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WHY IS EUROPE LAGGING ON NEXT GENERATION ACCESS NETWORKS?

WOLFGANG BRIGLAUER, CARLO CAMBINI AND MICHAŁ GRAJEK

Highlights

- Fibre-based next generation access (NGA) roll-out across the European Union is one of the goals of the European Commission's Digital Agenda strategy. By enabling entirely new broadband services, NGA networks have the potential to trigger productivity gains on a massive scale. There remains considerable uncertainty, however, about how the roll-out goal can best be achieved.
- The underlying differences between the economics of copper-based and new fibre-based broadband infrastructures should lead to a revision of the regulatory framework for telecommunications markets. While the current regulatory measures have been useful in the past decade to sustain competition and facilitate entry into a market with already-existing infrastructures, the need to create new, much faster broadband networks calls for a rethink of the scope and strictness of regulation.

Wolfgang Briglauer (briglauer@zew.de) is a senior researcher at the Centre for European Economic Research (ZEW), Mannheim. Carlo Cambini (carlo.cambini@polito.it) is professor of industrial organisation and regulation at Politecnico, Turin. Michał Grajek (grajek@esmt.org) is a Bruegel non-resident scholar and associate professor of economics at the ESMT European School of Management and Technology.

Telephone
+32 2 227 4210
info@bruegel.org

www.bruegel.org

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1 INTRODUCTION

Next generation access (NGA) networks, a fibre-based high-speed broadband infrastructure, are a general purpose technology with the potential to trigger productivity gains on a massive scale. These gains might take years to accrue, because new applications and new organisational and production designs that use NGA networks need time to be developed. Nevertheless, we consider wide NGA infrastructure roll-out to be welfare enhancing and that it should therefore be an objective of the European Union. This is consistent with the view taken by the European Commission. The Commission's Digital Single Market strategy, adopted on 6 May 2015, promises that in 2016 an ambitious overhaul of the telecoms regulatory framework will be proposed, and will focus, among other aims, on investment in high-speed broadband infrastructure (European Commission, 2015).

EU markets for electronic communications networks and services are regulated according to the 2002 eCommunications framework. Among its main provisions is the mandated sharing of telecommunications infrastructure, which allows entrants to compete with incumbents. The eCommunications framework was created for copper-based legacy networks, but has been extended to cover NGA networks, which provide users with radically improved broadband access to data, based on fibre-optic cable technologies. Academic research shows that, among various cost and demand side factors that have an impact on the deployment of NGA networks, regulatory access policies play a crucial role. In this Policy Contribution, we discuss how these regulations – devised at EU level and implemented at national level – might affect the deployment of NGA networks.

We start with an analysis of recent NGA trends in EU member states, and assess if the European Commission's policy goals are being met[1]. We then review the experience with broadband deployment in the EU and other selected economies. We discuss the differences and similarities in the economics of the 'old' broadband (using legacy networks based on copper and coaxial cables) and the 'new' broadband (using NGA networks), and assess the extent to which lessons learned about regulation of legacy networks can be transferred to NGA networks. We then discuss the current regulatory framework for NGA networks and in Box 1 on page 9 highlight case studies of EU member states that did particularly well in terms of NGA deployment. This enables us to highlight the key trade-offs involved in regulation of NGA networks and to formulate a set of recommendations to policymakers.

Our key finding is that the underlying differences between the economics of the 'old' and the 'new' broadband infrastructures should lead to a revision of the current regulatory framework for telecommunications markets. While the regulatory framework for copper-based networks was useful in the past decade to sustain competition in a market with already existing infrastructures, the need to create new broadband networks calls for a rethink.

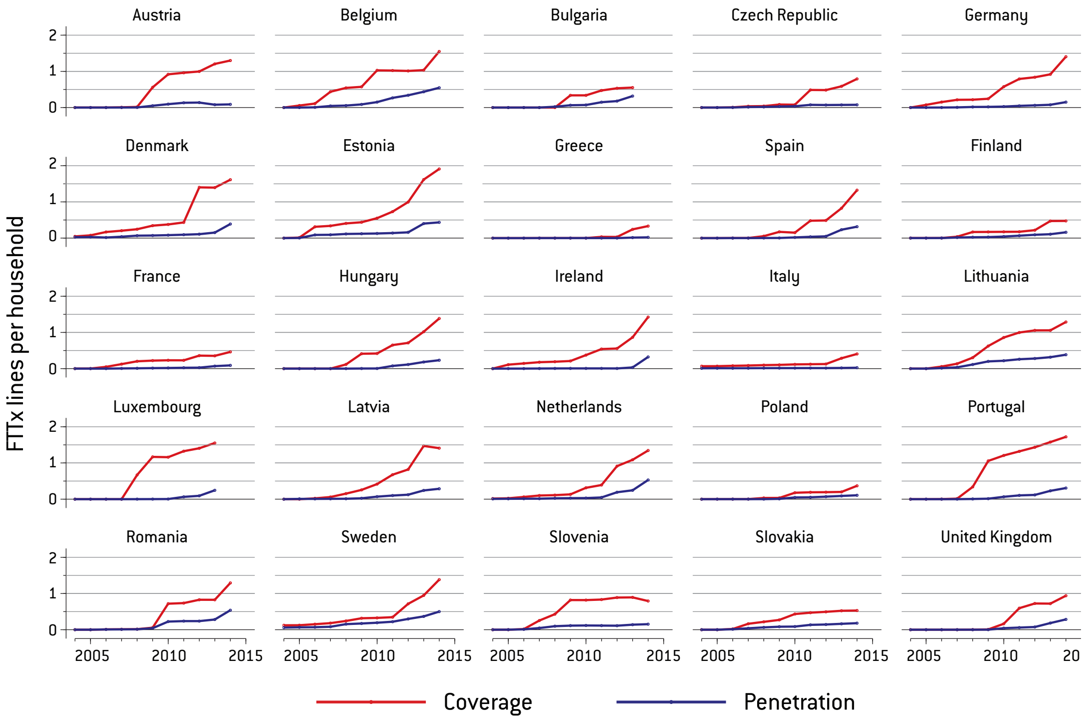
2 NGA COVERAGE, PENETRATION AND TAKE-UP RATES

Figure 1 shows NGA coverage and NGA penetration for 25 EU member states. NGA coverage is measured by the total number of lines that enable fast broadband internet access that are available to homes or businesses ('homes passed'[2]) . Network coverage thus refers to the number of consumers that in principle have access to fast broadband. NGA penetration refers to the actual number of NGA subscribers. Figure 1 captures almost the entire period of NGA deployment in EU member states and shows that the coverage and

1. These are specified in the Digital Agenda, one of seven flagship initiatives of the Europe 2020 strategy to prepare the EU economy for the next decade. See: http://ec.europa.eu/digital-agenda/digital-agenda-europe.

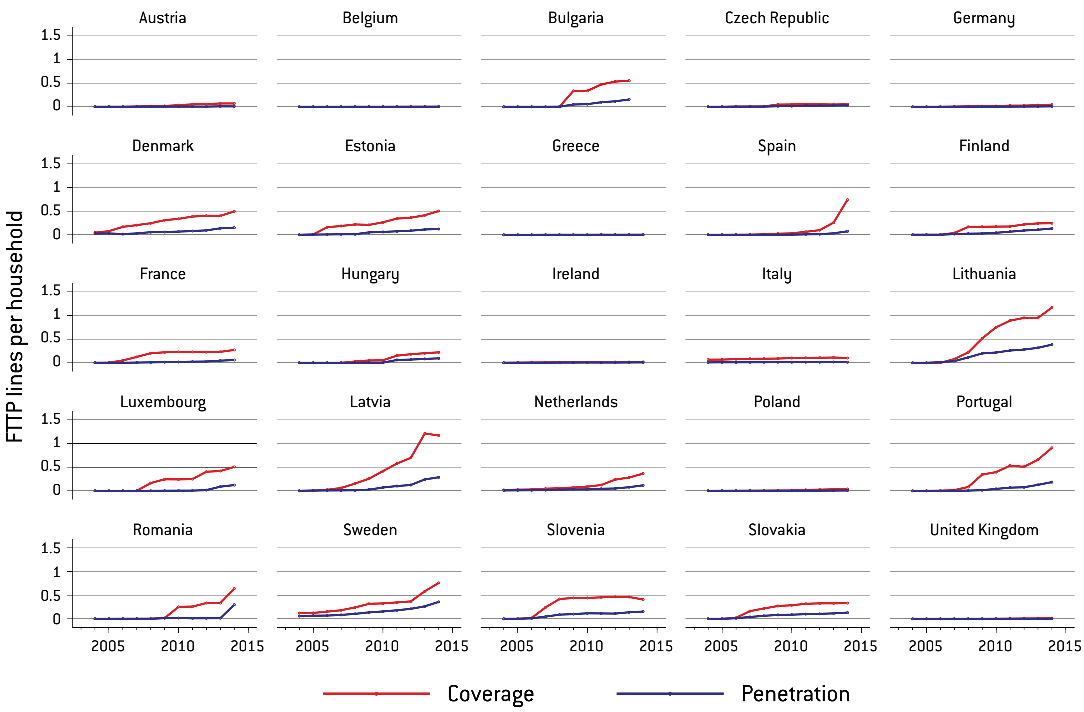
2. We define 'fast broadband' as broadband based on 'fibre to the x' (FTTx) technologies, which are much faster than the previous copper-based technologies; see the technical annex.

Figure 1: Fast broadband coverage and penetration rates per household in 25 EU member states for the years from 2005 to 2014



Source: FTTH Council Europe. Note: Data are available from FTTH Council Europe for the group of the EU25 member states (Malta, Cyprus and Croatia are excluded). The coverage for Luxembourg is 2.31 in 2014, which is not reported, because we have restricted the presentation to an upper-bound of 2 for illustrative purposes.

Figure 2: Ultra-fast broadband coverage and penetration rates per household in 25 EU member states for the years from 2005 to 2014



Source: FTTH Council Europe. Note: Data are available from FTTH Council Europe for the group of the EU25 member states (Malta, Cyprus and Croatia are excluded).

the penetration follow a more or less dynamic diffusion process. Even though some EU member states do particularly well in terms of NGA deployment, as Figures 1 and 2 show, Europe lags behind a number of non-European nations, including Japan, Korea and the United States (FTTH Council Europe, 2015; Yoo, 2014; OECD, 2013).

In order to stimulate greater NGA coverage and penetration, the European Commission's Digital Agenda strategy, of which the Digital Single Market plan is a part, said that the EU should *"ensure that, by 2020, (i) all Europeans have access to much higher internet speeds of above 30 Mbps and (ii) 50 percent or more of European households subscribe to internet connections above 100 Mbps"* (European Commission, 2010). In Figures 1 and 2, the horizontal lines at penetration and coverage values equal to 0.5 and 1 mark the Digital Agenda goals. The mean value of fast broadband coverage already equalled approximately 100 percent in 2014, which on average fulfils goal (i) of the Digital Agenda for the 25 member states in our analysis. Ultra-fast broadband coverage, however, is much lower with an average mean value of only about 35 percent (Figure 2)[3].

There also appears to be a substantial gap in penetration rates. The average NGA penetration rates for fast broadband and ultra-fast broadband are only 25 percent and 10 percent, respectively. Overall, when comparing fast broadband deployment in terms of coverage and penetration with ultra-fast broadband, one finds similar growth patterns but notably lower levels for the latter in most EU states. In some countries (such as Austria, Belgium, Germany and the United Kingdom), ultra-fast broadband deployment has started on very small scale or not at all. Instead, operators focus on much less cost-intense upgrades to the traditional copper and coaxial cable technologies. Hence, the Digital Agenda's goal (ii) for connection speeds above 100 Mbps is still far from being realised.

In fact, numbers on NGA coverage and penetration overestimate the actual coverage and penetration because of double counting in many member states. In particular, in urban areas, there is double counting of homes passed by cable television operators and traditional telecommunications operators. In addition, business establishments, which promise high returns, might be passed by parallel NGA infrastructures. This is why the coverage levels in Figures 1 and 2 sometimes exceed 100 percent. This is the case for Germany, for example, but in fact only 74.6 percent of all German households actually had access to ≥ 30 Mbit/s fixed-line broadband technologies at the end of 2014 (TÜVRheinland, 2014).

3 LEGACY-BASED INFRASTRUCTURE REGULATION

The EU regulatory framework for electronic communications markets has established a broad system of cost-based access pricing since voice telephony markets started to be liberalised in 1997-98 (European Commission, 1998; European Commission, 2002). This allowed market entrants to offer narrowband voice telephony products, which substantially reduced average call prices in the first phase of sector-specific regulation. The EU regulatory framework then implemented mandated wholesale access to the local loop (European Commission, 2000), thus enabling market entrants to offer consumers narrowband voice and broadband either as bundled or stand-alone services. Incumbent operators were required to 'unbundle' the legacy access infrastructure, ie to rent parts of it to new entrants based on cost-based access charges, and to allow entrants to collocate their infrastructure at a switching office close to the users.

Four access options have provided entrants with a variety of viable business cases, thereby allowing them to effectively compete with the incumbent in offering broadband services:

- Full unbundling, which implies that entrants rent the entire local loop to offer a voice-broadband bundle to consumers;
- Shared access (ie line sharing), which means that entrants rent the upper line's bandwidth in order to offer broadband only;
- Bitstream access, ie mandated wholesale access to the incumbent's networks at a more elementary level of the value chain; the access point for bitstream is beyond the

3. We define 'ultra-fast broadband' as based on the fastest of the FTTx architectures, ie FTTP; see the technical annex for more details. The division of various technologies into the fast (over 30 Mbps) and ultra-fast (over 100 Mbps) categories, is somewhat blurred. Our approach is to count as ultrafast only those technologies that can guarantee 100 Mbps for every subscriber at all times.

local loops and usually closer to the entrants' core network, but entrants also have less ability to differentiate the broadband services based on bitstream compared to full unbundling or line sharing;

- Simple resale, which requires the least network investment; resale means that the access-seeking operators receive and resell a wholesale input from the incumbent without any scope for technological product differentiation (Briglauer *et al*, 2015).

Figure 3 shows the hierarchy of access options, as viewed by the European Commission. This view was based on the ladder-of-investment hypothesis, according to which the different access options lead to a gradual increase in infrastructure investment by new entrants over the liberalisation period (Cave, 2006; Cave and Vogelsang, 2003). Thus, by facilitating entry, access regulation was intended to promote broadband take-up by keeping consumer prices in check and simultaneously creating incentives for new infrastructure investment. Ultimately, entrants were expected to deploy their own access infrastructure and engage in fully-fledged facilities-based competition with incumbents[4].

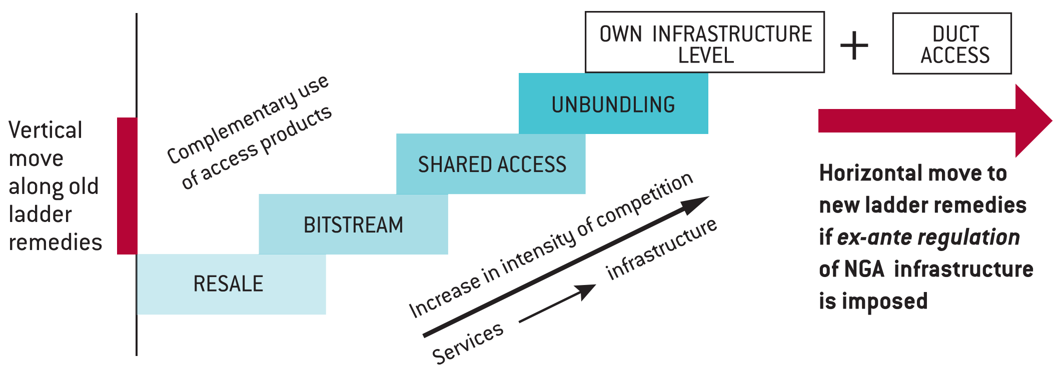
More than a decade of broadband access regulation in Europe has shown, however, that the ladder-of-investment hypothesis works mainly for the lower rungs of the investment ladder. This calls for comparatively low investment requirements, especially, for moves from resale to bitstream access. Empirical evidence suggests that mandatory local loop unbundling has not led entrants to ramp up access network infrastructure as expected. In fact, unbundling might have even reduced total industry investment, meaning that investment by entrants has not been sufficient to offset the unrealised investments of incumbents[5]. The fact that the *ex-ante access* obligations did not result in the service-based entrants deploying enough access infrastructure can be interpreted as the "*natural outcome of the economics of fixed broadband access*" (Vogelsang, 2013). In essence, by depressing the prices of retail broadband services, mandatory wholesale access policies render investment in competing technologies, such as cable broadband, less attractive. Similarly, telecoms entrants often prefer to rent unbundled elements at mandated access rates rather than build their own parallel infrastructure. As access conditions become more favourable, entrants' opportunity costs for self-deployed access infrastructure increase and "*wait and see strategies*" (Guthrie, 2006) become more attractive. In our view (see section 5) this is not necessarily bad for economic welfare, especially if the unrealised investment would merely duplicate existing access network infrastructure. But it should be acknowledged as an outcome of mandated wholesale access. This lost investment is also likely to be a by-product of regulation of NGAs, as we discuss in the next section.

In contrast to the EU, in 2005 the US regulator largely removed the unbundling regime, which was rather comprehensive at that time. The decision to deregulate broadband markets was based on the almost nationwide duopoly market structure, which was considered to ensure enough competitive pressure. In fact, facilities-based com-

4. Only mandated access to passive infrastructure components such as ducts that the entrants may use to reach access points is supposed to be necessary at this final stage of liberalisation.

5. For critical assessments of the ladder of investment hypothesis, see Bouckaert *et al* (2010) and Bourreau *et al* (2010). Econometric evidence is provided by Grajek and Röller (2012), who show that stricter access regulation depressed total investment in telecoms in EU member states. Bachace et al (2014) find partial support for the ladder-of-investment theory, showing that in the EU, entrants mostly climb the 'shorter' ladder from bitstream to unbundling but do not reach the 'higher' rung from unbundling to fibre. Nardotto *et al* (2015) show that unbundling in the UK resulted in no increase in broadband penetration but had a strongly positive impact on the quality of service.

Figure 3: Hierarchy of wholesale access remedies



Source: European Commission (2010).

petition emerged in the US telecommunications market almost entirely because of the cable operators with prior access infrastructure (Vogelsang, 2015)[6]. With the ladder-of-investment hypothesis, the European Commission took the opposite approach, although it has never been coherently applied (Vogelsang, 2015).

Although the EU broadband access regulations have been only partly successful in facilitating infrastructure investment and facilities-based competition, the eCommunications framework should not be judged as ineffective, especially in international comparison. Table 1 shows that all OECD countries experienced a similar pattern of growth of first-generation fixed-line broadband subscriptions from 2009-13. A country's position in the ranking highly correlates with its economic development level: the richest countries generally have higher subscription rates per 100 inhabitants. The level of economic development alone does not tell the full story, however. Japan and the US are only slightly above the OECD average. In contrast, the major western European economies, including France, Germany, the Netherlands and the United Kingdom, which are comparable to US in levels of economic development, do much better in terms of 'old' broadband penetration. The Scandinavian countries, which have a long tradition of public subsidies for broadband and a high level of consumer ICT-affinity (Briglauer and Gugler, 2013), also beat the US and Japan in the ranking. Overall, the EU access regulations seem to have worked relatively well in facilitating broadband take-up by consumers.

The favourable outcome in terms of European broadband penetration does not mean that the fundamental trade-off inherent in wholesale access policies does not work. Reducing market prices through mandated access fosters the take-up of broadband services, but hinders investment in infrastructure. Note that the broadband penetration figures (Table 1) capture the result of both the demand and the supply factors and thus simply illustrate how this trade-off played out in the past. The underlying differences between the economics of 'old' and 'new' broadband infrastructures, however, are likely to tilt the trade-off in an unfavourable direction by aggravating the negative impact on investment of access regulation in the case of NGA networks. Investment in NGA networks, in particular ultra-fast broadband, is more likely to suffer from the hold-up problem because investment in the 'old' broadband access upgrade was more incremental, while it is very substantial for 'new' broadband. Thus, the situation is very different on the supply side of the equation: the software and equipment needed to upgrade the legacy network to support

6. By facilities-based competition we mean competition between operators that own infrastructure, which allows each of them to deliver broadband services without needing to rent infrastructure from competitors. In contrast, service-based competition relies on mandated infrastructure sharing.

Table 1: Total fixed-line basic broadband subscriptions per 100 inhabitants

OECD country	2009	2010	2011	2012	2013
Switzerland	35.6	38.191	40.252	42.586	45.239
Netherlands	37.094	38.099	38.928	39.722	40.441
Denmark	36.167	37.228	37.616	38.833	40.209
France	30.655	32.778	34.683	36.396	37.649
Korea	33.239	34.797	35.876	36.501	37.471
Norway	33.87	34.528	35.216	36.219	36.946
Iceland	32.818	33.651	34.484	34.811	35.775
United Kingdom	29.675	31.471	33.011	34.258	35.559
Germany	30.456	31.911	33.243	34.063	34.838
Belgium	28.866	30.843	32.145	33.284	34.393
Canada	29.591	30.703	31.701	32.417	33.473
Sweden	31.627	31.924	31.97	32.218	32.738
Luxembourg	29.185	30.718	31.501	32.107	32.52
Finland	28.729	28.577	30.082	30.966	31.536
New Zealand	22.83	24.851	26.611	28.77	30.197
United States	25.501	26.716	27.7	28.726	29.695
Japan	24.714	26.565	27.273	27.671	28.044
OECD – Total	**22.963**	**24.389**	**25.356**	**26.111**	**26.958**
Spain	21.308	23.359	24.477	24.646	26.309
Greece	17.118	20.177	22.14	24.208	26.234
Austria	21.105	22.899	24.222	25.002	26.149
Australia	22.997	23.998	24.155	24.831	25.994
Estonia	22.463	23.279	24.764	24.537	25.488
Israel	23.473	23.856	24.204	24.704	25.124
Slovenia	21.537	22.812	23.755	24.405	25.115
Ireland	19.179	20.646	21.709	22.649	24.434
Portugal	17.757	19.78	21.113	22.594	24.124
Hungary	17.812	19.562	20.922	21.88	23.067
Italy	20.024	21.585	22.11	22.133	22.273
Czech Republic	12.915	14.555	15.776	16.633	17.383
Poland	12.832	13.816	14.899	15.706	15.638
Slovakia	11.586	12.788	13.833	14.768	15.629
Chile	9.711	10.405	11.584	12.378	13.002
Mexico	8.394	9.813	10.335	10.618	11.276
Turkey	8.854	9.73	10.251	10.492	11.192

Source: OECD (oecd.org/sti/ict/broadband). Note: based on total population; subscriptions with ≥ 256 kbit/s download speed.

first-generation broadband services were much cheaper to install than new physical access infrastructure such as fibre-optic cables. On the demand side, there is still a significant uncertainty about the willingness of consumers to pay for higher-speed broadband access. Because the regulatory approach to legacy networks has been by and large extended to the NGA networks, we expect underinvestment in the NGA infrastructure in the EU, especially in ultra-fast broadband.

4 NGA INFRASTRUCTURE REGULATION

The directives of the eCommunications framework have been supplemented by European Commission recommendations on "*regulated access to next generation access networks*" (European Commission, 2010) and "*consistent non-discrimination obligations and costing methodologies to promote competition and enhance the broadband investment environment*" (European Commission, 2013) to form the relevant EU regulatory framework for the emerging NGA infrastructure. This framework imposes rather comprehensive and strict access obligations compared to the US (Briglauer and Gugler, 2013). The Commission's approach to the regulation of NGAs can be seen as a direct extension of the eCommunications framework created for the 'first-generation' legacy networks.

The regulatory remedies dealing with access to NGA infrastructure fall into two broad categories, passive and active. The passive remedies grant access to civil engineering infrastructure – in particular ducts – which significantly lowers the costs of laying cables for entrants. To varying degrees, most EU national regulators implement the passive remedies[7]. Active remedies require the dominant operators to provide access to their physical network infrastructure. This includes wholesale 'bitstream' access to NGA infrastructure, which is much less investment intensive for potential access seekers than laying their own cables. In contrast to passive remedies, member states implement the active remedies very differently in terms of timing and scope (Briglauer *et al*, 2015). Some EU countries started to introduce regulations on wholesale access (such as Belgium, Denmark, Italy, Netherlands or Spain) and fibre unbundling (Finland and the Netherlands) already in 2011 (WIK, 2012). Some, such as Belgium and Germany, have still not decided, at time of writing, on access conditions or prices. The scope of access regulations varies widely depending on the network architecture and the competition conditions in national markets. The national regulatory authorities take also different positions on how to price NGA-specific capital costs. Some (such as Denmark, Hungary and Ireland) have followed the Commission's recommendation and have applied incremental cost-oriented access prices. Others, such as Bulgaria, Estonia and Spain, so far have not[8].

As we have discussed, access regulations can significantly hold-up investment. We expect this problem to be less acute in the case of passive remedies, especially in areas where the ducts have already been built. Active remedies, however, especially when coupled with incremental cost-based access pricing, can substantially impede fibre deployment, because of the hold-up problem.

As well as affecting total investment volumes, active remedies involved in NGA regulation can also be expected to have an impact on which companies invest and which do not. The asymmetric nature of fibre unbundling as required by the eCommunications framework, to a great extent deters investment by incumbents, most of which still hold significant market power, according to the European Commission's methodology. In fact, it appears that the incumbent operators' legacy-like market dominance is fading. For instance, as of December 2014, investment by incumbents was responsible for only 27.7 percent of EU homes passed by ultra-fast connections. Among entrants, municipalities and utilities were responsible for 4.9 percent, and alternative operators, mostly cable companies, were responsible for the largest part, 67.4 percent (FTTH Council Europe, 2015; the remaining share was accounted for by other firms such as housing companies). NGA infrastructure owned by entrants is not subject to regulated access.

Similar to the legacy-based infrastructure regulation, the Commission foresees multilevel access to the NGA infrastructure that belongs to operators holding significant market power, with

7. The exceptions are Belgium, the Czech Republic, Finland, Ireland, Malta, the Netherlands and Romania.

8. Information on the mandated NGA regimes in the EU comes from WIK (2012) and notifications submitted by EU member states under Articles 7 and 7a of the Electronic Communications Framework Directive (2002/21/EC), available at https://circabc.europa.eu/faces/jsp/extension/wai/navigation/container.jsp.

varying degrees of investment for access seekers. The ladder-of-investment approach is again considered as a guiding principle for regulating NGA infrastructure (European Commission, 2010, recital 3: *"The appropriate array of remedies imposed by a national regulatory authority should reflect a proportionate application of the ladder of investment principle"*). Considering the deployment costs, the duplication of NGA infrastructure is, however, unlikely to be more common than the duplication of legacy networks. Thus, reaching the ultimate goal of infrastructure-based competition on NGA networks (last rung of the ladder-of-investment) is unlikely[9]. Compared to legacy networks, the unbundled fibre access products are much closer to previous bitstream access products, ie at a lower point of the value chain (OECD, 2011).

Taking the ladder-of-investment perspective, national regulatory authorities should aim to induce optimal movements up both the legacy and the NGA ladders, and optimal incentives for migration between the ladders (Cave, 2010). Even if the NGA infrastructure is not regulated, the copper access charges imposed on the old infrastructure will still exert a crucial impact on the incentives for NGA investment (Bourreau *et al*, 2012). If a broad NGA roll-out is considered to be welfare enhancing, incumbents and entrants should ideally switch from investing in the 'old' infrastructure and requesting legacy-based access products, to investing up the 'new' NGA ladder. However, operators are not only confronted with the regulatory access policies imposed under the old and new ladders, but also experience uncertainty about the demand for new services that will be possible once the NGA networks are in place. Thus, the NGA investment decision is far more complex than it was for first-generation broadband on the legacy networks.

The theoretical research on migration from legacy to fibre-based infrastructure, points out that the regulation of legacy networks affects in many ways the incentives to invest in fibre infrastructures (Bourreau, Cambini and Dogan, 2012; Inderst and Peitz, 2012; and Bourreau *et al*, 2014). Moreover, the expected effects significantly differ for incumbents and new entrants. Incumbents might invest more in new infrastructure when the access price to the old network is low, and thus the opportunity cost of the investment is low. This effect might however be dampened or even reversed, if the low prices discourage customers from switching away from the legacy network. By contrast, entrants will most likely speed up the deployment of new infrastructure when access charges for copper are high. In general, NGA investments 'cannibalise' economic profits from first-generation broadband services provided via legacy infrastructure, which might thus reduce profitability and the incentive to invest in NGA infrastructure. This effect is reinforced if conventional broadband services enjoy broad consumer acceptance, which establishes non-negligible switching costs for consumers and hinders migration to the new technology, unless its incremental benefits are sufficiently large and transparent. In sum, there is no clear effect of regulated access to legacy networks on NGA investment.

A social-welfare perspective further suggests that strict regulation to ensure access to legacy networks safeguards consumers against paying higher prices for faster broadband services they might not really need. In areas where NGA networks will replace legacy networks, the legacy-like quality of service (and the related access regulation) could be sustained in order to prevent those operators that lack their own infrastructure from becoming stranded. These operators would then provide the 'old' broadband services, but over fibre. Needless to say, as legacy networks will continue to exist in parallel with NGA networks, consumers will still be able to use the 'old' broadband if they do not need higher speeds.

Interestingly, 10 out of the top 20 ranked European economies in terms of ultra-fast broadband penetration are eastern European countries (including Russia and Ukraine; FTTH Council Europe 2015). There, the lack of well-established legacy infrastructure meant there was an opportunity to directly deploy high-end network architectures at comparatively low cost (Briglauer and Gugler, 2013; Briglauer, 2014).

In line with the above analysis, the empirical research *"indicates a negative impact of ex-ante access regulations on NGA investment incentives"* (Briglauer *et al*, 2015). This corroborates the

9. According to WIK (2008), a competitive duplication of fixed access network infrastructure is at most economically feasible in very densely populated areas. But still, even in such a case, the second operator needs to have a high market share.

BOX 1: SOME CASE STUDIES

Interesting insights about the link between regulation and NGA investment can be obtained from an examination of the frontrunners in NGA deployment: those EU member states that reached 100 percent coverage in terms of fast broadband and 50 percent coverage in terms of ultra-fast broadband by 2014 (Figures 1 and 2). These are Denmark, Estonia, Latvia, Lithuania, Luxembourg, Portugal, Romania, Spain and Sweden.

A number of these countries have a GDP per capita below the EU average. Nevertheless, Estonia, Latvia and Lithuania in particular have proved very successful in deploying NGA networks. What the three Baltic States have in common is relatively low first-generation broadband penetration – Estonia, the leader in the region, is still below the OECD average (Table 1) – and the lack of strict cost-oriented fibre access obligations. The former factor is shared with other eastern European EU members. The latter is not. Hungary, Poland, Slovenia and Slovakia all introduced stricter fibre access regulations than the Baltic States and have achieved less spectacular investments in fibre. The exception is the Czech Republic, where NGA network expansion has been rather weak despite the lack of strict regulation. The examples of Bulgaria and Romania seem to corroborate this picture. Both lacked a well-developed legacy infrastructure, have abstained from strict NGA regulation and have been very successful in deploying fibre, albeit only the ultra-fast architecture in Bulgaria.

Additionally, EU funds have helped to subsidise the broadband infrastructure in the eastern member states. Partly in response to the European Commission's Digital Agenda strategy, most EU member states developed national broadband plans which usually included public funding measures. For the 2007-13 financing period, €2.3 billion in EU structural funds was allocated to meet the Digital Agenda targets for broadband roll-out. The Commission also approved under EU state aid rules about €3.4 billion of member state spending from 2003 to 2010 for high-speed broadband development projects[10] .

Among the other NGA frontrunners, the mix of weak legacy infrastructure and lax access regulation, which has proven very effective in incentivising operators to invest, also pertains in Portugal and Spain. In contrast, Greece and Ireland, which introduced incremental-cost oriented fibre unbundling, have not successfully deployed NGA infrastructure, despite weak legacy broadband penetration.

Countries with well-developed first-generation broadband infrastructure have generally found it difficult to successfully deploy NGA networks. The exceptions are Denmark, Luxembourg and Sweden. Each has introduced strict NGA obligations, which might suggest that in this group, access regulation actually spurs investment. A closer look, however, reveals a more nuanced picture. In two cases, large-scale broadband deployment has been triggered by more or less direct public subsidies. Large public investments in ultra-fast broadband played a significant role in Sweden (Yoo, 2014). In Luxembourg, P&T Luxembourg, the state-owned incumbent, is working towards the government's ambitious target of providing all citizens with a minimum of 1 Gbps downstream access by 2020 (FTTH Council Europe, 2013a).

Denmark is an interesting example because of the unusual ownership structure of the broadband providers. The incumbent telecom operator, TDC, owns most of the cable companies. This allows TDC to deploy high-speed cable broadband, access to cable being unregulated. The mandated access to fibre on the telecom networks remains unused. Instead, the entrants, mostly energy companies, invest in ultra-fast fibre infrastructure themselves (Yoo, 2014). As operators without significant market power, the entrants are not subject to the mandated unbundling. As a result, competition between cable and telecom high-speed broadband operators happens entirely outside of the regulatory framework, making Denmark similar to the US in this respect.

In sum, lax fibre access regulation seems to promote NGA deployment in countries that lack well-developed broadband infrastructure based on legacy networks. In countries that have well-developed first-generation broadband, the impact of regulation is less obvious. The business case for fibre in these countries seems, however, not obvious either. In fact, incentives for consumers to migrate from the legacy to the fibre-based broadband crucially depend on the retail price differential, 'the fibre premium'. Consumer willingness to pay for high-speed broadband services seems to be rather limited so far (DotEcon, 2012).

10. Information on the national broadband plans of EU member states is available at: http://ec.europa.eu/digital-agenda/en/high-speed-broadband. See also the European Commission's press release of 20 January 2011: http://europa.eu/rapid/press-release_IP-11-54_en.htm.

results of the literature that studies first-generation broadband, surveyed in Cambini and Jiang (2009), which finds similar albeit less-pronounced empirical evidence. There is, however, no empirical research that specifically considers the joint presence of copper-based-access and NGA regulations and their joint impact on investment incentives.

5 DISCUSSION OF THE KEY POLICY ISSUES FOR NGA DEPLOYMENT

The experience with first-generation broadband deployment in Europe shows that, in general, lowering market prices through mandated access fosters the take-up of broadband services, but might hinder investment in infrastructure. Against this backdrop, the unbundling of legacy networks in Europe has worked rather well. In particular, the penetration rates compare favourably to the leading economies worldwide. Furthermore, the unrealised infrastructure investment, which is the downside of access regulation, might not necessarily have been bad for economic welfare, especially if the investment would have merely led to duplication of the existing access network infrastructure. The European experience shows, however, that access policies suppress fully-fledged facilities competition and, as a result, tend to be permanent rather than transitory. This is also likely to be true for NGA networks and should be acknowledged as an important constraint of mandated fibre access.

Will the qualified success of regulated access be replicated in the future? Our analysis shows that this is doubtful. For NGA networks, the underlying differences between the economics of the 'old' and the 'new' broadband infrastructures are likely to aggravate the negative impact of access regulation on investment. Investment in NGA networks is more likely to suffer from the hold-up problem, because laying the fibre-optic elements of the local loops needed for ultra-fast broadband is much more expensive than the upgrades needed for the 'old' broadband. As a result, under the current regulatory regime we expect continuing underinvestment in NGA infrastructure and therefore underachievement of Digital Agenda goals, especially for the more costly ultra-fast broadband infrastructure.

Although we have focused on sector-specific access regulations, NGA deployment is also influenced by other public policies. Most notably, public funding programmes, housing regulations[11] and regulations on net neutrality will have a strong influence on the development of market-based business models and firm profitability and hence on NGA investment. Public subsidies (direct or indirect) for NGA infrastructure are an effective way of stimulating investment, as the examples of Japan and Luxembourg show most clearly[12]. EU structural funds provided to the eastern European countries might have also played an important role. More generally, subsidies appear essential in areas where private investment is not profitable but NGA roll-out might still be desirable in view of externalities or equity motives. Other forms of subsidy, such as publicly-sponsored eHealth programmes might also give a push to the deployment of fast broadband infrastructure. Net neutrality regulations might render infrastructure investment more profitable if network operators are given more leeway to provide high-quality access to content providers at premium prices.

Our basic assumption is that wide NGA roll-out will be welfare enhancing for Europe because of the potential positive externalities, which are likely to increase over years and decades. This leads us to formulate three recommendations to the regulators.

First, while a nationwide NGA roll-out might be efficient and justified by equity concerns, we recommend de-emphasising fully-fledged facilities-based competition as the ultimate goal of the eCommunications framework. Large-scale facilities based competition has proved unrealistic in most member states and, in fact, not consistent with the economics of mandated fixed-broadband access. Instead, regulators should acknowledge that access regulation is likely to persist for the foreseeable future and should commit to a clear methodology for calculating access prices. The focus of the regulation should shift towards efficient investment, meaning provision of a single infrastructure needed for ultra-fast broadband, especially in areas where the natural market structure is a monopoly. Note that efficient investment might also include mobile broadband to a greater extent in the mid

11. Korea is an example of smart housing regulations boosting investment in fibre. See OECD (2013).

12. The detailed discussion of how informal subsidies boosted large-scale NGA deployment in Japan can be found in Ota (2009).

and long term, particularly in areas where no wired NGA infrastructure exists.

Second, the eCommunications framework should provide *additional* incentives to invest in ultra-fast broadband infrastructure. This could for instance be achieved by relaxing cost-oriented pricing of fibre access for a limited period. At this end of this period, consumers would further benefit from service-based competition enabled by a cost-oriented access policy. Co-investment models might also provide a relevant alternative to prevent infrastructure duplication. We concur with Vogelsang (2013), who argued that incentivising efficient NGA investment requires a shift in the regulatory frontier towards softer regulation, including symmetric regulations that enhance co-investment models.

Third, we recommend taking a more holistic and evidence-based approach to access regulation. As we have shown, there is a range of alternative public policies that might spur investment in access networks. These policies should be given serious consideration. Also, the regulation of access to the legacy copper networks can be expected to have significant effects on NGA deployment. The migration from copper to fibre thus involves an intertwined set of incentives on the demand and the supply sides. It is not clear whether sustaining incremental-cost-oriented access to the legacy networks helps the NGA roll-out. One important reason, however, to maintain the current regulation of the legacy networks, is to safeguard consumers against paying higher prices for ultra-fast broadband services they do not really need. Overall, more evidence is needed as a basis for sound policy advice in this domain.

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TECHNICAL ANNEX: BROADBAND ARCHITECTURES

Historically, fixed-line legacy networks based on copper-wire infrastructure were built to support narrow-band voice telephony services only. Later, these legacy networks were upgraded with so-called xDSL technologies to deliver first-generation broadband services[13]. However, the performance of xDSL technologies based on copper infrastructure, and of coaxial cable data transmission technologies (ie for cable television, CATV), is strongly limited by the remaining local access loop's length. Hence, for xDSL to yield higher bandwidth levels, fibre-optic cables have to be deployed closer to the customer premises in the access networks.

Depending on the fibre reach, different NGA architectures are distinguished. One refers to FTTC (fibre to the cabinet or curb, sometimes also referred to as fibre to the node, FTTN) when the modern very-high-bit-rate digital subscriber line (VDSL) technologies, such as VDSL2 and VDSL2 vectoring, are run on a hybrid network (ie fibre-based network, which extends to street cabinets, and copper lines, which typically extend about 500 metres from street cabinet to the customers' premises). Fibre to the distribution point (FTTDp) supported by VDSL/G.fast stands for another recent hybrid copper-fibre transmission technology. FTTDp is very similar to FTTC/N but is one-step closer to the customer with the copper 'last mile' of normally less than 200 metres. VDSL-based hybrid solutions can provide bandwidths of between 20 Mbps and several hundred Mbps. Fibre to the building (FTTB) requires the fibre-optic cables close to or inside a building, eg in the basement of a multi-dwelling unit. In this architecture, the only copper-based connections remain between the customers' premises and the building's switch. FTTB yields bandwidths between 100 Mbps and up to 1Gbps. When technical or economic considerations render it feasible to completely eliminate copper lines, then each subscriber can be connected by a dedicated fibre access line, an architecture referred to as fibre to the home (FTTH). FTTH infrastructure is said to be 'future proof', because data transmission speed is limited by the terminal equipment rather than the fibre infrastructure. The resulting bandwidth capacity is almost unlimited in view of current applications. Finally, FTTP (fibre to the premises) is used as a blanket term for the high-end FTTB/H architectures (Briglauer, 2014; FTTH Council Europe, 2014 ; Wikipedia, 'Fibre to the x').

Besides the FTTC/N/Dp/B/H architectures, NGA networks might also be realised by upgrading CATV networks. This architecture is called fibre-to-the-last-amplifier (FTTLA) and means high-speed access enabled by the DOCSIS 3.0 technology on hybrid fibre-coaxial cables[14]. In principle, this cable transmission architecture is able to provide bandwidths between 100 and 200 Mbps. As customers share cable coax infrastructure, however, they might be confronted with a substantial reduction in bandwidth at peak times. In addition, CATV networks are optimised asymmetrically for downstream usage and thus upstream capacity is more limited than in the fibre and hybrid technologies (FTTH Council Europe, 2013b). The newer version of DOCSIS, the 3.1 version, can theoretically provide speeds up to 10 Gbps.

Mobile broadband services are also feasible. In particular, the long-term evolution (LTE) technologies offer data transmission rates in ranges comparable to fixed-line hybrid-fibre NGA architectures. Mobile broadband represents a shared resource, however, because the access quality parameters depend heavily on the number of concurrent users at a given location. Available bandwidth for the individual mobile broadband user also crucially depends on the distance to the cell tower. For these reasons, we consider LTE to be a viable outside alternative to fixed wire NGA broadband but not a close substitute for most consumer segments, at least not in the medium term. Because of the different geographical coverage and forms of usage some studies have even found LTE to be complementary to NGA broadband[15].

13. xDSL is a generic term used for the Digital Subscriber Line technologies, which provide internet access by transmitting digital data over telephone lines. Asymmetric Digital Subscriber Line (ADSL) represents the most commonly installed first-generation xDSL technology, which can offer bandwidth up to 20 Mbps. A more modern example is VDSL, which stands for Very-high-bit-rate Digital Subscriber Line

14. DOCSIS stands for Data Over Cable Service Interface Specification.

15. Using a detailed dataset of subscribers to a single mobile operator from a single town in a European country which has full coverage with LTE and fixed (ADSL and FTTH) broadband technologies, Grzybowski and Liang (2015) find evidence that mobile broadband is complementary to fixed broadband access for quadruple play subscribers. Similar results have been found in Srinuan *et al* (2012) using a survey database of 4,000 individuals collected by the Swedish government.