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Regulation and Investment in Next Generation Access Networks:
Recent Evidence from the European Member States

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Abstract

Fibre-deployment of future telecommunications networks (“Next Generation Access” - NGA) is 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 identifies the most important determinants of NGA deployment, using data from the EU27 member states for the years 2005 to 2010. Our results indicate that stricter previous broadband access regulation has a negative impact on NGA deployment, while competitive pressure from broadband and mobile affects NGA deployment in an inverted U-shaped manner. We further find that there are severe adjustment costs and stickiness towards the desired long-term level of NGA infrastructure. It appears that the approach of the European Commission of strict cost-based access regulation will not elicit the huge new investment needed for a comprehensive NGA roll-out.

Keywords: Next generation access networks; telecommunications; sector-specific regulation; competition; investment

JEL: H5, L38, L43, L52

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1 Introduction

In recent years, fibre-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 fulfil needs for growing demand for bandwidth, arising from new/interactive multimedia services like streamed video on demand, high definition television, 3-D applications, cloud computing, Web 2.0 services, etc.\(^1\) The renewal of existing networks and their (partial) replacement by fibre-optic infrastructure require high investment volumes.\(^2\) The future central importance of ultra-high-speed broadband infrastructure as a key socio-economic factor is well recognised.\(^3\) However, investment in (“second or next generation”) fibre-based network infrastructure varies significantly in international comparison. Whereas leading Asian countries such as Japan and South Korea already reached fibre coverage levels of around 35% by mid of 2011, some Eastern European and Scandinavian countries were lagging behind with coverage levels at 10 and 15%. The majority of countries (including e.g. Germany and United Kingdom (UK)) still show coverage levels of around 1%. NGA coverage in the United States (US) of ~ 7% was significantly above the average of the 27 European member states (EU27) of 4.7% by the mid of 2011.

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, fibre 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 fibre networks as 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 appropriate ex ante regulation in place. In any case, ex ante investment incentives in NGA infrastructure will be crucially influenced by the respective regulatory approach.

\(^1\) According to “Nielsen’s Law”, bandwidth demand grows by 50% each year.

\(^2\) Total investments for a nationwide NGA deployment depend on the network topology employed and the targeted population coverage and add up to billions of euros (wik consult, 2008). In the United Kingdom, for instance, estimated deployment costs are up to €25 billion to achieve population coverage of 90% (Analysys Mason, 2008, pp. 7-8).

\(^3\) 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).
Whereas leading Asian countries take a state aid driven approach,\(^4\) 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.\(^5\) The European Union (EU), in contrast, primarily relies on competitive market forces subject to a set of strict sector-specific regulations (see Huigen and Cave, 2008). The UK used to be a typical European case with a rather heavy-handed regulatory approach and low NGA deployment levels so far. The British communications regulator (OFCOM) even played a pioneering role in introducing a mandatory functional separation obligation which is considered to be the last resort remedy within the EU framework (Cullen International, 2011, Table 17). However, in view of NGA related investment incentives, OFCOM recently considered to move away from its regulatory approach by departing from the tradition of cost-based access prices and by allowing for partial deregulation in terms of geographically differentiated markets (Cave, 2010, pp. 82-83). We cannot finally resolve this debate but, in line with related literature,\(^6\) our results indicate that the stricter broadband access regulation is the lower is NGA infrastructure roll-out.

Our paper represents the first European-based attempt to quantify the determinants of recent and actual NGA deployment. Based on an unbalanced panel of the EU27 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 does competition in related markets influence the extent of NGA deployment? iii) Finally, how do the dynamics and the adjustment process of NGA deployment and the corresponding short and long run effects look like? It should be emphasised here that our focus is on NGA deployment/investment only, not on welfare.\(^7\)

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 on the preceding broadband market years ago to investment activities in an emerging (NGA) market. Although specific

\(^4\) For instance, Korea’s world leading role in terms of broadband and NGA penetration rates is due to massive public initiatives of the government issued as early as in 1987 in order to promote use of broadband technologies in the private and public sectors. For its ambitious NGA roll-out (“ultra-broadband convergence network”) the government allocated public subsidies of ~ €1 billion (Falch and Henten, 2010, p. 5).

\(^5\) Since then the US experienced substantial growth in fibre investment with the largest fixed-line provider, Verizon, investing about $23 billion for its fibre-based network roll-out (RVA LLC, 2010, pp. 6-8).


\(^7\) However, more investment is likely to be better also from a welfare point of view. In telecommunications, the “Averch-Johnson” effect (too much capital employed) can be expected to be small due to ex ante regulation and service-based as well as infrastructure competition that have been established for more than ten years. Moreover, there are huge positive externalities of NGA investment (OECD, 2009).
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.\(^8\) We argue that past regulation in preceding markets clearly shapes expectations for NGA regulation. Generally, the European regulatory framework has established a broad system of cost-based access pricing since the very beginning of the liberalisation process in communications markets in 1997/1998. This has also been recently confirmed in NGA relevant recommendations and consultation documents of the European Commission as well as court decisions.\(^9\) We therefore acknowledge both sources of endogeneity problems, which are only partly, if at all, addressed in the literature. Multiplicity of methods as well as a broad set of explanatory and control variables serve as important robustness checks. Our results indicate that stricter previous broadband access regulation has a negative impact on NGA deployment, while competitive pressure from broadband and mobile affects NGA deployment in an inverted U-shaped manner.

The remainder of the paper is organised 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 0 presents the empirical specification and related econometric issues. Section 7 describes and interprets the main results. Section 8 summarises and compiles the 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,

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8 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 (2011, Tables 4, 9 and 10).

9 See the NGA recommendation of the European Commission (2010a) in conjunction with recent NGA related consultations of the European Commission on “costing methodologies for key wholesale access prices” and on “non-discrimination” (available at: http://ec.europa.eu/information_society/policy/ecomm/library/public_consult/cost_accounting/index_en.htm). These documents – as well as former draft versions – clearly indicate that the Commission is very much determined to extend its cost-based regulatory approach to new communications infrastructure. The reader is also referred to the earlier decision of the German government to exempt the incumbent operator (Deutsche Telekom) from wholesale access obligation to its new infrastructure network (“regulatory holidays”). The European Commission, however, announced to take Germany to court over this legal provision in 2007, which finally decided against it in 2009 (C-424/07).
however, a few theoretical contributions related to NGA deployment and the efficiency trade-offs involved, 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 NGA related investment incentives are affected by access regulation charges on the old copper networks via three effects: i) a replacement effect, according to which strict access regulation leads to higher investment since it reduces the incumbent’s “old” profits ii) a wholesale revenue effect, according to which a high access charge increases the incumbent’s opportunity cost of investment to the extent that the incumbent’s investment reduces the costs of the entrant’s new investment and iii) a business migration effect, whereby a low access charge on the old infrastructure implies low retail prices and thus lower profit opportunities for new investment. Nitsche and Wiethaus (2011) analyze the effects of different regulatory regimes on investment incentives and welfare, and find that regimes of fully distributed costs or regulatory holidays are most positive for investment. Their simulations further 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. 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 access charges increase facility-based competition and decrease retail prices. Brito et al. (2010) address the problem of investment in NGA in a duopoly model where a vertically integrated incumbent and a downstream entrant compete. They show that introducing two-part access charges can solve the dynamic inconsistency problem in terms of regulatory opportunism and therefore enhance the incentives to invest in NGA infrastructure. 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 efficiency if the access charge is set in a way that firms share the investment costs in proportion to the infrastructure used.

Early related empirical studies concentrate mostly on US experience with wholesale access regulation, suggesting that regulated cost-based access charges 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. They find that access regulation negatively affects both total industry and individual firm
investment. Investment, however, is quantified rather broadly by tangible fixed assets of telecommunications operators and, thus, does not explicitly refer to broadband, let alone NGA deployment. Wallsten and Hausladen (2009) estimate effects of broadband access regulation on NGA connections within the EU. They find a significant negative correlation between the number of unbundled broadband connections per capita and the number of fibre connections. 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 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 properly reflect real investment activities. Finally, other non-EU based work also measures the impact of access regulation on broadband penetration (e.g. Wallsten, 2005, 2006), which indicates that extensive unbundling mandates and some types of price regulation can reduce broadband investment incentives. 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.

Summarising, the general trade-off between static and dynamic efficiency is well recognised 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\textsuperscript{10} 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 broadband services by means of DSL transmission technology.\textsuperscript{11} 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

\textsuperscript{10} This term refers to networks already in existence and usually formerly fully owned by incumbent operators.

\textsuperscript{11} 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 30 Mbit/s in the direction to the customer (downstream), depending on DSL technology, condition and length of the local loop, and service-level implementation.
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 realise NGA characteristic 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 fibre-based backbone network is referred to as “fibre 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. Fibre to the building (FTTB) is an implementation scenario in which the optical fibre 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 (“fibre to the home” - FTTH). From a technical point of view, this form of implementation would be the ideal solution, as it enables 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 realised via cable television networks (based on hybrid-fibre 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)\textsuperscript{12} technology to be able to offer data transmission rates in the same range. Although both last-mentioned technologies heavily rely on fibre in their backbone networks, only coaxial cable is of current relevance as a substitute for 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 a 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.\textsuperscript{13} Also, the different scenarios of fibre deployment will come along with varying degrees of sunk and adjustment costs: Compared to duct costs and fibreglass, digging costs are of major importance (60-80% of total costs) 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, \textsuperscript{12} 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.
\textsuperscript{13} The extensive study of wik consult (2008) gives a good insight into this topic.
the costs of second generation networks are not sunk before the investment decision is actually made. But, foreseen sunk costs might delay any future investment or make them even unprofitable (see Cave and Martin 2010, p. 1). Finally, the roll-out of 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 outlined in section 3, 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 amortisation periods (20-25 years), 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.\textsuperscript{14}

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.\textsuperscript{15} Stricter access regulation will reduce investment activities, because 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). Regulated infrastructure operators criticise that ii) access regulation ignores opportunity costs of real options\textsuperscript{16} (Guthrie, 2006) and that iii) risks were distributed asymmetrically as service-based operators benefit from a risk-free option due to mandatory access obligations imposed on the incumbent operator (Pindyck, 2007). Moreover, (iv) risks associated

\textsuperscript{14} The need to compensate for increased risk was explicitly mentioned by the European Commission (2010a, see for instance recitals 2, 23 or 37).

\textsuperscript{15} As outlined in the introduction, it is highly likely that operators have to expect a systematic continuation of the previous cost-based access regime.

\textsuperscript{16} 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.
with legacy networks were deemed to be not much different from the overall company risk within the EU framework. Our discussion in section 3, however, implies that NGA risk is substantially different from overall company risk which has not been appropriately considered so far. As already mentioned, according to Nitsche and Wiethaus (2011), a regime of fully distributed costs or regulatory holidays would have the most positive effects 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 tried to resolve the trade-offs of dynamic and static efficiency with reference to the so-called “ladder of investment” (Cave and Vogelsang 2003; Cave 2006), which is also deemed to be a guiding principle for NGA networks (European Commission, 2010a, recital 3). 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 liberalisation, 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 the availability of access instruments and the level of access charges during the liberalisation process. However, 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, Bourreau et al., 2010, pp. 690-691). 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 goal of infrastructure-based competition (last rung of the ladder) was largely forestalled. 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.

Summarising, the direct impact of strict access regulation on infrastructure-based operators is likely to be negative and we also do not expect a positive indirect impact of broadband regulation on NGA deployment via service-based competition as idealised by the ladder of investment hypothesis. Therefore, our first hypothesis is that the stricter access regulation is the lower NGA infrastructure investment will be.

17 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.

18 See the discussion on replicability in Section 3. 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).
4.2 Competition

With respect to the potential impact of competition, one has to consider the so-called “replacement effect”, “escape competition effect” as well as the “Schumpeterian effect” as outlined in Aghion et al. (2005): First, at low levels of competition the replacement effect (Arrow, 1962) occurs, because NGA investment would “cannibalise” quasi-monopolistic profits from preceding broadband services and thus reduce profitability and the incentive to invest. With higher levels of competition, this replacement effect becomes less important as economic rents to be replaced are smaller. Second, more 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 has 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 were liberalised. 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 and substantially reduced the replacement effect in many EU countries. The NGA network upgrade can also be seen as the “last chance” for traditional fixed-line operators to escape successfully broadband competition stemming from these alternative infrastructure platforms with innovative and high-bandwidth demanding services. At the same time, well-established infrastructure-based competition can counteract investment in NGA by making NGA projects riskier, with lower expected profits to be appropriated or even losses. 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.”

Summarising, due to the existence of these opposing effects, we expect a non-linear relationship between NGA investment and the intensity of infrastructure-based competition from cable and mobile broadband services.

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19 See Bourreau et al. (2010) for a more general description of the replacement effects in the communications industry.
4.3 Dynamics, 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 also likely that adjustment to optimal infrastructure stocks will take place only gradually over time.

Demand and willingness to pay will depend on the overall market size in terms of relevant information and communications technology (ICT) expenditure 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 will also be driven by the degree of innovation and usage intensity 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 relevant regulatory variables on wholesale broadband access as well as cable and DSL related data for our competition variables. Our second main source is the database of FTTH Council Europe, which includes bi-annual numbers of deployed NGA lines for all EU27 member states. EUSTAT provides data on ICT expenditure and labour costs. We use the International Telecommunications Union (ITU) “World Telecommunication/ICT Indicators Database” for survey data on the percentage of the population using mobile internet services via 3G and the percentage of heavy internet users. Finally, the World Bank’s “World Development Indicators” and the “World

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21 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.
Economic Outlook” of the International Monetary Fund (IMF) 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 countries for the time range from 2005-2010.

5.1 Dependent variable

In line with the technical description in section 3, our dependent variable represents the number of homes passed by FTTx 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 number of households exhibiting a sufficient willingness to pay and actively using one of the FTTx technologies. Our dependent variable thus directly reflects the existing NGA infrastructure stock, which we consider the most suitable proxy for both empirical as well as conceptual reasons.

Figure 1 gives an overview of FTTH/B deployment patterns in selected countries as of June 2011. Some countries (such as Japan and Korea) already reached fibre maturity and are still far beyond, especially when compared to the average level of the EU27 (4.7%, not reported in Figure 1) and the US (6.7%). The leading Asian countries are Japan (37.5%) and South Korea (~34%) followed by Lithuania (31.9%) and a couple of other Eastern and Northern European economies (“followers”) with coverage levels between 16.2% (Sweden) and 11.6% (Estonia). Please note that for countries like Japan and South Korea these numbers imply almost full coverage in terms of households passed. Whereas the progress in NGA infrastructure deployment in the Nordics is mainly due to the comprehensive state aid policies with respect to the deployment of conventional broadband infrastructure, the Eastern European countries benefit from low migration costs towards NGA infrastructure since legacy infrastructure typically existed only in rudimentary form which largely eliminated the replacement effect right from the beginning. Remarkably, out of the group of central, average household size in Japan, e.g., was 2.46 in 2010 (source: ITU World Telecommunication/ICT Indicators Database) implying 92% coverage.

27 This includes FTTH/B, Fibre to the curb, VDSL, VDSL2, Fibre to the last amplifier (cable and FTTx/LAN). Full definitions available at: http://s.ftthcouncil.org/files/FTTH-Definitions-Revision_January_2009_0.pdf.
28 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 (2010b, section 2.4) on the “digital agenda”.
29 Since there is a lack of data on FTTC for Asian countries, FTTH/B is used in Figure 1 instead of FTTH/B/C for comparison. Due to further data restrictions, NGA coverage in the US refers to FTTH deployment only, thus the corresponding values of FTTH/B coverage would be higher.
30 Average household size in Japan, e.g., was 2.46 in 2010 (source: ITU World Telecommunication/ICT Indicators Database) implying 92% coverage.
western and southern European countries only very few, such as France and the Netherlands, show some progress in NGA coverage (“starters”). However, the vast majority of the EU27 still show rather low coverage levels including major economies such as Germany or the UK with disastrous levels of around 0.5% by mid of 2011.

(Figure 1 about here)

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.

Our regulation variable, \( ms_{\text{reg}} \), 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 remedial measures of wholesale broadband regulation as outlined in section 3, but it also provides a direct measure of their effectiveness at the same time by counting the percentage of (regulated) lines actively used by service-based competitors.\(^31\) Furthermore, as outlined in section 4.1, it can be argued that the effectiveness of regulation of the “old” (broadband) network infrastructure, \( ms_{\text{reg}} \), is exogenous with respect to the “new” (NGA) infrastructure. We expect a negative sign on \( ms_{\text{reg}} \), since tight access regulation of existing broadband services creates corresponding expectations on future NGA access regulation for infrastructure operators and 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: \( ms_{\text{cable}} \) is the ratio of cable connections provided by entrant cable operators 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 variables is ambiguous due to the opposing competition effects outlined in section 4.2. Thus, we expect a non-linear, inverted-U-shaped relationship of investment with respect to \( ms_{\text{cable}} \) and \( iu3g \).

Demand and cost shifters are included as control variables. GDP per capita, \( GDP_{\text{pc}} \), captures income effects throughout our country set. Information technologies expenditures, \( ict_{\text{exp}} \), act as a proxy for the market size of the ICT industry and, thus, for the overall willingness to pay for

\(^{31}\) 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, but is available only until 2006. Moreover, that index does not capture the substantial differences as regards the actual importance of the individual broadband access regulations.
broadband services in a country. Furthermore, we include the variable iday, which provides the share of the population that uses the internet frequently. The share of a country’s urban population, urban_pop, reflects different cost structures due to varying shares of rural and densely populated areas. The variable lab_cost gives an annual labour cost index normalised to 100 in 2005 and serves 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 fibre, 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. All sources and variable definitions are listed in Table 1, descriptive statistics are provided in Table 2.

(Tables 1 and 2 about here)

6 Empirical specification

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, static models are not appropriate, as these would only account for effects that have an immediate impact on the infrastructure stock. We use a partial adjustment approach as our econometric model, since 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

\[
Ftx^*_{it} = X_{it} \beta' + \theta_i + \epsilon_{it},
\]

where \( Ftx^*_{it} \) reflects the long-run optimal infrastructure stock for country \( i \) at time \( t \), \( X_{it} \) is a matrix of explanatory variables, the \( \theta_i \) are the country-specific fixed effects and \( \epsilon_{it} \) is an error term assumed to be i.i.d. We assume that the change in infrastructure stock follows the partial adjustment process:

\[
Ftx_{it} - Ftx_{it-1} = \alpha \left( Ftx^*_{it} - Ftx_{it-1} \right) + \mu_{it}.
\]

where \( Ftx_{it} \) is the actual number of homes passed per capita in country \( i \) at time \( t \). Every period, \( \alpha' \) percent of the gap between the desired and actual infrastructure stock level is closed, with \( \alpha' \) being the speed of adjustment, and \( 0 < \alpha' < 1 \). Substituting (1) in (2) yields the empirically testable equation.
\( Ftx_{it} = \alpha Ftx_{i,t-1} + X_{it} \beta + \alpha \theta_t + u_{it}, \)

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

In our empirical baseline specification, equation (4), we use the homes passed by FTTx normalised to population as the dependent variable and lag the explanatory variables, because usually firms need some time to react to changing market or regulatory policy conditions:

\[
Ftx_{i,t} = \beta_0 + \alpha Ftx_{i,t-1} + \beta_1 ms_{reg}_{i,t-1} + \beta_2 ms_{cable}_{i,t-1} + \beta_3 ms_{cable}^2_{i,t-1} + 
\beta_4 iu3g_{i,t-1} + \beta_5 iu3g_{i,t-1}^2 + \beta_6iday_{i,t-1} + \beta_7gdp_{pc}_{i,t-1} + \beta_8ict_{exp}_{i,t-1} + 
\beta_9urban_{pop}_{i,t-1} + \beta_{10}lab_{cost}_{i,t-1} + \theta_t + \theta_t' + u_{it},
\]

The \( \theta_t \) and \( \theta_t' \) are country-specific and time-specific fixed effects, respectively, and \( u_{it} \) are the error terms assumed to be i.i.d.

### 6.1 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-DIFF) 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-DIFF 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 firms’ previous investment decisions and the corresponding infrastructure stocks 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 was implemented by NRAs many years ago. In order to

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32 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.
underline this argument, we will perform Granger causality tests (see for instance, Cambini and Rondi, 2011). At the same 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.

7 Discussion of main results

The regressions in Table 3 show the results using GMM-SYS for our full model containing all control variables (1), regressions (2)-(4) in the table serve as robustness checks consecutively eliminating control variables. While apart from ict_exp_{t-1} the coefficients of the control variables are insignificant throughout our estimations, we keep ict_exp_{t-1} and urban_pop_{t-1} as the most important demand and cost side controls in the final results, which are displayed in Table 4. Table 4 shows our main estimation results of GMM-DIFF, GMM-SYS, LSDVC and fixed effects (FE) models. Comparing the regressions of Table 3 with Table 4 reveals that the major results as regards regulation and competition are quite similar both across specifications as well as across estimation methods. All GMM models employ t-2 and t-3 lags of the dependent variable as internal instruments. Endogenous variables lagged two or more periods are valid instruments provided that there is no second-order autocorrelation in the first-differenced idiosyncratic error terms. 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. The Sargan test does not suggest rejection of the over-identifying restrictions at conventional levels. 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.

(Tables 3 and 4 about here)

Before we discuss the main variables of interest, we look at our control variables. In line with our hypotheses in section 4.3, we find a significant positive impact of our demand variable (ict_exp_{t-1}) in most regressions in Table 3 and Table 4, which captures willingness to pay for broadband services. However, the cost variable (e.g. urban_pop_{t-1}) is insignificant throughout all estimation methods and models. In addition to country fixed effects, this might be attributed to two opposing effects: First, in densely populated areas, FTTx deployment can serve more customers at once reducing the costs for a single fibre line. Second, however, digging costs are usually lower in areas with low population density due to the higher proportion of greenfield constructions. Other NGA-specific cost factors as

33 Due to the possible problem of too many instruments we restrict the number of lags used as instruments to a maximum of two.

34 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.
for example, labour costs ($lab\_cost$), seem to be highly dependent on national circumstances and hardly vary across time (Neumann 2010, p. 6). Introducing $lab\_cost$ as a further cost proxy basically leaves the structure and significance of the main variables of interest unchanged. Our presumption that fixed effects are largely driven by diverse cost factors gets reasserted as fixed effects estimates turn out to be highly negative for all countries.

Our main results show a significantly negative coefficient of around -0.04 on our regulatory variable ($ms\_reg_{t-1}$) throughout all estimations. This strongly supports our hypothesis outlined in section 4.1 that stricter previous ex ante regulation leads to a negative impact on NGA infrastructure investment. Hence, it appears that the expectations on strict cost-based future NGA-related regulation outweigh potential dynamic efficiency gains via service-based competition as stipulated by the ladder of investment hypothesis. Our estimations imply that, for a country like the UK, with a market share of regulated lines of 61%, a decrease by 10 percentage points would increase the FTTx infrastructure stock in this country by 40%.

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 A1 and in Table A2 in the Appendix. The results obtained here do not give any indication of a reversed causality pattern between NGA deployment and previous broadband regulation or competition.

Using a partial adjustment model allows us to disentangle short and long-run effects according to the model framework in section 0. With $\alpha' \equiv 0.39 (0.42)$ for GMM-SYS and GMM-DIFF (LSDVC), the respective long-run coefficient ($\beta' (= \frac{\beta}{\alpha})$) of each explanatory variable rises significantly, which indicates substantial long-run economic effects. Our results suggest that around 40% of the gap to the desired infrastructure stock is closed in every period and 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 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 NGA infrastructure.

Our estimated EU average desired infrastructure stock from equation (4) implies an FTTx coverage of 50.9% of European households. Compared to this, the explicit policy goal of the

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

36 When including the squared term of $ms\_reg$, both, $ms\_reg$ as well as $ms\_reg^2$ are insignificant. This also 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.

37 We actually estimated the number of lines per population in our main equation. To be able to compare the implied optimal long-run coverage with the aims of the European Commission (2010b), we have to take into
European Commission’s digital agenda that all Europeans should have access to internet speeds of above 30 Mbps (European Commission, 2010b, p. 19) seems to be rather unrealistic under current investment conditions.

As regards our infrastructure-based competition variables \((ms\_cable_{t-1}; ms\_cable_{t-1}^2; iu3g_{t-1}; iu3g_{t-1}^2)\), all estimation models show a non-linear relationship between investment and cable as well as mobile competition variables. The variables are significant in GMM and partially significant in LSDVC estimations. Generally, the coefficients on the linear terms of cable tend to be more significant and higher and thus evoke a larger competitive pressure and investment to escape it. This is perfectly in line with intuition: 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, also cover different needs or geographical areas and therefore constitute a more complementary form of broadband access for narrow-bandwidth users and specific broadband services. Hence, they 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 (6)) that a market share of cable entrants and a mobile internet usage rate of around 22% and 9%\(^{38}\), respectively, are optimal for NGA investment. The average market share of cable entrants is 24.7% in our data set and, thus, is broadly in line with this optimum value for NGA investment. In contrast, the average penetration rate of mobile internet is 3.6% and thus well below the 9% threshold.\(^{39}\)

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 an average increase of FTTx population coverage of 21.6%. With 22% of cable penetration in 2010, the UK is close to the optimal level for NGA investment. But, with a share of the population using high speed mobile services of as low as 0.4% in 2010, a rise up to the European mean of 3.6% would result in an average increase of FTTx population coverage of 22% in the UK.

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\(^{38}\) 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).

\(^{39}\) Of course, more intense competition could lead to more static efficiency and the optimum values with respect to total welfare is unclear but likely to be higher.
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 NGA deployment is determined by regulation and 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 via shaping expectations for NGA regulation has negatively affected NGA deployment.

Our 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. Considering sector-specific regulation, our results reaffirm recent US policy 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. 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, might be considered as relevant, especially to supply white areas with next generation communications networks. According to our results, applying neither of these as the EU suggests in its sector-specific regulatory framework, and neglecting inherent trade-offs between static and dynamic efficiency, would not allow achieving the ambitious goals outlined in the Digital Agenda.
References


Figure 1: FTTH/B coverage in international comparison (“homes passed per capita”)
Table 1: Variable definitions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTTx Homes passed/population, <em>Fitx</em></td>
<td>Number of deployed FTTx lines normalised to population</td>
<td>FTTH Council Europe</td>
</tr>
<tr>
<td>Effectivity of wholesale broadband regulation, <em>ms_reg</em></td>
<td>Percentage of total retail broadband lines that are regulated (local loop unbundling, bitstream, resale)</td>
<td>EU Progress Report</td>
</tr>
<tr>
<td>Cable broadband competition, <em>ms_cable</em></td>
<td>Percentage of cable and DSL lines that are run by entrants</td>
<td>EU Progress Report</td>
</tr>
<tr>
<td>Mobile broadband competition, <em>iu3g</em></td>
<td>Percentage of population using mobile internet services via 3G networks (UMTS or higher bandwidth)</td>
<td>ITU</td>
</tr>
<tr>
<td>Heavy internet users, <em>iday</em></td>
<td>Percentage of population using internet services every or almost every day</td>
<td>ITU</td>
</tr>
<tr>
<td>GDP per capita, <em>gdp_pc</em></td>
<td>Gross domestic product per capita in US$</td>
<td>IMF</td>
</tr>
<tr>
<td>ICT expenditures, <em>ict_exp</em></td>
<td>Percentage of expenditures on information technologies to GDP</td>
<td>EUROSTAT</td>
</tr>
<tr>
<td>Urban population, <em>urban_pop</em></td>
<td>Percentage of urban to total population</td>
<td>World Bank Development Index</td>
</tr>
<tr>
<td>Labour costs, <em>lab_cost</em></td>
<td>Annual labour cost index (for each country normalised to 100 in 2005)</td>
<td>EUROSTAT</td>
</tr>
</tbody>
</table>
Table 2: Descriptive statistics

<table>
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<th>Variable</th>
<th>Number of observations</th>
<th>Mean</th>
<th>Standard Deviation</th>
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<th>Max</th>
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</thead>
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<td>log(fttx)</td>
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<td>-4.199</td>
<td>2.552</td>
<td>-10.539</td>
<td>-0.648</td>
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<td>ms_reg</td>
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<td>19.486</td>
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<td>97.1</td>
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<td>ms_cab</td>
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<td>24.661</td>
<td>16.051</td>
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<td>82.792</td>
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<td>iu3g</td>
<td>132</td>
<td>3.592</td>
<td>3.867</td>
<td>0</td>
<td>20.4</td>
</tr>
<tr>
<td>iday</td>
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<td>40.504</td>
<td>16.918</td>
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<td>76.4</td>
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<td>gdp_pc</td>
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<td>30980.09</td>
<td>20829.53</td>
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<td>3743.413</td>
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<td>ict_exp</td>
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<td>urban_pop</td>
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<td>15.564</td>
<td>15.99</td>
<td>97.759</td>
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<td>lab_cost</td>
<td>129</td>
<td>107.558</td>
<td>11.886</td>
<td>80.04</td>
<td>150.27</td>
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### Table 3: Determinants of NGA investment (Full model)

<table>
<thead>
<tr>
<th>GMM SYS</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>log(fttx)_{t-1}</td>
<td>0.730*** (0.000)</td>
<td>0.718*** (0.000)</td>
<td>0.732*** (0.000)</td>
<td>0.600*** (0.000)</td>
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<tr>
<td>ms_reg_{t-1}</td>
<td>-0.054*** (0.003)</td>
<td>-0.039* (0.057)</td>
<td>-0.041* (0.073)</td>
<td>-0.033* (0.075)</td>
</tr>
<tr>
<td>ms_cable_{t-1}</td>
<td>0.658*** (0.004)</td>
<td>0.568*** (0.002)</td>
<td>0.596*** (0.004)</td>
<td>0.415** (0.016)</td>
</tr>
<tr>
<td>ms_cable_{t-1}^2</td>
<td>-0.014*** (0.000)</td>
<td>-0.013*** (0.000)</td>
<td>-0.014*** (0.000)</td>
<td>-0.009*** (0.009)</td>
</tr>
<tr>
<td>ms_cable_{t-1}</td>
<td>0.409* (0.066)</td>
<td>0.366* (0.083)</td>
<td>0.353* (0.054)</td>
<td>0.228 (0.143)</td>
</tr>
<tr>
<td>ms_cable_{t-1}^2</td>
<td>-0.025** (0.049)</td>
<td>-0.021* (0.074)</td>
<td>-0.019* (0.055)</td>
<td>-0.006 (0.427)</td>
</tr>
<tr>
<td>urban_pop_{t-1}</td>
<td>0.078 (0.209)</td>
<td>0.076 (0.207)</td>
<td>0.071 (0.194)</td>
<td>0.034 (0.483)</td>
</tr>
<tr>
<td>ict_exp_{t-1}</td>
<td>0.876 (0.466)</td>
<td>1.753* (0.078)</td>
<td>1.938** (0.026)</td>
<td></td>
</tr>
<tr>
<td>iday_{t-1}</td>
<td>-3.342 (0.305)</td>
<td>-4.141 (0.169)</td>
<td>-5.022 (0.135)</td>
<td></td>
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<tr>
<td>gdp_pc_{t-1}</td>
<td>-0.000 (0.428)</td>
<td>-0.000 (0.642)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>lab_cost_{t-1}</td>
<td>-0.016 (0.176)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Constant</td>
<td>-7.531 (0.178)</td>
<td>-10.35* (0.083)</td>
<td>-10.90* (0.081)</td>
<td>-6.015 (0.213)</td>
</tr>
</tbody>
</table>

AR(1) test p-value: 0.428, 0.486, 0.527, 0.630
AR(2) test p-value: 0.679, 0.588, 0.598, 0.991
Sargan-test p-value: 0.746, 0.858, 0.870, 0.267
N: 71, 76, 76, 79

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. * p < 0.10, ** p<0.05, ***p<0.01.
Table 4: Determinants of NGA investment (Final model)

<table>
<thead>
<tr>
<th>Dependent variable: log(fttx)</th>
<th>(5) GMM DIFF</th>
<th>(6) GMM SYS</th>
<th>(7) LSDVC</th>
<th>(8) FE</th>
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</thead>
<tbody>
<tr>
<td>log (fttx)_{t-1}</td>
<td>0.610***</td>
<td>0.606***</td>
<td>0.576***</td>
<td>0.420***</td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td>(0.000)</td>
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<tr>
<td>ms_reg_{t-1}</td>
<td>-0.037**</td>
<td>-0.040*</td>
<td>-0.038*</td>
<td>-0.038**</td>
</tr>
<tr>
<td></td>
<td>(0.042)</td>
<td>(0.083)</td>
<td>(0.074)</td>
<td>(0.040)</td>
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<td>ms_cable_{t-1}</td>
<td>0.452***</td>
<td>0.557***</td>
<td>0.280*</td>
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<tr>
<td></td>
<td>(0.003)</td>
<td>(0.008)</td>
<td>(0.055)</td>
<td>(0.140)</td>
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<td>-0.012***</td>
<td>-0.008***</td>
<td>-0.006**</td>
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<td>(0.000)</td>
<td>(0.001)</td>
<td>(0.003)</td>
<td>(0.032)</td>
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<tr>
<td>iu3g_{t-1}</td>
<td>0.304**</td>
<td>0.288*</td>
<td>0.066</td>
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<td>(0.019)</td>
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<td>iu3g_{t-1}^2</td>
<td>-0.017**</td>
<td>-0.016*</td>
<td>-0.005</td>
<td>-0.012</td>
</tr>
<tr>
<td></td>
<td>(0.025)</td>
<td>(0.063)</td>
<td>(0.700)</td>
<td>(0.188)</td>
</tr>
<tr>
<td>ict_exp_{t-1}</td>
<td>1.419*</td>
<td>1.808**</td>
<td>1.484</td>
<td>1.825</td>
</tr>
<tr>
<td></td>
<td>(0.073)</td>
<td>(0.018)</td>
<td>(0.129)</td>
<td>(0.105)</td>
</tr>
<tr>
<td>urban_pop_{t-1}</td>
<td>-0.150</td>
<td>0.056</td>
<td>0.586</td>
<td>0.491</td>
</tr>
<tr>
<td></td>
<td>(0.783)</td>
<td>(0.319)</td>
<td>(0.261)</td>
<td>(0.118)</td>
</tr>
<tr>
<td>Constant</td>
<td>4.470</td>
<td>-12.310**</td>
<td>-38.550*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.907)</td>
<td>(0.032)</td>
<td>(0.070)</td>
<td></td>
</tr>
</tbody>
</table>

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 (5)-(8) include country-specific fixed effects which are not reported for reasons of 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.
## Appendix

**Table A1: Granger causality tests (direction: reverse causality) – GMM-SYS**

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>log fttx(_{(t-1)})</td>
<td>-0.00975</td>
<td>-0.00162</td>
<td>0.00130</td>
</tr>
<tr>
<td></td>
<td>(0.460)</td>
<td>(0.380)</td>
<td>(0.300)</td>
</tr>
<tr>
<td>ms(<em>{reg})((</em>{t-1}))</td>
<td>0.944***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.000)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ms(<em>{cab})((</em>{t-1}))</td>
<td></td>
<td>0.635***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.000)</td>
<td></td>
</tr>
<tr>
<td>iu3g(_{t-1})</td>
<td></td>
<td></td>
<td>1.273***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.000)</td>
</tr>
<tr>
<td>_cons</td>
<td>0.000</td>
<td>0.068**</td>
<td>0.015**</td>
</tr>
<tr>
<td></td>
<td>(1.000)</td>
<td>(0.012)</td>
<td>(0.036)</td>
</tr>
</tbody>
</table>

*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 A2: Granger causality tests (direction: reverse causality) – LSDVC**

<table>
<thead>
<tr>
<th>Dependent variable</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>log fttx(_{(t-1)})</td>
<td>0.013</td>
<td>0.000</td>
<td>0.001</td>
</tr>
<tr>
<td></td>
<td>(0.250)</td>
<td>(0.720)</td>
<td>(0.490)</td>
</tr>
<tr>
<td>ms(<em>{reg})((</em>{t-1}))</td>
<td>0.489***</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.009)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ms(<em>{cab})((</em>{t-1}))</td>
<td></td>
<td>0.569***</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.000)</td>
<td></td>
</tr>
<tr>
<td>iu3g(_{t-1})</td>
<td></td>
<td></td>
<td>0.958***</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(0.000)</td>
</tr>
</tbody>
</table>

*Times dummies* | Yes | Yes | Yes
*N* | 60 | 60 | 59

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