their competitor can decide to co-invest in these areas.

While the pure effect of risk on investment decisions and regulated retail prices, as translated into a "risk premium", has been studied elsewhere (see e.g. Guthrie et al., 2006, and Guthrie, 2012),[6] we focus on the strategic aspects specific to decisions under demand uncertainty. More precisely, we assume that at the time the access charge and the investment decisions are committed to the future level of demand is still unknown. This assumption reflects the fact that access prices are often set on the basis of forward-looking engineering studies, in particular for "green-field" (new) deployments. However, the true state of demand will be observed before firms ask for access. In order to isolate the interaction between access regulation and the "access option", we abstract away from other issues such as risk aversion.

In this framework, we analyze whether co-investment increases total coverage or if this form of cooperation only increases the area of infrastructure-based competition. We find that, indeed, co-investment leads to more areas with infrastructure-based competition than when firms invest independently. On the other hand, it only increases total coverage if the reduction in investment costs due to co-investment is large and/or services are sufficiently differentiated.

As one would expect, demand uncertainty has a negative effect on coverage. However, and more interestingly, if the co-investment coverage is lower than

[6]See also the survey by Guthrie (2006).

total coverage, co-investment is less sensitive to demand risk than coverage by a single firm, because the investment risk is spread between the co-investing firms. This implies that a higher probability of low demand decreases co-investment coverage less than total coverage.

Second, we analyze the case where the investing firms jointly have to grant access to their infrastructure to third parties which decide to enter the market only if demand is high. We show that regulated access increases total coverage only if services are sufficiently differentiated and access charges are high; otherwise, the obligation to provide access to third parties is detrimental to investment. Apart from the well-known effect that an access obligation reduces the returns from investment, we show that it also increases the opportunity cost of entering co-investment agreements, because firms have the option of requesting access instead of investing. Therefore, access obligations doubly undermine co-investment incentives.

Third, we consider voluntary access provided jointly by the co-investors. Under joint access provision infrastructure owners do not compete in individual access offers, but rather make a single access offer for their network.[7] As a result, access is provided if and only if it raises the profits of the co-investing firms. These higher profits can occur through a combination of two factors. On the one hand, if entry involves a strong demand expansion effect, then co-investors provide access in order to reap the additional wholesale profits. On the other hand, the very existence of access provision creates an opportunity cost for stealing customers from access seekers, through lost wholesale revenues. Economic costs (retail plus wholesale) of selling additional units increase, which implies that voluntary access provision can serve as a means for supporting higher retail prices. Therefore, while joint access provision will increase investment incentives due to higher profits, it may lower welfare unless services are highly differentiated.

[7] While the rules at the European level are not clear on this matter (see BEREC, 2012), joint access provision seems a natural outcome of co-investment contracts.

Related Literature. Our paper merges two different strands of literature. The first one deals with R&D joint ventures and patent pools, while the second one studies the interaction between investment and access regulation in network industries.

The literature on R&D joint ventures and their effect on innovation and retail competition is rather vast. Seminal papers by Grossman and Shapiro (1986) and d'Aspremont and Jacquemin (1988), as well as the more recent contributions by Miyagiwa and Ohno (2002) and Miyagiwa (2009), show that R&D joint ventures may increase investment in innovation. Equally, co-investment agreements may come at a cost: Since R&D cooperation is more likely to preserve symmetry among firms, tacit collusion among competitors is facilitated. Patent licensing, that is, "third-party access to innovations", is often mandated to preserve market competition. However, patents may be pooled and, depending on the characteristics of these patents, the effect of patent pools and cross-licensing is either welfare-enhancing or welfare-reducing (see Lerner and Tirole, 2004; Choi, 2010). We depart from this branch of literature in several directions. First, as in Goyal et al. (2008) and Bourreau and Doğan (2010), we consider a hybrid form of cooperation, where firms cooperate to build a joint infrastructure in some areas, while building independent (and possibly competing) infrastructures in other areas. Second, access to the infrastructure may be mandated at a specific regulated price. Third, and finally, we analyze the effect of such access obligations on investment incentives.

The second strand of literature applies to the impact of access regulation on firms' investment.[8] There are studies investigating the investment incentives by either the incumbent (Foros, 2004; Brito et al., 2010; Nitsche and Wiethaus, 2011) or the alternative operators (Bourreau and Doğan, 2005 and 2006) as a function of the access regime. Several other papers (Gans, 2001 and 2007; 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. Additional papers analyze how access rules affect the migration from an old

[8] Cambini and Jiang (2009) provide a recent and comprehensive review of both theoretical and empirical papers on broadband investment and regulation.

to a new infrastructure, such as the Next Generation Access networks in the telecoms industry (Bourreau et al., 2012; Brito et al., 2012; Inderst and Peitz, 2012a).

Since access regimes play a fundamental role in determining investment incentives, some recent papers analyze the adoption of specific access charges that are not fixed but rather depend on the investment level. In particular, Klumpp and Su (2010) analyze the link between investment and access regulation, showing that a revenue-neutral access scheme—that is, an access price that lets firms share the investment costs in proportion to predicted infrastructure usage—enhances dynamic efficiency, without negatively affecting static efficiency. However, this access scheme may fail to stimulate investment in presence of demand uncertainty, as it does not take into account the ex-ante risk that the investor faces. As the authors claim, some form of risk sharing might be useful in this case, but they do not formally analyze how risk sharing may work. All these papers address in a different vein the problem of investment and access regulation, but none of them specifically looks at the issue of joint ventures in infrastructure investments and their impact on network coverage, which is the focus of our paper.

There are very few papers that address specifically the problem of co-investment in new infrastructure. Inderst and Peitz (2012b) show that cooperation boosts investment but is likely to dampen competition, hence calling for some kind of ex-ante intervention. Krämer and Vogelsang (2012) present a laboratory experiment on the effect of cooperation in broadband markets, in a model where not cooperating would be the individually optimal choice. They find that, still, cooperation arises due to communication between players, and that it facilitates collusion while not stimulating further investment. We differ from these papers by focusing on the role of uncertainty and investigating regulated and voluntary access to third parties.

The rest of the paper is organized as follows. In Section 2 we set out the modeling framework, and in Section 3 we consider market outcomes without the possibility of access. Section 4 analyzes the interaction between access and co-investment, and Section 5 considers voluntary access provision. Finally, Section 6 concludes.

2 Model Setup

Two incumbent firms, numbered 1 and 2, invest in coverage of a new infrastructure,[9] while a potential entrant, firm e, can request access but does not invest.[10] An infrastructure firm can also ask the other incumbent for access. Finally, firms compete in retail services.

Demand uncertainty. Retail demand is uncertain *ex ante*. Its value becomes known to all (risk neutral) firms and a sectoral regulator after the access charge and the coverage decisions are committed to, but before entry decisions by access seekers are made. More specifically, we assume that retail demand can be either high or low, and we denote the probability of the latter by θ. Thus, higher values of θ imply higher investment risk.[11] In order to focus on the effect of cream-skimming, we assume that firms will only ask for access in the high demand state. If demand is low, the entrant remains out of the market and the outcome is the same as in the absence of access.

Infrastructure costs. Firms build infrastructures in different areas of a country which consists of two "regions", that is, two continuous areas $Z_i = [0, \overline{z}]$, $i = 1, 2$, with $\overline{z}$ large enough so that some areas in each region remain uncovered in equilibrium. Firm i gives priority to region Z_i to build its infrastructure. For example, firm i might have already deployed facilities in this area, which would then constitute its priority region for infrastructure

[9] For example, the two firms may invest in so-called Next Generation Access Networks (NGANs) to provide very high speed Internet access services to consumers.

[10] We could consider more than one entrant, but the effect of access obligations on co-investment would be qualitatively similar.

[11] In an extension of their baseline model, Klumpp and Su (2010) introduce uncertainty about the effectiveness of a quality-enhancing investment in a similar way. However, in their setting, the access charge is set after the realization of uncertainty, whereas in our model, it is set *ex ante*.

deployment.[12]

Areas are defined in such a way that demand in each area is identical, whereas the cost of coverage increases with z, for example because of lower population density. Formally, the sunk cost of firm i to cover area $z \in Z_i$ independently is $c(z)$, with $c(z) > 0$ and $c'(z) > 0$. The total cost of covering the areas $[0, z]$ for firm i is then

$$C(z) = \int_0^z c(x)dx,$$

with $C'(z) = c(z) > 0$ and $C''(z) = c'(z) > 0$. We refer to these areas as the single infrastructure areas (SIAs hereafter). The two incumbent firms have the same investment cost function.

Firms 1 and 2 may also decide to cooperate in deploying their infrastructure. Similar to the legal framework implemented in some European countries,[13] we assume that firm $i = 1, 2$ must announce the areas it plans to cover in region Z_i, after which firm $j \neq i$ can express its interest for co-investing in these areas. Both the announcement and the expression of interest are binding. In the case of co-investment, the total investment costs for the joint infrastructure are split equally, as will be any profits from providing access. Own network usage by co-investors is billed at marginal cost (which is normalized to zero), or equivalently, is not billed but appears as shared wholesale costs.[14]

We assume that the total investment cost for covering area z with a joint infrastructure (co-investment area, or CIA hereafter) is $\gamma c(z)$, where $\gamma \in (0, 2)$.

[12] This assumption allows us to obtain equilibria that are symmetric in network investments. Alternative assumptions about timing and strategy spaces (e.g., each firm investing in the two regions) would lead to multiple (and possibly asymmetric equilibria). For example, Bourreau et al. (2012) show that a coverage game between two incumbent firms with a single area has two asymmetric equilibria. Such outcomes would require complex distinctions of cases, but would not lead to different economic insights.

[13] For a synthesis of different cases in the EU telecoms industry, see BEREC (2012).

[14] An access price above cost for jointly-owned infrastructure would raise retail prices in time-honoured fashion, and thus pave the way for tacit collusion. We assume that market regulation does not permit this. Note that setting the access charge for (non-investing) access seekers is a different matter, which we analyze below.

If $\gamma = 1$, the total investment cost for a joint infrastructure is the same as for a single investor. If $\gamma < 1$, there are economies in investment costs from joint deployment, and if $\gamma > 1$, diseconomies. For example, co-investing may reduce the financial risk, which lowers the cost of outside financing, and therefore, the total cost of investment. There might also be synergies from joint development. By contrast, co-investment may necessitate the deployment of more equipment or generate transaction costs, which tends to raise the total investment cost. Depending on which effect prevails, γ will be below or above 1.

In Appendix A we provide an illustrative model where both cases, $\gamma < 1$ and $\gamma > 1$, can occur. We build a simple model of infrastructure investment where a single investor or two co-investors ask for loans to finance part of the investment. Loan providers believe that there is a positive probability of default. We show that when co-investment entails additional costs that are low enough, then $\gamma < 1$ due to risk-sharing. Otherwise, if the additional costs from co-investment are larger, $\gamma > 1$ occurs.

Profits. In contrast to the literature on uniform pricing obligations (e.g., Valletti et al., 2002 and Hoernig, 2006), we assume that firms can set distinct prices in different areas. In equilibrium, these prices depend on the state of demand, wholesale conditions and the number of retail competitors.

We specify the per-area profits (gross of investment costs) as follows. The high and low demand states are indicated by the indices H and L, respectively, and we assume that profits in the high demand state are higher than those in the low demand state. The superscripts indicate the market structure. In Appendix B, we provide an illustrative market model which satisfies the assumptions we make below.

A monopolist makes profits π_H^M or π_L^M, and duopolists make profits π_H^D or π_L^D. While for sufficiently homogeneous services total duopoly profits are lower than the monopoly profit, that is, $2\pi_k^D < \pi_k^M$, we allow for the possibility that $2\pi_k^D \geq \pi_k^M$ (for both $k = L, H$), which would result from a large demand expansion effect due to consumers' strong valuation of variety.

Profits are also affected by the possibility of access. As mentioned above, we assume that requests for access only arise if demand is high; that is, even for a very low access charge, entry is not attractive if demand is low. The incumbents receive π_L^M or π_L^D in SIAs and CIAs, respectively, while the entrant has zero profits. For high demand, in SIAs the infrastructure owner receives $\pi_H^S(a)$, where a denotes the access charge, and the access seekers $\pi_A^S(a)$, while in CIAs the co-investors each receive $\pi_H^C(a)$ and the entrant receives $\pi_A^C(a)$ (in all cases profits include access revenues). We assume that the access charge is low enough so that all three firms enter each market where infrastructure has been deployed, and that having co-invested leads *ex post* to higher profits than asking for access, i.e., $\pi_H^C(a) > \pi_A^S(a)$. Finally, we assume that infrastructure owners' profits increase and access seekers' profits decrease in the access charge over the relevant range. In Section 4 we consider that the access charge is applied uniformly in all areas, while in Section 5 we allow for different access regimes in areas with a single or a joint infrastructure.[15]

The per-area consumer surplus for the different scenarios is indexed identically, that is, S_H^M denotes consumer surplus under monopoly (M) and high demand (H), and similarly for the other cases. Per-area welfare is defined as the sum of per-area consumer surplus and profits of all active firms, e.g., $w_H^M = S_H^M + \pi_H^M$, etc.

Timing. The timing of our game is as follows:

– Stage 0: A sectoral regulator sets the access charge a.

– Stage 1: Firms $i = 1, 2$ announce which areas $[0, z_i] \subseteq Z_i$ they will cover with infrastructure.

– Stage 2: Firms $i = 1, 2$ announce in which areas $[0, x_i] \subseteq Z_j$, with $x_i \leq z_j$, they will co-invest, and all investments take place.

– Stage 3: The state of demand is revealed.

[15] See also Bourreau, Cambini and Hoernig (2012) for a more thorough exploration of geographically differentiated access charges.

– Stage 4: Access offers are made, and all firms 1, 2 and e decide whether to ask for access in the areas they have not covered.

– Stage 5: In each area z, firms compete in selling retail services, and profits are realized.

Stages 0 and 4 are left out when we consider the no-access benchmark. We model market outcomes as subgame-perfect equilibria.

3 No Access: Coverage and Co-Investment

In this section we analyze network coverage and market outcomes if no access is granted. Our main question is whether co-investment can increase coverage. To begin with, we determine the equilibrium under co-investment, and compare it with the equilibrium without co-investment.

If firms i, j have covered areas $[0, z_i]$ and $[0, z_j]$ in regions Z_i and Z_j, respectively, and co-invested in areas $[0, x_i]$ and $[0, x_j]$ of their rival's region, network i's expected profits are

$$\Pi_i^C = (x_i + x_j)\, E[\pi^D] + (z_i - x_j)\, E[\pi^M] - \frac{\gamma}{2} C\,(x_i) - C(z_i) + \left(1 - \frac{\gamma}{2}\right) C\,(x_j)\,, \tag{1}$$

where $E[\pi^k] = \theta \pi_L^k + (1-\theta)\, \pi_H^k$ denotes the expected profits in CIAs (when $k = D$) and SIAs (when $k = M$).

Equation (1) reads as follows. Firm i obtains duopoly profits in the areas of region Z_i where firm j has co-invested (x_j), and in the areas of firm j's region where it has co-invested (x_i). Firm i also obtains monopoly profits in the areas of region Z_i where it has rolled out a network and where firm j has not co-invested ($z_i - x_j$). Finally, $\gamma C(x_i)/2$ is the cost of firm i's co-investment in firm j's network, and $C(z_i) - (1 - \gamma/2)\, C(x_j)$ is firm i's investment cost in region Z_i, net of the savings due to firm j's co-investment.

We wish to compare infrastructure coverage with co-investment to a benchmark case without co-investment. For this, we assume that in the absence of co-investment, in stage 2 of the game, firm $i = 1, 2$ can deploy a separate network in the rival incumbent's region. Given that firm j rolls out infrastructure in the areas $[0, z_j]$, firm i decides to duplicate firm j's network up to the area $y_i \leq z_j$. Without co-investment, firm i's profits are then

$$\Pi_i^N = (y_i + y_j) \, E[\pi^D] + (z_i - y_j) \, E[\pi^M] - C(y_i) - C(z_i). \tag{2}$$

Define z^M, z^C and z^D by $c(z^M) = E[\pi^M]$, $c(z^C) = 2E[\pi^D]/\gamma$ and $c(z^D) = E[\pi^D]$, respectively. As Proposition 1 below shows, z^M represents the equilibrium (monopoly) coverage in SIAs under both co-investment and no co-investment, whereas z^C and z^D represent equilibrium duopoly coverage with co-investment and in its absence, respectively. Total coverage is then equal to $\max\left\{z^M, z^C\right\}$ under co-investment, and to $\max\{z^M, z^C\}$ under no co-investment. We have the following result.

Proposition 1 *In the absence of access, the following holds, as compared to the case without co-investment:*

1. *Co-investment increases* total coverage *(i.e., $z^C > z^M$) if investment cost savings and/or the demand expansion effect are large enough.*
2. *Co-investment always increases* duopoly coverage *(i.e., $z^C > z^D$).*

Proof. Since there is no access, we start solving the game (backwards) at stage 2. First, consider the case where there is no co-investment, but duplication of infrastructure is possible up to $y_i \leq z_j$. Given (z_j, y_j), if firm i invests up to z_i and duplicates the other firm's infrastructure up to $y_i \leq z_j$, its profits are given by (2). The profit-maximizing duplication in stage 2 is given by the first-order condition $E[\pi^D] = c(y_i)$ if the maximum over $y_i \in [0, z_j]$ is interior, and $y_i = z_j$ otherwise. Thus, firm i duplicates firm j's infrastructure in all areas up to $y_i(z_j) = \min\left\{z_j, z^D\right\}$. Similarly, we have $y_j(z_i) = \min\left\{z_i, z^D\right\}$.

In stage 1, given z_j and $y_j(z_i)$, network i maximizes its profit over z_i, which is given by the continuous function

$$\begin{cases} z_i E[\pi^D] - C(z_i) + \left\{ y_i E[\pi^D] - C(y_i) \right\} & \text{if} \quad z_i \leq z^D \\ z_i E[\pi^M] - C(z_i) + \left\{ y_i E[\pi^D] - C\left(y_i\right) - z^D \left(E[\pi^M] - E[\pi^D] \right) \right\} & \text{if} \quad z_i > z^D \end{cases},$$

where the terms in curly brackets do not depend on z_i. On the first branch, the maximum is obtained at the border point $z_i = z^D$. Thus, since firm i's profit is continuous at $z_i = z^D$ and the expression for the second branch increases in z_i for $z_i \in \left[z^D, z^M \right]$, the global maximum is on the second branch, at $z_i = z^M > z^D$. Similarly, we find that $z_j = z^M$.

Now, we consider the case where there is co-investment. From (1), the corresponding first-order conditions for optimal co-investment are $E[\pi^D] = \gamma c(x_i)/2$ if the maximum over $x_i \in [0, z_j]$ is interior, and $x_i = z_j$ otherwise. Thus, firm i co-invests on all areas up to $x_i\left(z_j\right) = \min\left\{ z_j, z^C \right\}$. Similarly, we have $x_j(z_i) = \min\left\{ z_i, z^C \right\}$. In stage 1, given z_j and $x_j(z_i)$, firm i maximizes its profit over z_i, which is given by the continuous function

$$\begin{cases} z_i E[\pi^D] - \frac{\gamma}{2} C(z_i) + \left\{ x_i E[\pi^D] - \frac{\gamma}{2} C(x_i) \right\} & \text{if} \quad z_i \leq z^C \\ \begin{array}{c} z_i E[\pi^M] - C(z_i) + \\ \left\{ x_i [\pi^D] - \frac{\gamma}{2} C(x_i) - z^C \left(E[\pi^M] - E[\pi^D] \right) + \left(1 - \frac{\gamma}{2}\right) C\left(z^C\right) \right\} \end{array} & \text{if} \quad z_i > z^C \end{cases}.$$

Again, the maximum on the first branch is at the border value, z^C. The global maximum is then found on the second branch at $z_i = z^M$ if $z^M > z^C$, and at z^C otherwise. That is, in equilibrium firms cover up to $z_i = z_j = \max\left\{ z^M, z^C \right\}$.

Co-investment increases total coverage if and only if $z^C > z^M$, that is, if

$$\gamma < \frac{2E[\pi^D]}{E[\pi^M]},$$

which implies statement 1. The second statement follows directly from $z^C > z^D$, due to the fact that $2/\gamma > 1$ since $\gamma \in (0, 2)$. ■

Without co-investment, firms cover areas $[0, z^M]$ in their preferred region and duplicate infrastructure on $[0, z^D]$ in the other firm's region. Since co-investment does not affect firms' incentives when they invest alone, the SIA coverage z^M does not change when the possibility of co-investment is introduced. What changes, though, is the extent to which both incumbents offer services to the same customers, since the co-investment region exceeds that of duplication. There are two reasons for this: (i) investment costs are shared; (ii) cost-sharing may lead to a further decrease in investment costs, as captured by the factor γ.

Whether total coverage is affected by the possibility of co-investment depends on the extent of cost reduction and on whether total profits in duopoly are high enough as compared to monopoly profits. The latter depends on how homogeneous services are. If they are almost homogeneous, the sum of duopoly profits lies far below the monopoly profit and it is very unlikely that total coverage will increase. By contrast, if services are very heterogeneous, the sum of duopoly profits exceeds the monopoly profit[16] and coverage will increase.

As a next step, we analyze the effect of demand risk on coverage. Define $\Delta^k = \pi_H^k - \pi_L^k$, for $k = M, D$. We find that a higher probability of low demand reduces the difference between SIA and CIA coverage if the latter is low. More precisely, we have the following result.

Proposition 2 *A higher probability of low demand θ always reduces single-firm coverage and co-investment coverage. It reduces the distance $z^M - z^C$ between single-firm coverage and co-investment coverage if*

$$\gamma > \frac{c'\left(z^M\right)}{c'\left(z^C\right)} \frac{2\Delta^D}{\Delta^M}.$$

Proof. Using the fact that $c' > 0$, $E[\pi^k] = \pi_H^k - \theta\left(\pi_H^k - \pi_L^k\right)$, and $\pi_H^k > \pi_L^k$, for $k = M, D$, we find that z^M and z^D decrease with θ. Besides, we have

$$\frac{\partial\left(z^M - z^C\right)}{\partial\theta} = -\frac{\Delta^M}{c'\left(z^M\right)} + \frac{2}{\gamma}\frac{\Delta^D}{c'\left(z^C\right)}.$$

[16] At the extreme, as Inderst and Peitz (2012b) argue, if co-investment lead to collusion in the retail market, it would imply an even larger coverage, due to higher profits. In Appendix B, we show that, for our illustrative market model, the sum of duopoly profits exceeds the monopoly profit if services are sufficiently differentiated.

Therefore, $\partial\left(z^M - z^C\right)/\partial\theta < 0$ iff $\gamma > 2c'\left(z^M\right)\Delta^D/(c'\left(z^C\right)\Delta^M)$. ■

From Proposition 1, if the economies from joint investment are strong enough, co-investment extends total coverage. But in that case, from Proposition 2, it is likely that the expansion in coverage decreases with the probability of low demand. On the other hand, if the economies from joint investment are limited, total coverage is not affected by co-investment. However, it is likely that the distance between total coverage and co-investment coverage shrinks as the probability of low demand becomes higher.[17]

Our result therefore characterizes an interesting property of the co-investment agreement. Since co-investing spreads the investment risk due to demand uncertainty between investors, the co-investment agreement also mitigates the risk in terms of network coverage. If the co-investment coverage is lower than total coverage, it also tends to be *less* sensitive to a change in the probability of low demand. This means that a higher probability of low demand decreases co-investment coverage less than total coverage.

4 Access and Co-investment

Imposing third-party access is a means of increasing static efficiency in local markets, but is widely seen as reducing investment incentives. In this section we study how regulated access interacts with co-investment and network coverage if requests for access only arise after investments are sunk and demand uncertainty is resolved.

The game now involves all stages. The payoffs from the retail competition stage 5 have been defined above. At stage 4, access offers and requests are made. Firms do not ask for access if demand, which is revealed in stage 3, turns out to be low. In this case, the incumbents' profits are π_L^D in CIAs and π_L^M in SIAs. If demand is high, the entrant asks for access in all covered areas, while incumbents optimally ask for access to the other incumbent's SIAs. At

[17] In Appendix B, we show that, in our example setting, there is a threshold value of γ such that if γ is below the threshold, $z^C > z^M$ and $z^C - z^M$ decreases with θ. Whereas, if γ is above the threshold, then $z^C < z^M$ and $z^M - z^C$ decreases with θ.

stage 2, incumbent i's expected profits, for any (z_j, x_j) and $x_i \leq z_j$, are then

$$\begin{aligned} \Pi_i^A &= (x_i + x_j)\left[\theta \pi_L^D + (1-\theta)\,\pi_H^C(a)\right] \\ &\quad + (z_i - x_j)\left[\theta \pi_L^M + (1-\theta)\,\pi_H^S(a)\right] \\ &\quad + (z_j - x_i)(1-\theta)\,\pi_A^S(a) - \frac{\gamma}{2}C(x_i) - C(z_i) + \left(1 - \frac{\gamma}{2}\right) C(x_j)\,, \end{aligned} \tag{3}$$

where a denotes the access charge. The first two terms in (3) capture the expected profits in CIAs and SIAs. The third term contains firm i's profits when it asks for access to firm j's SIAs in the high demand state, while the last terms contain the same investment costs as in the previous section. The following Proposition characterizes equilibrium coverage.

Proposition 3 *Under access, co-investment occurs on* $\left[0, z^C(a)\right]$, *and single investment in all areas* $\left(z^C(a), z^M(a)\right]$ *if* $z^C(a) < z^M(a)$, *where* $z^C(a)$ *and* $z^M(a)$ *are defined by*

$$c(z^C(a)) = \frac{2}{\gamma}\left\{\theta \pi_L^D + (1-\theta)\left[\pi_H^C(a) - \pi_A^S(a)\right]\right\}, \tag{4}$$

$$c(z^M(a)) = \theta \pi_L^M + (1-\theta)\,\pi_H^S(a). \tag{5}$$

Both $z^C(a)$ *and* $z^M(a)$ *increase in* a. *Co-investment coverage increases with access if and only if* $\pi_H^C(a) - \pi_A^S(a) > \pi_H^D$.

Proof. The proof is similar to that of Proposition 1. In stage 2, given z_i, z_j and x_j, network i maximizes Π_i^A over $x_i \leq z_j$. The first-order condition for an interior maximum at $z^C(a) \leq z_j$ is

$$\theta \pi_L^D + (1-\theta)\left[\pi_H^C(a) - \pi_A^S(a)\right] = \frac{\gamma}{2} c\left(z^C(a)\right).$$

Thus, $x_i(z_j) = \min\left\{z_j, z^C(a)\right\}$, and similarly, $x_j(z_i) = \min\left\{z_i, z^C(a)\right\}$. In stage 1, firm i maximizes over z_i, given z_j and $x_j(z_i)$, the continuous function

$$\left\{ \begin{array}{ll} z_i\left[\theta \pi_L^D + (1-\theta)\,\pi_H^C(a)\right] - \frac{\gamma}{2}C(z_i) + K_1 & \text{if} \quad z_i \leq z^C(a) \\ z_i\left[\theta \pi_L^M + (1-\theta)\,\pi_H^S(a)\right] - C(z_i) + K_2 & \text{if} \quad z_i > z^C(a) \end{array} \right.,$$

where K_1 and K_2 contain the terms that do not depend on z_i. Since $\pi_A^S(a) \geq 0$, the maximum on the first branch is at the border point $z_i = z^C(a)$, while the maximum on the second branch is at $z^M(a)$, which is given by $c\left(z^M(a)\right) = \theta\pi_L^M + (1-\theta)\,\pi_H^S(a)$. Total coverage is then $\max\left\{z^C(a), z^M(a)\right\}$.

Finally, both $z^C(a)$ and $z^M(a)$ increase in a because $\pi_H^C(a) - \pi_A^S(a)$ and $\pi_H^S(a)$ increase in a, and $z^C(a) > z^C$ iff $\frac{2}{\gamma}\left\{\theta\pi_L^D + (1-\theta)\left[\pi_H^C(a) - \pi_A^S(a)\right]\right\} > \frac{2}{\gamma}\left\{\theta\pi_L^D + (1-\theta)\,\pi_H^D\right\}$, which leads to the last statement. ■

We obtain the common result that networks' incentives to invest alone in the most remote areas is directly affected by access provision. In the high demand state, profits in these areas (i.e., $\pi_H^S(a)$) decrease with a lower access charge. If access is provided and $z^M(a) > z^C(a)$, coverage is larger than in the no-access benchmark if and only if $z^M(a) > z^M$, which occurs if services are sufficiently differentiated and the access charge is high enough.

Similarly, co-investment coverage decreases with a lower access charge. More importantly, though, under access there is an additional factor that reduces co-investment: any potential co-investor, instead of co-investing in an additional area, could equally well ask for access in that area. This creates an additional opportunity cost of co-investing, which is captured by the term $(1-\theta)\,\pi_A^S(a)$ in $z^C(a)$. While it is still possible in principle that co-investment exceeds monopoly coverage, for example if the co-investment cost is much lower than the single-firm investment cost, this opportunity cost makes it less likely.

Thus, the possibility of asking for access creates perverse incentives which reduce the potential benefits of co-investment schemes. The regulator has therefore to trade off between encouraging co-investment in CIAs and developing competition via access in SIAs.[18] Naturally, this trade-off could be solved if it were possible to prohibit co-investors from asking for access in SIAs; but from a legal point of view this may not be a feasible option. Conversely, an access policy which sets a lower access charge for (co-)investors, compared to pure entrants, would actually reinforce the opportunity cost, and hence, disincentivize co-investment.

[18] Note that this trade-off is present even if there is no access in CIAs.

5 Voluntary Access Provision

Instead of imposing access at a regulated price in co-investment areas, the regulator could decide to introduce a lighter regulatory regime by allowing co-investors to provide access voluntarily, while maintaining regulation of the access charge a in SIAs. The motivation for such a policy would be that co-investment reduces the necessity of regulated access as it is close to infrastructure-based competition, while voluntary access allows for additional entry to increase further consumer surplus and welfare. We show below that the latter objective may actually not be achieved even if access is granted.

We still assume that the co-investors provide access jointly, rather than individually, if they choose to do so, and decide on an access price $\widetilde{a}$ for access to their joint infrastructure after investments have been made. This access charge is therefore the one that maximizes their local profits, subject to the constraint that the entrant is at least marginally active, that is, $\widetilde{a}^* = \arg\max_{\widetilde{a}} \pi_H^C(\widetilde{a})$ s.t. $\pi_A^C(\widetilde{a}) \geq 0$.

Before discussing the local market outcomes under voluntary access, we characterize very generally what effect access will have on coverage.

Proposition 4 *If voluntary access is provided, co-investment coverage (weakly) increases as compared to both the no-access and regulated-access scenarios.*

Proof. Since co-investors decide jointly on the access charge for their joint infrastructure, they will agree on providing access if and only if their profits under access, $\pi_H^C(\widetilde{a}^*)$, are at least as large as their profits without providing access, π_H^D.

In that case, since coverage increases in local profits (from Propositions 1 and 3), it follows that coverage increases compared to the case of no access, if voluntary access is granted. Coverage will also increase compared to the regulated access case, since voluntary access will be provided at the access charge $\widetilde{a}^*$ that maximizes $\pi_H^C(\widetilde{a})$. ■

This Proposition implies that allowing more flexibility to co-investors on the price conditions for granting access to their network might increase their incentives to invest, but only if they actually make use of this flexibility. We argue below, though, that this is quite likely to happen. The positive effect of voluntary access on joint investment would work not only through avoiding access obligations, which firms might find onerous, but also by allowing the co-investors to tap additional demand.

The above result however does not imply that co-investment and voluntary access are always socially preferable, due to their impact on local market outcomes and welfare. The provision of voluntary access to potential entrants generates several different effects on market outcomes. Providing access brings in additional wholesale profits, but also reduces the co-investors' retail profits due to more intense competition downstream. More importantly, access may change the strategic interactions in the retail market. This latter effect is subtle and not immediately obvious. But as we will argue now, it can outweigh the others.

Proposition 5 *Compared to the no-access situation, voluntary access provision increases local welfare when services are sufficiently differentiated, whereas it reduces local welfare when services are little differentiated.*

Proof. First, assume that the services provided by the three firms are completely differentiated, i.e. independent products. In this case, the entrant provides a positive quantity of a new service. Providing access to the entrant then increases access providers' profits and local (per-area) welfare.

At the other extreme, if services are almost homogeneous, entry generates a strong "business-stealing effect", reducing co-investors' retail profits. We now argue that the profit-maximizing access price will be at a level which makes the entrant produce only a small quantity. At the same time, the access charge appears as an opportunity cost in the co-investors' conditions for the equilibrium retail price. In other words, setting a high access charge makes the access-providing co-investors less aggressive competitors in the downstream market due to the "fat-cat effect" (Fudenberg and Tirole, 1984), and their retail prices rise as compared to the duopoly outcome without access. Since the entrant's output is small, the total effect is to increase incumbents' profits but to lower welfare.

By continuity, there will be a threshold level of differentiation above which local welfare rises, and correspondingly below which it decreases. ■

Since voluntary access expands co-investment coverage from Proposition 4, the last Proposition implies that, compared to the no-access benchmark, voluntary access increases welfare when service differentiation is sufficiently high, and decreases welfare when service differentiation is very low. Another interesting and related question is how voluntary access compares to regulated access. We have the following result.

Proposition 6 *Compared to the regulated access situation, voluntary access provision increases welfare if services are highly differentiated and the regulated access charge is high, whereas it decreases welfare if services are little differentiated and the regulated access charge is low.*

Proof. If services are highly differentiated and a is high, then $w^C(\widetilde{a}^*) > w^C$ from Proposition 5, and $w^C(\widetilde{a}^*) > w^S(a)$. Since per-area welfare increases in co-investment areas and the co-investment coverage increases from Proposition 5, social welfare increases with voluntary access. Similarly, welfare decreases in the other case where services are little differentiated and a is low, as $w^C(\widetilde{a}^*) < w^C$, and $w^C(\widetilde{a}^*) < w^S(a)$. ■

This Proposition highlights that whether voluntary access is welfare-enhancing or decreasing depends on whether investment is favored over competition, or the reverse. If the regulator plans to set a high access charge in SIAs to encourage investment and firms are expected to provide highly differentiated services, letting infrastructure firms to provide access to their joint infrastructure on a voluntary basis is welfare-enhancing. By contrast, if the regulator favors local welfare over investment, and firms provide services which are close substitutes, voluntary access is welfare-decreasing.

6 Conclusion

Investments in new infrastructures are crucial in network industries, as well as the preservation of a competitive environment via access obligations. We study the role of co-investment in such a context, and its interplay with access obligations when the demand for the new infrastructure is uncertain.

In the absence of access obligations, we find that co-investment allows firms to share the investment risk, which extends the areas with infrastructure competition. It also increases total coverage if service differentiation and/or cost savings from co-investment are sufficiently high. If co-investment does not expand total coverage, it may be nonetheless less sensitive to the demand risk than total coverage.

Unless services are sufficiently differentiated and the access charge is high enough, imposing access to the new infrastructures undermines investment. An interesting additional insight from our model is that access undermines co-investment incentives in two ways. This is because potential co-investors have the option to ask for access, which gives rise to an opportunity cost of co-investment. From a policy point of view, this means that the regulator faces a trade-off between encouraging infrastructure competition through co-investment and allowing for service-based competition via access obligations.

Allowing more flexibility to co-investors for setting the access conditions to their joint infrastructure has a positive effect on investment, but it may come at the cost of higher retail prices in the areas with a joint infrastructure, due to the "fat cat" effect.

Further research will explore the effects of asymmetry between co-investors, i.e. incumbency effects, and the choice of rules for sharing investment cost and access profits, from both of which we have abstracted away in this paper.

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Appendix

Appendix A: A model of investment with financing costs

In this appendix, we propose a model where firms ask for loans to finance their infrastructure investment, and show that co-investment can reduce total investment cost due to risk-sharing.

Single investor. Assume that a single investor wants to invest in area z in a new infrastructure of total cost (gross of financing costs) K. Denote by r the riskless interest rate. The single firm contributes its own capital, $k_0 < K$, to finance the investment, but also asks for a loan to cover the residual expenditure $k = K - k_0$. Lenders assume that there is a probability of default $p \in (0, 1)$.[19] Under default, lenders receive back only a fraction of the capital lent, $(1 + w)\,k$, where $w \in [-1, 0)$ denotes the write-down on the loan. Assuming a perfectly competitive financial market, the competitive interest rate, s, is defined by:

$$(1 + r)\,k = p\,(1 + w)\,k + (1 - p)\,(1 + s)\,k,$$

that is, $r = pw + (1 - p)\,s$, from which we obtain

$$s = \frac{r - pw}{1 - p}.$$

Note that $\partial s/\partial p > 0$; that is, the competitive interest increases in the probability of default. The total cost of investment for a single investor in area z is then

$$c\,(z) = K + sk = (1 + s)\,K - sk_0. \tag{6}$$

Two co-investors. Assume that the total investment cost under co-investment is equal to βK, with $\beta \geq 1$. The factor β may be strictly larger than 1 due

[19] We could assume that the probability of default depends on the probability of low demand, but for simplicity we do not pursue this idea.

to the necessity of additional expenditures in infrastructure. The amount of capital needed for financing the joint investment is $k = \beta K - 2k_0$, with each co-investor contributing his own funds k_0 and taking responsibility for paying back $k/2$ plus interest. Independently of how the two firms' defaults are correlated we again obtain the competitive interest rate

$$s = \frac{r - pw}{1 - p}.$$

The total investment cost in area z for the two co-investors becomes:

$$\gamma c(z) = \beta K + sk = (1 + s) \beta K - 2sk_0, \tag{7}$$

where γ represents the ratio of investments costs under co-investment to investments costs with a single investor. Using (6) and (7), we obtain that investment costs in case of co-investment are multiplied by the factor

$$\gamma = \frac{(1 + s) \beta K - 2sk_0}{(1 + s) K - sk_0}.$$

If $\beta = 1$ (i.e., there is no diseconomies from joint investment), then $\gamma < 1$, due to risk sharing; in that case, co-investment reduces total investment costs due to the smaller size of the loan. This is also true if β is not too high. Otherwise, we can have $\gamma > 1$ if β is sufficiently high.

Appendix B: An illustrative retail market model

In this appendix, we present closed-form expressions for per-area profits, using a specific example with zero marginal cost and a linear demand system. We assume that in each local market there is a representative consumer with the following quasi-linear utility function, symmetric in the quantities q_i, $i = 1, 2, e$,

$$U(m, q_1, q_2, q_e) = m + A \sum_i q_i - \frac{1 - \delta}{2} \sum_i q_i^2 - \frac{\delta}{2} \left(\sum_i q_i \right)^2,$$

where m represents the numeraire good, $A > 0$, q_i is firm i's quantity, and $\delta \in (0,1)$ measures the degree of homogeneity between the firms' services (a higher δ corresponding to a higher degree of homogeneity). We assume that $A = A_L$ with probability θ and $A = A_H$ with probability $(1-\theta)$, with $A_H > A_L$ and $\theta \in (0,1)$. Equating $\partial U / \partial q_i$ to p_i for $i = 1, 2, e$, and solving for the q_i leads to the three-good demand system

$$Q_i^3 = \frac{A}{1+2\delta} - \frac{p_i}{1-\delta} + \frac{\delta}{1-\delta} \frac{\sum_k p_k}{1+2\delta},$$

for $i = 1, 2, e$. When the entrant is not active, we set $q_e = 0$ and solve $\partial U / \partial q_i = p_i$ for $i = 1, 2$, $j \neq i$. We obtain

$$Q_i^2 = \frac{A}{1+\delta} - \frac{p_i - \delta p_j}{1-\delta^2}.$$

Similarly, we find that the demand under monopoly is $Q_i^1 = A - p_i$.

In the following we state profits for a generic A. The monopolist i solves $\max_{p_i} p_i Q_i^1$, which leads to the monopoly profits $\pi^M = A^2/4$. Under duopoly, each firm $i = 1, 2$ maximizes $p_i Q_i^2$ given the other firm's price, which leads to the following equilibrium prices, quantities, profits and welfare

$$p^D = \frac{1-\delta}{2-\delta} A,\ q^D = \frac{A}{(1+\delta)(2-\delta)},\ \pi^D = \frac{(1-\delta) A^2}{(\delta+1)(2-\delta)^2},\ w^D = m + \frac{(3-2\delta) A^2}{(2-\delta)^2 (\delta+1)}.$$

Under access, in SIAs the infrastructure owner i maximizes $p_i Q_i^3 + a \left(Q_j^3 + Q_e^3\right)$, while both access seekers $j \neq i$ and e maximize $(p_k - a) Q_k^3$, for $k = j, e$. Equilibrium prices are

$$p_1 = \frac{1-\delta}{2} A + \frac{\delta (2\delta + 3)}{3\delta + 2} a < p_2 = p_e = \frac{1-\delta}{2} A + \frac{2\delta^2 + 2\delta + 1}{3\delta + 2} a,$$

and the corresponding equilibrium profits are

$$\begin{aligned}\pi^S(a) &= \frac{1-\delta^2}{4+8\delta}A^2 + \frac{\delta^2+2\delta+2}{3\delta+2}Aa - \frac{2\delta^3+9\delta^2+10\delta+4}{(3\delta+2)^2}a^2, \\ \pi_A^S(a) &= \frac{\left(1-\delta^2\right)\left((3\delta+2)A-2(1+2\delta)a\right)^2}{4(1+2\delta)(3\delta+2)^2}.\end{aligned}$$

The per-area welfare is

$$w^S(a) = m + \frac{3(\delta+1)(3-\delta)}{8(1+2\delta)}A^2 - \frac{1-\delta}{2}aA - \frac{6\delta^3+11\delta^2+6\delta+2}{2(3\delta+2)^2}a^2.$$

These expressions are valid if and only if $q_e \geq 0$, that is, if

$$a \leq \overline{a}^S = A\frac{3\delta+2}{2(1+2\delta)}.$$

Finally, we find that $\pi^S(a)$ is maximized at

$$a^{S*} = \frac{A(2+3\delta)\left(2+2\delta+\delta^2\right)}{8+2\delta(2+\delta)(5+2\delta)} < \overline{a}^S.$$

In CIAs, the incumbents i and j maximize $p_k Q_k^3 + \frac{1}{2}aQ_e^3$ (sharing wholesale profits), where $k=i,j$, and the entrant maximizes $(p_e-a)Q_e^3$. Equilibrium prices are

$$p_1 = p_2 = \frac{1-\delta}{2}A + \frac{\delta(\delta+1)}{3\delta+2}a < p_e = \frac{1-\delta}{2}A + \frac{2\delta^2+3\delta+2}{6\delta+4}a,$$

quantities are

$$q_1 = q_2 = \frac{\delta+1}{4\delta+2}A + \frac{\delta^2}{2(3\delta+2)(1-\delta)}a > q_e = \frac{\delta+1}{4\delta+2}A - \frac{(\delta+1)(2-\delta)}{2(3\delta+2)(1-\delta)}a,$$

and profits are

$$\pi^C(a) = \frac{1-\delta^2}{4+8\delta}A^2 + \frac{1}{4}\frac{2\delta^2+3\delta+2}{3\delta+2}aA + \frac{(\delta+2)(\delta+1)\left(2\delta^2-\delta-2\right)}{4(1-\delta)(3\delta+2)^2}a^2,$$

$$\pi_A^C(a) = \frac{(\delta+1)\left((3\delta+2)(1-\delta)A-(2\delta+1)(2-\delta)a\right)^2}{4(3\delta+2)^2(1-\delta)(1+2\delta)}.$$

Finally, the per-area welfare is

$$w^C(a) = m + \frac{3(\delta+1)(3-\delta)}{16\delta+8}A^2 - \frac{1-\delta}{4}aA - \frac{(\delta+1)\left(4-6\delta^3+\delta^2+4\delta\right)}{8(1-\delta)(3\delta+2)^2}a^2.$$

These expressions are valid if and only if $q_e \geq 0$, or

$$a \leq \bar{a}^C = A\frac{(3\delta+2)(1-\delta)}{(2\delta+1)(2-\delta)} < \bar{a}^S,$$

which is a stronger requirement than in single-investment areas because life is harder for the entrant. Finally, $\pi^C(a)$ is maximized at

$$a^{C*} = \min\left\{\frac{A(1-\delta)\left(2\delta^2+3\delta+2\right)(3\delta+2)}{2(\delta+2)(\delta+1)\left(2+\delta-2\delta^2\right)}, \bar{a}^C\right\}.$$

We find that $a^{C*} < \overline{a}^C$ if $\delta < 0.70$, and $a^{C*} = \overline{a}^C$ otherwise.

Model assumptions.

We check that this specific market model satisfies the assumptions of our general model. First, as profits increase with A, the assumption that profit is higher under high demand ($A = A_H$) than under low demand ($A = A_L < A_H$) is satisfied. Second, we find that $\pi^M > 2\pi^D$ if $\delta \in (0.61, 1]$, that is, if service differentiation is low, whereas $\pi^M < 2\pi^D$ if $\delta \in [0, 0.61)$. Third, we find that $\pi_H^C(a) - \pi_A^S(a)$ decreases with a, and that it is non-negative for all $a \leq \bar{a}^C$. Fourth, and finally, from the profit expressions, we find that access seekers' profits, $\pi_A^S(a)$ and $\pi_A^C(a)$, both decrease with a. Define $\overline{a} = \min\left\{a^{S*}, a^{C*}\right\}$ as the relevant range for the access charge a. Then, from the definition of a^{S*} and

a^{C*}, the infrastructure owners' profits, $\pi_I^S(a)$ and $\pi_I^C(a)$, both increase with a, for $a \in [0, \overline{a}]$.

Demand risk and co-investment coverage.

We assume that $c(z) = z^2$. From the analysis in Section 3, using the market model and the specific investment cost function, co-investment increases total coverage iff

$$\gamma < \overline{\gamma} = \frac{2E[\pi^D]}{E[\pi^M]} = \frac{8(1-\delta)}{(2-\delta)^2(1+\delta)},$$

with $\overline{\gamma} \in (0, 2)$. Furthermore, from Proposition 2, we have $\partial\left(z^M - z^C\right)/\partial\theta >$ 0 iff

$$\gamma < \frac{c'\left(z^M\right)}{c'\left(z^C\right)}\frac{2\Delta^D}{\Delta^M} = \frac{\sqrt{E[\pi^M]}}{\sqrt{2E[\pi^D]/\gamma}}\frac{2\Delta^D}{\Delta^M} = \frac{2\sqrt{2}\sqrt{\gamma\left(1-\delta^2\right)}}{2+\delta-\delta^2},$$

or again $\gamma < \bar{\gamma}$. Thus, for $\gamma < \overline{\gamma}$ we have $z^C > z^M$ and $\partial\left(z^C - z^M\right)/\partial\theta < 0$, and for $\gamma > \overline{\gamma}$, we have $z^C < z^M$ and $\partial\left(z^M - z^C\right)/\partial\theta < 0$.

Voluntary joint access provision.

With voluntary access provision, co-investors choose the access charge that maximizes their joint profits, that is, $\widetilde{a}^* = \arg\max_{\widetilde{a}} \pi_H^C(\widetilde{a})$, subject to the constraint $q_e(\widetilde{a}) \geq 0$. With our linear demand system, we obtain

$$\widetilde{a}^* = a^{C*} = \min\left\{\frac{A(\delta-1)\left(2\delta^2+3\delta+2\right)(3\delta+2)}{2(\delta+2)(\delta+1)\left(2\delta^2-\delta-2\right)}, \bar{a}^C\right\},$$

where $\bar{a}^C$ is defined such that $q_e(\widetilde{a}) \geq 0$ iff $\widetilde{a} \leq \bar{a}^C$. We find that $\widetilde{a}^* < \overline{a}^C$ if $\delta < 0.70$, and $\widetilde{a}^* = \overline{a}^C$ otherwise. In other words, if $\delta \geq 0.70$, that is, if goods are almost homogeneous, access is provided to the entrant, but it has zero quantity in equilibrium.

Let us now analyze market outcomes above and below the threshold on δ.

CASE I - *Interior maximum at* $a^* < \bar{a}^C$.

Consider the case where $\delta < 0.70$. We need to verify if in this case co-investors are willing to provide access to third parties, comparing the co-investment profits with the duopoly profits. We find that

$$\pi_H^C(\widetilde{a}^*) = \frac{(\delta-1)(3\delta+2)\left(10\delta^2+19\delta+10\right)A^2}{16\left(2\delta^2-\delta-2\right)(\delta+1)(\delta+2)(2\delta+1)} > \pi_H^D.$$

Therefore, co-investors do want to provide voluntary access. Comparing co-investors' retail prices at $\widetilde{a}^*$, we obtain:

$$p^C(\widetilde{a}^*) = A\frac{(3\delta+2)(-1+\delta)}{(\delta+2)\left(2\delta^2-\delta-2\right)} > p^D = \frac{1-\delta}{2-\delta}A.$$

This is true for all $\delta \in (0,1)$, implying that retail prices go up in CIAs when co-investors voluntarily provide access and products are sufficiently differentiated. However, entry generates additional benefits for consumers in terms of more product variety. We then have to compare local welfare under voluntary access to local welfare in the no-access case. We have:

$$\begin{aligned} w^C(\widetilde{a}^*) &= m + \frac{496+744\delta^6+1776\delta-1312\delta^3+196\delta^7+1512\delta^2-2305\delta^4-243\delta^5}{32\left(2\delta^2-\delta-2\right)^2(\delta+1)(\delta+2)^2(2\delta+1)}A^2 \\ &> w^D = m + \frac{(3-2\delta)A^2}{(2-\delta)^2(\delta+1)} \end{aligned}$$

iff $\delta < 0.60$. This result implies that welfare goes up if $\delta < 0.60$, that is, if services are sufficiently differentiated, and that it decreases otherwise, when services are less differentiated.

CASE II - *Corner maximum at* $a^* = \bar{a}^C$.

Consider now the case where $\delta > 0.70$. Comparing the profits under co-investment and duopoly, we have

$$\pi_I^C(\widetilde{a}^*) = \frac{(1-\delta)(5\delta+2)(\delta+2)}{4(2\delta+1)^2(\delta-2)^2}A^2 > \pi_H^D.$$

Again, we obtain that co-investors voluntarily give access to third parties, but at an access price that just keep the entrant's quantity at zero. Comparing co-investors' retail price to that in duopoly, we find that

$$p^C(\widetilde{a}^*) = \frac{1-\delta}{2}A + \frac{\delta(\delta+1)(1-\delta)}{(2\delta+1)(2-\delta)} > p^D = \frac{1-\delta}{2-\delta}A,$$

hence, as above, for all $\delta \in (0,1)$, retail prices go up. Since the entrant's quantity is equal to zero, this implies that welfare decreases as compared to duopoly without access.

To sum up, we find that access is always voluntarily provided, but at a high access price. If goods are sufficiently homogeneous, access is only nominal since the entrant will have zero quantity – access serves only to create a "fat cat effect" through the introduction of wholesale opportunity costs and raises retail prices. If goods are sufficiently differentiated, the access charge is chosen so that the entrant sells a strictly positive quantity, but retail prices still go up; welfare then increases if goods are sufficiently differentiated.