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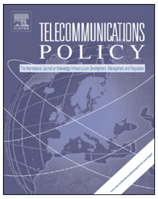

The deployment and penetration of high-speed fiber networks and services: Why are EU member states lagging behind?

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ABSTRACT

One of the most controversial regulatory issues in Europe (and elsewhere) is whether the emerging next-generation access (NGA) infrastructure should be subjected to cost-based access regulation or whether at least a temporary removal of ex ante obligations ("regulatory holidays") should be granted. Likewise, the role of NGA-specific state aid policies is increasingly capturing the attention of policy makers and the academic literature.

In answering the questions raised above, we examine the previous and foreseeable EU regulatory framework and show that currently it does not provide sufficient incentives for NGA deployment and hence for increased penetration of NGA services. On the basis of an international comparison and by means of a diffusion analysis with recent NGA data, we argue that deregulatory and/or state-aid-driven approaches targeted at the demand (subscribers) and supply side (coverage) are more promising.

1. Introduction

Fiber deployment of telecommunications networks is currently a great challenge for sector-specific regulators and national governments, as well as for investing operators. The central importance of ultra-high-speed broadband infrastructure as a key socio-economic factor in any information society is broadly accepted. However, investment in fiber-based ("next-generation access", NGA) network infrastructure and the penetration of high-speed broadband services vary significantly in international comparison.

Whereas many of the leading Asian countries are taking a state-aid-driven approach, the United States (US) has adopted a deregulatory and primarily market-driven strategy. The European Union (EU), in contrast, relies on competitive market forces subject to a set of strict sector-specific regulations (Huigen & Cave, 2008). One of the most controversial regulatory disputes in Europe (and elsewhere) is whether the emerging NGA infrastructure should be subjected to cost-based access regulation or more light-handed forms of ex ante regulation, or whether at least a temporary removal of ex ante obligations ("regulatory holidays") should be granted. A further main point of discussion is the role of national and local governments in promoting the necessary funding of NGA business models.[1]

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[1] The subject area is even more extensive, as a systematic fiber-based roll-out is no longer just a matter of traditional telecommunications operators. Rather, public utilities from other network industries, such as energy and transport, might have opportunities and incentives to expand their product portfolio.

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Our paper addresses the following research question: can different patterns in NGA deployment and penetration be systematically related to different sector-specific and governmental policies? In view of the theoretical contributions on the trade-off between static and dynamic efficiency, as well as the vast majority of the empirical literature, we first show that the current EU regulatory framework of a rather strict regime of cost-based access pricing is likely to lower both NGA infrastructure investment in terms of coverage ("homes passed") and, as a consequence, penetration levels in terms of subscriptions ("homes connected"). Clearly, our basic underlying premise is that high network coverage represents the main pre-condition for high penetration of NGA services. Second, given the extremely high investment requirements and risks of NGA roll-outs, it is a priori unlikely that broad-scale investment activities will be induced by competition alone. For non-profitable ("white") areas, in particular, public funding will be the only driver of NGA deployment (via supply-side subsidies) as well as of penetration (indirectly or via direct demand stimuli). It is important to note here that our main purpose is not to identify the determinants of NGA deployment and penetration but to examine the differential impact of alternative NGA policy strategies.

In order to examine our research question, we use the following methodological approach: first, we assess the EU regulatory framework for electronic communications markets regarding the incentives to invest in new communications infrastructure and discuss the economic rationales of subsidizing NGA projects. As a result of this qualitative analysis, we derive hypotheses that are, secondly, examined by means of a twofold empirical analysis. In the first step, we compare the EU framework with the regulatory and state aid policies in non-EU27 countries and with the respective NGA deployment and penetration patterns. In the second step, we run non-linear diffusion regressions in order to examine the different diffusion stages of the NGA country clusters identified in the previous step. The empirical analysis employs recent biennial data for the time range from 2001 to 2011.

Whereas the qualitative analysis does not consistently focus on a specific NGA scenario, the empirical analysis utilizes a narrow definition of NGA deployment and penetration throughout which it exclusively refers to the fiber-to-the-home and fiber-to-the-building (FTTH/B) scenarios. We argue that focusing on a narrow NGA definition makes good sense, because it helps to make the role of regulation and state aid policies more explicit, as in the case of FTTH/B roll-outs the investment requirements and risks are the highest.[2]

The remainder of the paper is organized as follows. We review the telecommunications-related empirical literature in Section 2. Section 3 describes our basic hypotheses on investment and regulation as well as on the economic relevance of public subsidies to NGA deployment and penetration. Section 4 outlines the data and definitions underlying our empirical examination. Section 5 contains the empirical analysis and interprets the main results of the international comparison and the diffusion analysis. Section 6 summarizes and concludes with some qualifying remarks.

2. Literature review

Early empirical studies related to the impact of regulation on investment concentrate mostly on the US experience, suggesting that regulated cost-based access charges reduce the investment incentives for incumbents and for alternative operators (e.g. Chang, Koski, & Majumdar, 2003; Crandall, Ingraham, & Singer, 2004; Ingraham & Sidak, 2003). Cambini and Jiang (2009) survey the empirical literature related to investment in telecoms infrastructures and find also that the majority of the studies conclude that service-based competition in terms of cost-based access regulation diminishes both incumbents and alternative operators incentives to invest. More recent work with data for European countries exhibits similar results: Grajek and Röller (2011) investigate the relationship between regulation and total investment in the telecommunications industry. Investment is quantified therein rather broadly by the tangible fixed assets of telecommunications operators and, thus, does not explicitly refer to broadband or NGA deployment. Wallsten and Hausladen (2009) are the first to estimate the effects of broadband access regulation on NGA investment with data from the EU member states for the years from 2002 to 2007. They find that countries where unbundling is more effective experience lower NGA deployment, but their data only cover the NGA roll-out at the very early stage. Briglauer et al. (in press) investigate the determinants of NGA investment with a direct measure of more recent NGA investment activities for the years from 2005 to 2011. They find that the more effective wholesale broadband access regulation and hence service-based competition is, the more negative is the impact on NGA deployment. Competitive pressure from cable and mobile networks affects NGA deployment in a non-linear manner.

Regarding the empirical literature on the impact of regulation on penetration, there are quite a few contributions related to broadband markets: early US-related work (Burnstein & Aron, 2003) shows that infrastructure-based competition has a positive impact on broadband diffusion in the longer term, whereas regulatory-induced service-based competition has a positive impact only in the initial market phase. Wallsten (2005) finds that only a few regulatory policies have any significant impact on broadband penetration. Using OECD country-level data for the years from 1999 to 2003, Wallsten (2006) finds a negative effect of subloop unbundling, whereas full local loop unbundling has no significant effect. Boyle et al. (2008) examine the impact of local loop unbundling on broadband penetration using yearly OECD data from 2002 to 2005. The authors find that the contribution of local loop unbundling at the level of national broadband uptake is statistically insignificant. Lee, Marcu, and Lee (2011), who analyze the determinants of broadband diffusion for the years from 2000 to

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[2] Because the length of FTTH/B lines is longer compared with other NGA technologies and thus they service a smaller customer base in the last section, the average costs of FTTH/B implementation scenarios are disproportionately higher (WIK Consult, 2008).

2008, find a positive effect of unbundling obligations on the speed of diffusion. The authors admit, however, that OECD countries are highly heterogeneous as regards regulatory unbundling regimes. Crandall, Jeffrey, and Ingraham (2013) is a recent OECD based study that utilizes data over a ten-year period (2001–2010). The authors find that unbundling obligations have almost no significant impact on broadband penetration in the short run but a significantly negative impact on penetration in the long run. Furthermore, the authors argue that extending unbundling obligations to fiber infrastructure increases the risk of regulatory errors substantially. Some contributions also refer to data from European countries: Höffler (2007) examines data for Western European countries for the years from 2000 to 2004. The author concludes that broadband deployment was predominantly triggered by infrastructure-based competition, with service-based competition relying on regulated DSL services playing a secondary role. However, infrastructure duplication might lead to welfare losses. Briglauer (2013) is the first to examine the determinants of NGA penetration with EU27 data for the years from 2004 to 2012. The author finds that stricter previous broadband access regulation has a negative impact on NGA penetration, while competitive pressure from mobile networks affects NGA penetration in a non-linear manner. Finally, the reader is referred to Berkman Center (2010, pp. 96–121) for more comprehensive review of quantitative studies that focus on the impact of broadband regulations on both investment and penetration.

3. Hypotheses

This section sets out our hypotheses, which are first derived in Section 3.1 from an analysis of the impact of the EU regulatory framework on the incentives to invest in broadband and NGA infrastructure. Section 3.2 then outlines the specific risks and describes the main economic rationales for subsidizing NGA deployment.

3.1. *Regulation and NGA deployment*

The recommendation of the European Commission (EC) on regulated access to next-generation access networks,[3] in conjunction with its recent consultation on the future regulation of NGA infrastructure,[4] forms the starting point of our discussion. Whereas the EC's “Digital Agenda” defines basic targets regarding the deployment and penetration of high-speed broadband connections and services,[5] the NGA recommendation describes in more detail how efficient investment in new infrastructure can be enhanced subject to the high risks incurred by operators and the regulatory concerns with maintaining effective competition. The consultation document takes a step further in discussing the main principles of cost-based access pricing, which national regulatory authorities (“NRAs”) should implement in order to create positive investment incentives. After describing the basic EU framework in Section 3.1.1, Section 3.1.2 provides a critical assessment.

3.1.1. *The EU regulatory approach*

In the EU, regulated wholesale broadband access prices are usually based on diverse cost-oriented standards that have been established since the very beginning of the liberalization process in communications markets in 1997/1998. Tight cost-based regulation of existing broadband access products has most likely already created corresponding expectations about the future regulation of NGA access products. Indeed, some European countries started to introduce such regulations on wholesale broadband access over NGA (such as Belgium, Denmark, Italy, the Netherlands or Spain), on fiber unbundling (Finland and the Netherlands), or on NGA-specific capital costs (the Netherlands) in 2010 (Cullen International, 2011, Tables 4, 9, 10).[6] The EC's recommendation, in conjunction with its consultation document on costing methodologies (p. 9), expresses clearly that there will be an ongoing need for ex ante regulation of the emerging NGA infrastructure (European Commission, 2010a, recitals 18, 32, art. 14, 20, 25, 30, 35).[7] Full deregulation of fiber access or temporary removal of ex-ante obligations (“regulatory holidays”) as fundamental alternatives[8] are not provided for in the NGA recommendation but

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[3] European Commission (2010a), hereinafter referred to as the “(NGA) recommendation”. Although a recommendation is not legally binding on member states, it has to be considered as “the utmost account” in regulatory decision-making processes. Moreover, the “Telecoms Package” amended in 2009 provided the EC with additional influence and power vis-à-vis national regulators.

[4] Consultation document on “costing methodologies for key wholesale access prices in electronic communications” (hereinafter referred to as the “(NGA) consultation document”) and results retrieved from http://ec.europa.eu/information_society/policy/ecomm/library/public_consult/cost_accounting/index_en.htm.

[5] The Digital Agenda “seeks to ensure that, by 2020, (i) all Europeans have access to much higher internet speeds of above 30 Mbps and (ii) 50% or more of European households subscribe to internet connections above 100 Mbps” (European Commission, 2010b, p. 19). Both the NGA recommendation, which predominantly uses the acronym FTTH, and the diffusion target of the Digital Agenda (ii) indicate a tentative preference for high-speed FTTH/B implementation scenarios.

[6] See also the NGA progress report of WIK Consult (2012) for a recent overview of NGA-related remedies imposed in the EU member states.

[7] See also Ruhle and Lundborg (2010), who examine the draft version of the NGA recommendation and show that the EC is determined to continue and evolutionarily develop the regulatory framework.

[8] Deregulatory tools could also entail the complete withdrawal of some or all of the wholesale access obligations at a predetermined date (Cave, 2006). Such “sunset clauses” provide the ultimate incentives to build one's own infrastructure but might be subject to the regulatory commitment problem. Indeed, the lack of credibility of sunset clauses was experienced in the Netherlands and in Canada (Bourreau, Dogan, & Manant, 2010, pp. 690–691).

restricted to some exceptional circumstances only.[9] In the EC's view, the superiority of a consistent[10] cost-orientated access regulation has been proven to guarantee (i) to stimulate effective competition via service-based downstream competition, (ii) ultimately to generate higher consumer welfare, and (iii) to bring about appropriate investment signals (p. 2 of the consultation document). However, the EC acknowledges the considerable risks of NGA investment and recommends that higher risk should be reflected in the cost of capital of the regulated operator (European Commission, 2010a, recitals 18, 23, art. 25).

More fundamentally, the EU regulatory framework aimed at balancing retail competition with wholesale access regulation in compliance with the "ladder of investment" approach (Cave, 2003, 2006; Cave & Vogelsang, 2003).[11] The latter is also seen as a guiding principle for the future regulation of NGA networks (European Commission, 2010a, recital 3). On p. 4, the consultation document states that access pricing should be designed to "safeguard the investment ladder principle" and to guarantee consistent regulation across wholesale access products. According to this hypothesis, regulatory-induced service-based competition serves as a stepping stone for entrant operators to engage progressively in backward integration, which ultimately results in infrastructure-based competition (top of the ladder). In order to climb up the ladder, service-based competition is seen as an indispensable prerequisite for infrastructure-based competition, which manages without any ex-ante regulatory intervention. Thus, the ladder of investment hypothesis rests on two propositions (Cave, 2010, p. 84): infrastructure-based competition is preferred when it is reasonably achievable and NRAs can implement suitable regulatory instruments to achieve that goal.

In order to foster the switch from the "old" copper ladder to the "new" NGA ladder, the consultation document (p. 10) suggests fostering NGA investment by gradually eliminating rents from the old (legacy) network infrastructure if migration to the new network infrastructure is deemed to be insufficient in view of the targets of the EC's Digital Agenda. Obviously, such a policy aims to eliminate the so-called replacement effect (Arrow, 1962). The replacement effect would occur if NGA investments were to "cannibalize" the economic profits from the preceding broadband (xDSL) services provided via the legacy infrastructure, which would ceteris paribus reduce profitability and the incentive to invest in new infrastructure. As can be inferred from Table A.1 in the Appendix, the replacement effect can, indeed, be expected to be crucial in view of an average European (EU27) household fixed broadband penetration rate of ~62.8% in 2011.

3.1.2. Assessment of the EU regulatory approach

In its recommendation, the EC stipulates that cost-based regulation of NGA wholesale access products will remain relevant in the future. The key argument in favor of such a policy refers to the necessity to impose a time-consistent access regulation, which would have proved to be a beneficial and effective approach over many years from the point of view of the EC. Alternative pricing regimes targeted at increasing pricing flexibility[12] are not mentioned in the consultation document, and deregulatory approaches have clearly been dismissed, having already been announced in previous publications (e.g. European Commission, 2007).

According to the simulation calculations in Nitsche and Wiethaus (2011), a regime of fully distributed costs or regulatory holidays would have the most positive effects on NGA investment, whereas access charges set on a more strict long-run incremental cost basis turn out to be inferior. Indeed, for the following reasons, the established strict cost-based access regulation can be expected to reduce the investment activities of infrastructure operators: (i) cost-oriented wholesale access charges curtail the upside profits of the regulated firm, which results in an asymmetric distribution of the expected profits and, therefore, in a lower net present value of investment projects (Valetti, 2003). Moreover, regulated infrastructure operators criticize access regulation (ii) for typically ignoring the opportunity costs of real options (Guthrie, 2006). Indeed, the option value of delaying ex ante investment decisions subject to high sunk costs and market and regulatory uncertainty ("wait and see") might be quite substantial. In turn, (iii) service-based operators receive risk-free access at the same time without facing significant sunk costs due to the regulatory obligations imposed on the incumbent operator, who is exposed to the full downside risk (Pindyck, 2007). Finally, (iv) within the EU regulatory framework, risks were measured within the scope of the firm's capital costs related to legacy networks and deemed not to differ greatly from the overall company risk (Cullen International, 2010, Tables 10, 15, 16). Although the NGA recommendation accounts for risk, in principle, this approach does not provide sufficient investment signals in the case of low retail demand, since in this case even a rather high risk premium at the wholesale level cannot compensate the operator for the financial losses.[13] Further risk adjustments above the standard measures of cost of capital would be necessary in order to account for the option value of "wait and see strategies" (DotEcon, 2012, p. 25). Moreover, other ways to incorporate NGA-specific risks might be more favorable.

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[9] "In exceptional circumstances, NRAs could refrain from imposing unbundled access to the fiber loop in geographic areas where the presence of several alternative infrastructures, such as FTTH networks and/or cable, in combination with competitive access offers on the basis of unbundling, is likely to result in effective competition on the downstream level" (European Commission, 2010a, recital 20).

[10] From the EC's viewpoint, consistency must be understood over time and within member states (European Commission, 2010a, recitals 3, 6, art. 6).

[11] The initial ideas developed by Cave and Vogelsang (2003) were incorporated into a report for the EC (Cave, 2003) and were then elaborated in more detail in Cave (2006).

[12] NRAs might for instance also consider retail-minus, combinatorial regulatory approaches (e.g. Briglauer & Vogelsang, 2011), co-operation models, or more light-handed cost-oriented approaches (e.g. fully distributed costs instead of long-run incremental cost standards) as relevant alternatives.

[13] Granting NGA-specific risk premia might also be subject to a regulatory commitment problem, since regulators have an incentive to set access prices close to the marginal cost after the investment is made (Brito, Pereira, & Vareda, 2011, p. 821). Unless NRAs can commit credibly to the announced policies in advance, the investment incentives will be lower.

Nitsche and Wiethaus (2011) show that a risk-sharing approach is best from a welfare point of view. Ideally, such an approach diversifies risks between access seekers and infrastructure operators, or NRAs might also enable joint investment projects.

The requirement of a consistent approach for regulating the NGA infrastructure across EU member states must be questioned as well. Consistency per se is neither necessary nor sufficient for economic efficiency or maximizing welfare in view of country-specific differences, such as different deployment costs, building law requirements, rights of way, regulations on and availability of ducts or the number of greenfield constructions, demographic and topographical differences (in particular, population density and housing structure in terms of the proportion of multiple dwelling units), or differences in labor costs (in particular, civil engineering).[14] Similarly, there might be systematic differences as regards the demand for NGA services. One might think of country specifics concerning the affinity with ICT and the diffusion of consumer electronics, cultural differences, the proportion of "digital natives", or household income as proxies for the local appetite for high-bandwidth broadband services. Also, there is no clear evidence that differences in NGA wholesale access prices induce negative cross-border effects and thus lower welfare among member states.

Overall, the above arguments suggest that the requirement to impose a consistent and cost-oriented access pricing methodology will be detrimental to investment in new infrastructure where no legacy monopoly-like structure exists. Traditional incumbent operators typically own some strategic assets and may benefit from certain cost advantages in upgrading legacy networks. However, migration towards an FTTH/B infrastructure will basically constitute "symmetric markets" with new market players (Bourreau et al., 2010, p. 693), which questions the conception of asymmetric ex ante regulation, especially if the new infrastructure is not yet in place. The basic economic rationale for unbundling first generation infrastructure – the pre-existence of non-replicable network facilities – is simply much less compelling in view of emerging NGA infrastructure which is subject to much higher infrastructure-based competition (Crandall et al, 2013, p. 271).

With respect to the well-established fixed legacy infrastructure, the EC intends to neutralize the replacement effect, which, however, would not only bring about the destruction of assets of copper, which still has – although largely depreciated – a positive economic value, especially in light of the potential of "second-life" technologies (VDSL/FTTC, vectoring VDSL with bandwidth up to 100 Mbit/s or above). Moreover, such policy ignores other effects at the wholesale and retail levels that influence the transition to FTTH/B networks: (i) lowering access charges for copper infrastructure will most likely enforce expectations of strict and heavy-handed regulation of future NGA wholesale products, which will mitigate or at least postpone the incentives to invest in NGA infrastructure. Although the net impact of copper access charges on the incumbent's incentive to migrate is not undisputed,[15] the above reasoning in items (i)–(iv) suggests that the lower the access charges are, the lower is the migration towards high-speed broadband networks. In addition, (ii) lower access charges increase the opportunity cost to invest for service-based entrants, which reduces their incentives to bypass the existing infrastructure. Furthermore, (iii) lower access charges for copper will also be translated into lower retail prices given the competitiveness of broadband markets, which, in turn, will have an effect on the prices of substitute FTTH/B products. Lowering the copper prices will therefore impair the business case and incentives to invest in FTTH/B networks. This holds especially in the case in which consumers do not yet show sufficient demand for ultra-fast broadband applications or are largely satisfied with their existing broadband services. Whether "fiber premium" consumers are willing to pay for FTTH/B services depends on the perceived product differentiation and the degree of substitution. The current evidence suggests that there is only limited willingness to pay for high-speed broadband services.[16]

Finally, the ladder of investment approach can be criticized as well, as it requires NRAs to micromanage the industry, which is immediately related to the standard problems of asymmetric information.[17] Also, empirically, there has been hardly any convincing support for the successful implementation of the ladder of investment concept so far.[18] The dynamic concept of transition from service-based towards infrastructure-based competition becomes even more unlikely against the backdrop of NGA deployment, as the economic replicability will be even lower in view of NGA-network topologies ("economies of density"), which applies in particular to FTTH/B roll-outs.[19] As a consequence, the ladder of investment for new wholesale access products tends to be reduced to a few rungs for service-based operators. Indeed, recent regulatory decisions[20] suggest that service-based providers rather have to take a step back down on the NGA ladder (OECD, 2011, pp. 23–24).

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[14] For instance, Finnie (2012, p. 18) points out the enormous differences in construction costs across Europe, which vary "from €150 per household in Russia's FTTB builds, to as much as €1.500 per household in some Danish builds".

[15] According to WIK Consult (2011), for instance, lower copper access charges will induce higher FTTH/B migration as the decision to invest is mainly driven by the difference between copper and fiber access charges.

[16] The reader is referred to the empirical studies cited in DotEcon (2012, pp. 51–55).

[17] See Crandall et al. (2013, p. 264) who critically discuss (i) design, (ii) pricing, (iii) enforcement and (iv) adaption as the most challenging tasks of regulatory regimes.

[18] See Bouckaert, van Dijk, and Verboven (2010), as well as Bourreau et al. (2010, pp. 689–690), who review the empirical evidence on the ladder of investment. Bacache, Bourreau, and Gaudin (2012) test the ladder of investment hypothesis econometrically and find that there is no support with respect to the last rung and only weak support for the transition from bitstream to unbundling lines.

[19] According to the extensive study by WIK Consult (2008), a competitive duplication of fixed access network infrastructure is at its most economically feasible in very densely populated areas. Still, even in such a case, the second operator needs to have a high market share.

[20] For example, the well-known wholesale fiber-access product of the British regulator ("virtual unbundled local access", VULA) is, with respect to the degree of product differentiation and technical control, much closer to previous bit-stream access products than to access based on local loop unbundling.

Summarizing, the assessment in Section 3.1.2 is broadly in line with the majority of the empirical literature reviewed in Section 2, as it appears that the EU regulatory framework of asymmetric cost-based access regulation does not provide sufficient incentives for NGA infrastructure investment. The direct impact of strict cost-based access regulation on infrastructure-based operators is likely to be negative and we also do not expect a positive indirect impact of access regulation on NGA deployment as stipulated by the ladder of investment hypothesis. To the extent that NGA coverage and penetration are highly correlated, we subsequently also expect a negative impact on NGA penetration.

3.2. *Economic rationales for subsidizing NGA networks*

Compared with duct costs and fiberglass, digging costs are of major importance and are largely and literally sunk in nature (ERG, 2007, pp. 16–17). Whereas incumbent operators owning legacy networks are confronted with a largely depreciated infrastructure, the costs of second-generation networks are not sunk before the investment decision is actually made. However, foreseen sunk costs might delay any ex-ante investments or even make them unprofitable (Cave & Martin, 2010, p. 1). Next to the risks associated with the intrinsic sunk cost nature of NGA investment, potential investors also have to consider the following risks: long amortization periods of network infrastructure, the economic risk of unknown demand for new services, and, last but not least, regulatory risks to which investors might be subject, since the actual design of ex ante obligations to be levied upon NGA network operators is still to be defined or implemented in many countries and might also be subject to the regulatory commitment problem, once NGA regulation is implemented.[21]

In view of the high risks and investment requirements of NGA projects, and FTTH/B deployment in particular, the total willingness to pay for high-speed broadband services might simply be insufficient to make NGA (FTTH/B) investment profitable. The FTTH Council Europe (2012a) calculates the total subsidy requirements for non-competitive EU27 areas to be in the region of €73 billion.[22] However, this does not automatically imply that NGA investment is socially undesirable. In the case that the societal benefits of NGA deployment are not fully reflected in the willingness to pay of customers, this might give rise to market failure, which justifies public intervention.[23] Most notably, NGA infrastructure roll-outs are expected to induce positive external effects related to major economic sectors. According to the OECD (2009), spillover effects in the form of cumulated cost savings of between 0.5% and 1.5% in health care, electrical power, transport, and education over 10 years would on average justify high-cost national FTTH deployments. The positive impact on efficiency and productivity is due to the fact that broadband networks constitute complementary investments and a necessary transaction platform for most other infrastructure technologies (DotEcon, 2012, pp. 66–67). Indeed, recent empirical research confirms that there is a positive linkage between (high-speed) broadband Internet deployment/penetration on the one hand and employment, economic growth, and productivity on the other hand,[24] which is reminiscent of the huge infrastructure projects of the past in transport and electricity (DotEcon, 2012, p. 13). Finally, NGA-related subsidies might be justified in view of equity motives, inasmuch as policy makers want to guarantee universal service of high-speed Internet connections and consider a “digital divide” to be undesirable.

To summarize, substantial and positive externalities accruing in major sectors of the economy represent a strong economic argument for public subsidies. Hence, we expect that governments actively push funding programmes targeted, in particular, at covering unprofitable (“white”) areas and providing high-speed/high-cost NGA connections.

4. Data and definitions

The database of the FTTH Council Europe, which includes biannual numbers of deployed NGA lines (“homes passed”) as well as of NGA subscribers (“homes connected”) for European countries for the period from 2004 to 2011, serves as our main source.[25] For non-European countries, we use data from the FTTH Council Europe's sister organizations for the period from 2001 to 2011. In addition, we complete the series with data from the “progress reports” of the EU[26] as well as a few other individual sources. Finally, we use the “International Telecommunications Union (ITU)” database for the number of households (*HH*) per country in order to normalize all the NGA figures of interest.[27]

NGA deployment in terms of real investment in physical units is represented by the number of homes passed by FTTH/B per household, *FTTHB_cov*. Homes passed refers to the number of households that have access via FTTH/B but need not necessarily have a corresponding retail contract and therefore differs from the actual number of homes connected, which is the number of households using at least one of the FTTH/B services under a commercial retail contract. Again, the number of

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[21] A more general discussion of NGA-specific risks can be found in ERG (2009).

[22] According to the estimates of the European Investment Bank, meeting the targets of the Digital Agenda requires total investment of between €143 billion and €221 billion, depending on the quality characteristics of NGA connections (DotEcon, 2012, p. 12). According to the estimates of the FTTH Council Europe (2012a), a completely newly built FTTH network within the EU27 states will result in total deployment costs of €202 billion.

[23] Also, consumers choices might be based on incomplete or incorrect information about the true value of high-speed broadband services and thus lack the experience in quality differences. The latter might also be adversely affected by advertisements that promise unrealistic quality levels of current FTTC or cable connections (DotEcon, 2012, pp. 59-60).

[24] See inter alia Crandall, Lehr, and Litan (2007), Czernich, Falck, Kretschmer, and Wößmann (2011), Garbacz and Thompson (2007), or Koutroumpis (2009).

[25] *Source*: 〈http://www.ftthcouncil.eu/resources?category_id=6〉.

[26] *Source*: 〈http://ec.europa.eu/information_society/policy/ecomm/library/index_en.htm〉.

[27] *Source*: 〈http://www.itu.int/ITU-D/ict/publications/world/world.html〉.

Table 1
Variable definitions and sources.

Variable	Description	Source
FTTHB	Number of households connected to FTTH/B lines	Main sources: FTTH Council Europe, FTTH Council North America, FTTH Council Asia Pacific
FTTHB_pen[a]	Number of households connected to FTTH/B lines normalized to total households	Complementary sources: EU Progress report for Latvia, Lithuania, Slovenia, Slovakia (2004–2006) ITU for South Korea (2001–2007) Ministry of International Affairs and Communications (http://www.soumu.go.jp/english/) for Japan (2001–2005) RVA LLC (2010) for the US (2001–2007)
FTTHB_cov	Number of households passed by FTTH/B lines normalized to total households	FTTH Council Europe, FTTH Council North America, RVA LLC (2010), FTTH Council Asia Pacific
HH	Number of households per country	ITU World Telecommunication/ICT Indicators Database
date	The number of elapsed half years since 1 January 1960	Stata's internal numeric date

[a] 12.5% and 20% of the raw data had to be created by using our own estimations and linear interpolation for European and non-European countries, respectively.

Table 2
Descriptive statistics.

Variable	Obs.	Mean	Std Dev.	Min.	Max.
FTTHB	608	710,320.9	2,521,031	0	2.22e+07
FTTHB_pen	608	0.0446772	0.0942733	0	0.5850197
FTTHB_cov[a]	43	0.2926	0.308268	0.05	1
HH	638	1.36e+07	2.35e+07	116,030	1.22e+08
date	638	95.37774	4.864888	82	103

[a] The data refer to cross-sectional observations as of June 2011.

homes connected by FTTH/B, *FTTHB_pen*, is normalized to households.[28] FTTH/B represents fiber lines/connections in the narrower sense, whereby the fiber infrastructure terminates inside or no more than two meters away from the consumer's building, either the basement, the house, or the apartment.[29] All the variable definitions and sources as well as the descriptive statistics are listed in Tables 1 and 2.

Focusing on FTTH/B excludes alternative and much less costly NGA implementation scenarios, such as fiber to the curb (FTTC), VDSL, VDSL2, and fiber to the last amplifier (DOCSIS 3.0 and FTTx/LAN) from our empirical analysis. The same applies to 3G(+) wireless broadband connections. Whereas the GPRS, EDGE, UMTS, and HSDPA standards offer bandwidth levels that are far below the alternative wireline NGA scenarios, LTE promises much higher bandwidth rates in the future, but there is still some way to go before becoming marketable in most countries.

We argue that focusing on FTTH/B scenarios makes good sense for the following reasons: first, as already indicated in the introductory section, FTTH/B is associated with much higher risks and investment requirements, which emphasize more explicitly the importance of regulatory incentives and state aid policies. Second, there is a case for FTTH/B in view of the technological limitations of the alternative NGA scenarios, which are based on copper or coax infrastructure and DSL and DOCSIS 3.0 technologies, respectively (FTTH Council Europe, 2012b, pp. 10–11). As a consequence, and if one is willing to interpret the Digital Agenda as referring to guaranteed levels of symmetric connection speed that can provide consistently high bandwidth with low latency and jitter, FTTH/B is to be preferred to the other NGA scenarios (DotEcon, 2012, p. 11). Finally, Nielsen's Law is an empirical observation that states that network connection speeds for high-end home users constantly increase by 50% per year. Accordingly, the demand for connection speed in 2020 might be far beyond the targets of the Digital Agenda and hence beyond the capabilities of DSL technologies.

5. Empirical analysis

In Section 5.1, we contrast NGA deployment and penetration patterns in EU27 member states with those in the US and leading Asian and other non-EU27 countries.[30] As European countries are quite heterogeneous with respect to their

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[28] Instead of household-related data, one might also refer to per capita terms. However, the former seems to be the more correct measure, as fixed-wireline (NGA) connections are typically related to a single household but not to an individual subscriber (which is the case with wireless subscriptions). Furthermore, Briglauer (2013), who examines the determinants of NGA penetration, finds that the econometric estimates remain virtually unchanged if the dependent variable (NGA household penetration) is normalized with respect to the population.

[29] Full definitions of terms can be retrieved from http://s.ftthcouncil.org/files/FTTH-Definitions-Revision_January_2009_0.pdf.

[30] These regions clearly represent the global "fiber hotspots" as of mid-2012, with 58 million FTTH/B subscribers in Asia, 12.25 million subscribers in Europe (including 6.3 million in Russia), and 10.9 million subscribers in the US. The other regions represent fewer than 1 million FTTH/B subscribers (FTTH Council Europe, 2012c).

market structures, we also have to look more closely at the conditions within these states. This cross-sectional comparison allows us to identify European and non-European groups ("clusters") of countries with distinctively different competitive conditions and public policies as regards sector-specific regulation and state aid. In Section 5.2, we contrast the progress in NGA roll-out and penetration with the most comprehensive public funding initiatives in the world. Finally, in Section 5.3, we run diffusion regressions to analyze the dynamics of the take-up process in each of these countries (clusters).

5.1. Global FTTH/B ranking and sector-specific regulation

In Section 3.1.2, we critically scrutinize the adequacy of cost-based access regulation and the role of service-based competition against the background of NGA investment incentives. Fig. 1 contains a global ranking of FTTH/B deployment and penetration rates, including all the economies with household penetration greater than 1% as of June 2011.[31] Thus, individual countries are ranked according to subscription rates but supplemented with their coverage levels.[32] As Fig. 1 shows, the most mature fiber nations are KR, JP, and HK ("Asian frontrunners"), with nearly full coverage (> 90%) and penetration levels between ~52% and ~42%. The leading Asian countries (including TW and AE) are followed by a couple of Northern and Eastern European economies ("European followers") with penetration levels between ~26% (LT) and ~7.6% (EE).

Interestingly, within the group of the top 25 ranked economies, no fewer than 10 can be assigned to the cluster of "Eastern European followers". One can safely assume that the lack of well-established legacy infrastructure simplified migration towards new infrastructure considerably and seems to have opened up an opportunity to deploy investment-intensive ("high-end") FTTH/B networks directly at a comparatively low cost right from the beginning (Finnie, 2012, p. 17). While looking at Table A.1, it is striking that the penetration of first-generation broadband lines is much lower in Eastern European countries, and becomes most obvious with respect to incumbents' DSL connections (see columns 2 and 3 in Table A.1 with two-letter codes in column 1 in italics for Eastern European countries). Not only do Eastern European followers benefit from the absence of a replacement effect on the supply side, but consumers are consequently also much less confronted by switching costs.

The group of "Northern European followers" (NO, SE, IS, DK) shows – similarly to the broadband strategies in JP and KR – a long-lasting history of state aid programmes that made the Scandinavian nations European forerunners in an international comparison of broadband penetration (Picot & Wernick, 2007, p. 667 and Section 5.2). Moreover, in Northern Europe, energy utilities and municipalities became the most important alternative operators, which now dominate the FTTH/B market in the Nordic countries and NL (Crandall, 2013, p. 274; Finnie, 2012, p. 8; OECD, 2011, p. 8).

Remarkably, out of the group of Central, Western, and Southern European countries, only NL and PT are ranked within the top 25 FTTH/B economies but still below the US ("laggards"). The disproportionally high coverage rate in PT can be in part attributed to the ambitious funding programmes of the Portuguese Government (see Section 5.2, Table 3). Furthermore, the regulatory regime in PT largely exempted the incumbent operator from active and passive wholesale remedies (Cullen International, 2010, Table 4). NL is unique in Europe with respect to the above-mentioned involvement of municipalities (and housing authorities) and the long-established duopoly structure in the Dutch fixed broadband market with almost 100% broadband coverage. However, most of the other EU states ("European starters") show rather low subscription levels, at ~2.1% (FR) or even as low as ~0.5% (such as DE, PL, EL, or UK). Overall, the vast majority of European starters are still at the beginning of FTTH/B deployment and take-up.

In line with our theoretical discussion in Section 3.1.2, it is no surprise that the major European incumbents, in particular, have played a secondary role in FTTH/B deployment so far.[33] For instance, Deutsche Telekom is among the most active proponents of FTTC/VDSL network roll-outs, with only limited commitment to future FTTH/B roll-outs. The same is basically true for the NGA strategy of British Telecom, which is also confronted with less intense competition in the fixed broadband markets and thus seems to be delaying large-scale FTTH/B investment in favor of a "wait and see strategy". French Telecom, Telefonica, and Telecom Italia appear to be more committed to rolling out FTTH/B networks, especially in several cities, not least because of intense infrastructure-based competition in urban areas (Finnie, 2012, pp. 24–41).[34] Apart from the market conditions, however, the incumbency persistence against FTTH/B deployment is most likely due to the negative impact of asymmetric legacy-like regulation and regulatory uncertainty on infrastructure investment. The latter, in combination with massive sunk costs, implies a substantial option value of delaying FTTH/B investment and upgrading the existing broadband

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[31] The two-letter country codes (CC) in Fig. 1 and below follow the ISO standard.

[32] There is a strong and positive correlation between coverage and penetration, with a Pearson's correlation coefficient of $\rho = 0.87$ for the observational units in Fig. 1 as of June 2011. Substantial and positive correlation appears to support our basic assumption.

[33] According to data from the FTTH Council Europe (2012c) as of mid-2012, only around 22% of FTTH/B deployments in Europe (EU39) are due to the investment activities of European incumbent operators. The rest are due to municipalities and utilities (~6%) and alternative telecommunications operators (~72%).

[34] In line with the theoretical literature (Aghion, Bloom, Blundell, Griffith, & Howitt, 2005), one has to expect a non-linear impact of (infrastructure-based) competition on investment: at low or moderate levels of competition, operators have an incentive to innovate and jump ahead of rivals in order to gain a competitive advantage; beyond a certain level of competitive intensity, however, a further increase negatively affects firm profits and investors would no longer be able to recover their investment outlays. For recent empirical evidence on the non-linear impact of intermodal competition on NGA investment, see Briglauer et al. (2013).

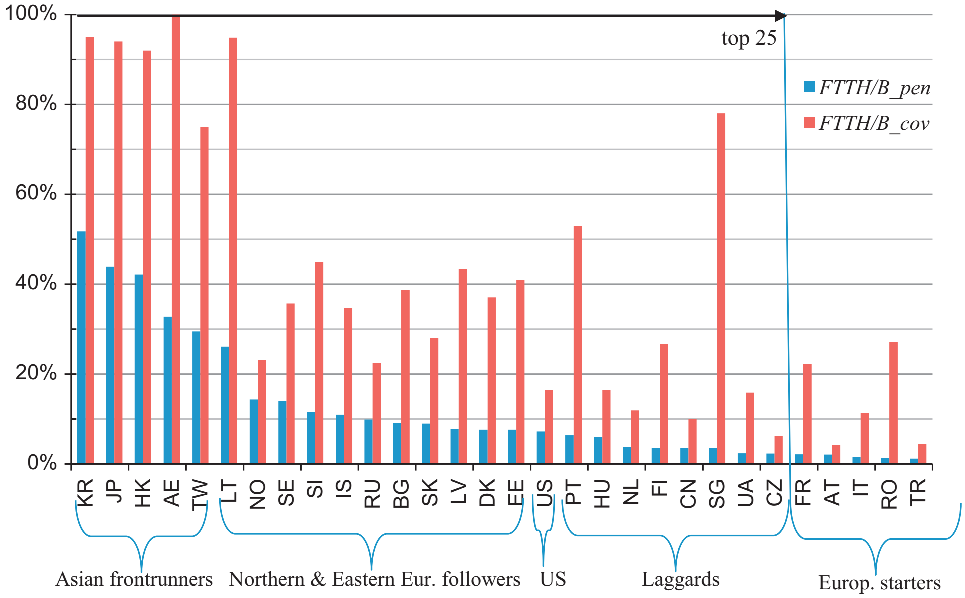

Fig. 1. Global FTTH/B ranking of penetration and coverage levels (June 2011).

Table 3
Current national and EU high-speed broadband funding programmes.

CC	Vol.	Description of program	Time	White	Source
KR	18.4 (1)	The Government builds an ultra-broadband convergence network in combination with private investments. Goals: 100 Mbit/s for 14 million users until 2012; starting in 2012, the Government builds Gbit/s networks in big cities; wireless should be upgraded to 100 Mbit/s	2009–2012	Yes	Analysys Mason (2010), Doose, Elixmann, and Jay (2009), p. 30
JP	13.7 (1.73)	Broadband network is fully funded by the Government, but entirely constructed by a private company. Goals: FTTH/B high-speed broadband with 90% coverage in 2010	2009–2010	Yes	Doose et al. (2009), pp. 14–16; Berkman Center (2010)
TW	27.2 (0.63)	Direct investment in passive infrastructure. Goals: deploying optical fiber pipelines and advancing ICT by promoting wireless broadband services	2003	No	Analysys Mason (2010)
US	8.5 (5)	Direct funding of individual projects to promote universal broadband access. Goals: different NGA technologies; 100 Mbit/s for 100 million users and at least one Gbit/s connection to every municipality	2010–2020	Yes	Analysys Mason (2010)
SG	261 (0.55)	The Government establishes two vertically separated operating companies. Goal: to connect all homes and businesses with fiber by 2015, with some homes obtaining the 1 Gbit/s access services by 2010	2009–2015	No	Analysys Mason (2010), Doose et al. (2009), pp. 27–29
SL	19.7 (0.04)	Public funds cover about 30% of the investment. The FTTH projects taken into consideration are “open broadband networks”. Goal: to provide FTTH access in white spots	2008	Yes	Analysys Mason (2010)
EE	47.7 (0.06)	The Government plans to construct a nationwide high-speed broadband network. Goals: 100 Mbit/s coverage to 90% of the country by 2012, with the remainder of the population to be connected by 2015	2009-2016	Yes	Analysys Mason (2010)
FI	12.3 (0.07)	Public funds paid to the builders of active and passive infrastructure. Goals: Internet access for 100% at speeds of > 1 Mbit/s by end of 2010 and 100 Mbit/s by 2015	2008–2015	Yes	Analysys Mason (2010), Cullen International (2011)
PT	75 (0.8)	The Government offers funding while private operators are collaborating. Goals: 50% population coverage via FTTH/C in each rural area within two years from when contract becomes effective	2009–2029	Yes	Analysys Mason (2010), Cullen International (2011)
EU	2 (1)	Direct co-funding (Structural and Rural Development EU Funds) of individual projects subject to broadband/NGA state-aid guidelines and open tender procedures. Goals: Digital Agenda for Europe: 30 Mbit/s for 100% of households (coverage) and 100 Mbit/s for 50% (subscriptions)	2010–2020	Yes	European Commission (2008, 2009)
AU	1202 (> 15)	The Government establishes a new corporation, and holds the majority of shares during construction; corporation and incumbent are vertically separated; private co-investment is expected. Goals: up to100 Mbit/s for 90–93% of fiber to homes, workplaces, and schools by 2018; wireless for remaining 7–10% with 12 Mbit/s	2010–2018	Yes	Analysys Mason (2010); Given (2010, pp. 4–8)
NZ	169 (> 0.8)	The Government establishes investment corporation; vertical separation of incumbents. Goals: up to100 Mbit/s for 75% of population by 2018	2010–2018	Yes	Analysys Mason (2010), Given (2010, p. 544)

legacy networks (DotEcon, 2012, p. 12). Significantly lower investment costs of FTTC and coax upgrades in combination with well-established first-generation broadband infrastructure make this strategy very attractive to many European infrastructure operators. The replacement effect appears to be particularly intense for incumbents here (see columns 2 and 3 in Table A.1), which becomes reinforced in view of the above-mentioned progress on "second-life" copper technologies. Remarkably, even the major incumbent operators with the most ambitious FTTH/B roll-out activities, such as French Telecom, are also expressing an interest in bonding and vectoring technologies (Finnie, 2012, p. 21).

The US is ranked just below the group of European followers (7.2%) but well above the average of the EU27 countries (~2%, number not reported in Fig. 1). With reference to the FTTH/B coverage levels, the difference between the developments in the US (~16.4%) and those in the EU27 (~11%) is similar. It is worth emphasizing that the US regulator (FCC) has fully reversed its comprehensive unbundling regime imposed on the access network in the first phase of liberalization. In 2003, the FCC began to remove line-sharing obligations and largely to exempt fiber infrastructure from unbundling obligations (Triennial Review Order 2003, refined in 2004). The decision was based on dynamic efficiency considerations and on the conclusion that incumbents (owning legacy infrastructure) had no significant cost advantage in deploying new network infrastructure (ITU, 2009, p. 80). Verizon's request for the removal of any ex-ante regulation for high-speed broadband infrastructure was adopted by the FCC in March 2006. Similar forbearance relief followed for other major US network operators in 2007 (OECD, 2011, p. 11).[35] Since the beginning of broadband/NGA deregulation, the US has experienced remarkable growth in FTTH/B investment and subscriptions (see Fig. 2c), with the largest fixed-line provider, Verizon, investing about $23 billion in its fiber-based network roll-out. In its most recent market forecast, RVA LLC (2013) predicts that the total investment in FTTH networks will be $18 billion over the next five years. Verizon has now by a very large margin the most FTTH subscribers in the US (~4.1 million) and ranks among the top ten FTTx operators worldwide (IDATE, 2011). Finally, the US situation is also characterized by an almost ubiquitous competing cable broadband infrastructure which is similar to the market structure in NL in Europe. Cable operators have been offering services based on DOCSIS 3.0 (65 million) since 2008 with high levels of bandwidth and service quality (IDATE, 2011).

The regulatory regimes in (leading) Asian economies are much more heterogeneous than those within the EU. Some countries, such as JP, impose wholesale access obligations that are similar to the EU framework. The Japanese incumbent operator has been subject to comprehensive unbundling obligations including line sharing (for DSL services) as well as unbundling fiber loops and interoffice fiber since 2001 (ITU, 2009, p. 70; OECD, 2012, p. 45). However, the extension of unbundling obligations to fiber infrastructure appeared to be ineffective so far and hence the Japanese fiber take-up is unlikely to be driven by those access regulations (Crandall et al., 2013, pp. 272–273). The Korean Government mandated unbundling relatively late, in 2002, with an initial hands-off approach in broadband markets. There are, however, no unbundling obligations imposed with respect to the NGA infrastructure (Choi, 2011, pp. 811–812). In other leading Asian countries (HK, TW), comparable wholesale access regimes are not implemented (ITU, 2009, pp. 67, 78; FTTH Council Asia-Pacific, 2009). Besides such differences in regulatory regimes, the governments of most of the leading Asian fiber nations show a high degree of interventionism in terms of coordinating ICT development, in combination with massive financial support to stimulate both the supply and the demand of high-speed broadband services.

5.2. Global FTTH/B ranking and public funding

According to the economic rationales in Section 3.2, we expect that major public NGA funding programmes are in place, which are linked to high-speed broadband connections and white areas, in particular. Table 3 provides an overview of the major public NGA funding inside and outside Europe. The focus is on the most prominent and far-reaching national NGA funding policies in Asia, Europe, and the US. Thus, state aid programmes targeted at conventional broadband technologies as well as municipal and other non-national activities are excluded, as are a few high-ranked countries where either no major NGA public funding projects are known or data are not available (such as AE). In addition, Table 3 includes the supranational funding activities of the EU as well as the extensive state-aid programmes in AU and NZ in separate rows at the end of Table 3. Countries with two-letter country codes in column 1 are listed according to the household penetration rates in Fig. 1. Column 2 contains the volumes of national funding programmes expressed in euros per capita as well as in billions of euros (in parentheses). Column 3 gives a brief description of the individual funding programmes and the goals that have to be reached within a predefined time frame (column 4). Finally, column 5 indicates whether the state aid program is also targeted to supply white areas.

From Table 3, we first infer that within the cluster of Asian frontrunners, massive public subsidies are already determined and in place (KR, JP, TW, but also SG). Especially for KR and JP, these programmes represent a systematic continuation of the public initiatives for broadband deployment that were already initiated decades ago. Public funding and industry collaboration have been regarded as complementary measures after market liberalization.[36] Through these funding

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[35] The FTTH/B/C market in the US is basically dominated by two major operators: whereas Verizon focused on FTTH deployment (21.5 million homes passed), AT&T opted for FTTC technology (29 million).

[36] Korea's world-leading role in terms of broadband and FTTH/B penetration rates is due to massive public initiatives of the Government issued as early as 1987 (Falch & Henten, 2010, p. 5). The "Korean Information Infrastructure Inititative" was established in 1994, followed by various other governmental programmes, in order to promote a nationwide ultra-high speed broadband network. The "e-Japan strategy" was initiated in 2001 with the goals of becoming the most advanced ICT nation and having 30 million high-speed subscribers (> 10 Mb/s). The Government extended this program in 2003 ("e-Japan strategy II") and provided additional resources by means of subsidies, tax incentives, and zero-interest loans for broadband providers. Finally, the

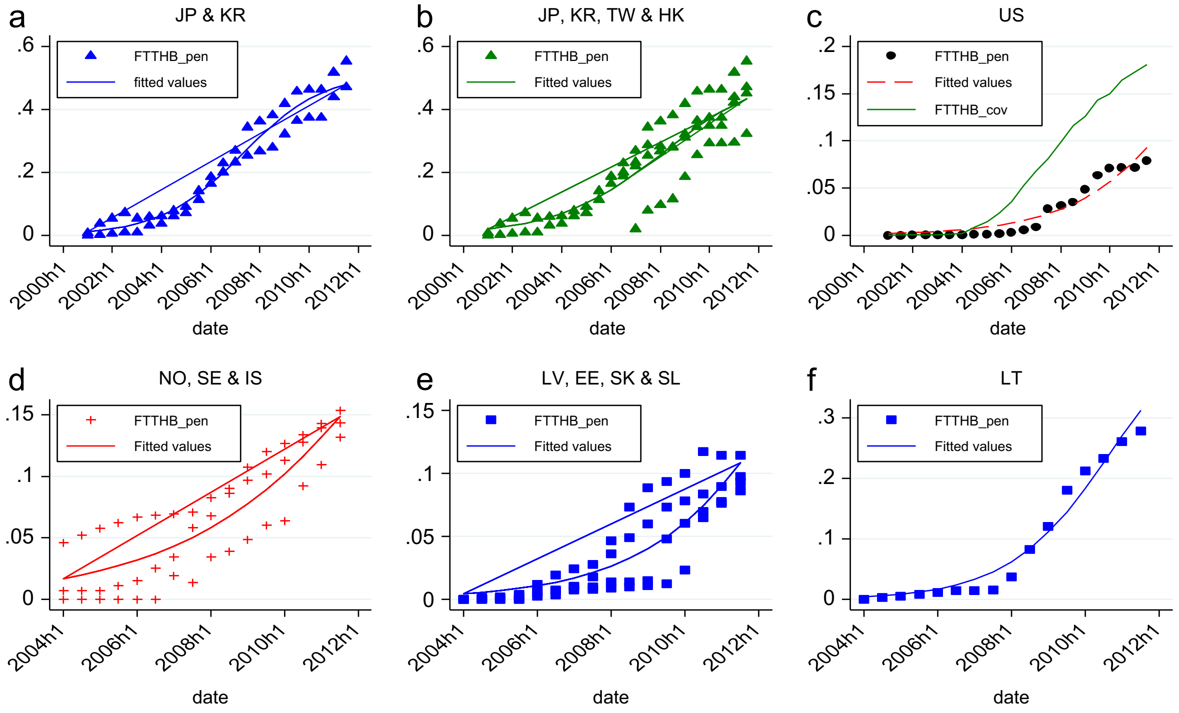

Fig. 2. FTTH/B diffusion processes in selected countries and clusters.

initiatives, the governments not only provided substantial subsidies for infrastructure deployment but also enacted effective stimuli on the demand side. HK is an exceptional case in this cluster, as it relies almost entirely on infrastructure-based competition as the main driver of NGA deployment. HK exhibits high coverage and penetration levels without any complementary state aid initiatives, which appears to be due to intense platform competition in conjunction with a hands-off regulatory approach, as well as geographic and demographic cost advantages[37] (FTTH Council Asia Pacific, 2009; ITU, 2009, pp. 66–67). In the US, in turn, state funding for NGA is deemed to be necessary despite its deregulatory approach to NGA infrastructure.

Among the leading Northern and Eastern European followers, only FI, EE, and SL have currently implemented moderate state aid programmes. However, as mentioned in Section 5.1, the other Northern European fiber nations (DK, SE, NO) show a long-lasting history of broadband state aid, which also made the Scandinavian nations the European forerunners in terms of broadband coverage and penetration.[38] In addition, it should be remembered that in the Nordic countries energy utilities and municipalities became quite important alternative FTTH/B operators, whose financing role is not captured in Table 3.

Regarding the European states, Table 3 indicates that only a few governments have already launched substantial state aid programmes in order to stimulate NGA deployment and that these countries (SL, EE, FI, PT) also belong to the top 25 in Fig. 1. In turn, it is striking that within the clusters of European laggards and starters, national governments have not yet determined any (BE, DK, FR, DE, GR, IE, IT, NL, SE, CH) or any substantial (AT, ES, NO, UK) public NGA funding so far (Cullen International, 2011, Table 29). As Table A.1 in the Appendix shows, all the Western, Southern, and Northern European states exhibit a rather well-established first-generation broadband legacy infrastructure, which might not only give rise to a substantial replacement effect at the firm level, but also to reluctance towards subsidizing second-generation infrastructure at the level of national governments. This becomes reinforced further the more consumers are content with the existing broadband services and the more promising the second-life copper technologies are.

(*footnote continued*)
Government launched the “ubiquitous-net Japan” strategy in 2004 and the “IT New Reform” strategy in 2006 with the goal of providing broadband services to every household by 2010 (Atkinson, Correa, & Hedlund, 2008, appendix D).

[37] With a very high population density of 6349/km^2, HK ranks fourth just below SG (7148/km^2). *Source*: 〈http://en.wikipedia.org/wiki/List_of_sovereign_states_and_dependent_territories_by_population_density〉.

[38] For instance, the Norwegian “Hoykom” program lasted from 1998 to 2008 with total grants of €95.7 million. SE implemented a national broadband support program from 2001 to 2007 with state funds of ~€375 million (Cullen International, 2011, Table 29). Broadband development in DK is based on a plan issued by the Danish Government in 2001 (“Vision 2015: 100 megabits for all”), which systematically supports the demand side through the promotion of ICT usage in the public sector, education, and research programmes (Berkman Center, 2010, pp. 261–263).

As opposed to European starters, AU and NZ are examples of non-European countries with well-established legacy infrastructure and that are also still lagging far behind in terms of current FTTH/B coverage and penetration, but where the national governments reacted quite differently, with far-reaching and probably the most extensive public funding programmes worldwide (in per capita terms).

When looking at Europe as a whole, the EC approved €1.8 billion in public funds for high-speed broadband development projects in EU member states in 2010.[39] These funds are especially targeted towards broadband deployment in rural and remote (white) areas, as is the case with most national funding programmes (column 5).[40] The amount approved by the EC in 2010 is more than four times the amount in 2009, which indicates that there is an awareness that a great deal of catching up has to be carried out in EU member states. Also, in its NGA recommendation, the EC emphasizes the necessity to lower deployment costs by granting access to passive infrastructure elements, simpler access to rights of way, and allowing co-investment and co-ordination of civil works (European Commission, 2010a, recitals 12, 15, 19, 27, art. 13, 16), which can be seen as another public initiative to support NGA roll-outs actively. Indeed, according to the FTTH Council Europe (2012a), tens of billions could be saved by reusing and sharing network infrastructure components. Regarding future subsidies for broadband investment, the EU plans to provide around €7 billion for high-speed broadband infrastructure via the "Connecting Europe Facility" funds from 2014 to 2020. The funding is deemed to complement private investment in the form of equity and debt instruments as well as grants. Again, the aim is to support less profitable, densely populated (white) areas.[41]

5.3. *Diffusion analysis*

Based on the cross-sectional and comparative analysis in Sections 5.1 and 5.2, we now look at the dynamics of FTTH/B penetration by examining the different stages of the diffusion processes. We apply this kind of quantitative analysis to fiber-leading countries with a sufficient number of observations as well as to "clusters" of countries that appear to be sufficiently homogenous according to the analysis in the previous two sections.

5.3.1. *Methodology*

The vast majority of the related empirical literature finds that diffusion processes are best described through an S-shaped curve, such as the Gompertz, log reciprocal, or logistic functional forms. The latter is most widely used for estimating S-shaped diffusion processes of new communications technologies with aggregate data.[42] The logistic curve captures the network effects that typically underlie all ICT diffusion processes: the value of a new technology increases with the subscriber base, as more and more content will be provided by operators and due to learning effects. However, ultimately, the growth will decline as the stock of subscribers converges to the total number of potential subscribers. In the case of fixed broadband communications, this number is limited by the number of households (*HH*) per country, whereas mobile subscription eventually converges to the total population.[43]

Our empirical baseline specification draws on Grajek and Kretschmer (2009) and takes the following form with three interpretable parameters:

$$FTTHB\_pen_{it} = \frac{FTTHB\_pen_{it}{}^{*}}{1+\exp(-\beta(t-\lambda))} + \varepsilon_{it} \tag{1}$$

$FTTHB\_pen_{it}$ denotes the actual number of subscribers ("homes connected") in country/cluster i at time t. $FTTHB\_pen^{*}_{it} = \gamma HH_{it}$ denotes the maximum number of adopters or the saturation level and therefore the parameter γ denotes the maximum share of households.[44] The parameter λ, the point of inflection, measures the timing of the diffusion process, as it shifts the logistic curve forwards and backwards on the time line. Since the logistic curve is symmetric around the inflection point, λ represents the number of periods in which half of the saturation level is reached. At the inflection point, the diffusion curve takes its maximum value of the growth rate ($d^2(FTTHB\_pen_{it})/dt^2 = 0$). When differentiating Eq. (1) with respect to time, one can see that the parameter β measures growth relative to its distance to the saturation level ("speed of

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[39] See the press release of the EC retrieved from 〈http://europa.eu/rapid/pressReleasesAction.do?reference=IP/11/54&format=HTML&aged=0&language=EN&guiLanguage=en〉.

[40] Exceptions (such as TW and SG) are due to country-specific demographic and topographic conditions.

[41] See the press release of the EC, IP/11/2011, Brussels, 19 October 2011. Retrieved from http://europa.eu/rapid/press-release_MEMO-11-709_en.htm?locale=en.

[42] See inter alia e.g. Czernich et al. (2011), Geroski (2000), Grajek and Kretschmer (2009), Gruber and Verboven (2001), or Lee et al. (2011). According to Czernich et al. (2011), the logistic form captures appropriately the so-called "extensive margin of diffusion", i.e. penetration, which we are interested in, whereas it would fail to capture the "intensive margin of diffusion", i.e. usage intensity.

[43] In mobile communications, the saturation levels might even exceed the total population due to the co-existence of pre-paid and post-paid products and multiple SIM cards. However, in the case of non-mature and household-related FTTH/B deployment, it is safe to assume that the fraction of subscribers is bound between 0 and 1.

[44] Note that $FTTHB\_pen_{it} \rightarrow FTTHB\_pen^{*}_{it}$ as $t \rightarrow \infty$.

Table 4
Estimation results for diffusion Eq. (1).

Model no. Cluster label Cluster definition	(1) **Asian_1** Fig. 2(a)	(2) **Asian_2** Fig. 2(b)	(3) **US_sat** Fig. 2(c)	(4) **Nordics_sat** Fig. 2(d)	(5) **Eastern_sat** Fig. 2(e)
γ	0.517^{***}	0.523^{***}	–	–	–
(Saturation l.)	(16.99)	(5.99)	–	–	–
β	0.301^{***}	0.230^{***}	0.196^{***}	0.166^{***}	0.230^{***}
(Speed of diff.)	(9.23)	(4.61)	(9.91)	(9.54)	(9.92)
λ	94.58^{***}	96.20^{***}	110.5^{***}	108.2^{***}	108.6^{***}
(Inflection p.)	(163.78)	(54.02)	(104.09)	(111.35)	(131.46)
Adj. R^2	0.982	0.935	0.949	0.910	0.871
F	786.0	316.9	207.6	244.5	217.4
$RMSE$	0.0370	0.0700	0.00844	0.0240	0.0182
N	44	66	22	48	64

*** $p < 0.01$. t-statistics in parentheses. The non-parametric "runs" test indicates positive serial correlation in the residuals. However, the inclusion of heteroskedasticity- and autocorrelation-consistent variance estimators (Newey–West) leaves the t-statistics virtually unchanged and highly significant. Shapiro–Wilk and Shapiro–Francia tests indicate that we cannot reject the null hypothesis that errors are normally distributed in models (1) and (3) as well as in the case of LT (Fig. 2(f)). Cluster heterogeneity in the other models, however, induces non-normality and less efficient estimators. Saturation levels ("sat") are fixed at $\gamma=0.5$ for models (3), (4), and (5).

diffusion")[45]

$$\frac{dFTTHB\_pen_{it}}{dt}\frac{1}{FTTHB\_pen_{it}}=\beta\frac{FTTHB\_pen_{it}*-FTTHB\_pen_{it}}{FTTHB\_pen_{it}*} \tag{2}$$

Eq. (1) is estimated by non-linear least squares, where the error term, ε_{it}, is assumed to be i.i.d.

5.3.2. Main results

Fig. 2 depicts the actual and fitted values of the FTTH/B diffusion process for the selected countries and clusters. First of all, the non-linear nature becomes evident in Fig. 2(a–f), which is re-emphasized for clusters by adding linear regression lines. A linear specification does not capture the epidemic character of the diffusion process and would overestimate the saturation, especially when the process started later. The sigmoid-shaped relationship becomes most visible for the single-country presentations for the US (c) and for LT (f) but also for JP & KR (a).[46]

Table 4 provides the estimates of the diffusion parameters, in which a reference is made to Fig. 2 in the heading that defines the cluster labels. The saturation parameter (γ) can be estimated consistently in the case of a sufficiently materialized diffusion process, which basically holds for the leading Asian countries only, and most notably for JP and KR. For the Asian clusters (Asian_1 and Asian_2), the estimated saturation level suggests a maximum household penetration of slightly above 50%. Obviously, this number is close to the corresponding penetration rates shown in Fig. 1 and thus suggests that saturation levels had almost been reached in JP and KR in 2011. Since the FTTH/B penetration is still in an early stage in the non-Asian countries, the saturation parameter cannot be estimated consistently, and therefore we had to use an exogenously fixed saturation level. For the Nordic countries and the US, we decided to refer to the level of conventional broadband penetration at the beginning phase of FTTH/B penetration (Czernich et al., 2011). According to the OECD broadband statistics, the broadband penetration per household in these countries was around 50% in 2006.[47] A similar argument is, however, not applicable to Eastern European countries, where broadband penetration based on first-generation copper and coax infrastructure was quite low in 2006 ("no legacy"). Nevertheless, in view of one of the major broadband objectives of the Digital Agenda,[48] it seems to be meaningful to apply the same saturation level to Eastern European countries (Fig 2e and f). Moreover, since a maximum penetration rate of around 50% has been estimated for leading and highly broadband affine Asian countries, we are confident that this saturation level represents a realistic ceiling for the other countries as well, at least for the foreseeable future.

The inflection point parameter (λ) is measured in periods elapsed since the first half year of 1960 (date). For instance, a date value of 100 stands for the first half year of 2010 (2010h1). The diffusion process started in date period 82=2001h1 and in date

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[45] Note that as $FTTHB\_pen_{it} \rightarrow FTTHB\_pen_{it}^{*}$ then growth rate $(d\text{FTTHB\_pen}_{it}/dt)(1/\text{FTTHB\_pen}_{it}) \rightarrow 0$.

[46] Whereas the logistic diffusion curve underlying eq. (1) assumes symmetry around the inflection point, the Gompertz function is asymmetric. Fitted values for the Gompertz function show a rather similar diffusion process in comparison with the logistic S-shaped curve. However, on average the Gompertz function systematically overestimates the saturation levels. Therefore, and in line with the literature cited in footnote 43, we are confident that the logistic diffusion curve is the most appropriate functional form for our estimation purposes.

[47] *Source*: http://www.oecd.org/document/7/0,3746,en_2649_34225_38446855_1_1_1_1,00.html.

[48] Recall that the EU "seeks to ensure that, by 2020 [...] 50% or more of European households subscribe to internet connections above 100 Mbps" (European Commission, 2010b, para 2.4).

period 88=2004h1 in Fig. 2(a–c) and Fig. 2(d–f), respectively. From Table 4 we can infer that the inflection point is reached in leading Asian countries in 2007h2 (Asian_1) and 2008h1 (Asian_2). In turn, if we impose a 50% saturation level ("sat") for the US and European countries, the inflection point is reached much later. For instance, the inflection point and thus half of the saturation level will not be reached before 2015 ($\lambda=110.5$) and 2014 ($\lambda=108.2/108.6$) in the US (US_sat) and Northern/Eastern European countries (Nordics_sat/Eastern_sat). In this view, the previously mentioned target of the Digital Agenda seems to be too ambitious for most European followers (~5 years) in terms of FTTH/B scenarios, let alone for European laggards and starters.

The speed of diffusion (β) is highest in the leading Asian countries, with $\beta=0.3$ in JP and KR (Asian_1) followed by the extended cluster of leading Asian fiber nations (Asian_2) and Eastern European economies (Eastern_sat) with $\beta=0.23$.[49] Our analysis in Sections 5.1 and 5.2 suggests that the progress in the Asian clusters appears to be due to massive public government initiatives and demand- and supply-side country characteristics, whereas the high FTTH/B growth rates in Eastern European economies appear to be primarily due to much lower consumer migration costs in conjunction with a hardly pre-existing replacement effect at the beginning of the diffusion process. In turn, the growth rates for the Northern European frontrunners ($\beta=0.17$) as well as for the US ($\beta=0.2$) are substantially lower. Needless to say, the growth rates in other European countries (laggards and starters) are much lower and cannot even be estimated consistently.

6. Summary and conclusions

Europe's gap in high-speed broadband deployment and penetration has been recognized by the EC and is explicitly addressed in its Digital Agenda. The penetration targets specified therein in conjunction with the NGA recommendation seem to express some preference for FTTH/B deployment. However, in line with the literature cited in Section 2, our qualitative analysis shows that the strict cost-based mandatory access regime underlying the EU regulatory framework is at odds with achieving the goals of the Digital Agenda. An international cross-sectional comparison indicates strong reluctance of European incumbent operators to undertake FTTH/B deployment and that there are essentially three ways to achieve a fast and comprehensive FTTH/B roll-out: (i) market-based incentives, such us US-like deregulation strategies in conjunction with substantial infrastructure competition, proved to stimulate FTTH/B investment and penetration effectively; (ii) direct state subsidies, as seen in many East Asian countries and, more recently, also in AU, NZ, and SG, can be considered relevant, especially to supply white areas and to complement private investment; (iii) as the case of Eastern European and East Asian fiber nations has shown, progress in infrastructure roll-out and penetration is also due to favorable country-specific conditions.

These results are also reflected in our diffusion analysis, according to which most European countries are lagging far behind the leading Asian fiber nations, such as JP, KR, TW, and HK, but also behind the development in the US in terms of both FTTH/B coverage and FTTH/B penetration. Remarkably, the FTTH/B penetration in China is now already higher than that in most Western European countries (Finnie, 2012, p. 20). According to our estimates, JP and KR are around 6.5 years ahead of the European followers. However, some Northern and Eastern European countries experienced considerable growth. Whereas the progress in FTTH/B deployment and penetration in the Nordic countries is mainly due to the long tradition of comprehensive state aid broadband policies and strong participation of municipalities and energy utilities, the Eastern European countries benefit from low migration costs towards new fiber infrastructure and hence have experienced the highest growth in penetration rates in Europe.

Our findings are of significant relevance for future policy decisions, as the setting of the regulatory design for emerging NGA infrastructure is still an open issue in many EU27 member states. In order to reduce the negative ex ante investment incentives and push penetration, ex-ante regulation should be directed to increasing the pricing flexibility in the direction of full deregulation and – in view of the long-term nature of NGA investment – should be binding and stable and defined as early as possible in order to help to reduce the overall investment risk. Ideally, NRAs switch from the asymmetric (legacy-based) regulatory paradigm to a more symmetric one in which NGA regulation is primarily directed towards lowering the total costs by means of an industry coordinating role and enabling cooperation models in the actual building and sharing of infrastructure (Gomez-Barroso & Feijob, 2010). This argument is supported by the fact the regulatory design of NGA access obligations is more complex than those related to copper networks which additionally increases the risk of regulatory failure (Crandall et al., 2013, pp. 271–279). Although the NGA recommendation provides for forms of co-investment, this might still be insufficient as it ex ante limits cooperation to specific industry configurations (DotEcon, 2012, p. 35). A recent draft recommendation of the EC seems to be more promising in this regard, as it holds out the prospect of departing from the strictly cost-based access regulatory approach in the case in which NRAs impose sufficient non-discrimination obligations in conjunction with competitive safeguards (European Commission, 2012, pp. 10–11). It appears that the massive criticism expressed in the comments to the NGA consultation document on costing methodologies indeed triggered a partial reversal of the sector-specific EU framework in the direction of more deregulatory policies.

Regarding NGA-specific state aid, we argue that there are plausible economic justifications for public intervention. Indeed, an increasing number of national governments as well as the EU have launched substantial NGA funding programmes in recent years. However, public subsidies might also be subject to governmental failure, which occurs for example whenever private investment is crowded out in non-white areas. Briglauer and Holzleitner (2012) outline the inefficiencies involved in the design of most real-world NGA funding projects in the presence of asymmetric information.

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[49] The speed of diffusion would be higher for Eastern_sat if we also included LT in model (5). However, LT is growing much faster than the other Eastern European countries, which would bring about additional cluster heterogeneity and poorer fit statistics.

The reader is reminded that our empirical results are derived from a narrow NGA definition that focuses on FTTH/B scenarios only. Although there are good reasons for this approach, the future market potential of FTTC/DSL second life NGA technologies to realize connection speeds up to and above the “gold standard” of 100 Mbps is from today's point of view simply uncertain. Accordingly, our empirical estimates might be biased and our predictions too pessimistic. Also, the main downside of the FTTH/B implementation scenarios refers to the total deployment costs, which are much higher than in the case of network upgrades based on DSL or DOCSIS 3.0. More fundamentally, one might also question the adequacy of the Digital Agenda's mid-term targets, which exogenously predefine coverage and penetration levels in spite of exceptionally high market uncertainties and information requirements. Consequently, there might be a considerable gap between socially desirable targets in terms of economic efficiency and targets that are the result of a political process that is not clearly comprehensible. Furthermore, predefining target values might also be in conflict with the principle of technological neutrality, according to which competition must not be distorted in favor of certain communications technologies (European Commission, 2009, recital 51).

To conclude, it can be said that the higher the potential for governmental failure or planning uncertainty and the higher the adverse effects of sector-specific regulation on efficiency and welfare (“regulatory failure”) are, the more the burden of proof is shifted in favor of a market-driven approach that adheres to the principle of technological neutrality on the supply side and to the actual market needs for high-speed broadband services on the demand side.

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Appendix

See Table A.1

Table A.1
Fixed broadband infrastructure in the EU27 in ascending order.[a]

	Total retail DSL lines per household	Total retail DSL lines per capita		Total retail broadband lines per household	Total retail broadband lines per capita
BG	0.1146113	0.045257	***SK***	0.3768167	0.1637171
RO	0.1211023	0.0438264	***BG***	0.3938625	0.1555261
LT	0.1462043	0.0635459	***RO***	0.4047865	0.1464905
SK	0.1694904	0.0736392	***PL***	0.4244743	0.163598
LV	0.1909849	0.0760979	***LV***	0.4847693	0.1931562
HU	0.1914865	0.0838023	***HU***	0.4886316	0.213845
CZ	0.2123821	0.0845412	***LT***	0.4966371	0.215857
PL	0.2134685	0.0822736	**IT**	0.5337507	0.2229154
EE	0.2704728	0.1189291	**PT**	0.5477993	0.208518
PT	0.2818543	0.1072869	***CZ***	0.5544376	0.2207004
SE	0.3418468	0.1709775	**AT**	0.5902852	0.256038
BE	0.3904608	0.1675807	***EE***	0.6055381	0.26626
SI	0.4051435	0.1391652	**FI**	0.6139741	0.2923813
AT	0.4067859	0.1764446	**EL**	0.6286534	0.2079167
FI	0.4359578	0.2076079	**SE**	0.6485685	0.324387
MT	0.4472053	0.1576923	**ES**	0.6588914	0.2399649
DK	0.4702032	0.2193092	**DE**	0.661214	0.3267364
IE	0.4760593	0.1626345	**IE**	0.6898633	0.2356756
NL	0.4914237	0.2204883	**SI**	0.7015657	0.2409851
IT	0.5216685	0.2178694	**CY**	0.708532	0.2521248
ES	0.5230494	0.1904919	**BE**	0.733851	0.3149593
DE	0.5564328	0.2741342	**UK**	0.747331	0.3238497
UK	0.5752826	0.249294	**DK**	0.8262762	0.3853865
EL	0.6268259	0.2073123	**MT**	0.8498021	0.299655
CY	0.6327838	0.2251705	**FR**	0.8549504	0.3386708
LU	0.7696536	0.2820745	**LU**	0.856344	0.3138461
FR	0.7938271	0.3144581	**NL**	0.8752053	0.3926806
EU27	0.39913583	0.16155202	**EU27**	0.62803005	0.25614228

[a] *Source:* Data from the EU progress report as of July 2011. The DSL penetration numbers for Germany (DE) in columns 2 and 3 refer to October 2010 data. The total retail broadband lines include, most notably, coax and copper infrastructure; WLL, leased lines, satellite, FTTC, PLC, and public access WIFI hotspots are included as well, but the actual market importance of these access technologies is negligible.

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