European University Institute

ROBERT SCHUMAN CENTRE FOR ADVANCED STUDIES

EUI WORKING PAPERS

RSCAS 2016/61
Robert Schuman Centre for Advanced Studies
Florence School of Regulation

Cooperative Investment, Access, and Uncertainty

Marc Bourreau, Carlo Cambini and Steffen Hoernig

European University Institute
Robert Schuman Centre for Advanced Studies
Florence School of Regulation

Cooperative Investment, Access, and Uncertainty

Marc Bourreau, Carlo Cambini and Steffen Hoernig

EUI Working Paper **RSCAS** 2016/61

This text may be downloaded only for personal research purposes. Additional reproduction for other purposes, whether in hard copies or electronically, requires the consent of the author(s), editor(s).
If cited or quoted, reference should be made to the full name of the author(s), editor(s), the title, the working paper, or other series, the year and the publisher.

ISSN 1028-3625

© Marc Bourreau, Carlo Cambini and Steffen Hoernig, 2016

Printed in Italy, November 2016
European University Institute
Badia Fiesolana
I – 50014 San Domenico di Fiesole (FI)
Italy
www.eui.eu/RSCAS/Publications/
www.eui.eu
cadmus.eui.eu

Robert Schuman Centre for Advanced Studies

The Robert Schuman Centre for Advanced Studies (RSCAS), created in 1992 and directed by Professor Brigid Laffan, aims to develop inter-disciplinary and comparative research on the major issues facing the process of European integration, European societies and Europe's place in 21st century global politics.

The Centre is home to a large post-doctoral programme and hosts major research programmes, projects and data sets, in addition to a range of working groups and *ad hoc* initiatives. The research agenda is organised around a set of core themes and is continuously evolving, reflecting the changing agenda of European integration, the expanding membership of the European Union, developments in Europe's neighbourhood and the wider world.

Details of the research of the Centre can be found on:
http://www.eui.eu/RSCAS/Research/

Research publications take the form of Working Papers, Policy Papers, and e-books. Most of these are also available on the RSCAS website:
http://www.eui.eu/RSCAS/Publications/

The EUI and the RSCAS are not responsible for the opinions expressed by the author(s).

Florence School of Regulation

The Florence School of Regulation (FSR) is a partnership between the Robert Schuman Centre for Advanced Studies (RSCAS) at the European University Institute (EUI), the Council of the European Energy Regulators (CEER) and the Independent Regulators Group (IRG). Moreover, as part of the EUI, the FSR works closely with the European Commission.

The objectives of the FSR are to promote informed discussions on key policy issues, through workshops and seminars, to provide state-of-the-art training for practitioners (from European Commission, National Regulators and private companies), to produce analytical and empirical researches about regulated sectors, to network, and to exchange documents and ideas.

At present, its scope is focused on the regulation of Energy (electricity and gas markets), of Communications & Media, and of Transport.

This series of working papers aims at disseminating the work of scholars and practitioners on current regulatory issues.

For further information
Florence School of Regulation Transport Area
Robert Schuman Centre for Advanced Studies
European University Institute
Via delle Fontanelle 19
I-50014 Fiesole (FI)
Tel.: +39 055 4685 795
Fax: +39 055 4685 755
E-mail: fsr.transport@eui.eu
Web:
www.eui.eu/DepartmentsAndCentres/RobertSchumanCentre/Research/Programmes/FlorenceSchoolRegulation.aspx

Abstract

This paper compares the impacts of traditional one-way access obligations and the new regulatory scheme of co-investment on the roll-out of network infrastructures. We show that compulsory access leads to smaller roll-out, first because it reduces the returns from investment, and second because in the presence of uncertainty it provides access seekers with an option whose exercise hurts investors. Co-investment without access obligations leads to risk sharing and eliminates the access option, implying highest network coverage. Allowing for access on top of co-investment actually decreases welfare if the access price is low.

Keywords

Co-investment; Access obligations; Next generation networks; Uncertainty

JEL Classification: L96; L51

1 Introduction

The Issues at Hand. In high-tech industries, continuous investments in physical assets and innovation are necessary for competitive success and welfare-enhancing market outcomes. Here, cooperation has become an important phenomenon – joint investments are common, for example, in the automotive, electronic, and pharmaceutical industries. A similar trend also is present in the energy and electronic communications industries.

In the latter, technological evolution and market pressures are pushing operators to invest in new high-bandwidth networks. However, their construction is extraordinarily expensive,[1] and existing wholesale regulation, which imposes access obligations on network owners, interferes with investment decisions. These access obligations were introduced in Europe during the first phase of broadband roll-out, in order to create the possibility of retail competition over the monopoly copper network. In terms of retail market outcomes, this policy has been largely successful; it is considered less propitious, though, for creating incentives for investment in new high-speed networks.

For this reason, the recent proposal of a Directive on the European Electronic Communications Code, issued by the European Commission in September 2016,[2] invites national regulatory authorities to adopt co-investment as an alternative to standard access obligations.[3] Co-investment is viewed as a way to share investment expenditures among different players, thereby stimulating the nation-wide rollout of new infrastructures. 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.

A host of network operators in Europe already has adopted co-investment agreements,[4]

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

[2] See https://ec.europa.eu/digital-single-market/en/connectivity-european-gigabit-society

[3] The Directive 2009/140/EC ("Better Regulation Directive") already incited network operators to cooperatively invest in the creation of new infrastructures, but had little impact.

[4] 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,

but the academic literature has not accompanied this development. It has focused on access pricing as the main regulatory instrument to facilitate entry and enhance market competition. Access obligations on new infrastructures however involve a complex trade-off between lower retail prices and higher coverage. In this paper, we focus on co-investment as an alternative regulatory obligation to spur market competition and investment incentives. With co-investment, an entrant can request access to an incumbent's infrastructure by sharing the investment cost of the infrastructure after an investment plan has been announced. The first question we address is whether co-investment can stimulate infrastructure investments and enhance social welfare in comparison to a standard access pricing regime. We consider two different regulatory regimes based on co-investment: one in which co-investment is the only option available to the entrant ("pure co-investment"), and one in which access and co-investment are both available to the entrant ("co-investment with access"). We then compare these three regimes in terms of infrastructure coverage and social welfare.

A second relevant issue we wish to address is the role of demand uncertainty. It is often hard to predict the level of demand before new infrastructures are constructed and used. This implies that an investor must invest before final demand is known, while an access seeker can wait until enough information is available to decide whether to enter. Thus, access provides entrants with a cream-skimming option that is exercised exactly when market outcomes are good. Thus the network investor bears all the downside risk, while the returns on the upside are shared. We study how demand uncertainty affects the relative effectiveness of co-investment, where commitments must be made before uncertainty is resolved, and the trade-off between the different regulatory regimes.

Contribution and Results. We describe an incumbent firm that rolls out a new infrastructure in areas which differ in terms of deployment costs, and add an entrant who can decide to enter in areas where an infrastructure has been deployed to compete with the

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).

incumbent. We consider three regulatory regimes that allow the entrant to use the incumbent's infrastructure. The "pure access" regime corresponds to the standard access regime: the entrant can ask for access in all the areas where the incumbent has deployed its network; it then pays a linear access tariff fixed by the regulator. In the "pure co-investment" regime, the entrant can ask the incumbent to share its infrastructure in covered areas, by taking on half of the investment cost, but access is not available. Finally, the "co-investment with access" regime allows the entrant to decide whether to ask for access or to co-invest in each covered area.

Clearly, the adoption of a standard access obligation on new infrastructures involves the classical trade-off between static efficiency and investment in coverage. We find that compared to this pure access regime, the pure co-investment regime leads to more intense competition in the areas where the firms operate a shared network and also to larger coverage. On the downside, it involves a monopoly area where retail prices are higher (but a large part of this region would not be covered at all under the access regime). Adding an access obligation on top of co-investment reduces the incumbent's profit in the marginal areas, therefore total coverage is lower in this regime than under pure co-investment. In addition, co-investment coverage is also lower. This is because the access option offered to the entrant constitutes an opportunity cost of co-investment, reducing co-investment incentives compared to the pure co-investment regime. In terms of social welfare, we find that if the access price is relatively low, social welfare is higher if no access is granted, because a low access charge both reduces the incentives for the entrant to co-invest and the incumbent's incentives to cover costly areas.

Finally, we study how demand uncertainty affects the equilibrium coverage. We assume that at the time the access price is set and investment decisions are made, the level of demand is still unknown. However, the entrant can wait for the true state of demand to be realized before asking for access. We show that the existence of this "access option" for the entrant reduces investment incentives: Larger uncertainty leads to lower total coverage. The pure co-investment regime involves a pre-commitment and does not suffer from this problem, and therefore appears as a preferred regulatory regime when the degree of uncertainty about demand is high.

Related Literature. Our paper is related to the literature on access and investment in network industries. Several formal studies have investigated the impact of access regulation on investment incentives by incumbent and entrant firms.[5] Others have analyzed how access pricing affects the migration from an old to a new infrastructure, such as next-generation access networks in the telecoms industry (Bourreau et al., 2012; Brito et al., 2012; Inderst and Peitz, 2012). In these papers, the only regulatory tool is a (per-unit or two-part) access tariff. None of them considers co-investment as an alternative regulatory regime, as we do in this paper.

Some recent papers have analyzed the adoption of specific access schemes that depend on the investment level. Klumpp and Su (2010) showed that a revenue-neutral access scheme—i.e., a per unit access price defined by the regulator that lets firms share in equilibrium the investment cost in proportion to their predicted infrastructure usage—enhances dynamic efficiency, without negatively affecting static efficiency. However, this access rule does not imply any pre-commitment from the entrant on the investment, and therefore does not correspond to a co-investment obligation. Nitsche and Wiethaus (2011) compared different regulatory regimes, namely, a per-unit access price depending on the investment level and a risk-sharing regime where firms jointly decide on the investment level to maximize their joint profits. They found that risk-sharing achieves higher consumer surplus, compared to the other regimes. Nitsche and Wiethaus did not model co-investment as an obligation, but rather as a joint venture decision, and in addition they did not consider the standard access regime. Therefore, they did not compare how co-investment fares compared to standard access, which is the focus of our paper.

[5] See, for example, Foros (2004), Bourreau and Doğan (2006), Hori and Mizuno (2006), Gans (2007), Brito et al. (2010), Vareda and Hoernig (2010).

Very few papers specifically study co-investment in new infrastructures. As in our paper, Inderst and Peitz (2013) modeled co-investment as firms sharing the fixed costs of investment. In their paper, investment is a quality improvement of an old technology, whose success is uncertain *ex ante*, and after investment firms jointly charge the monopoly price. We differ from their paper in several aspects. First, we consider the geographical dimension of investments: in our model, different market structures can emerge in different areas and co-investing firms compete with each other *ex post*. If regulation cannot be tailored at the local level, then the regulator faces trade-offs when designing the regulatory policy for the whole country. In our model, we specifically take into account these trade-offs, which are not present in their paper. Second, we compare a combination of regulatory approaches, namely the standard access regime and two alternative regimes based on co-investment: pure co-investment and co-investment with access.

Finally, Krämer and Vogelsang (2016) performed a laboratory experiment to study the effect of cooperation in broadband markets, with an underlying model where not cooperating would be the individually optimal choice. They found that, still, cooperation arises due to communication between players, and that it facilitates collusion while not stimulating further investment. Whether this increased chance of collusion materializes in actual markets is still an open question; at least in the cases mentioned above co-investment has indeed led to higher roll-out.

Our paper is also related to the literature on R&D joint ventures. This strand of literature, which has been vibrant since the seminal contributions by Grossman and Shapiro (1986) and d'Aspremont and Jacquemin (1988), shows that R&D joint ventures may increase investment in innovation, but may come at a cost: since R&D cooperation is likely to preserve symmetry among firms, tacit collusion among competitors is facilitated. We depart from this branch of literature in two directions. First, as in Goyal et al. (2008), we consider a "hybrid" form of cooperation, where firms cooperate to build a joint infrastructure in some areas, while building independent infrastructures in other areas. Second, access to the infrastructure may be regulated, and we analyze the effect of such access obligations on investment incentives.

The rest of the paper is organized as follows. In Section 2 we set out our modeling framework, and compare the coverage equilibria under the three regulatory regimes (pure access, pure co-investment, co-investment with access). In Section 3 we study the impact of demand uncertainty on infrastructure coverage in the three regimes. Section 4 concludes.

2 Access versus Co-Investment

2.1 Model Setup

We consider a country consisting of a continuum of areas $z \in \mathbb{R}_+$, which have identical demand but different sunk costs to be covered with an NGA network. More precisely, we assume that the cost of covering area z is $c(z)$, where $c(0) = 0$ and $c(.)$ is strictly increasing and continuously differentiable. Covering the areas $[0, z]$ then costs $C(z) = \int_0^z c(x)\,dx$.

There is one incumbent, firm 1, and one potential entrant, firm e. We assume sequential investment decisions. The incumbent first decides on the areas $[0, z_1]$ where it will invest. Then, the entrant decides where it will co-invest or ask for access, depending on whether we have (i) access only, (ii) pure co-investment, or (iii) co-investment with access. Finally, firms compete in local areas and profits are realized.

We do not provide an explicit model of retail competition, but rather base our results on some generic properties of the resulting equilibrium profits and their relation to the access charge. We consider the coverage and co-investment outcomes in subgame-perfect equilibrium.

2.2 Pure Access

Firms' profits in a given local area depend on the market structure in the area. We denote by π^m the local monopoly profit, and by $\pi_1^d(a)$ and $\pi_e^d(a)$ the local duopoly profits of firm

1 and firm e, respectively, for a given access charge a set by the regulator. We assume that the entrant makes positive duopoly profits up to a maximum access price, $a^{\max}$. We also assume that duopoly profits are continuously differentiable functions of the access charge, and that $d\pi_1^d(a)/da \geq 0$ and $d\pi_e^d(a)/da \leq 0$ for $a < a^{\max}$. If $a \geq a^{\max}$, firm e is foreclosed and firm 1 makes the monopoly profit π^m. The marginal cost of access is normalized to zero, and $\pi_1^d(0) = \pi_e^d(0) \equiv \pi^d$. Finally, we assume that $\lim_{a \to a^{\max}} \pi_1^d(a) \leq \pi^m$.

Similarly, we denote by w^m and $w^d(a)$ the local welfare in a monopoly and a duopoly area, respectively. We define $w^d \equiv w^d(0)$, and we assume that $dw^d(a)/da \leq 0$ and that $\lim_{a \to a^{\max}} w^d(a) \geq w^m$.[6]

Entrant's decision. Assume that $a < a^{\max}$ (otherwise, there would be no access). Given an incumbent's announcement to invest up to the area z_1, the entrant decides on the areas up to $z_e \leq z_1$ where it will ask for access to the incumbent's infrastructure. The entrant's profit is $\Pi_e = z_e \pi_e^d(a)$. Since it is increasing in z_e, the entrant optimally chooses $z_e = z_1$, i.e., it asks for access in all the areas where the network has been rolled out.

Incumbent's decision. The incumbent's profit is

$$\Pi_1 = z_1 \pi_1^d(a) - C(z_1).$$

Maximizing the incumbent's profit with respect to z_1, we obtain that in equilibrium total coverage is $z_1^* = z_e^* = \bar{z}^a(a) \equiv c^{-1}\left(\pi_1^d(a)\right)$, and the entrant asks for access everywhere.

We have $d\bar{z}^a(a)/da \geq 0$ since $\pi_1^d(a)$ increases with a and $c^{-1}(.)$ is an increasing function; as expected, a lower access price leads to less investment.

[6] In the Appendix, we provide an illustrative model of price competition with linear demand that satisfies these assumptions.

Social welfare. Aggregate social welfare is given by the local surplus in covered markets minus the total investment cost, that is,

$$W^a(a) = \bar{z}^a(a)w^d(a) - C(\bar{z}^a(a)).$$

It is clear that the regulator faces a complicated trade-off when trying to set the access charge at the social optimum. On the one hand, a higher access charge leads to a larger coverage (or dynamic benefits) $\bar{z}^a(a)$, but on the other it reduces the local (static) benefits $w^d(a)$.

2.3 Pure Co-Investment

We assume that co-investment works as follows: firm 1 announces the areas $[0, z_1]$ it is going to cover; then, firm e can propose (and impose) co-investment in the areas $[0, z_e]$, with $z_e \leq z_1$, taking on half of the investment cost.

With this assumption, co-investment is an alternative to access: similar to the pure access regime, the entrant can ask for access through co-investment, and the incumbent cannot refuse.[7]

The retail profits in each co-investment area correspond to the retail profits at a zero (cost-based) access charge, i.e., $\pi_1^d(0) = \pi_e^d(0) = \pi^d$, with corresponding social welfare w^d. If $z_e < z_1$, the incumbent retains the monopoly areas $(z_e, z_1]$, where the entrant does not want to co-invest because of the high cost of coverage, with profits per area of π^m.

Entrant's decision. Under co-investment, the entrant's profit is $\Pi_e = z_e\pi^d - C(z_e)/2$. The FOC of its decision problem holds for $\bar{z}^c \equiv c^{-1}(2\pi^d)$. The profit-maximizing co-investment coverage is then $z_e = \min\{z_1, \bar{z}^c\}$.

[7] We also considered the case where both firms coordinate on the co-investment coverage and found qualitatively similar outcomes.

Incumbent's decision. The incumbent chooses its coverage taking into account how much of it will later be matched by the entrant's co-investment. The incumbent's profit function has two branches, depending on whether there are monopoly areas or not.

If the incumbent chooses a low coverage $z_1 \leq \bar{z}^c$ (no monopoly areas), the entrant co-invests everywhere. The incumbent's profits in this case are $\Pi_1 = z_1\pi^d - C(z_1)/2$, which are maximized at the boundary solution $z_1 = \bar{z}^c$. Thus, the incumbent will choose some $z_1 \geq \bar{z}^c$.

For a higher coverage $z_1 > \bar{z}^c$, the entrant co-invests up to the area $z_e = \bar{z}^c$ and the incumbent has a monopoly in the areas $(\bar{z}^c, z_1]$.[8] The incumbent's profits are

$$\Pi_1 = (z_1 - \bar{z}^c)\pi^m + \bar{z}^c\pi^d - C(z_1) + C(\bar{z}^c)/2.$$

The optimal coverage for the incumbent is then $z_1^* = \bar{z}^m \equiv c^{-1}(\pi^m)$ if $\pi^m > 2\pi^d$, and $z_1^* = \bar{z}^c$ otherwise. In other words, if services are sufficiently homogeneous such that the monopoly profits outweigh joint profits under duopoly, total coverage is equal to the monopoly coverage. By contrast, if goods are sufficiently differentiated so that $2\pi^d > \pi^m$, co-investment itself leads to higher coverage than a single firm could achieve.

To sum up, the coverage equilibrium with co-investment is given by $z_1^* = \max\{\bar{z}^m, \bar{z}^c\}$ and $z_e^* = \bar{z}^c$. There is a duopoly with co-investment in the less costly areas $[0, \bar{z}^c]$, and a monopoly in the most costly areas $(\bar{z}^c, \bar{z}^m]$ if services are sufficiently homogeneous.

Proposition 1 *Compared to the pure access regime, pure co-investment leads to higher total coverage ($\bar{z}^m > \bar{z}^a(a)$). The co-investment coverage itself is higher than total coverage under access ($\bar{z}^c > \bar{z}^a(a)$) if the access price is low or products are sufficiently differentiated.*

Proof. First, we have $\bar{z}^m > \bar{z}^a(a)$ since $\pi^m > \pi_1^d(a)$, thus total coverage is higher under co-investment than under access for any access price such that entry is profitable. Second, we have $\bar{z}^c > \bar{z}^a(a)$ iff $2\pi^d > \pi_1^d(a)$. Note that this true if $a = 0$ and wrong if $a = a^{\max}$

[8] Since $\pi_1^d(a) \leq \pi^m$ for all $a \leq a^{\max}$, the incumbent has no incentives to offer access voluntarily in the monopoly areas.

and services are sufficiently homogeneous (since in this case $\pi_1 = \pi^m > 2\pi^d$). Since $\pi_1^d(a)$ increases with a, either $\bar{z}^c > \bar{z}^a(a)$ for all a (if $\pi^m < 2\pi^d$, which is the case if products are sufficiently differentiated), or there is a threshold $\overline{a} > 0$ such that $\bar{z}^a(a) > \bar{z}^c$ if and only if $a > \overline{a}$. ■

Compared to the pure access benchmark, co-investment increases total coverage. It does this either by decoupling the coverage decision from access provision (when there are monopoly areas), or by dividing the investment costs.

At the same time, co-investment also intensifies retail competition in low-cost areas, since access is priced at cost. This lowers the entrant's marginal cost, and eliminates the incumbent's wholesale opportunity cost of fighting for customers. Thus, the equilibrium with co-investment would be equivalent to a regime with cost-based access in the co-investment areas and no access regulation in the monopoly infrastructure areas, if the size of these areas were exogenously determined and thus not subject to disincentives for investment. In reality, the presence of access regulation changes both firms' optimal coverage choices, as we will show below.

Social welfare. Aggregate social welfare is given by the local surplus in covered markets minus the investment cost, that is,

$$W^c = \left(\max\{\bar{z}^m, \bar{z}^c\} - \bar{z}^c\right) w^m + \bar{z}^c w^d - C(\max\{\bar{z}^m, \bar{z}^c\}).$$

2.4 Co-Investment with an Access Obligation

We now assume that the regulator has imposed an obligation on firm 1 to provide access to its network in all locations not subject to co-investment at an access price $a < a^{\max}$, and that the entrant can decide separately for each local area whether to co-invest or ask for access. In particular, we will focus on how the possibility of asking for access affects the entrant's co-investment incentives.

Entrant's decision. Assume that firm 1 has covered the areas $[0, z_1]$ and consider the entrant's decision to enter some area $z \in [0, z_1]$. Firm e has two choices:

- It can co-invest with firm 1, obtaining a net profit of $\pi^d - c(z)/2$ in the area.
- It can ask for access, in which case it obtains the profit $\pi_e^d(a)$ (Note that asking for access always dominates not entering, as $\pi_e^d(a) \geq 0$).

Firm e prefers co-investment over access if and only if $\pi^d - c(z)/2 \geq \pi_e^d(a)$. That is, the possibility of entering the market by asking for access creates an *opportunity cost* for the co-investment decision. As a result, incentives to co-invest are lower than in the case without access if $\pi_e^d(a) > 0$. Co-investment is chosen at all location z such that

$$z \leq c^{-1}\left(2\left[\pi^d - \pi_e^d(a)\right]\right) \equiv \overline{z}^{ca}(a).$$

Note that $\overline{z}^{ca}(a)$ increases with a (a higher access price reduces the opportunity cost of co-investment) and that $\lim_{a \to a^{\max}} \overline{z}^{ca}(a) = \bar{z}^c$. Therefore, as just mentioned, imposing an access obligation, in particular at a low access price, reduces the incentives to co-invest.

Summing up, this analysis shows that if $z_1 > \overline{z}^{ca}(a)$, firm e co-invests in the areas $[0, \overline{z}^{ca}(a)]$ and asks for access in the areas $(\overline{z}^{ca}(a), z_1]$. If $z_1 \leq \overline{z}^{ca}(a)$, firm e co-invests in the areas $[0, z_1]$ and does not ask for access anywhere else.

Incumbent's decision. We now turn to firm 1's coverage decision, assuming that it correctly anticipates firm e's entry strategy (in terms of access/co-investment). If $z_1 \leq \overline{z}^{ca}(a)$, firm e will co-invest everywhere and firm 1's profits are $\Pi_1 = z_1\pi^d - C(z_1)/2$. Since $\overline{z}^{ca}(a) < \overline{z}^c$, profits are increasing on this branch, so firm 1 chooses $z_1 \geq \overline{z}^{ca}(a)$. On the latter branch firm 1's profits are

$$\Pi_1 = [z_1 - \overline{z}^{ca}(a)]\,\pi_1^d(a) + \overline{z}^{ca}(a)\,\pi^d - C(z_1) + C(\overline{z}^{ca}(a))/2.$$

The FOC with respect to z_1 has the interior solution $z_1 = \bar{z}^a(a)$, i.e., it is equal to the coverage with access but without co-investment. This is the optimum on this branch if and only if $\bar{z}^a(a) \geq \bar{z}^{ca}(a)$, thus the optimal coverage for firm 1 is $z_1^* = \max\{\bar{z}^a(a), \bar{z}^{ca}(a)\}$, and co-investment occurs up to $\bar{z}^{ca}(a)$.

Proposition 2 *For co-investment with an access obligation, the incumbent invests up to* $\max\{\bar{z}^a(a), \bar{z}^{ca}(a)\}$*; the entrant co-invests up to* $\bar{z}^{ca}(a)$ *and asks for access in the remaining covered areas. Thus:*

1. *When an access obligation is introduced on top of co-investment, a) co-investment coverage decreases (since* $\bar{z}^{ca}(a) < \bar{z}^c$*); b) total coverage decreases (since* $\bar{z}^m > \bar{z}^a(a)$ *and* $\bar{z}^c > \bar{z}^{ca}(a)$*).*

2. *When co-investment is introduced on top of an access obligation, a) the entrant will co-invest if the access price is above cost, and b) total coverage decreases unless* $\bar{z}^{ca}(a) > \bar{z}^a(a)$.

Total coverage under pure co-investment is as large as possible without further interventions or subsidies, since it is driven by monopoly profits in the most outlying areas. Imposing access leads to lower profits per area and thus lower total coverage. Co-investment coverage itself is also lower with access than without, because now the entrant can ask for access instead of committing to co-invest, thus he is provided with an "access option". The profits derived from using this option constitute an opportunity cost for co-investment, implying lower incentives for co-investment. It is important to note here that this opportunity cost is created directly by regulatory imposition. Still, the entrant will co-invest at least in some areas, i.e., $\bar{z}^{ca}(a) > 0$, as long as the access charge is above cost, i.e., $\pi_e^d(a) < \pi^d$.

On the other hand, if a co-investment option is introduced on top of an existing access obligation, total coverage decreases if the following condition holds:

$$\bar{z}^{ca}(a) \leq \bar{z}^a(a) \iff \pi_1^d(a) \geq 2\left[\pi^d - \pi_e^d(a)\right]. \tag{1}$$

Condition (1) holds for access charges sufficiently close to cost, because of continuity and at $a = 0$ we have $\pi^d > 2\left[\pi^d - \pi^d\right] = 0$. At $a = a^{\max}$, this condition becomes $\pi^m \geq 2\pi^d$, which also holds unless services are very differentiated.

Assume that there is at most one access charge a where Condition (1) holds with equality. Then, either there is a threshold value $a^* < a^{\max}$ such that Condition (1) holds for $a \leq a^*$ but does not hold otherwise, or Condition (1) is always true (in which case we write $a^* = a^{\max}$).[9] Then, co-investment increases total coverage if and only if services are sufficiently differentiated ($a^* < a^{\max}$) and the regulator imposes an access charge that is high enough ($a > a^*$). However, in this case, total coverage – at $\bar{z}^{ca}(a)$– remains below $\bar{z}^c$ because returns to investment beyond this area are depressed by the access obligation.

Social welfare. Under co-investment with access, social welfare is given by

$$W^{ca}(a) = \begin{cases} \left[\bar{z}^a(a) - \overline{z}^{ca}(a)\right] w^d(a) + \overline{z}^{ca}(a)\, w^d - C(\bar{z}^a(a)) & if \quad a \leq a^* \\ \overline{z}^{ca}(a)\, w^d - C(\overline{z}^{ca}(a)) & if \quad a > a^* \end{cases}.$$

The second branch is only relevant if $a^* < a^{\max}$.

2.5 Comparison of the Three Regimes

We have considered three potential regimes: pure access; pure co-investment; and co-investment with access. Table 1 below summarizes the duopoly and total equilibrium coverage in these three regimes.

We now analyze how these three regimes compare in terms of social welfare.

[9] In our illustrative model, there is indeed at most one access charge where Condition (1) holds with equality. We have $a^* < a^{\max}$ if services are sufficiently differentiated, and $a^* \geq a^{\max}$ otherwise.

Regime	Duopoly coverage	Total coverage
Pure access	$\bar{z}^a(a)$	$\bar{z}^a(a)$
Pure co-investment	$\bar{z}^c$	$\max\{\bar{z}^c, \bar{z}^m\}$
Co-investment with access	$\max\{\bar{z}^{ca}(a), \bar{z}^a(a)\}$	$\max\{\bar{z}^{ca}(a), \bar{z}^a(a)\}$

Table 1: Equilibrium coverage in the three regimes

Co-investment with access *versus* pure access. For $a \le a^*$, we can rewrite the welfare in the co-investment with access regime as

$$W^{ca}(a) = W^a(a) + \bar{z}^{ca}(a)\left(w^d - w^d(a)\right) \ge W^a(a).$$

For $a > a^*$, we have from $\bar{z}^{ca}(a) > \bar{z}^a(a)$ and the fact that welfare is still increasing in coverage at $\bar{z}^{ca}(a)$[10] that

$$W^{ca}(a) > \bar{z}^a(a)w^d - C(\bar{z}^a(a)) > W^a(a).$$

Thus, $W^{ca}(0) = W^a(0)$ and $W^{ca}(a) > W^a(a)$ for all $a > 0$: Introducing co-investment on top of existing access provisions increases social welfare. This increase in welfare stems from shared access at cost in co-investment areas, plus potentially a higher total coverage (if $a > a^*$). Thus, pure access is dominated by co-investment with access for each level of the access charge a, and therefore even more so at the respective optimal access charges.

It is also interesting to compare the level of access charges that would be chosen by the regulator. For simplicity, assume that the socially optimal access charge a^{CA} under co-investment with access lies below a^*, i.e., total coverage in both cases is equal to $\bar{z}^a(a)$. In this case, the socially optimal access charge under pure access, a^A , is strictly lower than a^{CA}, since the term $\bar{z}^{ca}(a)\left(w^d - w^d(a)\right)$ is increasing in a: At $a = a^A$, raising the access charge increases the cost-investment area by lowering opportunity costs; at the same time,

[10] Let $W^d(z) = zw^d - C(z)$. The welfare-maximizing coverage is $z^w = (c^{-1})(w^d)$. Since $w^d = 2\pi^d + CS > 2\pi^d$, we have $z^w > \bar{z}^c$. Hence, since $\bar{z}^c > \bar{z}^{ca}(a)$, W^d is increasing in coverage at $\bar{z}^{ca}(a)$.

this increases the welfare gain from moving to co-investment.

Since co-investment with access dominates pure access, we now just have to compare co-investment with access to pure co-investment to determine the preferred regulatory regime.

Co-investment with access *versus* pure co-investment. Under co-investment with access, it is possible to replicate pure co-investment by setting a sufficiently high access price, thus

$$W^{ca}\left(a^{CA}\right) \geq W^{ca}\left(a^{\max}\right) = W^{c}.$$

Thus, if the regulator sets the *optimal* access price under co-investment with access, in principle introducing access over pure co-investment cannot lower welfare. Still, it is possible that the access price must be set so high that no access will be demanded. Therefore, it is still a useful exercise to compare welfare at specific (non-optimal) access price levels.

Consider first an access price so low that total coverage under access falls below pure co-investment coverage, i.e., $\bar{z}^{a}(a) < \bar{z}^{c}$, or $\pi_1^d(a) < 2\pi^d$, and also that $a < a^*$ (implying that $\bar{z}^{ca}(a) < \bar{z}^{a}(a)$). Then, we can write

$$W^{c} = W^{ca} + \underbrace{\left[\bar{z}^{a}(a) - \bar{z}^{ca}(a)\right]\left[w^{d} - w^{d}(a)\right]}_{(+)} + \underbrace{\int_{\bar{z}^{a}(a)}^{\max\{\bar{z}^{m},\bar{z}^{c}\}} \left[\tilde{w}(z) - c(z)\right] dz}_{(+)},$$

where $\tilde{w}(z) = w^{d}$ for $z \in [\bar{z}^{a}(a), \bar{z}^{c}]$ and $\tilde{w}(z) = w^{m}$ for $z \in (\bar{z}^{c}, \bar{z}^{m}]$ (if $\bar{z}^{m} > \bar{z}^{c}$). Since the second term (additional co-investment coverage) and third term (higher total coverage without access) on the right-hand side are positive, we have $W^{c} > W^{ca}$, that is, introducing access on top of co-investment reduces social welfare if the access charge is set too low.

On the other hand, assume that $a^* < a^{\max}$ and that $a > a^*$. We have $W^{ca}(a) = \bar{z}^{ca}(a)\, w^{d} - C(\bar{z}^{ca}(a))$, and we can write

$$W^{c} = W^{ca} + \underbrace{\int_{\bar{z}^{ca}(a)}^{\max\{\bar{z}^{m},\bar{z}^{c}\}} \left[\tilde{w}(z) - c(z)\right] dz}_{(+)},$$

where $\tilde{w}(z) = w^d$ for $z \in [\bar{z}^{ca}(a), \bar{z}^c]$ and $\tilde{w}(z) = w^m$ for $z \in (\bar{z}^c, \bar{z}^m]$. Since the second term on the right-hand side is positive, we have $W^c > W^{ca}$ in this case too.

Thus, co-investment with access can only be strictly optimal if $a < a^*$ and for access charges high enough such that total coverage under access exceeds the co-investment coverage, i.e., $\bar{z}^a(a) > \bar{z}^c$. Even in this case, it unclear whether co-investment with access can strictly dominate co-investment. We can indeed rewrite W^c as follows:

$$W^c = W^{ca} + \underbrace{\left(\bar{z}^c - \bar{z}^{ca}(a)\right)\left(w^d - w^d(a)\right)}_{(+)} + \underbrace{\left(\bar{z}^a(a) - \bar{z}^c\right)\left(w^m - w^d(a)\right)}_{(-)} + \underbrace{\int_{\bar{z}^a(a)}^{\bar{z}^m} \left[\tilde{w}(z) - c(z)\right] dz}_{(+)},$$

where $\tilde{w}(z) = w^m$ for $z \in (\bar{z}^a(a), \bar{z}^m]$. Therefore, adding access on top of co-investment increases static efficiency in monopoly areas, but at the cost of lower static efficiency in other areas (due to a lower co-investment coverage) and lower total coverage.

We summarize this analysis with the following proposition:

Proposition 3 *Co-investment with access always dominates pure access, and also (weakly) dominates pure co-investment at the optimal access charge. If the access charge is low ($\bar{z}^a(a) < \bar{z}^c$), or if services are sufficiently differentiated ($a^* \geq a^{\max}$) and the access charge is very high ($a > a^*$), though, social welfare is higher if no access is granted.*

This result shows that when the regulator has to trade-off between investment incentives and static welfare, co-investment is a more efficient regulatory instrument than pure access. In our general model, under specific conditions, and in particular when the access price is relatively high, a combination of co-investment and access might outperform pure co-investment. However, this combination is difficult to emerge: we ran simulations with our illustrative model reported in the Appendix, and found that in the regime with co-investment and access, the regulator would optimally set the access charge so high that there is no access in equilibrium.[11]

[11] We ran these simulations for a quadratic cost function, and various values of the parameters.

3 Demand Uncertainty

When operators invest in a new infrastructure, they may face uncertainty about the demand for the services supported by the new network. In this section, we analyze how the different regulatory regimes are affected when there is such demand uncertainty.

We assume that demand is uncertain *ex ante*, when firms make their investment and/or co-investment decisions. However, access provides an option to firm e, which instead of co-investing can wait for demand to be realized before asking for access.[12]

Formally, we consider that the profits introduced above are measured per unit mass of consumers, but that the demand level δ is uncertain *ex ante*. We assume that δ is uniformly distributed over $[1-\sigma, 1+\sigma]$, with $\sigma \in (0,1)$. The expected level of demand is then $E[\delta] = 1$, and $\sigma^2/3$ is its variance. Hence, we interpret σ as the degree of demand uncertainty.

Furthermore, we assume that under access, firm 1 and firm e make local profits that are the difference between a gross profit and an interconnection (fixed) cost, i.e., the incumbent makes a net profit $\delta\widehat{\pi}_1^d(a) - f$ in duopoly areas, for a demand level δ, and the entrant a net profit $\delta\widehat{\pi}_e^d(a) - f$. From an *ex ante* perspective, their expected profits are then $\widehat{\pi}_1^d(a) - f \equiv \pi_1^d(a)$ and $\widehat{\pi}_e^d(a) - f \equiv \pi_e^d(a)$, where $\pi_1^d(a)$ and $\pi_e^d(a)$ represent the duopoly profits of firm 1 and firm e, respectively, in the baseline model. Finally, we define $\widehat{\pi}^d \equiv \widehat{\pi}_1^d(0) = \widehat{\pi}_e^d(0)$ and $\pi^d \equiv \widehat{\pi}^d - f$.[13]

With these assumptions, as we will see, the entrant does not ask for access if the level of demand turns out to be too low.

[12] We abstract away from additional channels that may affect investment decisions under uncertainty, such as risk aversion of firms or credit providers. These market features would also favour co-investment over access provision.

[13] See the illustrative model in the Appendix, where we introduce such interconnection costs. Assuming that the incumbent incurs the same fixed interconnection cost as the entrant ensures that the two firms obtain symmetric profits when $a \to 0$.

3.1 Pure Co-Investment

Since co-investment is decided *ex ante*, before demand is realized, the analysis is the same as in the main model. Firm e decides to co-invest in an area z if and only if

$$E[\delta]\widehat{\pi}^d - f = \pi^d \geq c(z)/2.$$

We assume that $\pi^d = \widehat{\pi}^d - f > 0$, otherwise the entrant would never co-invest. Firm e then co-invests in area z if and only if $z \leq \overline{z}^c = c^{-1}\left(2\pi^d\right)$. In equilibrium, the incumbent deploys its network up to the area $\max\{\overline{z}^m, \overline{z}^c\}$ and the entrant co-invests in the areas $[0, \overline{z}^c]$. Therefore, demand uncertainty does not affect the coverage equilibrium under pure co-investment.

3.2 Pure Access

Entrant's decision. As a benchmark, first assume that firm e asks for access *before* demand is realized. Firm e asks for access in (all) the areas covered by firm 1 if and only if $E[\delta]\,\widehat{\pi}_e^d(a) - f \geq 0$. We assume that this condition is not satisfied, i.e., $\widehat{\pi}_e^d(a) < f$: Committing to access is not a viable option *ex ante*, and access will be requested only if the demand density turns out to be sufficiently high *ex post*. This assumption captures the idea that the access obligation provides the entrant with an "access option".[14]

Now, assume that firm e can ask for access *after* demand is realized. Firm e then asks for access if and only if $\delta\widehat{\pi}_e^d(a) \geq f$, that is, $\delta \geq f/\widehat{\pi}_e^d(a) = \underline{\delta}(a)$. From our assumption $\widehat{\pi}_e^d(a) < f$, we have $\underline{\delta} > E[\delta] = 1$. We assume furthermore that $\underline{\delta} < 1 + \sigma$, that is, access is profitable in the high states of demand. Since $\widehat{\pi}_e^d(a)$ decreases in the access charge a, the entry threshold $\underline{\delta}(a)$ increases in the latter.

[14] Note that our assumptions $\widehat{\pi}_e^d(a) < f < \widehat{\pi}^d$ require that $a > 0$.

The (*ex ante*) probability of entry is then given by

$$p^e = \int_{\underline{\delta}(a)}^{1+\sigma} \frac{d\delta}{2\sigma} = \frac{1+\sigma-\underline{\delta}(a)}{2\sigma}.$$

Therefore, a higher access charge makes entry less likely, whereas a higher degree of uncertainty makes entry more likely.

Incumbent's decision. When it makes its investment decision, firm 1's expected profit of covering the areas $[0, z_1]$ is $E[\Pi_1] = z_1 E[\pi_1^a] - C(z_1)$, with

$$E[\pi_1^a] \equiv \int_{1-\sigma}^{\underline{\delta}(a)} \delta\pi^m \frac{1}{2\sigma} d\delta + \int_{\underline{\delta}(a)}^{1+\sigma} (\delta\widehat{\pi}_1^d(a) - f) \frac{1}{2\sigma} d\delta = \omega\pi^m + (1-\omega)\widehat{\pi}_1^d(a) - p^e f,$$

and $\omega(a,\sigma) = \left[\underline{\delta}(a)^2 - (1-\sigma)^2\right]/(4\sigma)$.

Maximizing the incumbent's profit with respect to z_1, we obtain that firm 1's equilibrium coverage is $z_1^* = \widetilde{z}^a(a) \equiv c^{-1}(\omega\pi^m + (1-\omega)\widehat{\pi}_1^d(a) - p^e f)$, with $\widetilde{z}^a(a) \in (\overline{z}^a(a), \overline{z}^m)$.

We have $d\widetilde{z}^a(a)/da \geq 0$, as $\widehat{\pi}_1^d(a)$ and $\omega(a,\sigma)$ increase with a, p^e decreases with a, and $c^{-1}(.)$ is increasing. Note that if access had to be chosen *ex ante*, firm e would not ask for access and we would obtain a monopoly outcome with $z_1^* = \overline{z}^m$. Therefore, the access option allows competition to emerge, but at the price of a lower coverage.

Our question is: how does uncertainty affect investment incentives under pure access? After some computations, we find that

$$\frac{\partial\widetilde{z}^a(a)}{\partial\sigma} = \frac{\left(\pi^m - \pi_1^d(a)\right)\partial\omega/\partial\sigma - f\partial p^e/\partial\sigma}{c'\left(\widetilde{z}^a(a)\right)} < 0, \qquad (2)$$

where the inequality follows from $\pi^m > \pi_1^d(a)$, $\partial\omega/\partial\sigma < 0$ and $\partial p^e/\partial\sigma > 0$ (more uncertainty makes entry more likely, and hence decreases the weight of monopoly outcomes).

Therefore, a higher amount of risk reduces investment incentives under access. Due to the exercise of the access option by the entrant, the returns from better outcomes are curtailed, while worse outcomes continue to be supported by the incumbent only. From a regulatory viewpoint, this makes co-investment more preferable relative to pure access when demand is highly uncertain (i.e., σ is high).

3.3 Co-investment with Access

To account for demand uncertainty, we modify the timing in the co-investment with access regime as follows. First, firm 1 decides on the areas where it will invest. Second, firm e decides where it will co-invest. Third, demand is realized. Fourth, firm e decides where it will ask for access. Finally, firms compete in local markets and profits are realized.

Entrant's access decision. At Stage 4, the level of demand is known and firm e can ask for access in any covered area. Assume that firm 1 has covered the areas $[0, z_1]$, and that firm e has decided to co-invest up to area $z_e \leq z_1$. If $z_e = z_1$, firm e has co-invested in all covered areas; so, it does not ask for access anywhere. If $z_e < z_1$, firm e asks for access in the areas $(z_e, z_1]$ if and only if $\delta \geq \underline{\delta}(a)$.

Entrant's co-investment decision. At Stage 2, firm 1 has covered the areas $[0, z_1]$ but the level of demand is not yet known. Firm e has two choices in each area $z \in [0, z_1]$:[15]

- It can co-invest with firm 1, obtaining an expected profit of $\pi^d - c(z)/2$.
- It can wait and later ask for access. In this case, it will later ask for access if and only demand is high enough (i.e., $\delta \geq \underline{\delta}(a)$), and its expected profit is

$$E[\pi_e^a] \equiv \int_{\underline{\delta}(a)}^{1+\sigma} \left(\delta\widehat{\pi}_e^d(a) - f\right) \frac{1}{2\sigma} d\delta > 0.$$

Firm e co-invests in area z if and only $\pi^d - c(z)/2 \geq E[\pi_e^a]$, that is, if and only if $z \leq \widetilde{z}^{ca}(a) \equiv c^{-1}\left(2\left(\pi^d - E[\pi_e^a]\right)\right)$. Therefore, the access option introduces an opportunity

[15] The entrant would have no interest to commit not to enter area z, since *ex post*, when demand is realized, it will be profitable to enter in the high states of demand.

cost for co-investment, which reduces the co-investment coverage compared to the pure co-investment regime. The higher $E[\pi_e^a]$, the higher the opportunity cost, and the lower the co-investment coverage $\widetilde{z}^{ca}(a)$.

Incumbent's decision. We now turn to the first stage where firm 1 decides on total coverage. If $z_1 \leq \widetilde{z}^{ca}(a)$, firm e will co-invest everywhere and firm 1's expected profits are $E[\Pi_1] = z_1\pi^d - C(z_1)/2$. The maximum on this branch of firm 1's profit is obtained at $z_1 = \widetilde{z}^{ca}(a)$. If $z_1 > \widetilde{z}^{ca}(a)$, firm e co-invests up to area $\widetilde{z}^{ca}(a)$, and asks for access in the remaining areas if and only if $\delta \geq \underline{\delta}(a)$. Firm 1's expected profits are then

$$E[\Pi_1] = \widetilde{z}^{ca}(a)\pi^d + (z_1 - \widetilde{z}^{ca}(a))E[\pi_1^a] - C(z_1) + \frac{1}{2}C(\widetilde{z}^{ca}(a)).$$

The FOC on this branch of the incumbent's profit has the interior solution $z_1^* = \widetilde{z}^a(a)$, i.e., it is equal to the coverage with access but without co-investment. This is the optimum on this branch if and only if $\widetilde{z}^a(a) \geq \widetilde{z}^{ca}(a)$.

If $\widetilde{z}^a(a) \geq \widetilde{z}^{ca}(a)$, the incumbent invests up to $\widetilde{z}^a(a)$ and the entrant co-invests up to $\widetilde{z}^{ca}(a)$, asking for access in the remaining covered areas. From (2), we have $\partial\widetilde{z}^a(a)/\partial\sigma < 0$; that is, total coverage decreases with the degree of uncertainty.

If $\widetilde{z}^a(a) < \widetilde{z}^{ca}(a)$, the incumbent invests up to $\widetilde{z}^{ca}(a)$ and the entrant co-invests in all covered areas. We find that

$$\frac{\partial\widetilde{z}^{ca}(a)}{\partial\sigma} = \frac{\pi_e^d(a)\left[(\underline{\delta}(a)-1)^2 - \sigma^2\right]}{2\sigma^2 c'(\widetilde{z}^{ca}(a))} < 0,$$

since $\underline{\delta}(a) < 1+\sigma$. Therefore, in the co-investment with access regime, uncertainty has also a negative effect on total coverage.

We summarize the analysis in this section with the following proposition:

Proposition 4 *Total coverage under pure co-investment is insensitive to uncertainty. By contrast, total coverage under pure access or under co-investment with access decreases with* *the degree of uncertainty. Co-investment coverage is insensitive to uncertainty under pure co-investment, but decreases with uncertainty under co-investment with access.*

For the baseline model, we showed that total coverage is higher under pure co-investment than under pure access or co-investment with access (see Proposition 1 and Proposition 2). When there is demand uncertainty, the difference in total coverage increases with the degree of uncertainty. To the extent that the regulator favors investment, a high degree of demand uncertainty then makes the pure co-investment regime more desirable compared to the other regimes.

4 Conclusions

Investments in new infrastructures are crucial in network industries, as well as the preservation of a competitive environment, but the presence of wholesale regulation interferes with investment incentives. Some national regulators have introduced specific obligations to co-invest, in place of or on top of standard access obligations. We have studied the role of such an obligation to allow co-investment and its interplay with access obligations in a setting where an incumbent invests in infrastructure coverage and an entrant can use the incumbent's infrastructure via access and/or co-investment.

We have shown that co-investment performs better in terms of total coverage than the standard access regime. Offering access to the entrant, too, leads to both lower total coverage and lower co-investment coverage because the access option constitutes an opportunity cost that makes co-investment less attractive. Starting from a standard access regime, welfare is strictly increased if a co-investment obligation is added; on the other hand, adding access to co-investment reduces welfare if the access price is relatively low. Thus unless the regulator is willing to set a potentially very high access price, pure co-investment leads to higher welfare.

We have also considered the impact of demand uncertainty on infrastructure coverage and shown that total coverage is insensitive to the degree of uncertainty under pure co-investment, whereas in the standard access regime and with both access and co-investment, total coverage decreases with the degree of uncertainty. From a policy perspective, our results therefore suggest that a pure co-investment regime should be preferred to a pure access regime or a regime with co-investment and access, in particular when demand uncertainty is high.

Further research will explore the effects of asymmetries between co-investors, i.e., incumbency effects, and the choice of rules for sharing investment costs and access profits, two interesting questions that we have not considered in this paper.

References

Bourreau, M., Cambini, C., and Doğan, P. (2012). "Access Pricing, Competition, and Incentives to Migrate from "Old" to "New" Technology." *International Journal of Industrial Organization*, 30(6), 713-723.

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

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

Brito, D., Pereira, P., and Vareda, J. (2012). "Incentives to Invest and to Give Access to New Technologies." *Information Economics and Policy,* 24(3), 197-211.

Cullen International (2011). "Broadband Regulatory Strategy vs. Implementation in Latin America and EU." March.

d'Aspremont, C., and Jacquemin, A. (1988). "Cooperative and Noncooperative R&D in Duopoly with Spillovers." *American Economic Review*, 78, 1133-1137.

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

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

Goyal, S., Moraga-González, J.L., and Konovalov, A. (2008). "Hybrid R&D." *Journal of the European Economic Association*, 6(6), 1309-1338.

Grossman, G.M., and Shapiro, C. (1986). "Research Joint Ventures: An Antitrust Analysis", *Journal of Law, Economics and Organization*, 2(2), 315-337.

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

Inderst, R., and Peitz, M. (2012). "Market Asymmetries and Investments in NGA." *Review of Network Economics*, 11(1), article 2.

Inderst, R., and Peitz, M. (2013). "Investment under Uncertainty and Regulation of New Access Networks." *Information Economics and Policy*, 26(3), 28-41.

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

Krämer, J. and Vogelsang, I. (2016). "Co-Investment and Tacit Collusion in Regulated Network Industries: Experimental Evidence." Available at SSRN: http://ssrn.com/abstract=2119927 .

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

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

Appendix: Illustrative model

We build an illustrative model where the incumbent's profit is increasing and the entrant's profit is decreasing in the access price over the relevant range. The idea is that the regulator would never set an access price in a range where the incumbent's profit is decreasing. This is because the industry profit would be decreasing as well as the consumer surplus. Therefore, static efficiency would decrease, and there would be no benefit in terms of higher investments.

We first present the model set-up, and then derive the conditions under which the assumptions of the general model hold.

Set-up. Let the inverse demand for firm i be $p_i = \alpha - \beta q_i - \gamma\beta q_j$, with $\alpha, \beta \geq 0$ and $\gamma \in (0, 1)$. Without loss of generality, we assume that firms' marginal costs are equal to zero. We also assume that firm 1 and firm e have to incur a fixed interconnection cost f when firm e asks for access or co-invests in a given area. Firms' local profits are then given by $\pi_1 = p_1 q_1 + a q_e - f$ and $\pi_e = (p_e - a)\, q_e - f$, with $a = 0$ under co-investment. Finally, we assume that firms compete in prices.[16]

Assumptions of the general model. We solve for the equilibrium prices and define $a^m \equiv \arg\max_a \pi_1^d(a)$. We find that firm e's equilibrium profit, $\pi_e^d(a)$, is positive for $a \leq a^{\max}(f)$, with

$$a^{\max}(f) = a^{\max}(0) - \frac{(4-\gamma^2)}{2} \frac{\beta f}{(1-\gamma^2)},$$

and $a^{\max}(0) = \alpha\,(2+\gamma)\,/\,(2+2\gamma)$. We have $a^{\max}(0) > a^m$ and $a^{\max}(f)$ decreasing in f. We then find that $a^{\max}(f) > 0$ iff

$$f < \frac{\alpha^2 (1-\gamma)}{\beta\,(2-\gamma)^2 (1+\gamma)} \equiv f^{\max}.$$

[16] We obtained similar qualitative results for the same setting with quantity competition.

We also assume that f is sufficiently high such that $a^{\max}(f) < a^m$, which is true iff

$$f > \frac{\alpha^2 (1-\gamma)(2+\gamma^2)^2}{\beta (1+\gamma)(8+\gamma^2)^2} \equiv f_1^{\min}.$$

Finally, we assume that f is sufficiently high such that $\pi_1^d(a^{\max}(f)) < \pi^m$, which is the case iff

$$f > \frac{\alpha^2 (1-\gamma)}{9\beta (1+\gamma)} \equiv f_2^{\min}.$$

We have $f_1^{\min} < f_2^{\min} < f^{\max}$ (with equality iff $\gamma = 1$). If $f \in \left(f_2^{\min}, f^{\max}\right)$, we have as assumed in our general framework that (i) $\pi_e^d(a)$ is decreasing in a, (ii) $\pi_1^d(a)$ is increasing in a for $a < a^{\max}$, (iii) $\pi_e^d(a^{\max}) = 0$, and (iv) $\pi_1^d(a^{\max}) \leq \pi^m$.

Author contacts:

Marc Bourreau

Telecom ParisTech

Department of Economics and Social Sciences,

and CREST-LEI

Paris

Email: marc.bourreau@telecom-paristech.fr

Carlo Cambini

Politecnico di Torino, DIGEP

Corso Duca degli Abruzzi, 24

I-10129 Torino

EUI - Florence School of Regulation

Email: carlo.cambini@polito.it

Steffen Hoernig

Nova School of Business and Economics

Universidade Nova de Lisboa

Campus de Campolide

1099-032 Lisbon

Portugal

Email: shoernig@novasbe.pt