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Abstract

Our survey reviews the theoretical and empirical literature on all alternative policies to promote the deployment of new fiber-based communications infrastructure. Since such investment is expected to induce substantial positive externalities, dynamic efficiency becomes a particularly important policy goal. The available policies refer to i) different kinds of ex ante sector-specific regulations including cost-based access regulations as well as softer regulations such as regulatory holidays or geographically differentiated regulations, ii) deregulatory approaches based on effective competition law implementation and competitive market structures including allowance of co-investment models, and iii) public subsidies to cover non-profitable ("white") areas. Our survey identifies the most significant research gaps, finding that numerous studies related to the impact of access regulations exist, whereas only a much smaller branch of literature addresses the impact of competition policies, and even fewer studies analyze the impact of public subsidies on new communications deployment. Moreover, our work allows for a generic framework for policy recommendations that identifies the comparative advantages of the individual policy options for different market structures and for varying degrees of externalities. We find that public subsidies are the dominant policy alternative in white areas, whereas access regulations can be the preferred policy in white or "grey" areas, where only monopoly structure or co-investment models lead to private investment. Deregulatory policies might be preferable in grey areas, if there is sufficient pressure from competitive outside options and if competition law is strong. Finally, deregulatory policies including soft regulation are the dominant policy in "black" areas, where several independent infrastructure operators exist.

1 Introduction and motivation

Fibre-deployment of broadband access networks ("Next Generation Access (Networks)" – NGA(N)) have become a major issue for sector-specific regulators, competition authorities, national and local governments, as well as for investing firms. Operators of copper- and coax-based ("first generation") broadband networks have to speed up their networks to fulfil needs for high-bandwidth demanding services and are confronted with an increasing capacity demand of mobile operators who are subject to an explosion of mobile broadband services ("apps"). Moreover, proponents of a broad-scale roll-out refer to the general purpose technology character (Bresnahan & Trajtenberg, 1995) of NGAN and related spill-over effects towards major economic sectors. Indeed, numerous studies provide evidence for the positive impact of telecommunications infrastructure in general and of first-generation broadband infrastructure in particular on employment, productivity and economic growth.[1] Against this background, proponents of a broad-scale fibre-deployment argue that NGAN create new jobs in ICT and other related industries and involves a huge potential for productivity increases. For instance, new ways of working, reduced travel and office rental costs, better time management, more innovation and increased competitiveness for businesses might emerge. These potential societal benefits of NGAN have, in recent years, induced substantial theoretical and empirical research.

However, as market conditions appear to be insufficient in most countries so far to trigger broad-scale NGA roll-outs in view of high investment requirements (FTTH Council Europe, 2012) and risks,[2] identifying the right policy measures becomes crucial. Given that investment in NGAN and a higher related level of adoption of NGA-based broadband services are welfare enhancing[3] and given that most regulatory frameworks aim at achieving infrastructure- (or facility-) based competition, dynamic efficiency becomes particularly important. The question thus arises how policy makers can incentivize

[1] See inter alia Röller and Waverman (2001), Koutroumpis (2009) and Czernich, Falck, Kretschmer and Wößmann (2011) for the impact on GDP growth, Garbacz and Thompson (2007) for the impact on global productive efficiency, Bertschek, Cerquera and Klein (2013) for the impact on firm performance and Etro (2009) for the impact on business creation and employment.

[2] Next to the risks associated with the intrinsic sunk cost nature of NGA investment, potential investors are confronted with the risk of unknown future demand for new services and regulatory risks due to uncertainty of future regulation of NGAN (Briglauer & Gugler, 2013).

[3] In principle, as shown in Höffler (2007), costs of infrastructure overcapacities might also outweigh the benefits of the new infrastructure. However, regarding ex ante NGA investment, the "Averch-Johnson" effect (too much capital employed) can be expected to be small because service-based as well as infrastructure-based competition has already transformed legacy monopoly-like market structures into much more competitive market structures during the last two decades and migration towards NGA infrastructure constitutes typically more symmetric markets with new market players (Briglauer & Gugler, 2013) and thus even higher levels of competition. Moreover, as argued above, one can expect substantial positive externalities of NGA investment that are not captured in the markets.

investments most effectively. There is a considerable branch of literature that examines the impact of the different policy instruments available to public authorities, such as sector-specific regulation, antitrust/competition policy, and subsidies from national or regional/local governments. Based on a balanced reading of the related theoretical and empirical literature, we want to identify the impact of each of the relevant policy tools on NGA investment performance as well as the most relevant research gaps. These findings will then lead to much-needed policy recommendations in light of the perceived urgency of NGA deployment and in view of the huge variation of public policies as well as NGA investment activities in international comparison. For instance, while most of the fibre-leading East-Asian countries take a state aid-driven approach, the U.S. adopted a deregulatory and primarily market-driven strategy a decade ago. The European Union (EU), in contrast, relies on competitive market forces but still foresees a set of ex ante access regulations to foster NGA investment. Switzerland, which is not part of the EU, actively promotes NGA deployment on the basis of co-investment models. Thus, it appears that policy makers experiment with different policy tools which will inter alia be attributable to country-specific characteristics but most likely also to missing, ambiguous or intransparent research results.

This work aims to structure the overall discussion in terms of a meta-survey which is designed to be embracing and complementary to the existing and most related surveys in the telecommunications literature. Our work intends to first complement Cambini and Jiang (2009) who review the older and first-generation broadband related literature on investment and regulation. Second, our survey provides a broader (and more recent) review of policies than Bourreau, Cambini and Hoernig (2012)[4] who focus on the theoretical literature investigating ex ante regulations and co-investment in the transition to NGAN. Thirdly, Balmer (2013) reviews the empirical and theoretical literature as well as regulatory practice in the EU member states but focussing only on geographic (de-)regulation and cooperative investment in NGAN. Fourthly, Krämer and Schnurr (2014) provide a conceptual framework for analysing the impact of non-discriminatory open access policies on NGAN. Their literature review and framework encompasses mandatory open access regulations imposed on vertically integrated operators, public sector participation, co-investments and open access in the context of vertical separation and allows for a generic policy guideline to identify the most appropriate open access scenario. Finally, Vogelsang (2013) examines the future role of regulation in telecommunications based on five different policy areas (termination monopoly; local bottleneck access; net neutrality; spectrum management; universal service) in which the author also addresses their impact on NGA deployment. Vogelsang (2014) then surveys the same policy areas comparing the U.S. and EU telecommunications frameworks and examines whether these policies will eventually converge against the background of IP

[4] As Bourreau, Cambini and Hoernig (2012, p. 400) indicate, most of their reviewed papers were unpublished due to the fact that policy issues were rather recent and new at that time.

convergence, NGAN and mobile broadband deployment combined with fixed-mobile substitution and fixed-mobile integration.

Section 2 first provides a brief overview of the industry and outlines the NGA scenarios that are of relevance for our survey. The following sections then review the related theoretical and empirical literature on regulatory policies (section 3), competition policies (section 4) and public funding policies (section 5). Whereas sections 3 to 5 contain interim conclusions based on tabular summaries, the final section 6 provides some overall conclusions, develops a conceptual framework for policy recommendations and identifies an agenda for future research. As NGAN-roll-outs still represent a rather recent industry development and hence an even more recent research topic, it appears that a lot of further work on the theoretical and – even more so – on the empirical side still needs to be done.

2 Industry background: Relevant NGA scenarios

As outlined in the introduction, bandwidth of existing first-generation broadband networks is limited. In order to realise NGA characteristic connection speed and enable NGA specific applications, it is necessary to shorten the length of the copper-based local loops by placing the transmission equipment closer to the retail customers' premises, e.g. in the cabinets which house distribution frames (referred to as "fibre to the curb/cabinet" (FTTC)). Even higher bandwidths can be achieved if the final copper-wire line is extended to or into the building (Fibre to the building (FTTB)). In cases where technical and economic considerations render it feasible to also renew or replace the remaining in-house wiring and hence to eliminate copper lines entirely, fibre can be directly deployed to the individual apartment or home ("fibre to the home" - FTTH) (Briglauer, 2014a, p. 55). In addition to these deployment scenarios, the roll-out of high-speed communications networks might also be realised by upgrading traditional cable television (CATV) networks with DOCSIS 3.0 technology and mobile broadband networks using the wireless communication standard "Long Term Evolution" (LTE). Although both last-mentioned technologies heavily rely on fibre in their backbone networks, only fibre coaxial cable/DOCSIS 3.0 currently has substantial coverage in access networks and high adoption rates. LTE might reach similar coverage and adoption in view of the enormous popularity of mobile apps and also compete in terms of quality of service levels with FTTC architecture in the mid-term and we will thus consider LTE as a relevant outside option.[5]

[5] Note that even if LTE is not yet considered as a substitute product in the same relevant market, it still might exert significant competitive pressure on NGA based products; the same is true for first-generation wireline broadband services. Yoo (2014) shows that the LTE deployment took place much faster in the U.S. which is also ahead of Europe in terms of current LTE coverage. This might hold because Europe experienced higher coverage in terms of 3G(+) technologies and thus experiences a substantial replacement effect.

In the following sections we will use the generic term "fibre to the x" (FTTx) to refer to any of the wireline NGA scenarios described above.[6]

3 Impact of sector-specific regulations

The EU regulatory framework for electronic communications markets has established a broad system of (forward-looking) cost-based access pricing since the very beginning of the liberalisation process in 1997/1998. With respect to broadband services, alternative operators can rent the incumbent´s first-generation access infrastructure based on cost-oriented wholesale charges ("unbundling") and collocate their infrastructure at a switching office close to the subscriber. This allows service-based operators to provide traditional broadband services with scope for value added product features. Retail broadband services can also be provided via "bitstream" access which represents another wholesale service from the incumbent operator but at a more elementary level of the value chain. Entrants do not have to directly access the incumbent´s infrastructure, but they also have less ability to differentiate their services. Finally, broadband access via simple "resale" services means that access-seeking operators receive and resell a wholesale input of the incumbent without any scope of technological product differentiation. The U.S. regulator initially implemented a similar access regime, but began to fully reverse its – as regards unbundling even more comprehensive – regime imposed on the access network in 2002 (Vogelsang, 2014, 12-17). Unbundling obligations for fibre-based access were abolished in 2005. The regulatory regimes in broadband and fibre leading East-Asian economies are much more heterogeneous than those within the EU or in the U.S.

With respect to emerging NGA infrastructure the EU framework currently foresees the most comprehensive and intense access obligations in intercontinental comparison. New wholesale fibre-based access products in the EU focus on so-called virtual-loop-unbundling, which, in principle, should allow access similar to unbundling. However, the first implementing decisions of European regulators show that these new wholesale access products are actually much closer to previous bitstream access products and hence at a lower point of the value chain. Because the U.S. has been characterized by infrastructure-based duopoly competition since the initial stages of NGA deployment, the regulator refrained from imposing wholesale access remedies for NGA infrastructure ever since. Again, regulatory policies as regards NGA wholesale access differ significantly in

[6] Notwithstanding this definition, deployment costs vary significantly between relevant NGA scenarios: Most notably, the average costs and the required investments of FTTH/B are disproportionately higher than for the other FTTx technologies, because the length of fiber lines is longer and thus services a smaller customer base in the last section (WIK, 2008). Jay, Neumann and Plückebaum (2013) examine the cost differences between high-end FTTH access network architectures based on Point-to-Point and Point-to-Multipoint topologies.

Asian countries, showing a similar or lower degree of regulatory interventionism compared to the EU framework (Briglauer & Gugler, 2013).

Regarding the role of sector-specific regulations the most controversial questions therefore are whether the emerging NGA infrastructure should be subject to access regulations or whether "softer" regulations or deregulatory approaches (e.g., regulatory holidays, non-discrimination obligations, retail-minus pricing) should be granted (RQ(i)) and how existing broadband regulations, in particular the level of the access charges, impact migration incentives to NGAN (RQ(ii))?

In sections 3.1 and 3.2 below, we review in ascending chronological order (within relevant sub-sections) the related theoretical and empirical literature.[7]

3.1 Theoretical contributions

We start by focusing i) on the impact of different regulatory regimes on investment incentives of both incumbent and entrant(s). Afterwards, we review ii) contributions analysing the impact of the level of the regulated access charge, given that cost-based access regulation has been imposed. For both questions, we will discuss the literature in chronological order. Complementing the well-cited survey by Cambini and Jiang (2009) on investment in broadband infrastructure, we focus on recent contributions which are related to NGA investment.

(i) The impact of different regulatory regimes on investment incentives

Klumpp and Su (2010) consider a general model of a vertically related industry where an upstream resource is owned by a vertically integrated incumbent, who is obliged to share this resource with downstream competitors at a charge set by the regulator. The incumbent may invest to improve the quality of the upstream resource, which may be interpreted as an NGA investment. In a risk-free environment, the authors show that revenue-neutral open access to the resource would be a better regulatory regime than regulatory holidays. However, this result is reversed under demand uncertainty.

Nitsche and Wiethaus (2011) rank different regulatory regimes using the long run incremental costs (LRIC) as the regulatory benchmark model. In their model, the incumbent first decides about NGA investment while the demand for the new technology is uncertain. Afterwards, the incumbent competes in Cournot fashion with an entrant who may get access to the new technology due to regulation or negotiation. In a simulation-based comparison of four different regulatory regimes, the authors find that regulatory holidays or a regime of fully distributed costs induce the highest investment, while an LRIC regime provides the lowest investment incentives. However, one essential element of their LRIC benchmark regime is that the incumbent operator may recoup investment outlays through access prices only if NGAN represent the most efficient access technology.

[7] These sections build on the presentation in Briglauer and Frübing (2014).

Allowing joint investment in NGAN, which both incumbent and entrant can then use without paying a further access charge, generates intermediate investment incentives but the highest consumer surplus in the model.

Cambini and Silvestri (2012) also compare different regulatory regimes concerning their impact on investment and welfare. Notable differences to the model of Nitsche and Wiethaus (2011) include the determination of the access charge before quantities are set, qualitative differences between incumbent and entrant as well as the introduction of a dynamic setting. The authors focus on the timing of investment in a situation of demand uncertainty, rather than on the degree of investment. The regulatory regime of giving permission for joint investment with risk sharing emerges as the presumably best scheme for consumers and social welfare, while regulating access to the copper network but not to the NGAN induces the earliest investment.

Inderst and Peitz (2014) consider a framework with a particular focus on the uncertainty of NGA investment. In a model where both firms are risk-neutral but only the incumbent may invest in a new technology with an increase of consumer utility of unknown magnitude, the authors evaluate a wide variety of possible access price policies, identifying countervailing effects and inefficiencies with policies that make usage by non-investing firms optional. The authors highlight that with risk averse firms, a variable access payment that increases in the number of subscribers shifts risk to the investing firm compared to a fixed payment, implying that a regulator should prefer a fixed payment if a balanced allocation of risk is desired.

The main insight of Bourreau, Cambini and Dogan (2014) is that the regulator can improve the market outcome by setting regionally differentiated access charges. This is shown in a model with access regulation for both old and new technology, where the incumbent owns the old technology and may invest first in the new technology, with the entrant being able to demand access for the old technology. The investment costs differ across regions and the firms may invest in less expensive regions but not in expensive regions. Once any firm has invested in the new technology in a given region, the other can demand access to that technology for a regulated charge. The authors consider a regulatory regime where the access charge for the old technology differs depending on whether there has already been investment in the new technology in a particular region. While this regime would fail to completely solve the conflict between static efficiency in uncovered areas and the avoidance of excessive duplication of infrastructure costs, there would be an improvement over a regime with a single access charge in every region.

(ii) The impact of the level of the regulated access charge

The branch of the literature that assumes that some kind of cost-based access regulation is implemented, examines whether higher access charges imposed on old and/or new networks have a positive or negative impact on investment.

Vareda (2010) points out the role of different types of investment. The author builds a two-firm model of a non-matured market with an integrated incumbent, an entrant in the retail market and a regulator whose only policy tool is setting the access charge for the incumbent's legacy network. He finds that over a wide range of cost parameters a high access charge increases the incentives for the incumbent to invest in quality while reducing the incentives to invest in cost-reductions. However, there is a positive relationship between access charge and both types of investment if marginal costs of improving quality are low and there is a negative relationship for both types if the marginal costs of cost reductions are very low. There is no possibility for the entrant to undertake investments in this model and thus no proposition on his investment incentives.

Vareda and Hoernig (2010) consider a model where both firms may invest. The focus in this paper is on the timing of an investment in a new infrastructure for which investment costs are decreasing over time. The firm which invests in NGAN first immediately has to give access to its rival at a regulated charge which is known ex ante. By allowing for a two-part access charge, the authors are able to ensure that static efficiency is not affected by the transfer between the firms. The idea of delaying the second firm's entry by means of giving cheaper access is prevented by the regulator who enforces that access is granted at exactly the pre-defined access charge. Both firms are ex ante symmetric in this model, but the firm which invests first can make higher profits for some time, because it benefits from the service-based competition instead of the facility-based competition which emerges later, once a second network becomes profitable due to further reduced investment costs. The authors show that in this model, higher access charges induce earlier investment, while low access charges can lead to a waiting equilibrium.

Brito, Pereira and Vareda (2010) show that the relationship between the access charge and investment incentives might not be monotone. The authors consider a model of an integrated incumbent who owns the old technology and competes with an entrant who may demand access for the old technology which remains to some extent competitive even after an investment in a new technology. The incumbent decides whether to invest in the new technology depending on the quality differential to the old technology and the regulated access charge for the old technology. There is no access regulation for the new technology, but the incumbent may offer an access contract for the new technology to the entrant. If there is an offer, the entrant chooses between the two technologies and both firms compete in the retail market. The authors find that investment incentives are the lowest for a medium access charge. Moreover, the incumbent voluntarily gives access to the new technology if the innovation is non-drastic, i.e. if the entrant could also compete sufficiently well with the old technology. In addition to the model just described, the authors also consider a version where both firms may invest in the new technology and find that investment would take place for a larger set of access charges than if only the incumbent could invest. In this model the entrant would be more likely to invest than the incumbent, but due the possibility of excessive duplication of investment costs the welfare effects are ambiguous.

Mizuno and Yoshino (2012) contribute to the debate by examining whether spillovers from investment of the incumbent to the product quality of the entrant play a role concerning the impact of the level of the access charge on investment. In the standard setting with an integrated incumbent who must provide access to its infrastructure in exchange for a regulated access charge, the authors introduce the possibility of a quality-boosting investment in a new technology which would be demand-enhancing. This is also to the benefit of the entrant. The authors assume that no binding ex ante regulation is possible and the incumbent therefore undertakes its investment decision while taking possible regulatory changes afterwards into account. The main finding of this paper is that depending on the cost structure there may be overinvestment or underinvestment from a welfare perspective.

Inderst and Peitz (2012a) emphasize the asymmetries of telecommunications markets and find that higher or lower access charges might have a different impact on the incumbent and on the entrant. Using a reduced-form approach, the authors consider a strategic investment game between an incumbent owning the old technology and an entrant who has access to the old technology at a regulated charge. Assuming that both firms can invest in a new technology under the same conditions, the authors' main finding is that a higher access charge would reduce the investment incentives of the incumbent but increase those of the entrant. The reduced-form approach of this paper does not allow for a conclusion on total welfare.

Different results for the incumbent and the entrant concerning the impact of access charges on investment incentives are also found by Bourreau, Cambini and Dogan (2012). The authors analyse a model in which both firms first rely on the incumbent's copper network for which access is regulated. Both firms then decide sequentially on their investment in NGAN. The first-mover advantage for the incumbent is justified with the argument that the incumbent's control over the old infrastructure facilitates the deployment of NGAN. There are regionally differentiated investment costs and it is possible to price-discriminate between regions. The authors identify two countervailing effects for the incumbent. On the one hand, the business migration effect suggests that a lower access charge would imply that prices charged for NGA services have to be rather low as well or customers would not switch, implying negative effects of the access charge for investment. On the other hand, there is the wholesale revenue effect, which describes how low access charges lead to lower cannibalization losses, implying positive effects of a low access charge on investment. This is because high investment by the incumbent triggers high investment by the entrant, resulting in a loss of wholesale revenues, but this loss is smaller with lower access charges. Overall, in this model the effect of a higher access charge on investment incentives is ambiguous for the incumbent, but clearly positive for the entrant as the availability of a cheap access increases opportunity costs of the entrant's investment in new infrastructure. A further finding of the authors is that a decision to also regulate access for the new technology and not just for the old technology

as in the baseline model, would lead to less investment, even if both access charges are jointly optimized.

The contribution by Bourreau, Cambini et al. (2014) was already mentioned in subsection (i). In addition, the authors also take a closer look at the interdependence of access charges for old and new technology, aiming to set them optimally from a benevolent regulator's point of view. In an equilibrium where the incumbent has larger coverage for the new technology, both access charges should be positively correlated, while a negative correlation would be preferable if the entrant has larger coverage.

Bourreau, Dogan and Lestage (2014) enrich the discussion by arguing that the entrant's investment incentives do not only depend on the access charge for the old technology but also on other terms of access. This is examined in a model where the incumbent owns the infrastructure for the old technology, but the entrant has the options between building his own network or demanding access to the old network. The regulator can set an access scheme consisting of an access charge and a level of access which corresponds to the fraction of the incumbent's infrastructure the entrant may use. The entrant has to invest in complementary network elements to which he cannot acquire access. Investment costs in this model are sunk and there are no economies of scale. Investment incentives of the incumbent are not considered. The authors find that a high level of access charge would induce accelerated market entry but also delay infrastructure investment by the entrant. This holds even for lower access charges. From a welfare point of view, the optimal access charge varies non-monotonically with the level of access.

3.2 Empirical evidence

The empirical literature on the impact of broadband access regulations can be divided into two broad categories: i) quantitative analyses focusing on the regulatory impact on NGA investment and ii) quantitative analyses focusing on the impact on NGA adoption.[8] Due to data availability several of the empirical studies refer to measures of adoption. Adoption can proxy for investment and, at the same time, might provide a better proxy for consumer welfare[9] in efficiently functioning markets (Crandall, Jeffrey & Ingraham 2013, p. 266).

(i) The impact of regulation on investment

Minamihashi (2012) examines whether unbundling regulations imposed on the Japanese incumbent operator prevent entrants from self-deploying new infrastructure in terms of NGA cable deployment based on DOCSIS 3.0. The author employs data for Japan at the municipal level for the years from 2005 to 2009. Based on a dynamic entry game the author employs instrumental variable probit and nested likelihood estimation techniques

[8] A comprehensive overview of qualitative studies can be found in Berkman Center (2010, pp. 121-136).

[9] In most regulatory frameworks consumer welfare is at the heart of the relevant jurisdictions. See for instance the policy objectives and regulatory principles specified in Article 8, paragraph 2 (a) of the framework directive (European Commission 2002).

and finds that unbundling regulations hinder cable entrants from investing in own NGA infrastructure. During the years analysed the incumbent's NGA investments, however, are not hindered by the unbundling regulations.

Briglauer, Ecker and Gugler (2013) investigate the determinants of NGA investment in terms of homes passed by FTTx connections using data for the years from 2005 to 2011. Their empirical specification incorporates EU27 country-level data where estimates are obtained through various dynamic panel methods. Applying different GMM estimators as well as a bias-corrected fixed-effects estimation technique explicitly accounts for the endogeneity bias arising from their dynamic investment specification. The authors find that the more effective wholesale broadband access regulation and hence service-based competition is, the more negative is the impact on NGA investment. Competitive pressure from cable and mobile networks affects NGA investment non-linearly in terms of an inverted U-shape.[10] Furthermore, using a partial adjustment model the authors show that the NGA deployment process is subject to inherent inertia due to adjustment costs.

Yoo (2014) also examines the impact of service- and facility-based competition on NGA investment controlling for standard cable coverage using a recent but small sized panel data set for annual data for the U.S. and selected European countries. The author estimates a static investment equation using weighted least squares and ordinary least squares regression techniques that control for period effects. The author finds that service-based competition has a statistically significant negative correlation with total NGA investment as well as with rural NGA investment.

Bacache, Bourreau and Gaudin (2014) examine the incentives embedded in the EU regulatory framework on migration from old to new access infrastructures using biannual data from 15 European member states over the period from July 2002 to July 2010. The authors relate the number of access lines based on new access technologies to the number of unbundling and bitstream lines in order to test the validity of the so-called "ladder of investment" hypothesis (Cave and Vogelsang 2003; Cave 2006).[11] The authors estimate a dynamic adoption equation using a difference-GMM estimator. Whereas the authors find some support for the ladder of investment hypothesis for the migration from bitstream access to local loop unbundling at the lower rungs of the ladder, there is no empirical support for the hypothesis that the presence of multi-layer access regulation to local loop unbundling fosters entrants to invest in NGA infrastructures.

[10] However, as argued in Schmutzler and Sacco (2011) there is generally no clear prediction on non-linear shapes in partial equilibrium analysis. Rather, the relationship depends on the definition of the competitive intensity and the oligopoly framework. Indeed, a related and more recent empirical study by Briglauer (2014b) which employs a bigger sample size does not find evidence for a non-linear relationship. Hence, the earlier result in Briglauer et al. (2013) might also be attributed to the fact that polynomial terms show good in-sample fit but lower out of-sample validity.

[11] Among new access technologies the authors include FTTx as well as connections based on Power-line communication and wireless local loop.

(ii) The impact of regulation on adoption

Wallsten and Hausladen (2009) are the first to estimate the effects of broadband access regulation on FTTx connections with data from EU27 countries for the years from 2002 to 2007. Hence, this work covers the NGA roll-out at the very early stage. The authors employ a static adoption equation which is estimated by several forms of two-way fixed effects regressions. The authors find that countries where unbundled local loops or bitstream unbundling is more effective experience lower FTTx adoption. In turn, infrastructure-based competition from DSL and CATV networks exerts a positive impact on FTTx adoption.

Samanta, Martin, Guild and Pan (2012) examine the demand-side determinants of high-speed broadband deployment using ITU and OECD data on the number of FTTx connections for 25 countries for the years from 1999 to 2009. The authors estimate static specifications of an adoption model using generalized-least-squares regression technique. The authors employ a dummy variable to capture the extent of unbundling regulation and find that this variable has no significant impact on NGA adoption.

Jeanjean (2013) investigates the impact of copper access regulation in terms of both unbundling access charges and the share of wholesale access lines to the total number of retail DSL lines using quarterly data covering 15 European countries for the years from 2007 to 2012. He specifies static and dynamic models which are estimated using two-way fixed effects regression technique. The author finds that tight copper access regulation diminishes migration towards FTTx-based broadband services.

Briglauer (2014a) investigates the determinants of NGA adoption based on FTTx subscriptions for EU27 member states for the years from 2004 to 2013. The author estimates static and dynamic model specifications using fixed-effects estimators including a bias-corrected version for estimating a dynamic diffusion model. He finds that stricter previous broadband regulations in terms of unbundling, bitstream and resale obligations have a negative impact, while competitive pressure from first-generation broadband and mobile networks affects NGA adoption according to an inverted U-shape. Regarding the dynamics of the adoption process, the author also finds evidence for substantial network effects that give rise to a self-propelling endogenous growth process.

3.3 Conclusions on regulatory policies

Table 1 summarizes the main assumptions and findings of the theoretical literature reviewed in section 3.1. Regarding the impact of different regulatory regimes on incentives of incumbent and entrant to invest in NGA (RQ (i)), the theoretical literature considers mainly two different settings, namely one in which only the incumbent can invest and one in which both firms can invest but the incumbent is first-mover. For both settings, less restrictive access regulation, for instance the permission of risk-sharing and cooperation models, regionally differentiated access charges or temporary regulatory holidays in conjunction with voluntary access provision is suggested to improve social welfare (only Nitsche & Wiethaus, 2011) as well as to induce more NGA investment compared to more

restrictive regulatory regimes like cost-based access regulation. Given that cost-based access regulation is in place, the literature studies the impact of higher or lower access charges on investment both in settings where only the incumbent may invest in NGA and where both firms may invest. Important aspects in which the papers also differ include whether two-part tariffs are allowed, whether spillovers occur, to which extent the old technology remains competitive and how the investment costs are modelled. In general, the literature is suggesting that a higher access charge for the old technology is encouraging NGA investment by the entrant. However, there are countervailing effects for the incumbent suggesting ambiguity whether a higher or lower access is more likely to induce NGA investment by the incumbent and hence also with respect to aggregate NGA investment.

Table 2 summarizes the findings as well as the data and methodology employed in the empirical literature reviewed in section 3.2. From the empirical literature we infer that all studies that employ EU data or data from European countries find a negative impact of ex ante access regulations or related service-based competition on NGA deployment in terms of FTTx investment or FTTx adoption. Only one study that uses OECD and ITU data for FTTx adoption finds insignificant results (Samanta et al., 2012). Whereas all these studies use aggregate country level data, one study makes use of Japanese data at the municipal level and also finds that unbundling regulations have a negative impact on entrants´ incentive to invest in NGA infrastructure. The empirical literature overall indicates a negative impact of ex ante access regulations on dynamic efficiency in terms of NGA investment incentives (RQ(i) and RQ(ii)). These results seem to favour deregulatory approaches. In a similar vein, Vogelsang (2013, p. 215) concludes that emphasising dynamic efficiency shifts the regulatory frontier towards "softer regulation, cooperative investment, and deregulation or regulatory holidays". This appears to be largely in line with the older broadband related literature as surveyed in Cambini and Jiang (2009, p. 571) who summarize the empirical analysis as follows: "The majority concludes that local loop unbundling based on forward-looking cost methodology discourages both ILECs [=Incumbent Local Exchange Carriers] and CLECs [=Competitive Local Exchange Carriers] from investing in networks." At the same time the authors concede that a large part of the empirical analysis lacks reasonable time-series data which weakens the results. However, subsequent empirical analysis on regulation and broadband investment[12] as well as the NGA related studies reviewed in

[12] See inter alia Bouckaert, van Dijk and Verboven (2010), Grajek and Röller (2011) or Crandall et al. (2013). Gruber and Koutroumpis (2013), however, show that wholesale access regulations increase DSL investment. Their result could imply that incumbent DSL infrastructure exerts a substantial replacement effect which diminishes NGA investment incentives. Briglauer (2014a) provides some evidence by showing that the replacement effect indeed exists in Western European countries with well-established DSL infrastructure whereas there is no replacement effect in Central European countries (that do not exhibit first-generation infrastructure that is nearly the same in terms of coverage and quality).

section 3.2 seem to reemphasize the results in Cambini and Jiang (2009) and that their finding carries over – apparently even more strongly – to NGA infrastructure.

Table 1: Theoretical analysis on regulatory policies

Author(s)	Main assumptions	Main results
The impact of different regulatory regimes on investment incentives – RQ(i):		
Klumpp & Su (2010)	Only incumbent may invest. Linear access charge available for downstream entrants.	• In a risk-free environment revenue-neutral open access policy fosters incumbent investments in quality and downstream competition • Result is reversed under demand uncertainty
Nitsche & Wiethaus (2011)	Both firms may invest. Incumbent is first-mover. Uncertain demand.	• Regulatory holidays and fully distributed costs regimes allow highest investment, LRIC regulation the lowest • Regulatory holidays produce lowest consumer surplus, while risk sharing produces highest consumer surplus but mid investment incentives
Cambini & Silvestri (2012)	Only incumbent may invest. Ex ante access regulation for both technologies. Uncertain demand.	• Risk sharing leads to best consumer and social welfare • Investment is always undertaken later than the social optimum timing but access regulation restricted to the old network allows the earliest investment
Inderst & Peitz (2014)	Only incumbent may invest. Uncertain extra utility created by the investment. Different versions of ex ante access contracts (with or without commitment) as well as ex post access contracts are considered.	• Identifies forces of play for different scenarios Access policies with opt-out possibility – after uncertainty is resolved – must ensure option is used efficiently • Fixed payments optimal, if balanced risk allocation is desired and given no late-entry and/or foreclosure is feasible
Bourreau, Cambini et al. (2014)	latory Ecs may invest. Incumbent is first-mover. Investment costs differ among regions. Access regulation for both technologies.	• Regulator can improve market outcome by setting regionally differentiated access charges • Ex ante regulation to NGA infrastructure may yield even better outcomes • Access charge imposed on NGAN and on old technology should be positively correlated if incumbent dominates NGA investments
The impact of the height of the cost-oriented access charge on investment incentives – RQ(ii):		
Vareda (2010)	Incumbent may invest in quality-upgrading and/or cost-reduction. Regulated access charge, entrant cannot invest.	• High access charge boosts investment in quality but reduces incentive in cost-reduction • Access charge and both types of investment are positively correlated when marginal cost of quality-upgrading is low • With low marginal cost, correlation is reversed

Author(s)	Main assumptions	Main results
The impact of the height of the cost-oriented access charge on investment incentives – RQ(ii):		
Vareda & Hoernig (2010)	Two ex ante symmetric firms which may both invest. First investor has to give access at regulated two-part tariff. Investment costs decline over time.	• Higher access charges induce earlier investments • Under preemption equilibrium the result is reversed, if reduction in payoffs is the determinant factor • Low access charges lead to waiting equilibrium • First-best investment cannot be achieved, but efficiency can be improved
Brito et al. (2010)	Incumbent may invest in new technology and then may give access. Two part-access tariff. Old technology remains competitive.	• Two-part access tariffs incentivize investments for low values of cost • Investment incentives are lowest for a medium access charge • If regulator commits to a regulatory policy, regulatory moratorium may be socially optimal
Mizuno & Yoshino (2012)	Only incumbent may invest in quality, entrant may benefit of spillovers, if incumbent invests. Access charge is set after investment.	• Depending on the cost structure there may be overinvestment or underinvestment from a welfare perspective
Inderst & Peitz (2012a)	Both firms may invest in new technology. Various scenarios regarding asymmetry of firms, access tariffs, price-dependency of demand and further usage of old technology.	• Higher access charge does not incentivize incumbent's investment but increases entrant's one • No conclusions on total welfare
Bourreau, Cambini & Dogan (2012)	Both firms may invest. Incumbent is first-mover. Investment costs vary across regions. Old technology remains competitive. No access regulation for new technology.	• High access charge incentivizes entrant's investment but has ambiguous effects on incumbent's one • Ex ante regulated access to NGAN negatively affects investment • If both networks are regulated, access charges must be treated dependently
Bourreau, Cambini et al. (2014)	Both firms may invest. Incumbent is first-mover. Investment costs vary across regions. Old technology remains competitive. Access regulation for both technologies.	• If the incumbent has larger NGA coverage, it is socially optimal that access charges are positively correlated, negatively correlated in the other case
Bourreau, Dogan et al. (2014)	Only entrants´ investment is considered. In addition to an access charge, a level of access is set.	• High access charge incentivizes service-based competition if a small up-front investment for entry is required, but delays facility-based entry • Multiple access levels may delay investment • High access charges may accelerate investments, when allowing for market experience and/or market share acquisition

Table 2: Empirical analysis on regulatory policies

Author(s)	Data & period	Methodology	Main results
Quantitative analysis focusing on the impact on NGA investments – RQ(i):			
Minamihashi (2012)	Japan 2005-2009 Municipal-level	Instrumental variable probit and nested likelihood estimation regression.	• Unbundling regulations hinder cable entrants from investing in own NGA infrastructure
Briglauer et al. (2013)	EU27 countries 2005-2011 Country-level	Generalized method of moments estimators; bias corrected fixed effects regression; dynamic investment equation.	• The more effective is service-based competition, the more negative is the impact on NGA investment • Infrastructure-based competition from cable and mobile networks affects NGA investment non-linearly • Evidence of adjustment costs
Yoo (2014)	U.S. and European countries 55 observations Country-level	Weighted least squares and ordinary least squares regression; static investment model with period effects.	• Service-based competition and NGA investment are negatively correlated • Infrastructure-based competition from cable networks is positively correlated with NGA investment
Bacache et al. (2014)	15 European countries 17 semesters 2002-2010 Country-level	Generalized methods of moments estimators using dynamic regression models.	• Ladder of investment hypothesis supported at lower rungs • Presence of multi-layer access regulation to local loop unbundling does not increase NGA adoption
Quantitative analysis focusing on the impact on NGA adoption – RQ(i):			
Wallsten & Hausladen (2009)	EU countries, Japan and South Korea 2002-2007 Country-level	Static adoption equation using two-way fixed effects regression.	• The more effective is unbundled local loops or bitstream unbundling, the lower is NGA adoption • Infrastructure-based competition has a positive impact on NGA adoption
Samanta et al. (2012)	ITU/OECD 25 countries 1999-2009 Country-level	Generalized least squares and three stage least squares regression, static and dynamic adoption models.	• Unbundling regulation has no significant impact on NGA adoption
Briglauer (2014a)	EU27 countries 2004-2012 Country-level	Static and dynamic models using ordinary and bias corrected fixed-effects regression.	• Wholesale broadband regulation lowers NGA adoption • Infrastructure-based competition from first-generation broadband and mobile networks affects NGA adoption non-linearly • Network effects lead to an endogenous NGA adoption process
Quantitative analysis focusing on the impact on NGA adoption – RQ(ii):			
Jeanjean (2013)	15 European countries 2007-2012 Country-level	Static and dynamic models using two-way fixed effects regression.	• Tight copper access regulation decreases speed of NGA adoption

4 Impact of competition policies

To the extent that investment in NGAN is deemed welfare enhancing, the emphasis on dynamic efficiency results in a more deregulatory frontier involving a switch from ex ante regulation towards policies that lie in the intersection of ex ante and ex post authorities. Cooperative investment has increasingly received attention as a means of avoiding inefficient infrastructure duplication, sharing investment risks and thus inducing investment incentives and at the same time allowing for competition. One possibility refers to private co-operations in the actual building and sharing of infrastructure. Co-operating partners usually are telecommunications service providers (across the value chain), other public utilities (most notably, energy utilities) or real estate developers.[13] In Switzerland for instance, market-based agreements between the incumbent operator "Swisscom" and local utility companies guarantee mutual access to fibre infrastructure in different geographical areas (Neumann, 2010, pp. 14-16) without any mandatory fibre access obligations; this policy scenario can be regarded as a full substitute to sector-specific ex ante access regulations. Competition in emerging NGA markets will be determined by the number of co-investing firms and by whether mandatory access obligations co-exist as a competitive safe-guard or whether cooperative investments are exempted entirely from ex ante regulations. In the last case a strict supervision of ex post competition authorities becomes necessary to forestall potential collusion between co-investing operators (Vogelsang, 2013, pp. 216-217).[14] It should be noted here that reliance on competition law as a substitute policy crucially hinges upon its institutional implementation and effectiveness which varies considerably in international comparison.

Whereas the governments of most of the leading East-Asian fibre nations show a high degree of interventionism in terms of coordinating ICT development since the very beginning of broadband deployment, the EU in recent recommendations provided the opportunity for firms to co-ordinate and cooperate.[15] Moreover, European regulators increasingly introduced geographical deregulation acknowledging the development of infrastructure competition and as a tool for incentivizing investment in NGAN (Balmer, 2013). This section also covers the U.S.-style fully unregulated actual and potential competition between infrastructure-based NGA operators. Most notably, the incumbent´s legacy broadband infrastructure is confronted with infrastructure-based competition from CATV network operators that can serve around 95% of the U.S. population. The

[13] For the involvement of public entities and the impact of public subsidies in particular, the reader is referred to the discussion in Section 5.

[14] Indeed, collusion cannot be precluded a priori, because business case scenarios indicate that NGA co-investment is sustainable only for a limited number of operators (Rendon Schneir & Xiong, 2013).

[15] Most notably, the reader is referred to the Commission´s NGA recommendation (European Commission, 2010, recitals 12, 15, 19, 27, art. 13, 16).

deregulation of broadband infrastructure in 2002/2005 was largely based on the view that infrastructure duopoly was deemed sufficient to guarantee effective competition (Vogelsang, 2014, pp. 3, 14).

In the sections below we take a broad view that includes all relevant cooperation and deregulatory scenarios. We want to examine whether cooperation models induce additional NGA investment or not (RQ(i)) and whether deregulatory U.S. style policies induce additional NGA investment or not (RQ(ii)).

In sections 4.1 and 4.2 below, we review in ascending chronological order (within relevant sub-sections) the related theoretical and empirical literature.

4.1 Theoretical contributions

Do cooperation models induce additional NGA investment or not (RQ (i))?

The first paper analysing RQ (i) is Nitsche and Wiethaus (2011). The authors rank different regulatory regimes as described in section 3.1. According to their model, allowing joint investment in NGA deployment, which both incumbent and entrant can use without further access charge, generates intermediate investment incentives but the highest consumer surplus in their model.

Inderst and Peitz (2012b) examine the advantages of joint investment looking from a more general perspective at access contracts, either enforced by the regulator or mutually agreed between incumbent and entrant. Both ex ante and ex post contracts with respect to the time of the investment are considered in an initially symmetric Hotelling duopoly model. The authors find that both types of contracts can incentivize roll-out of NGAN and mitigate the problem of investment duplication, while ex ante contracts are more efficient in doing so. However, both types of contracts, but particularly ex ante contracts, may be used to weaken competition.

Cambini and Silvestri (2012), whose model we already described in section 3.1, also consider the regulatory regime of giving permission for joint investment with risk sharing. This emerges as the presumably best regulatory scheme for consumers and social welfare, while regulating access to the copper network but not to the NGAN induces the earliest investment.

Cambini and Silvestri (2013) extend their earlier model by introducing a joint venture between the incumbent and the entrant with transfers based on the difference to the case where the incumbent would invest alone. Moreover, the authors introduce a third company, which has the option to request access to the NGAN at a charge which is determined by either the regulator or the co-investing firms after the investment decision. The authors find that basic investment sharing is most likely preferable to allowing a joint venture, a result which also holds if there is a third firm outside the sharing agreement.

Bourreau, Cambini and Hoernig (2013) assess the extent of potential benefits from joint investments of two incumbents in NGA infrastructure by comparing the situation of joint

investment to simple duplication of investments. The authors identify a trade-off between advantages of joint investment, particularly lower costs per firm, and disadvantages, especially the danger that collaboration upstream leads to tacit collusion downstream. The latter problem may be avoided by access obligations but then the possibility of a third-party entry negatively effects co-investment. The strength of these effects is evaluated in a model with demand uncertainty and investment costs that differ across regions. The authors find that co-investment is more likely to provide an improvement if costs savings from the joint investment are high or if service differentiation between the incumbents is not too low. Voluntary access provision is seen as providing a larger infrastructure but less competition.

Do deregulatory U.S. style policies induce additional NGA investment or not (RQ(ii))?

With Vareda (2011) we are leading over to RQ (ii), discussing the impact of deregulatory policies. The author deals with the decision of the entrant to compete service-based or facility-based in a setting where the incumbent first decides how much to upgrade his network. The entrant also takes into account a two-part access tariff set by the regulator and may decide to start as a service-based competitor and build a bypass network later. The author finds that a higher initial investment of the incumbent delays the entrant's investment in a bypass network. He suggests that the regulator set an access charge depending on investment quality corresponding to the strength of the business-stealing effect of quality upgrades. Given the assumption that the investment costs of the entrant are declining over time due to technological progress, the author notes that deregulation could be better for society than access regulation.

Nitsche and Wiethaus (2011) – reviewed in section 3.1 – find that regulatory holidays lead to highest investment incentives dominating joint investment and an LRIC regime.

Flacher and Jennequin (2014) consider a multi-firm model with old and new access networks co-existing as imperfect substitutes. Access to the old technology is available for all firms at a cost-oriented access charge, while one type of operators faces opportunities to roll-out an NGAN and one type can only use the new network given sufficiently attractive access opportunities. The authors show that in their setting an unregulated situation provides higher welfare than ex post access price regulation. However, the authors show that NGA investment and social welfare are highest if both investment and access charge decisions are taken by a fully informed and benevolent regulator.

4.2 Empirical evidence

To the best of our knowledge, there are currently no studies that employ quantitative analysis utilizing NGA specific data. Therefore, we will consider NGA-related papers which provide qualitative or experimental evidence.

Bourreau, Cambini and Hoernig (2010) consider national FTTH plans in France, Portugal and Italy, finding that all three countries at this time were planning to allow cooperation between competitors while only France intended to regulate cooperative agreements. The

authors argue that evaluating ex ante which regulatory policy would be most efficient is not feasible, as additional and necessary evidence on the performance in practice can only be gathered if countries adopt different policies at least in the beginning.

Yoo (2014) compares NGA and LTE statistics in the U.S. with selected European countries using recent data from the European Commission as well as from the U.S. government. The author finds that the U.S. is far ahead of Europe in terms of total and rural coverage. In addition, he finds that the difference between the U.S. and European per household NGA coverage has increased following the financial crisis in 2008. He argues that his findings suggest that U.S. style deregulatory policies have been more effective than the approach under the EU regulatory framework.

Experimental evidence is provided by Krämer and Vogelsang (2012) who study a network competition game which assumes that firms first have to invest in a new infrastructure before they compete in offering a new service to one metropolitan, one urban and one rural area which differ in costs. Access regulation is foreseen which applies locally if the network is monopolized in a particular area only. For this general setting, the authors consider various scenarios, which differ for instance by whether co-investment is possible or by whether cheap talk about the investment decision is allowed. The experiment was conducted with economics students who had passed comprehension test before being allowed to participate. The results show that co-investment did not result in higher coverage, because there was a higher likelihood of tacit collusion between co-investing companies, despite market share asymmetry between firms which was created in order to hinder tacit collusion.

Experimental evidence is also provided by Henze, Noussair and Willems (2012), who evaluate regulatory holidays for new capacity, simple price cap regulation and price cap regulation with long term contracts and a secondary market in a setting with a single network operator and several other firms bidding in an auction for capacity. After acquiring the capacity, firms sell in a downstream market where aggregate demand is known but individual demand is private information. The network operator faces the challenge that installed capacity is causing costs every period once it is installed regardless of usage while there is no possibility to dismantle. With regard to the ability of generating efficient capacity investment, the authors find that the simple price cap regime is the most efficient regulatory policy, while the other two regimes induce underinvestment in the experiment.

4.3 Conclusions on competition policies

Table 3 summarizes the main assumptions and findings of the theoretical literature reviewed in section 4.1. The impact of co-investment models on NGA investment (RQ (i)) is usually studied in a setting where both incumbent and entrant may invest on their own or form an alliance upstream. The literature identifies gains from co-investment models, in particular the avoidance of unnecessary duplication costs provided that product differentiation is sufficiently high. The drawback, from a welfare perspective, is that

upstream cooperation may lead to downstream collusion. The natural reaction by the regulator would be to enforce access for non-co-investing parties, but this would reduce the incentive for NGA investment. Overall, the theoretical literature is suggesting that co-investment models improve NGA coverage in comparison to the situation where only traditional cost-based access regulation is in place, while there is disagreement on whether other regulatory regimes could lead to even higher coverage. For deregulatory approaches (RQ (ii)), the available papers suggest that (temporary) deregulation could lead to higher investment and might be especially beneficial for society when investment costs are decreasing over time.

Table 4 summarizes the methodology, setting and main findings of the empirical literature reviewed in section 4.2. Since there is only a very limited amount of empirical data available with respect to NGA specific approaches like allowing co-investment models (RQ(i)) or the introduction of regulatory holidays (RQ(ii)), we had to consider qualitative and experimental evidence. Several regulatory authorities including France, Germany, Italy, Portugal and Switzerland have allowed firms to co-invest in NGA infrastructure, but no clear evaluation is feasible yet. The experimental evidence casts some doubt on the positive view of co-investments in the theoretical literature, as both co-investment and regulatory holidays were not found to lead to higher NGA coverage in the experimental studies. For co-investment, this is explained with the strong effect of tacit collusion which was facilitated by the cooperation upstream. The underinvestment in case of regulatory holidays is caused by the incentive to exploit market power in the new market by reducing supply for the NGA product.

Balmer (2013, pp. 55-56) concludes that basic investment sharing models might represent a valid alternative to traditional access obligations. Regulators, however, define ex ante which co-investment models warrant deregulation under which external circumstances.

Table 3: Theoretical analysis on competition policies

Author(s)	Main assumptions	Main results
The impact of co-investment models on investment incentives – RQ(i):		
Nitsche & Wiethaus (2011)	Both firms may investment. Incumbent is first-mover. Uncertain demand.	• Investment incentives with risk-sharing are lower than with regulatory holidays or fully distributed costs, but higher than with cost-based regulation • Investment risk sharing leads to highest consumer surplus
Inderst & Peitz (2012b)	Symmetric duopoly. Access contracts may be mutually agreed or enforced by regulator ex ante or ex post. Mutually agreed ex ante contracts are interpreted as co-investment.	• Ex ante and ex post access contracts lead to fewer duplication of investments and to a wider roll-out • Ex ante and ex post access contracts dampen competition
Cambini & Silvestri (2012)	Only incumbent may invest. Ex ante regulation for both technologies. Uncertain demand.	• Risk sharing leads to best consumer and social welfare • Even with risk-sharing, investment is undertaken later than socially optimal
Cambini & Silvestri (2013)	Incumbent and entrant may share investment risk or form a joint venture. A third company may request access to NGA. Access charge determined after the investment decision by either the regulator or the co-investing firms.	• Basic investment sharing is preferable in terms of competition and investment incentives with respect to joint venture • Result still holds in presence of a third firm • Ex ante regulation avoids foreclosure, but it reduces investment incentives
Bourreau et al. (2013)	Two incumbents may form a joint venture or duplicate investment. Demand uncertainty. Investment costs differ across regions.	• Joint investment allows lower costs per firm, but leads to tacit downstream collusion • Access obligations avoid downstream collusion, but incentives for co-investment are negatively affected • Co-investment increases NGA coverage in case of high service differentiation and/or cost savings • Mandated access reduces incentives for co-investment • Voluntary access provision provides larger infrastructure but less competition
The Impact of deregulatory regimes on investment incentives – RQ(ii):		
Vareda (2011)	Incumbent first sets quality of NGAN. Entrant can decide to invest or request access. Two-part access tariff set by regulator. Entrant may still invest later if it first requests access.	• Higher incumbent's initial investment delays entrant's investment • Welfare improvement if access charge is set according to business-stealing effect of quality upgrades • Under declining investment cost, deregulation could be better for society than access regulation

Author(s)	Main assumptions	Main results
The Impact of deregulatory regimes on investment incentives – RQ(ii):		
Nitsche & Wiethaus (2011)	Both firms may investment. Incumbent is first-mover. Uncertain demand.	• Regulatory holidays lead to highest investment incentives • Consumer surplus lower than with risk sharing
Flacher & Jennequin (2014)	Multiple firms, representative types differ in ability to invest in NGAN or only demand access. Co-existence of old technology. NGA investment may differ geographically. Benevolent and fully informed regulator.	• No regulation provides a welfare improvement over ex post access price regulation • Investment incentives and welfare maximized if both investment and access charge are determined by benevolent and fully informed regulator

Table 4: Empirical analysis on competition policies

Author(s)	Methodology	Setting	Main results
The impact of co-investment models on investment incentives – RQ(i):			
Bourreau et al. (2010)	Qualitative (case study)	FTTH plans of France, Italy and Portugal are examined and compared.	• Cooperation between competitors planned/in existence in all countries, but only regulated in France • Different approaches desirable
Krämer & Vogelsang (2012)	Experiment	Network competition game with three regions and different investment costs. Local access regulation. Asymmetric firms.	• Co-investment did not lead to higher NGA coverage due to tacit collusion • Co-investment occurred in 50% of feasible cases
The Impact of deregulatory regimes on investment incentives – RQ(ii):			
Henze et al. (2012)	Experiment	One network operator invests in capacity for which other firms are bidding in an auction. They can then sell in growing downstream market.	• Regulatory holidays induce underinvestment • Price cap generates capacity investment which is close to social optimum
Yoo (2014)	Qualitative (case study)	U.S. and European countries are compared at the country level as regards NGA and LTE deployment.	• U.S. style deregulatory approaches appear to be more efficient in terms inducing NGA and LTE deployments

5 Impact of public subsidies

Public authorities seem to become more and more inclined to see high-speed broadband infrastructure as a necessary policy tool to attract and retain more business and to increase the competitiveness of their countries, regions and municipalities. Hence, a further main point of discussion is the role of national and regional governments as well as municipalities in promoting the necessary funding of NGA deployment projects. In most of the leading East-Asian fibre countries major public funding programs have already been put in place for years (Briglauer & Gugler, 2013). A similar huge public intervention can be observed in Australia, where the NGAN is constructed with public funds only, and New Zealand, where the NGAN is deployed through a public-private-partnership (PPP) between the national government and network operators (Given, 2010).[16] The conjectured substantial and positive externalities accruing in major sectors of the economy represent the main economic argument for public subsidies. Although we review public NGA subsidies in broad terms in this section, one should be aware of relevant conceptual distinctions at the institutional level: national state aid policies are largely meant to increase coverage/penetration in unprofitable ("white") areas where societal benefits of NGA deployment are not fully reflected in the willingness to pay of customers and hence neither NGA nor LTE deployment takes place; in contrast, municipal aid is typically meant to increase coverage in "grey" areas – where competition is not effective enough – or even (or particularly) in "black" areas – where competitive market structures are already well-established.[17] Two further distinctive features of municipal aid are that it is often combined with synergies from road repairs or common ducts and that it is more likely to crowd-out private investment than white area subsidies.

The main questions about public subsidies are whether the strong results on the positive externalities of first-generation infrastructure sufficiently extend to the move to NGA infrastructure in order to justify the funding costs (RQ(i)); if public subsidies crowd-out private investment (RQ(ii)); whether the expected positive impact of subsidies on NGA

[16] Public subsidies can be targeted towards either the demand or the supply side. Direct demand-stimuli include fiscal instruments or vouchers for all or specific groups of consumers. Direct supply-side stimuli not only include non-refundable public funds or facilitated loans but also PPPs, where national governments play a coordination and partial financing role and where both types of partners contribute with certain comparative advantages. PPPs are the most common form of contemporary public NGA stimulus programs, because total investment requirements are normally beyond the scope of public subsidizing, which makes sharing of investment risks among the partners involved attractive (Cave & Martin, 2010, p. 3; Briglauer & Holzleitner, 2014, p. 9).

[17] For a more formal definition see the European Commission´s Guidelines for the application of state aid rules in relation to the rapid deployment of broadband networks (European Commission 2013). Section 3.2.1 of the Guidelines describe the distinction between white, grey and black areas for basic broadband networks and section 3.3.1 the distinction between white, grey and black areas for NGAN.

deployment and adoption does actually occur (RQ(iii)), and finally, if there is a differential impact associated with the different institutional designs of public policies (RQ(iv))?

In sections 5.1 and 5.2 below, we review in ascending chronological order (within relevant sub-sections) the related theoretical and empirical literature.

5.1 Theoretical contributions

Jullien, Pouyet and Sand-Zantman (2010) consider the effect of public investments by local governments on private investments under a national regulatory framework. The authors examine whether local government intervention in the network infrastructure should be limited so that private investments are not crowded out. Their basic model consists of the regulator, the incumbent and a local government, whereby the two latter agents interact in Bertrand competition if both invest in an upgraded network. The authors include the case of multiple districts in their model. Due to externalities the investment decision of the local government in one district may influence the profitability of the private investment in another district. Additionally, the authors take into account that the incumbent cannot always perfectly foresee the investment decision of the local government and therefore has to operate under asymmetric information. Lastly, the authors consider that the objectives of the regulator and the local government might diverge, as the regulator optimizes not only the municipal agents' welfare. The authors conclude that public investment can be efficient in white areas, however, a ban of local government intervention can be welfare enhancing in grey areas in case of externalities, asymmetric information or conflicting goals between regulator and local governments. Accordingly, the national regulator has to bear these issues in mind when designing rules for the involvement of local authorities.

Fredebeul-Krein and Knoben (2010) develop a financing model for NGAN that is, in particular, applicable to PPPs. Based on a conceptual framework the authors derive an investment/pricing model that takes into account the characteristics of NGA investment projects. Accordingly, the model accommodates long-term risk-sharing contracts with participation by private and public investors in order to address the NGA specific investment uncertainties. While the investor builds and maintains the network, the access seeker leases a pre-defined network capacity for a pre-defined period of time. The access seeker owns the right to use the capacity but has to pay for it irrespective of the actual usage. The model thus also takes into account the real option value of the access seeker/non-investor which is typically not the case under standard (cost-based) access regulation regimes. The authors argue that their investment/pricing model induces the highest possible investment incentive for all potential operators thus maximizing investment in otherwise non-profitable deployment areas.

Briglauer and Holzleitner (2014) argue that the current funding practice of fixing ex ante targets for network expansion is inefficient given the uncertainty about future returns on fibre-based communications services and the public authorities' incomplete information

about the capital costs of the network provider. The authors analyze public financing of an NGAN in a region where such a network would not be commercially viable (white area) and derive an optimal linear sharing contract under the condition that the public authority has incomplete information about the NGA provider's capital costs in the contracting stage. The authors show that it is more efficient to delegate the choice of the network expansion and quality characteristics to the network operator instead of exogenously pre-fixing deployment targets. Furthermore, such contracts can be readily implemented based on existing accounting data and it is not necessary to undertake any additional verification of cost or demand data.

5.2 Empirical evidence

To the best of our knowledge, there are currently no studies that employ quantitative analysis utilizing NGA specific data. For this reason, this section reviews (i) quantitative studies related to first-generation broadband markets as well as (ii) qualitative case studies related to NGA deployments.

(i) Quantitative studies utilizing first generation broadband data

Belloc, Nicita and Rossi (2012) are the first to examine the impact of public policies on broadband adoption by utilizing a dataset for 30 OECD countries that describes public funding measures, as well as the countries' socio-economic and demographic conditions for the years from 1995 to 2010. The authors estimate the effect on broadband adoption in a cross-country panel regression model by firstly performing a random-effects estimation and secondly a quantile regression analysis. With the latter technique, the authors demonstrate that the positive and statistically significant effect of demand-side policies is higher when the broadband adoption is already developed, while the effect of supply-side policies decreases as the broadband market moves into its later stages. The authors therefore argue that policy makers should prepare measures by choosing out of available supply-side and demand-side policies which suit the government's goals and the country's broadband stage. The authors propose that demand-side policies, in particular, should be taken in order to increase broadband adoption, while the massive investment requirements of NGAN demand both kinds of policy.

Paleologos and Polemis (2013) also utilize data for 30 OECD countries for the years from 1988 to 2010 in order to examine the impact of the regulatory environment on telecommunications investments and economic growth controlling for the industry structure and competition in the market. The authors employ a broadly defined regulatory variable that captures a country´s legal framework, the extent of sector-specific regulation as well as state interventionism. The empirical results are firstly obtained through a two-stage generalized least squares fixed-effects method to estimate the static model. Secondly, the authors perform a dynamic generalized method of moments, as well as co-integration analysis. The authors find that the regulatory variable, as measured by the OECD "Regulatory Reform Index", has a significantly positive effect on both the level of

investments and economic growth in both the static and the dynamic model specifications. The authors therefore propose that in order to achieve the goal of increased investments, policy makers have to actively promote competition which also involves the use of public funding measures.

Montolio and Trillas (2013) measure how the level of broadband adoption is affected by the impact of regulation, the degree of centralization of regulatory decisions as well as industrial policy. The authors employ an industrial policy variable that stands as a proxy for public policies devoted to foster broadband penetration and is calculated as government subsidies to private and public companies as percentage of GDP. The authors utilize data sets for OECD and EU countries for the years from 1999 to 2006. Estimations are based on ordinary fixed-effects as well as instrumental variables fixed-effects panel regressions. The estimation results indicate a positive, albeit insignificant, effect of subsidies in all model specifications; however, the authors concede that the quality of the available data might not allow for a perfect test of the hypotheses which are derived from a simple theoretical framework.

(ii) Qualitative studies related to NGA funding

Sadowski, Nucciarelli and de Rooij (2009) examine the potential of PPPs to stimulate private operators to participate in deploying municipal FTTH networks. The authors focus on the specific case of a single PPP project in the Netherlands, called “Ons Net” in the city of Nuenen. In 2005, the viability of this PPP project was tested in an experimental setting using public subsides. The authors analyse the objectives, boundaries and viability of the project and find that PPPs are an effective way to attract private investment for deploying municipal fibre networks. Indeed, their techno-economic analysis shows that the experience of Nuenen served as a blueprint for other municipal networks as for instance in Eindhoven, Helmond or Amsterdam. The authors emphasize the role of subsidies and semi-public institutions through which commercial risk could be shared. The experiment was not only able to create a viable case for Nuenen, but it also created enough knowledge about cost and adoption requirements so that PPPs became viable in other municipalities even if there were already two or more competing networks existent.

Kenny and Kenny (2011) provide another case study examining whether public subsidies promoting high-end fibre roll-out in terms of FTTH network deployment goes along with sufficient societal benefits. The authors critically review the main arguments in favour of funding FTTH roll-outs and find that proponents often inappropriately attribute benefits of basic broadband services to FTTH-based services or attribute benefits of specific consumer segments, such as business premises, to all connected homes. Overall, societal benefits would be overstated. According to the authors there is no convincing evidence that subsidising high-cost FTTH roll-outs is justified by sufficient incremental externalities over other forms of NGA or first-generation broadband scenarios. Accordingly, the authors express concern that public policy makers might engage in over-ambitious and welfare reducing funding activities.

5.3 Conclusions on public funding policies

Table 5 and 6 summarize the main research topics, findings and methodologies employed in the theoretical and empirical literature reviewed in sections 5.1 and 5.2.

From the theoretical literature one can infer that public NGA subsidies entail the danger of crowding-out private investment (RQ(ii)) and that the current funding practice involves contracting inefficiencies in view of asymmetric information, externalities, risk allocation and conflicting goals between public entities (RQ(iv)). Given these warnings identified in the existing theoretical literature, one should opt for a narrowly defined role for governments in subsidizing NGAN: The efficient amount of government intervention should be determined endogenously in response to actual costs and demand and restricted to white areas taking account of risk-sharing elements and externalities. In grey areas funding activities of municipalities may create an efficiency trade-off by crowding out private investment but also delivering substantial cost advantages.

Empirical econometric evidence has only just developed and is available only with respect to first-generation broadband infrastructure so far. The results indicate a positive impact of public subsidy programs (RQ(iii)) and that policy makers should be aware that demand and supply-side stimuli might have differential effects depending on the market phase (RQ(iv)). From the available NGA related case studies one can infer that supply-stimuli in terms of PPPs might be a success (RQ(iv)) but also that high-cost intense FTTH deployments still lack conclusive evidence of sufficient incremental societal benefits to justify public subsidies (RQ(iii)).

Vogelsang (2013, pp. 29-30; 2014, pp. 248-252) argues that NGA funding programs can be regarded as a new type of universal service policy which gradually supersedes traditional universal service policies in conjunction with ubiquitous mobile (2G or higher) penetration in most developed countries. However, as the author remarks, such policies should be restricted to white areas and targeted for the poor. Even in those cases the efficiency of NGA funding programs remains doubtful in view of the increasing availability of mobile broadband (3G or higher) services. In order to minimize inefficiencies, the author further argues that NGA deployment based on state ownership should be restricted to the civil infrastructure level because of economies of scope with municipal networks. Furthermore, universal service funding should be based on an efficient tendering process that includes all relevant NGA technologies as well as LTE to provide a minimum amount of coverage and quality of high-speed broadband at lowest total costs.

It is important to recall that public subsidies for NGA deployment are subject to the basic premise that they are socially desirable. This could be justified by positive externalities of existing broadband infrastructure in conjunction with the expectation that externalities will carry over to NGA infrastructure. However, according to our reading of the literature, there is no evidence available so far that externalities and spill-over effects beyond those associated with broadband networks will emerge under NGAN (RQ(i)).

Table 5: Theoretical analysis on public subsidy policies

Author(s)	Main assumptions	Main results
Impact of public subsidies on private investment incentives – RQ(ii)		
Jullien et al. (2010)	Both operators and local government may invest in NGAN.	• Banning public intervention can be welfare-enhancing in grey areas
Impact of institutional designs of public subsidies on investment incentives – RQ(iv)		
Fredebeul-Krein & Knoben (2010)	Demand and regulatory uncertainty.	• Investment risks sharing enhances NGA deployment and wholesale competition
Briglauer & Holzleitner (2014)	Demand uncertainty. Asymmetric information about capital cost and demand.	• Endogenous NGA provider choice of network expansion is more efficient • Linear profit-sharing contracts incentivize NGA investment and minimize public subsidies

Table 6: Empirical analysis on public subsidy policies

Author(s)	Data & period	Methodology	Main results
Quantitative studies related to first-generation broadband funding – RQ(iii):			
Belloc et al. (2012)	30 OECD countries 1995-2010 Country-level	Random effects and quantile regression using static model specifications.	• Public policies positively affect broadband penetration in advanced stages of diffusion
Paleologos & Polemis (2013)	30 OECD countries 1988-2010 Country-level	Static and dynamic models using two-stage generalized least squares fixed-effects and generalized method of moments regression.	• Subsidies positively and strongly correlated with investments and economic growth • Privatization may incentivize investments
Montolio & Trillas (2013)	OECD/EU countries 1999-2006 Country-level	Estimations based on static fixed-effects and instrumental variables fixed-effects panel regression.	• Public subsidies are weakly positively correlated with broadband deployment • Centralization has no or negative impact on broadband penetration • Decentralized policies may be required with vertical and horizontal coordination
Quantitative studies related to first-generation broadband funding – RQ(iv):			
Belloc et al. (2012)	30 OECD countries 1995-2010 Country-level	Random effects and quantile regression using static model specifications.	• Demand-side policies positively affect broadband penetration in advanced stages of diffusion • Countries' initial conditions are relevant in policy choices
Qualitative studies related to NGA funding – RQ(iii) and RQ(iv):			
Sadowski et al. (2009)	Nuene District (Netherland) 2005 Municipal-level	Techno-economic analysis.	• PPPs are effective in deploying municipal NGAN
Qualitative studies related to NGA funding – RQ(i) and RQ(iii):			
Kenny & Kenny (2011)	Literature review	Critical appraisal of pro-NGA arguments.	• Social benefits may not be enough to justify FTTH subsidies

6 Overall conclusions, future research and policy recommendations

Our analysis indicates that the extent of the NGA related theoretical and empirical literature differs widely depending on the specific policies. Whereas numerous theoretical studies related to the impact of access regulations exist, only a much less pronounced branch of literature relates to the impact of competition policies, and even fewer studies analyse the impact of public subsidies on NGA deployment. Moreover, empirical studies are few in number, in particular regarding the assessment of competition policies and public subsidies. Those existing empirical studies hardly provide direct evidence on the predictions of the theoretical contributions. The latter, in turn, do not take into account some of the key features related to investment incentives so far. For instance, none of the reviewed contributions explicitly models the impact of expectations related to future market structures (e.g., collusion vs. Bertrand competition) and future regulatory policies (e.g., cost-based regulation vs. deregulatory policies and regulatory commitment) on ex ante investment incentives. Overall, our survey indicates that the current literature exhibits some substantial research gaps. For instance, future theoretical research should examine the welfare implications of policy measures. Future empirical research should also be based on firm-level data that allows tests of differential investment incentives and strategic effects as predicted by the theoretical literature.

Nevertheless, our analysis enables us to derive some generic policy guidance based on the comparative efficiency of the relevant policies examined. Since our policy recommendations are necessarily subject to several trade-offs (Krämer & Schnurr 2014) and depend on local conditions, they are based on a counterfactual approach (Cave 2014). As stated in section 3, the European regulatory framework currently foresees ex ante access obligations to be imposed on NGA infrastructure which thus represents the relevant status quo in Europe. In view of our discussion of the individual policies available the following alternatives to induce NGA investment emerge: i) deregulatory approaches including co-investment models subject to competition law, ii) reliance on public subsidies to cover white areas subject to the admissibility criteria of national and international competition law,[18] and iii) combinations of i) and ii). Obviously, the assessment of these alternatives will depend on the competitive intensity in relevant markets and regions in terms of subnational markets as well as on the effectiveness of competition law and LTE as the relevant outside options.[19]

[18] In addition, whenever NGA roll-out projects are (co-)financed by public subsidies within EU member states, then such co-operations (e.g. PPPs) must also adhere to the principles of State aid control for public service contracts following from Art. 106 and 107 of the Treaty on the functioning of the EU, as well as the specific broadband/NGA state aid guidelines (European Commission, 2009).

[19] As already indicated in section 2, standard wireline broadband products represent relevant substitutes for some consumer segments and thus also exert some competitive constraints for NGA pricing.

i) If the competitive intensity is deemed sufficient (black areas), then this alternative becomes the gold standard. The U.S. experience shows that an almost nation-wide duopoly infrastructure can be sufficient to ensure competition and trigger investment (Cave, 2014). This applies even more so if NGA deployment attracts new market players such as forward integrating municipalities or energy utilities in some European states or backward integrating Internet content providers like Google in the U.S. Furthermore, duopoly infrastructure or narrow oligopolies do not have to be established on a full nation-wide scale, if infrastructure operators are e.g. subject to a uniform pricing constraint that arises from retail demand or if they engage in a race to pre-empt each other or if they face pricing constraints from mobile broadband operators (LTE) which typically can cover areas where no parallel CATV infrastructure exists. The empirical literature as well as the theoretical models have considered duplication of NGA infrastructure resulting in NGA duopolies or narrow NGA oligopolies. One would expect that NGA oligopolies induce higher NGA investment in general which is preferable in case of high externalities arising from the NGA deployment.[20] In turn, NGA duopolies would be preferable over wider oligopolies in case of low NGA externalities or when costs of additional infrastructure duplication are higher than welfare gains from product differentiation.

The number of investing operators is also crucial for assessing the role of co-investment models in grey areas. Whereas co-investment largely avoids fixed cost duplication in case of several independent NGA deployments, it also evolves the danger of collusion among co-investing operators. A higher number of co-investors makes collusion less likely but also imposes a negative externality on the other members of the co-investment in terms of lower individual market shares and hence higher costs per user (Rendon Schneir & Xiong 2013). Assessing the overall impact of co-investment as an alternative in an unregulated setting is limited to experimental and anecdotal evidence so far. This alternative becomes more attractive if the above-mentioned intra- and intermodal competitive safe-guards are present and if co-investing parties have comparative cost advantages; the latter might be due to the prior ownership of passive infrastructure elements on the side of municipalities or utilities. In the absence of these conditions and if collusion ex post is likely, then ex ante NGA access obligations (or geographically differentiated access regulations in subnational markets) appear to be still necessary and justified.

ii) Provided strong enough externalities or spill-over effects exist, public subsidies are justified to cover white areas where private network deployment is not profitable even in case of a monopoly and where there is no danger to crowd-out private investment. Although access regulations typically include white areas at least formally, they appear to

[20] Lestage and Flacher (2014) examine infrastructure investment and access regulation distinguishing three different liberalization stages. The authors show that in the last stage of liberalization, where incumbent and entrant play a symmetric investment game, it might be socially optimal for a regulator to set access charges to promote infrastructure-based competition, even if operators tend to overinvest. The last stage with symmetric investment decisions appears to be a realistic description in view of NGA deployment conditions.

be practically ineffective in those regions in terms of inducing NGA investment. Hence, public subsidies represent a relevant and complementary alternative which might, but not necessarily should (Briglauer & Holzleitner 2014), be accompanied by further third party access obligations. An extreme case is the governmental involvement in Australia and New Zealand (Given 2010) where NGAN operators are subjected to vertical separation obligations which imply long-term ex ante access regulation. In case of vertical integration the regulator is also confronted with a wholesale monopoly but the operator might be subject to retail pricing constraints or compete at the retail level with substitute products in the mid-term.

iii) Ideally, policy combinations within i) and between i) and ii) specifically oriented for white, grey and black areas present even stronger alternatives to the current status quo of NGA access regulations. At this point it is necessary to note that the academic literature so far provides no guidance on the role of this counterfactual policy mix. Table 7 provides a synopsis which maps the different competitive areas (column 1) with the available policy options based on respective market structures (column 2). Column 3 reports the effect of policy options on expected investment where we assign ordinal values on the basis of the related empirical literature (section 3.2) which shows quite unambiguously that stronger regulation implies lower ex ante NGA investment incentives. In case of white areas we assume that the extent of the public subsidy is exogenous and hence expected investment is only dependent on the degree of ex ante regulations. Finally, column 4 presents a ranking of policy combinations based on expected externalities. According to the empirical literature review in section 5.2, there is no conclusive evidence available so far that NGA deployment also involves high externalities. Hence, we simply distinguish two broad cases in column 4 where high expected externalities imply that policy makers should focus on dynamic efficiency and incentivise investment. In turn, if expected externalities are low, than policies should be primarily based on static efficiency. Note that the categorisation of white, grey and black areas is endogenously determined by the chosen policy options and the expectations of policy makers.

Since policy choices crucially depend on expectations of the respective decision makers, the underlying information should be based on empirical evidence and rigorous analysis (Mayo, 2013). Our work has identified the main research gaps and trade-offs involved in the alternative policy options which should give some purposeful impulses for future research.

Table 7: Synopsis of policy alternatives

Area	Policies based on competitive intensity and competition law	Expected investment	Ranking of policy decisions based on expected externalities
White	Subsidized monopoly is vertically integrated (VI) =› – access regulation: competition law is weak – soft regulation: competition law is strong Subsidized monopoly is vertically separated (VS) =› – access regulation: irrespective of competition law	Low Medium Low	Expected externalities are high =› 1) VI and soft regulation 2) VI and access regulation*) 3) VS and access regulation Expected externalities are low =› No public subsidies: only low cost NGA/LTE funding based on universal service doctrine
Grey	Monopoly operator (M) =› – access regulation: LTE and competition law is weak – soft regulation: LTE and/or competition law is strong – no regulation: LTE and competition law is strong Co-investing operators (CI) =› – access regulation: LTE and competition law are weak and collusion expected – soft regulation: LTE and competition law are weak but no collusion expected – no regulation: LTE and competition law are strong and no collusion expected	Low Medium High Low Medium High	Expected externalities are high =› 1) CI and no regulation 2) M and no regulation 3) CI and soft regulation 4) M and soft regulation 5) CI and access regulation 6) M and access regulation*) Expected externalities are low =› Trade-off: avoidance of inefficient infrastructure duplication of co-investors vs. comparative cost advantage of co-investors
Black	Duopoly (D) =› – soft regulation: LTE and competition law are weak and collusion expected – no regulation: LTE and/or competition law is strong or uniform pricing constraint Oligopoly (O) =› – no regulation: irrespective of LTE and competition law	Medium High High	Expected externalities are high =› 1) O and no regulation 2) D and no regulation 3) D and soft regulation*) Expected externalities are low =› 1) D and soft regulation*) 2) D and no regulation 3) O and no regulation

*) Since these options are based on weak competition law/LTE, better options may not be available for those regions/countries.

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