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Abstract

Fiber-deployment of future telecommunications networks ("Next Generation Access" - NGA) is currently a major challenge for sector-specific regulators as well as for investing firms. Although the future socio-economic importance of new telecommunications networks is uncontroversial, the related investment activities vary substantially in international comparison.

This work intends to identify the most important determinants of previous NGA deployment using data from the EU27 member states for the years 2005 to 2010. For our analysis, we employ latest data on NGA deployment, relevant competition and regulatory indicators as well as other supply and demand side controls. Our econometric model incorporates: i) aggregated country level data; ii) structurally modeled dynamics of the deployment process which allows us to disentangle long-term and short-term effects; finally, iii) we argue that there is no endogeneity problem with respect to investment activities and regulation since we refer to regulation in preceding broadband markets. For our econometric analysis, we employ several dynamic panel data methods, such as GMM and LSDVC.

Our results indicate that stricter previous broadband access regulation has a negative impact on NGA deployment. As regards the dynamics of the adjustment process, we find that there are severe adjustment costs and stickiness towards the desired long-term level of NGA infrastructure.

1 Introduction

In recent years, fiber-deployment of telecommunications access networks (“Next Generation Access” - NGA) has become a major issue for sector-specific regulators as well as for investing firms. Operators of traditional (“first generation” copper-based) telecommunications networks have to speed up their networks to fulfill needs for growing demand for bandwidth, arising from new/interactive multimedia services like streamed video on demand, High Definition Television, 3-D applications, eHealth, eGovernment, Web 2.0 services, etc.[1]

The renewal of existing networks and their (partial) replacement by fiber optic infrastructure require high investment volumes.[2] For this reason and because of the associated growth potential of the information and communication technology (ICT) industry, such a venture is even seen as a “project of a lifetime”.[3] The future central importance of ultra-high-speed broadband infrastructure as a key socio-economic factor is well recognized.[4] However, investments in (“second or next generation”) fiber-based network infrastructures vary significantly in international comparison. Whereas leading Asian countries such as Japan and South Korea already reached fiber coverage levels of around 35% by the end of 2010, other countries (“followers”, such as some Eastern European and Scandinavian countries) were lagging behind with coverage levels at 10 and 25%. The majority of countries (“starters”, including e.g. Germany) still show coverage levels of around 1%. NGA coverage in the US (~ 6%) is significantly above the European average level (~ 3%) by the end of 2010 (in terms of homes connected, see Figure A1 in the Appendix).

Our paper represents the first European-based attempt to quantify the determinants of recent and actual NGA deployment. Based on an unbalanced panel of 27 European member states during the period of 2005 to 2010, this paper addresses the following research questions: i) What is the relation between relevant ex ante regulation on broadband markets and the extent of NGA deployment? ii) How do competition and relevant demand and supply side factors in related markets influence the extent of NGA deployment? iii) Finally, we are interested in the dynamics and the adjustment process of NGA

1 According to “Nielsen´s Law” bandwidth demand grows by 50% each year.

2 Total investments for a nationwide NGA deployment add up to billions of Euros (wik consult, 2008).

3 The subject area is yet more extensive than it might appear at first glance, because a systematic fiber-based roll-out is no longer just a matter of traditional telecommunications operators. Rather, public and municipal utilities from other network industries as energy and transport might have opportunities and incentives to expand their product portfolio into the telecommunications sector.

4 For evidence on the positive impact of broadband deployment on employment, productivity and economic growth, see for instance Röller and Waverman (2001), Crandall et al. (2007) or Czernich et al. (2011).

deployment and the corresponding short and long run effects. It should be emphasized here that our focus is on NGA deployment/investment only, not on welfare.[5]

Our empirical specification incorporates country level data where estimates are obtained through various dynamic panel methods. Applying GMM as well as LSDVC estimation techniques explicitly accounts for the endogeneity bias arising from the dynamic investment specification. Furthermore, we argue that there is no endogeneity problem with respect to investment activities and regulation in our case, as we relate the effectiveness of access regulation imposed years ago on the preceding broadband market to investment activities in an emerging (NGA) market. Any specific forms of NGA regulation will be defined and imposed by European regulators only in future decisions or, if already implemented, the effectiveness of these decisions remains to be seen.[6] Methodologically, we therefore care about both sources of endogeneity problems which are only partly, if at all, addressed in the literature; for instance, Grajek and Röller (2011), who are among the few to explicitly account for endogeneity between investment and regulation, ignore the dynamic endogeneity bias. Multiplicity of methods as well as a broad set of explanatory variables and controls serve as important robustness checks and should take account of our small-sized data set.

One of the most controversial regulatory issues in Europe (and elsewhere) is whether NGA infrastructure should be subjected to sector specific regulation or not. Former – mostly state-owned – telecommunications monopolists ("incumbents") argue that sector-specific ex ante regulation restricts their ability to generate future revenues. Accordingly, fiber roll-out could only, if at all, be done on the basis of deregulation of relevant markets; at least a temporary removal of ex ante obligations ("regulatory holidays") is deemed to be essential. Regulation of network access would, in turn, be detrimental to investment incentives and infrastructure innovation. Conversely, alternative operators who are dependent on access regulation ("service-based entrants") as well as national regulatory authorities (NRAs) fear the rise of another monopolistic infrastructure, if regulation is released or removed entirely. They argue that incumbent firms or other alternative infrastructure operators would gain an essential and long-lasting competitive ("first-mover") advantage which implies the need to have an appropriate ex ante regulation in place. Whereas leading Asian countries take an interventionist and state aid driven approach, the US adopted a deregulatory and primarily market-driven strategy which was initiated by the Federal Communications Commission´s „Brand-X decision" in August 2005. The European Union (EU) framework is in between as it relies on

[5] However, we do think that more investment is better also from a welfare point of view. In telecommunications, the "Averch-Johnson" effect (too much capital employed) can be expected to be very small due to ex ante regulation and related service-based competition as well as intermodal infrastructure competition that have established for more than ten years. Moreover, we can expect huge positive externalities as a result of NGA investment (OECD, 2009).

[6] In 2010, a few European countries started to introduce regulations on wholesale broadband access over NGA (such as Belgium, Denmark, Italy, Netherlands or Spain), on fibre unbundling (Finland and Netherlands) or on NGA specific capital costs (Netherlands); see Cullen International (2010, Tables 4, 9 and 10).

competitive market forces subject to a set of strict sector-specific regulations (see Huigen and Cave, 2008). We cannot finally resolve this debate but, in line with related literature (see Cambini and Jiang, 2009, for a survey and Nitsche and Wiethaus, 2011, and Klumpp and Su, 2010, for recent theoretical treatments of the various trade-offs), our results indicate that the stricter broadband access regulation is, the lower is NGA infrastructure roll-out.

The remainder of the paper is organized as follows: First, we review the telecommunications related literature on regulation and investment in section 2. Section 3 briefly provides necessary background information on the technical and regulatory context of NGA. Section 4 describes basic hypotheses concerning investment incentives on the one hand and the scope of sector-specific regulation and competitive intensity on the other hand. Section 5 outlines the data basis underlying our empirical examination. Section 6 presents the empirical specification and related econometric issues. Section 7 describes and interprets the main results. Section 8 summarizes and compiles most relevant aspects for future regulatory policy.

2 Literature review

Although there are a number of scientific studies that examine the impact of fixed-network regulation on traditional broadband or telecommunications deployment in total, there are actually no empirical studies which focus on the impact of regulation and competition on NGA deployment. There are, however, a few theoretical contributions related to NGA deployment and the involved efficiency trade-offs, which we review first.

Using a game-theoretic framework, Bourreau et al. (2011) analyze the incentives for incumbents and entrants to migrate from old technologies to NGA networks. They find that NGN investment incentives are affected by access regulation charges on the old copper networks via three negative effects: a replacement effect, a wholesale revenue effect and a business migration effect. Lowering the charges would reduce the wholesale revenue effect but increase the other two effects. Nitsche and Wiethaus (2011) analyze the effects of different regulatory regimes on investment incentives and welfare and find that a regime of fully distributed costs or regulatory holidays is most positive for investment, while their simulations show that a risk-sharing approach is best from a welfare point of view and that long run incremental cost regulation – the EU benchmark – is least conducive to investment. Brito et al. (2010) address the problem of investment in NGA and two-part access tariffs by solving static and dynamic trade-offs. In a similar way, but not related to NGA investment, Klumpp and Su (2010) show that access regulation does not automatically imply that dynamic efficiency must be sacrificed for gains in static (allocative) efficiency. Bender and Götz (2011) model broadband competition between an incumbent and an entrant firm which provide broadband access in regional markets with different population densities. They argue that the usual trade-off between static and dynamic efficiency does not apply, since higher regulated access fees increase facility-based competition, decrease retail prices and increase total demand.

Early related empirical studies concentrate mostly on U.S. experience with wholesale access regulation, suggesting that regulated cost-based access charges would reduce investment incentives for incumbents and for competitive bypass (e.g. Chang, Koski and Majumdar, 2003; Ingraham and Sidak, 2003; Crandall et al., 2004). More recent work exhibits similar results: Using data on European countries for the years 2002 to 2006, Waverman et al. (2007) show that the intensity of wholesale broadband access regulation negatively affects broadband infrastructure investment. However, the authors do not use any NGA specific data and their estimate on total broadband investment is derived from a simulation exercise. Grajek and Röller (2011) as well as Friederiszick et al. (2008) investigate the relationship between regulation and total investment in the telecommunications industry. These two studies are among the few which explicitly account for the endogeneity problem of regulation and investment. Investment, however, is quantified therein rather broadly by the tangible fixed assets of telecommunications operators and, thus, does not explicitly refer to broadband, let alone NGA deployment. Wallsten and Hausladen (2009), though, estimate effects of broadband access regulation on NGA connections within the EU. However, they only look at regulatory and income effects, but not at competition or any supply side variables. They use data from the EU's Communications Committee for the years 2002 to 2007, which is highly fragmentary and only covers the NGA roll-out at the very early stage. Moreover, their dependent variable reflects the number of homes connected instead of homes passed which does not account for lines actually deployed but not being used, and thus does not reflect real investment activities. Finally, other non-US based work measures the impact of access regulation on broadband penetration (e.g. Wallsten, 2005, 2006; DiStaso et al., 2006). Cambini and Jiang (2009) survey the empirical literature and find that the majority of the studies conclude that cost-based access regulation discourages both incumbents and alternative operators from investing in fixed networks.

Summarizing, the general trade-off between static and dynamic efficiency is well recognized in the theoretical as well as empirical literature. However, all previous empirical studies suffer from too broad or unsuitable measures of NGA investment to truly inform the debate on the optimal regulation and competition policy towards NGA infrastructure. Our work is the first that explicitly employs a direct measure of real and most recent NGA investment.

3 Institutional framework

Historically, legacy networks[7] deployed twisted copper-wire pairs to overcome the last mile ("local loop") to the subscriber. Originally, these networks were set up to provide narrow bandwidth voice telephony services (POTS/ISDN) only. Many decades later, they were made capable of supporting

[7] This term refers to networks already in existence, which were formerly owned by incumbent operators.

broadband services by means of DSL transmission technology.[8] In EU member states, where sector-specific regulation is in place, alternative operators can rent the local loop from the incumbent operator based on cost-oriented wholesale charges ("unbundling"). This allows alternative operators to use their own DSL equipment to provide (first of all) broadband services. Alternative operators may also offer retail broadband services by purchasing "bitstream" as a wholesale service from the incumbent operator. Just like unbundling, bitstream is usually associated with DSL services but at a more service-based level of the value chain. Finally, wholesale broadband access via simple resale services means that access seeking operators receive and resell a wholesale input of the incumbent operator without any scope of technological product differentiation, i.e., value added features only refer to the retail level, such as branding (see RTR, 2010, pp. 176, 179).

However, due to technical reasons, bandwidth of DSL technologies is rather limited. In order to realize significantly higher bandwidth, it is necessary to shorten the length of the copper-based local loops by placing the DSL transmission equipment closer to the retail customers' premises, e.g. in the cabinets which house distribution frames. Deployment of DSL transmission systems in such a cabinet and connection to the fiber-based backbone network is referred to as "fiber to the curb/cabinet" (FTTC). In the remaining copper-wire line of the last mile, VDSL is used as the latest DSL transmission technology. This solution can provide bandwidths of approximately 20 Mbit/s to 50 Mbit/s. Even higher bandwidths (above 100 Mbit/s) can be achieved if the final copper-wire line is shortened further. Fiber to the building (FTTB) is an implementation scenario in which the optical fiber is extended to or into the building. Only the remaining wiring inside the building relies on conventional copper-wires. In cases where technical or economic considerations render it feasible to renew or replace in-house wiring, it is possible to eliminate copper lines entirely. In such a scenario, the optical line is directly connected to the individual apartment or home ("fiber to the home" - FTTH). From a technical point of view, this form of implementation would be the ideal solution, as it would enable a large number of future services with nearly unlimited bandwidth. Therefore, FTTH can be regarded as the most future-proof technological solution (see RTR, 2010, pp. 189-191).

In addition to the conventional copper-wire networks, the roll-out of high-speed communications networks might also be realized via cable television networks (based on hybrid-fiber coaxial cable) and mobile networks. The latest cable transmission technology already allowed for bandwidths of approximately 150 Mbit/s. The mobile communications industry expects the future deployment of Long Term Evolution (LTE)[9] technology to be able to offer data transmission rates in the same range.

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[8] Digital Subscriber Line is a family of technologies (xDSL) that provides digital data transmission over the wires of a local telephone network. The data throughput typically ranges from 256 KB/s to 50 Mbit/s in the direction to the customer (downstream), depending on DSL technology, condition and length of the local loop, and service-level implementation.

[9] Mobile broadband access is already facilitated by the previous mobile technologies GPRS, EDGE, UMTS und HSDPA. Currently, LTE is in the test phase in a number of countries, mainly in urban areas.

Although both last mentioned technologies heavily rely on fiber in their backbone networks, only coaxial cable is of current relevance as a substitute NGA technology.

Since access networks branch out in a tree-like structure as they approach the final consumer, renewing access infrastructure involves fewer customers as one gets closer to the final consumer and higher average cost per customer. Investment in the access network therefore heavily depends on "economies of density", that is, a high density of customers will bring about lower average costs.[10] Finally, the different scenarios of fibre deployment will come along with varying degrees of sunk and adjustment costs: Compared to duct costs and fiberglass, digging costs are of major importance (60-80% of total costs) and are largely and literally sunk in nature (ERG, 2007, pp. 16-17). Also, roll-out of a new infrastructure is rather time-consuming as it involves complex technical network planning, and legal issues (such as rights of way and other allowances) have to be resolved beforehand.

4 Hypotheses

This section identifies determinants for previous NGA deployment in Europe (EU27) and sets out corresponding hypotheses, which are aligned to the research questions outlined in the introduction.

4.1 Regulation

As regards NGA development, investing firms are confronted with significant capital outlays as well as great uncertainty and high risks which affect investment decisions negatively. This is due to the high degree of sunk investment, long amortization periods (20-25 years) of network infrastructure,[11] the technical risk of the new technology and the economic risk of unknown demand for new services against the backdrop of consistently decreasing prices. Ideally, in the future design of optimal regulation, NRAs would take these risk factors into account in a way which simultaneously promotes static and dynamic efficiency and consumer welfare.[12]

Regulatory intervention may influence investment incentives in several ways. In the EU, regulated wholesale broadband access prices are usually based on diverse cost-oriented standards, where firm risk is included and measured by the NRA within the scope of the firm´s capital costs (see Cullen International, 2010, Tables 10, 15-16). On the one hand, we have to consider the direct effect of access regulation on infrastructure operators. Tight regulation of existing broadband access products will most likely create corresponding expectations about future regulation of NGA access products and

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[10] The extensive study of wik consult (2008) gives a good insight into this topic.

[11] Incumbent operators owning legacy networks are confronted with a largely depreciated infrastructure. From this situation, the costs of second generation networks are not sunk before the investment decision is actually made. However, foreseen sunk costs will delay or make any future investment even unprofitable (see Cave and Martin 2010, p. 1).

[12] The need to compensate for increased risk was explicitly mentioned by the European Commission (2009, Art. 3, p. 9, Art. 22, p. 13 and Annex I, pp. 17-20).

thus stricter access regulation will reduce investment activities since i) imposing cost-oriented prices for bottleneck inputs will typically reduce profits or preclude excess profits of the regulated firm which results in an asymmetric distribution of expected profits and therefore in a lower net present value of investment projects (Valetti, 2003). Furthermore, regulated infrastructure operators criticize that ii) access regulation ignores opportunity costs of real options[13] (Guthrie, 2006) and that iii) risks were distributed asymmetrically as service-based operators benefit at the same time from a risk-free option due to mandatory access obligations imposed on the incumbent operator (Pindyck, 2007).

Moreover, risks associated with legacy networks were deemed to be not much different from the overall company risk. Thus, the total risk resulting from NGA investment has not been appropriately considered to an NGA specific extent so far. Furthermore, pending decisions on future design of ex ante regulation of NGA access already lead to considerable regulatory uncertainty. As already mentioned, according to Nitsche and Wiethaus (2011), a regime of fully distributed costs or regulatory holidays would have the most positive effect on investment, whereas the current cost-standard, based on long run incremental costs, turns out to be inferior.

On the other hand, the EU regulatory framework for electronic communications tried to resolve the trade-offs on the subject of dynamic and static efficiency with reference to the so called "ladder of investment" (Cave and Vogelsang 2003; Cave 2006). According to this hypothesis, NRAs should initially encourage alternative operators to engage progressively in backward integration after having entered the market as simple resellers on the basis of cost-oriented charges. With respect to wholesale broadband access, resale and bitstream should have facilitated quick and easy market entry during the first stage of liberalization, followed by an increasing migration towards unbundling and ultimately self-deployed infrastructure investment. The latter would constitute the highest rung of the ladder where alternative operators were fully integrated and did not depend any longer on ex ante access obligations. Thus, at the bottom of this principle, there is the vision of a continuous transition path from monopoly towards self-sustaining competition, with ex ante regulation being only a necessary intermediate phase. The dynamics of the transition can be influenced by NRAs via availability of access instruments and the level of access charges during the liberalization process. However, previous forms of wholesale broadband regulation based on unbundling, bitstream access and resale obligations were related to legacy networks and, thus, have only provided rather indirectly effective instruments for alternative operators. Moreover, there has been hardly any convincing empirical support for the ladder of investment concept so far (Waverman et al., 2007, p. 7; Friederiszick et al. 2008, p. 8). In reference to past market outcomes, we did not observe such a continuous development for fixed-link network services. Especially, due to the natural monopoly characteristics of the last mile, reaching the

[13] These include for example the risk of bypass investments of alternative service-based providers and/or the corresponding decrease in demand. If the value of real options is not included in the access price, this leads to a distortion to the disadvantage of infrastructure operators.

goal of infrastructure-based competition (last rung of the ladder) was largely forestalled.[14] The dynamic concept of transition from service-based towards infrastructure-based competition becomes even more unlikely against the backdrop of NGA deployment, as economic replicability is even lower.[15]

Summarizing, we do not expect a positive dynamic and indirect impact of broadband regulation on NGA deployment via service-based competition as idealized by the ladder of investment hypothesis. Also, the direct impact of access regulation on infrastructure-based operators is likely to be negative and, therefore, the stricter access regulation is, the lower will be NGA infrastructure investment.

4.2 Competition

Basically, the following relevant competition effects can be identified: First, a "business migration effect" (Bourreau et al., 2011) appears at the retail level, because NGA investments would "cannibalise" quasi-monopolistic profits from preceding broadband services and thus reduces profitability and the incentive to invest. With higher levels of competition, this replacement effect becomes less important as economic rents will be eliminated.[16] Second, competitive markets bear incentives for innovation by giving the innovator the chance to jump ahead of rivals and earn temporary market power rents. This so-called "escape competition effect" will lead to a positive relation between competition and investment, if there is a reasonable threat of another firm investing in capturing these rents. However, a state close to perfect competition will eventually reduce potential rents and, thus, increasingly counteract investment because operators are not able to generate necessary profits from innovation. This appropriability effect can, third, be referred to as "Schumpeterian". Indeed, Aghion et al. (2005) showed that in view of these multiple effects an inverted U-shaped relationship is to be expected with respect to investment and competitive intensity.

In the context of NGA deployment, one might expect a non-linear relation for a similar line of reasoning. Telecommunications, by all means, has become one of the most dynamic industries after the electronic communications markets have been liberalized. Likewise, recent and future investment in NGA is driven by competitive pressure, most notably, from cable and mobile networks, which "threaten" copper-wire networks as regards new broadband services. At the same time, well-

[14] With respect to traditional broadband services, empirical evidence (Höffler, 2007) suggests that broadband deployment was predominantly triggered by infrastructure-based competition with service-based competition relying on regulated DSL-services playing a secondary role.

[15] See the discussion on replicability in Section 2. Also, it is unlikely that service-based entrants will initiate a "race" to update infrastructure as suggested in the context of pre-emption strategies (e.g. Gans, 2001).

[16] Considering regulated broadband access services, there might be also a replacement effect at the wholesale level at work: The tighter, i.e., the stricter wholesale access for the incumbent´s DSL products is regulated, the lower will be profits and the replacement effect. However, expectations about future regulation of NGA products would again counteract that wholesale replacement effect. We will combine these effects at the wholesale and retail level and refer to them as "total replacement effect". See Bourreau et al. (2010) for a more general description of the replacement effects in the communications industry.

established infrastructure-based competition can counteract investment in NGA by making NGA projects riskier with lower expected profits or even loss-making. As Bauer (2010, p. 69) concludes, the actual pattern is still to be explored: “[t]he empirical shape of this relation for the next generation network […] is not known and will only be revealed over time.”

Summarizing, due to the existence of these opposing effects, we expect a non-linear relationship between the intensity of infrastructure-based retail competition and NGA investment.

4.3 Dynamic, demand and supply side factors

The level as well as the speed of NGA deployment will also be influenced by variables related to consumer demand and (adjustment) costs of the infrastructure roll-out.

Costs will crucially depend on population or household density and topographic characteristics. Civil engineering and construction costs (including in-house wiring) represent by far the most relevant cost drivers for NGA deployment. Furthermore, costs will be determined by a variety of institutional factors such as rights of way or other allowances and technical standards and specifications which are partly still an open issue. Therefore, it is likely that adjustment to desired infrastructure investment levels will take place only gradually over time.

Demand and willingness to pay will depend on the overall market size in terms of relevant telecommunications and ICT expenditures and consumer wealth in general. Whereas traditional voice telephony exhibits fairly stable demand, demand for high-speed broadband services is much more uncertain and seems to have more luxury characteristics (Muselaers and Stil 2010, p. 6). Finally, demand for access to NGA services and usage intensity will also be driven by the quality and the degree of innovation of NGA based broadband services.

5 Data and variables

We use the following data sources: The “Progress Report on the Single European Electronic Communications Market” (sequentially referred to as the “EU Progress Report”) provides yearly data on all the relevant regulatory variables on wholesale broadband access as well as cable and DSL related data for our competition variables for the period of 2005-2009.[17] Our second main source is the database of FTTH Council Europe,[18] which includes bi-annual numbers of deployed NGA lines for all

[17] Source: http://ec.europa.eu/information_society/policy/ecomm/library/communications_reports/index_en.-htm and http://ec.europa.eu/information_society/digital-agenda/scoreboard/library/index_en.htm.

[18] FTTH Council Europe is a non-profit industry organisation, whose aim is to enforce deployment of fibre optic technology in Europe. Their data are collected by IDATE through desk research, direct contacts with FTTx players, information exchange with FTTH Council Europe members and from IDATE partners and are available to all members of the organization.

EU27 member states for the period of 2006-2010.[19] EUROSTAT[20] provides data on ICT expenditures and labor costs. We also use the International Telecommunications Union (ITU) "World Telecommunication/ICT Indicators Database"[21] for survey data on the percentage of population using mobile internet services via 3G and the percentage of heavy internet users. Finally, World Bank's "World Development Indicators"[22] and the "World Economic Outlook" of the International Monetary Fund (IMF)[23] provide us with the percentage of people living in urban areas and GDP per capita. As data availability varies by variable, we use an unbalanced panel data set of EU27 member states for the time range of 2005-2009 for yearly data provided by the EU Progress Report, EUROSTAT, ITU, World Bank and IMF and 2006-2010 for the data provided by the FTTH Council Europe. Descriptive statistics are reported in Table A1 in the Appendix.[24]

5.1 Dependent variable

In line with the technical description in section 2, our dependent variable represents the number of homes passed by FTTx[25] in per capita terms and, thus, real investment in physical units. The term "homes passed" refers to the number of households that have access via FTTx, but need not have a corresponding retail contract. The number of homes passed therefore significantly differs from the number of homes connected, which is the amount of households exhibiting sufficient willingness to pay and actively using one of the FTTx-technologies. Our dependent variable directly reflects the existing NGA infrastructure stock which we consider the most suitable proxy for both empirical as well as conceptual reasons.[26]

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19 Source: http://www.ftthcouncil.eu/resources?category_id=6.

20 Source: http://epp.eurostat.ec.europa.eu/portal/page/portal/information_society/data/database.

21 Source: http://www.itu.int/ITU-D/ict/publications/world/world.html.

22 Source: http://data.worldbank.org.

23 Source: http://www.imf.org/external/ns/cs.aspx?id=28.

24 Less than 1% of our data had to be created by using linear interpolation. Results are virtually the same if we use the raw data.

25 This includes FTTH/B, Fibre to the curb, VDSL, VDSL2, Fibre to the last amplifier (cable and FTTx/LAN). Full definition available at: http://s.ftthcouncil.org/files/FTTH-Definitions-Revision_January_2009_0.pdf.

26 For instance, using the firm level investment to capital stock ratio on the left hand side, as seen in the literature, would not provide us with NGA specific investment activities which we are interested in, but typically with investment in a broad mixture of telecommunications segments such as backbone, traditional wireline, broadband or even wireless networks. Conceptually, we argue that any normative objectives concerning the socially optimal infrastructure stock are much more likely formulated in real terms (percentage of population/households to be reached) as opposed to a certain monetary investment amount; see, for instance, the guidelines of the European Commission (2010, section 2.4) on the "digital agenda".

5.2 Independent variables

We can divide the explanatory variables into the following three categories: regulation, competition and control variables, with the latter focusing on demand and cost shifters. All variables and their sources are listed in Table A2 in the Appendix.

Our **regulation** variable, *ms_reg,* reflects the percentage use of total regulated wholesale broadband lines (including unbundling, bitstream and resale) related to total retail broadband lines. Therefore, this variable not only includes all relevant instruments of wholesale broadband regulation as outlined in section 2, it also provides a direct measure for their effectiveness at the same time by counting the percentage of lines actively used by service-based competitors.[27] Furthermore, as outlined in section 1, it can be argued that the effectiveness of regulation of the "old" network infrastructure, *ms_reg,* is exogenous with respect to the "new" infrastructure. We expect a negative sign on *ms_reg*, since tight access regulation of existing broadband services creates corresponding expectations on future NGA access regulation on the part of infrastructure operators. Also, the ladder of investment hypothesis is unlikely to become effective in terms of inducing service-based operators to engage in NGA infrastructure investment activities.

Competition is measured in two ways which account for the two main forms of infrastructure-based competition: *ms_cable* is the ratio of cable connections provided by entrant cable operators in the fixed broadband market to the total number of cable connections plus fixed DSL lines provided by both, incumbents and entrants. The second competition variable, *iu3g,* states the percentage of people using 3G technologies (such as UMTS and HSDPA) to access the internet. These variables measure the competitive pressure stemming from fixed and mobile broadband services. The overall effect of these competition variables is ambiguous due to the opposing "Schumpeterian" and "escape competiton" effects. Thus, we expect a non-linear, inverted-U-shaped relationship with respect to *ms_cable* and *iu3g*.

Finally, *dsl_share,* the percentage of DSL lines run by the incumbent to total broadband lines, directly measures to what extent fixed broadband competition is based on the incumbent´s conventional xDSL technology. As outlined in section 4.2, the effect of this variable is ambiguous as well.

Demand and **cost shifters** are included as control variables. GDP per capita, *GDP_pc,* captures income effects throughout our country set. Information technologies expenditures, *ict_exp*, act as a proxy for the market size of the ICT industry and thus for the overall willingness to pay for broadband

[27] As a consequence, we do not have to rely on broadly defined indices, dummy-based scorecards or other proxies which are commonly used in related literature but are hardly related to fixed broadband wholesale access regulations (such as the OECD regulatory index for the telecom sector). Grajek and Röller (2011) use Plaut´s regulatory index which explicitly covers broadband regulations, though, but it is available only until 2006. Moreover, that index does not consider the substantial differences as regards the actual importance of the individual broadband access regulations.

services in a country. Furthermore, we include the variable *iday* which provides the share of population that uses the internet frequently.

The share of a country´s urban population, *ratio_urban,* reflects different cost structures due to varying shares of rural and densely populated areas. The variable *lab_cost* gives an annual labor cost index normalized to 100 in 2005 and should serve as another cost proxy for infrastructure roll-out.

Finally, we include **country fixed effects** controlling for time invariant and unobserved heterogeneity. Most notably, NGA relevant and country specific differences might be related to certain cost conditions such as rights of way, regulations on digging, local availability of ducts and dark fiber, different levels of (regulated) capital costs or topographic and demographic characteristics. Demand and supply will also be influenced by state aid policies which show hardly any variation with regard to the time frame of our data set.

6 Empirical specification

6.1 The model

In our baseline model, the log of homes passed by FTTx normalized to population is our dependent variable. We use a dynamic approach to incorporate investment and deployment patterns appropriately. As the literature (e.g. Friederisczek et al. 2008; Cambini and Rondi 2010; Greenstein et al. 1995) suggests, sufficient static models are not appropriate, as these would only account for effects that have an immediate impact on the infrastructure stock. Rather, one wants to differentiate between long-run and short-run effects. Therefore, we use a partial adjustment approach as our econometric model, as firms are most likely not able to adjust their infrastructure stock to prevalent market conditions within one period. Thus, shocks today not only affect the current infrastructure stock, but also the stock in future periods, where the adjustment to a long-run optimal infrastructure stock is only gradual over time. This target per capita infrastructure stock is given by

$$(1) \qquad Fttx_{it}^{*} = X_{it}\beta' + \theta_i + \epsilon_{it},$$

where $Fttx_{it}^{*}$ reflects the long-run optimal infrastructure stock for country *i* at time *t*, X_{it} is a matrix of explanatory variables, the θ_i are the country-specific fixed effects and ϵ_{it} is an error term assumed to be i.i.d. We assume that the change in infrastructure stock follows a partial adjustment process which reads

$$(2) \qquad Fttx_{it} - Fttx_{i,t-1} = \alpha'\left(Fttx_{it}^{*} - Fttx_{i,t-1}\right) + \mu_{it}\ .$$

Every period, α' percent of the gap between the desired and actual infrastructure stock level is closed, with α' being the speed of adjustment, and $0 < \alpha' < 1$. Substituting (1) in (2) yields the empirically testable equation

$$(3) \qquad Fttx_{it} = \alpha Fttx_{i,t-1} + X_{it}\beta + \alpha'\theta_i + u_{it},$$

where $u_{it} = \alpha'\epsilon_{it} + \mu_{it}$ and $\alpha = 1 - \alpha'$, $\beta = \alpha'\beta'$. Short-run effects are given by β and estimates of β' $(= \frac{\beta}{\alpha})$ reflect the long-run effects of the X_{it} on the desired infrastructure stock.

In our empirical baseline specification, equation (4), we use lagged explanatory variables, because usually firms need some time to react to changing market or regulatory policy conditions:[28]

$$(4) \qquad Fttx_{i,t} = \beta_0 + \alpha\, Fttx_{i,t-1} + \beta_1 ms\_reg_{i,t-1} + \beta_2 ms\_cable_{i,t-1} + \beta_3 ms\_cable^2_{i,t-1} + \beta_4 iu3g_{i,t-1} + \beta_5 iu3g^2_{i,t-1} + \beta_6\, iday_{i,t-1} + \beta_7 gdp\_pc_{i,t-1} + \beta_8 ict\_exp_{i,t-1} + \beta_9 urban\_pop_{i,t-1} + \beta_{10} dsl\_share_{i,t-1} + \theta_i + \vartheta_t + u_{it},$$

where $Fttx_{it}$ is the actual number of homes passed per capita in country *i* at time *t* which is related to our set of independent variables. The θ_i and ϑ_t are country-specific and time-specific fixed effects, respectively, and u_{it} are the error terms assumed to be i.i.d.

6.2 Econometric issues

Using panel data allows us to take into account both, unobserved (country) heterogeneity and the dynamics of investment behaviour. However, estimating equation (4) by means of a fixed-effect (within or LSDV) estimator would yield inconsistent and biased results, since the lagged dependent variable and the fixed effects error terms would be correlated (Nickell, 1981). Bruno (2005) developed a bias-corrected LSDV estimator (LSDVC) for unbalanced panel data, which can be used if there is no endogeneity problem. Other methods are the general method of moments difference estimator (GMM-DIF) developed by Arellano and Bond (1991) and the general method of moments system estimator (GMM-SYS). Arellano and Bover (1995) and Blundell and Bond (1998) show by Monte Carlo analysis that their GMM-SYS estimator, using a system of first-differenced and levels equations, has a smaller bias than GMM-DIF for finite samples. In order to account for a potential unit root problem, we took the logarithm of the left hand side and the lagged dependent variables.

Related literature (e.g. Grajek and Röller 2011) suggests that reverse causality between regulation and investment has to be expected in general, as NRAs are likely to react to firm's previous investment decisions and the corresponding infrastructure stock today. However, in this paper we do not look at the impact of NGA regulation on NGA investment, but on the impact of previous regulation of (conventional) broadband services (based on DSL) on NGA investment. The usual objection that investment in one market influences the regulation of the same market, is thus not valid in our case. Indeed, one can hardly imagine that the current NGA deployment influences previous regulation on broadband markets which has been implemented by NRAs typically many years ago. At the same

[28] Therefore, we can assume that investment made at particular points in time is dependent on last year's conditions and it makes good sense to use a data set, where the right hand side variables are lagged once compared to the dependent variable.

time, previous regulation on broadband markets is a rather reasonable proxy for expected NGA regulation, inasmuch as it represents the most related remedial measures within the sector-specific EU framework for electronic communications markets. Furthermore, by lagging the explanatory variables, we relate NGA deployment to the effectiveness of previous broadband regulations. This should already eliminate any endogeneity problem. In order to underline this argument, however, we will perform Granger causality tests (see for instance, Cambini and Rondi, 2011).

7 Discussion of main results

The main results are reported in Table 1. Regressions (1)-(4) show estimation results of GMM-DIFF, GMM-SYS, LSDVC and Fixed Effects (FE) models. Our GMM models employ t-2 and t-3 lags of the dependent variable as internal instruments. Endogenous variables lagged two or more periods will be valid instruments provided that there is no second-order autocorrelation in the first-differenced idiosyncratic error terms.[29] The Sargan test does not suggest rejection of the over-identifying restrictions at conventional levels. The AR(1) as well as the AR(2) test statistics reveal absence of first and second order serial correlation in the first differenced errors. Both, GMM estimations as well as LSDVC, deal with the dynamic panel bias which is due to the lagged dependent variable on the right hand side of equation (4). Direct comparison with FE results shows that this kind of dynamic bias seems to matter substantially throughout our baseline model specification.[30]

Our results show a significantly negative coefficient on our regulatory variable (ms_reg_{t-1}) throughout all model estimations in Table 1 (regressions (1)-(4)). This strongly supports our hypothesis outlined in section 4.1, that stricter previous ex ante regulation lead to a negative impact on NGA infrastructure investment. Hence, it appears that the expectations on future NGA related regulation clearly outweigh potential dynamic efficiency gains via service-based competition as stipulated by the ladder of investment hypothesis.[31]

In order to examine our presumption on the exogeneity of our regulatory variable (ms_reg_{t-1}), we carry out Granger causality tests using GMM-SYS and LSDVC which are reported in Table A4 and in Table

[29] Due to the possible problem of too many instruments we restrict the number of lags used as instruments at a maximum of two.

[30] In contrast, Grajek and Röller (2011) “found little difference” between LSDV and LSDVC estimates and thus concluded that the dynamic bias can be ignored. Indeed, it seems to be quite obvious that using a broadly defined measure of investment (fixed tangible assets) implies much less stickiness and adjustment costs compared with a direct measure of real NGA investment.

[31] When including the squared term of *ms_reg*, both, *ms_reg* as well as ms_reg^2 appear to be insignificant. This indicates that *ms_reg* reflects expectations about regulatory policies rather than effectiveness of service-based competition, where, similarly to cable and mobile competition, a non-linear relationship could be expected in advance. Results are available from the authors upon request.

A5 in the Appendix. The results obtained therein do not give any indication of a reversed causality pattern between NGA deployment and broadband regulation or competition.

The magnitude of the coefficient on the lagged dependent variable indicates inherent inertia due to adjustment costs. This seems to be quite plausible with respect to diverse technological and economic impediments underlying the deployment of new infrastructure. As derived in section 6.1, the speed of adjustment is given by one minus the coefficient on the lagged dependent variable. Thus, our results suggest that around 40% of the gap to the desired infrastructure stock is closed in every period. Therefore, a shock today, e.g. a change in regulatory policy, has a long-lasting effect on the development of the infrastructure stock.

Our partial adjustment model allows us to disentangle short and long-run effects according to the model framework in section 6.1. With $\alpha' \cong 0.39$ for GMM-SYS and GMM-DIFF, the respective long-run coefficient (β' $(= \frac{\beta}{\alpha'})$) of each explanatory variable rises significantly which indicates substantial long-run economic effects. As regards the dynamics of the adjustment process, it would take around 4.6 years for the average European country to close 90% of the gap to the desired long-run infrastructure stock. The EU average desired infrastructure stock for FTTx is given by 21,2% of the population. It is interesting to contrast these numbers with the policy goals of the European Commission´s digital agenda. According to this guideline (i) all Europeans should have access to internet speeds of above 30 Mbps and (ii) 50% or more of European households should subscribe to internet connections above 100 Mbps by 2020 (European Commission, 2010, p. 19). Whereas this agenda seems to be realistic in terms of the scheduled time frame, it turns out to be rather optimistic with reference to the desired level of NGA infrastructure under current investment conditions.

As regards our infrastructure-based competition variables (ms_cable_{t-1}; $ms\_cable^2_{t-1}$; $iu3g_{t-1}$; $iu3g^2_{t-1}$), all estimation models show a non-linear relationship between cable as well as mobile competition variables and investment. The variables are significant in GMM and partially significant in LSDVC estimations. Broadband services of cable operators already exceed quality characteristics (such as bandwidth) of incumbents´ DSL or FTTC services at similar price levels. Mobile broadband technologies, in contrast, constitute a more complementary form of broadband access for narrow-bandwidth users and specific broadband services and, thus, have exerted much less competitive pressure in the past.

The maximum of the inverted U-shaped curve, showing the relationship between investment and competition, informs us about the optimal competitive market conditions for investment. For instance, one can infer from the corresponding coefficient estimates of our GMM-SYS model (regression (2)) that a market share of cable entrants and a mobile internet usage rate of around 22% and 9%,[32]

32 Respective values for regressions (1) and (3) are quite similar: GMM-DIFF: 19.3% (cable) and 9.1% (mobile); LSDVC: 16.5% (cable) and 6.4% (mobile).

respectively, are optimal for NGA investment. The average market share of cable entrants is 24.7 % in our data set and, thus, lies already above this optimum value for NGA investment. Contrary, the average penetration rate of mobile internet is 3.6% and thus well below the 9% threshold.[33] Therefore, in line with the remarks in sections 3 and 4.2, the Schumpeterian seems to outweigh the escape competition effect with respect to cable competition, while for mobile competition it is the other way round.

Our results indicate that, for example, in France, the country with the lowest cable penetration in 2010, an increase of cable penetration from 5,6% to the optimal level of 22% would lead to a mean increase of FTTx coverage of 21,6%. For a country like Hungary with cable penetration rates above this optimum level (43,3%), a further increase in cable competition of ten percentage points would reduce optimal FTTx coverage by 64%. Similarly, for a country like Romania, with a share of the population using high speed mobile services of as low as 0,6% in 2010, a rise up to the European mean of 3,6% would result in a mean increase of FTTX coverage of 22%.

With respect to the "total replacement effect", we could not find any significant evidence in our sample concerning the traditional broadband DSL services. Individual coefficients of the respective variable (dsl_share_{t-1}), which basically capture the incumbent´s DSL products at the wholesale and retail level, are reported in Table A3 in the Appendix.

Table A3 shows the results for a model containing also GDP (gdp_pc_{t-1}), and internet usage ($iday_{t-1}$) as further control variables. The coefficients of these variables are insignificant throughout our estimations and are therefore not included in the final results of Table 1. Comparing Table 1 with Table A3 reveals that the major results as regards regulation and competition are quite similar.

In line with our hypotheses in section 4.3, we find a significant positive impact of our demand variable (ict_exp_{t-1}) which captures willingness to pay for broadband services, using GMM estimation methods. However, the cost variable (e.g. $urban\_pop_{t-1}$) appears to be insignificant throughout all models. This might be attributed to the fact that country specific effects already take into account most of the explanatory power of this variable. Indeed, many NGA specific cost factors seem to be highly dependent on national circumstances and hardly vary across time (Neumann 2010, p. 6). Similarly, local labor costs (*lab_cost*)[34] do not exhibit substantial variation over our short time horizon which resulted in insignificant estimation coefficients.[35] Our presumption that fixed effects are largely driven

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[33] Of course, more intense competition could lead to more static efficiency and the optimum with respect to total welfare is unclear.

[34] Introducing *lab_cost* as a further cost proxy basically leaves the structure and significance of the main variables of interest unchanged. However, consideration of *lab_cost* would have brought about a significant reduction in the number of observations and thus further insignificancies. For this reason we decided to drop *lab_cost* from Table A3. Results are available from the authors upon request.

[35] Likewise, interest rates are fixed across most sample units (EU27 member states) and those show insufficient variation for estimation purposes.

by diverse cost factors gets reasserted as fixed effects estimates turn out to be highly negative throughout all observation units.

Table 1: Determinants of NGA investment (final model)

Dependent variable: log fttx	**(1) GMM DIFF**	**(2) GMM SYS**	**(3) LSDVC**	**(4) FE**
log $fttx_{(t-1)}$	0.610***	0.606***	0.576***	0.420***
	(0.000)	(0.000)	(0.000)	(0.000)
$ms\_reg_{(t-1)}$	-0.037**	-0.040*	-0.038*	-0.038**
	(0.042)	(0.083)	(0.074)	(0.040)
$ms\_cable_{(t-1)}$	0.452***	0.557***	0.280*	0.196
	(0.003)	(0.008)	(0.055)	(0.140)
${ms\_cable_{(t-1)}}^2$	-0.012***	-0.012***	-0.008***	-0.006**
	(0.000)	(0.001)	(0.003)	(0.032)
$iu3g_{(t-1)}$	0.304**	0.288*	0.066	0.218
	(0.019)	(0.052)	(0.735)	(0.142)
${iu3g_{(t-1)}}^2$	-0.017**	-0.016*	-0.005	-0.012
	(0.025)	(0.063)	(0.700)	(0.188)
$ict\_exp_{(t-1)}$	1.419*	1.808**	1.484	1.825
	(0.073)	(0.018)	(0.129)	(0.105)
$urban\_pop_{(t-1)}$	-0.150	0.056	0.586	0.491
	(0.783)	(0.319)	(0.261)	(0.118)
Constant	4.470	-12.310**		-38.550*
	(0.907)	(0.032)		(0.070)
AR(1) test p-value	0.651	0.597		
AR(2) test p-value	0.849	0.876		
Sargan-test p-value	0.949	0.827		
Wald(X^2)-test	93.08***	159.98***		
R-squared within				0.712
Number of observations	52	76	76	76

Regressions (1)-(4) include country-specific fixed effects which are not reported for brevity. We did not include year dummies, because they were not significant, neither jointly, nor individually. For the Arellano-Bond (AR(1) and AR(2)) tests and the Hansen-Sargan test of overidentifying restrictions, corresponding p-values are reported. P-values for estimated coefficients are reported in parentheses and are robust to heteroscedasticity and to within group serial correlation in GMM estimates. LSDVC standard errors are bootstrapped based on 300 iterations with bias correction for estimates up to order $o(1/NT^2)$; * $p < 0.10$, ** $p<0.05$, ***$p<0.01$

8 Conclusions and final remarks

In this paper, we determine the effects of regulation and competition on the infrastructure roll-out of next generation access networks in Europe. In doing this, we used a panel data set of EU27 member states on NGA investment as well as the main competition and regulatory variables. As opposed to previous related literature, our econometric specification does neither suffer from the dynamic panel bias nor from an endogeneity problem with respect to investment and regulation.

Our results indicate that previous NGA deployment is determined by the extent of infrastructure-based competition stemming from cable operators and mobile networks. Whereas the effect of competition corresponds to the inverted U-shaped hypothesis, stricter previous sector-specific broadband regulation has negatively affected NGA deployment, which largely accompanies with the empirical literature cited in section 2.

Although our work only provides preliminary conclusions, as NGA specific data are limited so far, these conclusions are of significant relevance for future regulatory decisions, as the setting of the regulatory agenda for network investment and innovation is currently to be implemented and specified by NRAs across most EU member states.[36] Considering sector-specific regulation, our results reaffirm recent US regulation adopting a deregulatory approach of broadband markets in 2005 and, since then, experiencing significantly higher NGA deployment levels and annual growth rates compared with the EU average (see Figure A1).

There are essentially two ways to achieve a fast and comprehensive NGA roll-out. First, market-based incentives, including US-like regulation strategies as, for example, regulatory holidays, are possible. Second, direct state subsidies as seen in many Asian countries and, more recently, in Australia and New Zealand, will be needed, especially to supply white areas with next generation networks. According to our results, applying neither of these and neglecting inherent trade-offs between static and dynamic efficiency as the EU suggests in their sector-specific regulatory framework, would not allow to achieve the ambitious goals.

If a quick deployment of NGA infrastructure is deemed to be of socio-economic importance, upcoming sector-specific regulation should thus be more accentuated towards investment incentives and reduce regulatory risk for infrastructure operators. As the "ladder of investment" hypothesis seems to be rather unlikely to hold in view of the economics of NGA networks, infrastructure-based competition should be at the heart of this regulatory process.

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[36] The reader is referred to the recent NGA related consultations of the European Commission on "costing methodologies for key wholesale access prices" and on "non-discrimination"; consultation documents (launched 3rd October 2011) are available at: http://ec.europa.eu/information_society/policy/ecomm/-library/public_consult/cost_accounting/index_en.htm.

Appendix

Figure A1: FTTH/B coverage in international comparison ("homes connected")

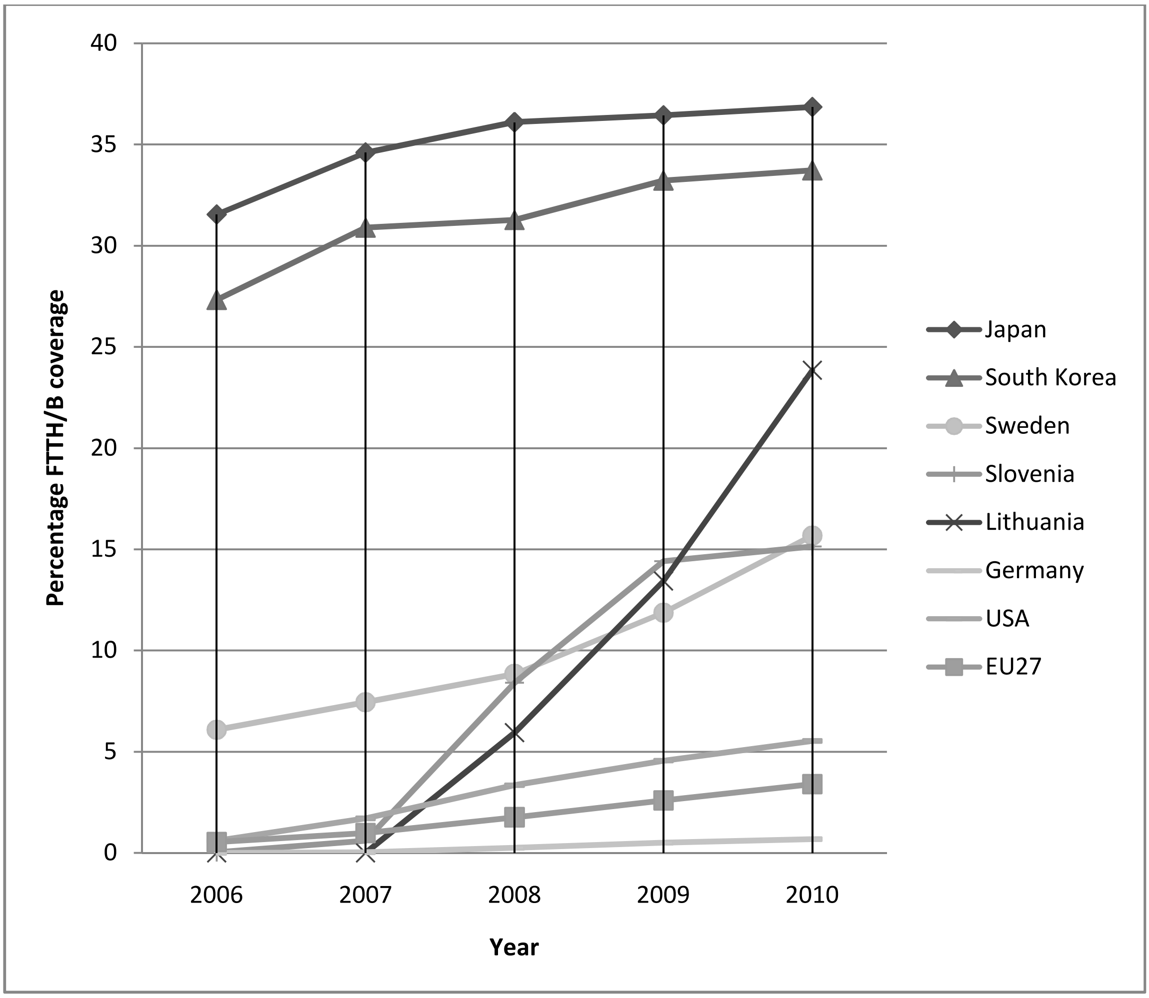

Figure A1 based on data by IDATE and FTTH Council Europe (2011). Some countries (such as Slovenia) already reached saturation, whereas other "followers" (such as Sweden and Lithuania) are still rapidly growing up to 2010. Japan and South Korea ("leaders") are still far beyond, especially when compared to the average level of the EU27 and the USA. Since there is a lack of data on FTTC for Asian countries, FTTH/B is used here instead of FTTH/B/C for comparison (for the technical definitions the reader is referred to section 3 and 5.1).

Table A1: Descriptive statistics

Variable	Number of observations	Mean	Standard Deviation	Min	Max
fttx	127	.0623	.091	0	.523
log(fttx)	111	-4.199	2.552	-10.539	-0.648
ms_reg	156	19.486	18.592	0	97.1
ms_cab	154	24.661	16.051	0	82.792
iu3g	132	3.592	3.867	0	20.4
dsl_share	158	66.628	20.568	7.257	99.585
iday	161	40.504	16.918	6.2	76.4
gdp_pc	162	30980.09	20829.53	3743.413	3743.413
ict_exp	101	2.047	.766	0	4.2
urban_pop	131	69.475	15.564	15.99	97.759
lab_cost	129	107.558	11.886	80.04	150.27

Table A2: Variable description

Variable	Description	Source
FTTx Homes passed/population, Fttx	Number of households with access to FTTx normalized to population	FTTH Council Europe
Effectivity of wholesale broadband regulation, ms_reg	Market share of regulated lines (local loop unbundling, bitstream, resale) related to total retail broadband lines	EU Progress Report
Cable broadband competition, ms_cable	Share of cable lines run by entrants related to cable and DSL lines run by both, incumbents and entrants	EU Progress Report
Mobile broadband competition, iu3g	Percentage of population using mobile internet services via 3G networks (UMTS or higher bandwidth)	ITU
DSL-share, dsl_share	Share of incumbent DSL lines to total broadband lines	EU Progress Report
Heavy internet users, iday	Percentage of population using internet services every or almost every day	ITU
GDP per capita, gdp_pc	Gross domestic product per capita in US$	IMF
ICT expenditures, ict_exp	Percentage of expenditures on information technologies of GDP	EUROSTAT
Urban population, urban_pop	Share of urban to total population, whereas urban population is defined by national statistical offices	World Bank Development Index
Labor costs, lab_cost	Annual labor cost index (for each country normalized to 100 in 2005)	EUROSTAT

Table A3: Results including GDP, DSL-share and internet use as additional control variables

Dependent variable: log fttx	(1) GMM DIFF	(2) GMM SYS	(3) LSDVC	(4) FE
log $fttx_{(t-1)}$	0.666***	0.720***	0.589***	0.377***
	(0.000)	(0.000)	(0.000)	(0.004)
$ms\_reg_{(t-1)}$)	-0.039**	-0.039*	-0.039*	-0.036**
	(0.026)	(0.053)	(0.081)	(0.012)
$ms\_cable_{(t-1)}$	0.437***	0.574***	0.247	0.125
	(0.000)	(0.002)	(0.134)	(0.389)
$ms\_cable^2{}_{(t-1)}$	-0.012***	-0.013***	-0.008**	-0.005
	(0.000)	(0.000)	(0.020)	(0.105)
$iu3g_{(t-1)}$	0.317**	0.356	0.015	0.145
	(0.032)	(0.107)	(0.942)	(0.379)
$iu3g^2{}_{(t-1)}$	-0.018**	-0.021*	-0.001	-0.008
	(0.038)	(0.094)	(0.935)	(0.412)
$dsl\_share_{(t-1)}$	0.067	0.030	0.110	0.106
	(0.346)	(0.694)	(0.154)	(0.151)
$iday_{(t-1)}$	-0.001	-0.033	0.019	0.046
	(0.832)	(0.408)	(0.675)	(0.407)
$gdp\_pc_{(t-1)}$	-0.000	-0.000	-0.000	0.000
	(0.787)	(0.453)	(0.952)	(0.696)
$ict\_exp_{(t-1)}$	1.193	1.592*	1.102	1.456
	(0.299)	(0.083)	(0.419)	(0.307)
$urban\_pop_{(t-1)}$)	-0.194	0.075	0.544	0.303
	(0.756)	(0.236)	(0.350)	(0.488)
Constant	4.642	-12.050		-34.120
	(0.913)	(0.119)		(0.243)
AR(1) test p-value	0.508	0.433		
AR(2) test p-value	0.588	0.583		
Sargan test p-value	0.822	0.796		
Wald($\boldsymbol{X}^2$)-test	227.52***	502.31***		
R-squared within				0.733
N	52	76	76	76

Regressions (1)-(4) include country-specific fixed effects which are not reported for brevity. We did not include year dummies, because they were not significant, neither jointly, nor individually. For the Arellano-Bond (AR(1) and AR(2)) tests and the Hansen-Sargan test of overidentifying restrictions corresponding p-values are reported. P-values for estimated coefficients are reported in parentheses and are robust to heteroscedasticity and to within group serial correlation in GMM estimates. LSDVC standard errors are bootstrapped based on 300 iterations with bias correction for estimates up to order o(1/NT2); * p < 0.10, ** p<0.05, ***p<0.01

Table A4: Granger causality tests (direction: reverse causality) – GMM-SYS

GMM SYS	(1)	(2)	(3)
Dependent variable	**ms_reg**	**ms_cab**	**iu3g**
log $fttx_{(t-1)}$	-0.00975	-0.00162	0.00130
	(0.460)	(0.380)	(0.300)
$ms\_reg_{(t-1)}$	0.944***		
	(0.000)		
$ms\_cab_{(t-1)}$		0.635***	
		(0.000)	
$iu3g_{(t-1)}$			1.273***
			(0.000)
_cons	0.000	0.068**	0.015**
	(1.000)	(0.012)	(0.036)
Time dummies	Yes	Yes	Yes
N	60	60	59

p-values in brackets, *<0.10, **<0.05, ***<0.01; one lag was used instead of two because otherwise there would not be a sufficient number of observations left. Results for GMM-DIFF were not computed for the same reason.

Table A5: Granger causality tests (direction: reverse causality) – LSDVC

LSDVC	(1)	(2)	(3)
Dependent variable	**ms_reg**	**ms_cab**	**iu3g**
log $fttx_{(t-1)}$	0.013	0.000	0.001
	(0.250)	(0.720)	(0.490)
$ms\_reg_{(t-1)}$	0.489***		
	(0.009)		
$ms\_cab_{(t-1)}$		0.569***	
		(0.000)	
$iu3g_{(t-1)}$			0.958***
			(0.000)
Times dummies	Yes	Yes	Yes
N	60	60	59

p-values in brackets, *<0.10, **<0.05, ***<0.01

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