J Regul Econ (2015) 48:194–217
DOI 10.1007/s11149-015-9283-1

ORIGINAL ARTICLE

How EU sector-specific regulations and competition affect migration from old to new communications infrastructure: recent evidence from EU27 member states

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Published online: 8 May 2015

Abstract In a time of rapidly increasing global digitalization, providers of communications networks find themselves confronted with huge growth in broadband-intense demand and hence must address the need to expand high-performance fiber optic networks. However, since deployment of fiber access networks is subject to high risk for operators, a core question faced by regulatory institutions is how to optimally design the regulatory framework to incentivize investment. This work employs recent EU27 panel data and examines the role of regulatory policies and competition controlling for relevant supply and demand side factors and the investment dynamics. The results indicate that relevant forms of previous broadband access regulation have a negative impact on investment in new fiber infrastructure. Furthermore, infrastructure-based competition from mobile operators and the replacement effect stemming from the incumbents' existing infrastructure exert a negative impact on investment incentives. Finally, there is clear evidence of adjustment costs underlying the fiber deployment process.

JEL Classification L38 · L43 · L52

1 Introduction and motivation

The Digital Agenda for Europe (DAE) aims to strengthen the competitiveness of Europe's economy with an explicit focus on digital communications technologies and

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defines specific policy goals in terms of network deployment, adoption and bandwidth characteristics. The DAE "seeks to ensure that, by 2020, (i) all Europeans have access to much higher internet speeds of above 30 Mbps and (ii) 50 % or more of European households subscribe to internet connections above 100 Mbps" (European Commission 2010a, p. 19). The future central importance of high-speed next generation networks (NGNs) as a key socio-economic factor in any information society is well recognized with reference to the general purpose technology character (Bresnahan and Trajtenberg 1995) of NGNs and related spill-over effects in terms of significant productivity improvements and growth across major economic sectors.[1]

However, market conditions have so far appeared to be insufficient to induce a broad-scale roll out of fiber infrastructure which is subject to high investment requirements and risks. Therefore, identifying the right regulatory policy measures becomes crucial. In view of the comparatively strict EU access regulation imposed on the existing ("first-generation") broadband infrastructure and as foreseen for emerging NGNs (Vogelsang 2014; Briglauer and Gugler 2013; European Commission 2010b), this paper examines the following research questions: (i) what is the impact of sector-specific broadband access regulation imposed on first-generation broadband markets and related service-based competition on NGN investment? (ii) what is the impact of infrastructure-based competition from mobile networks and wireline first-generation broadband networks on NGN investment?

The empirical investigation utilizes a comprehensive and most recent EU27 panel data set for the years from 2004 to 2013 for incumbent and entrant operators[2] which are all subject to the same EU regulatory framework for electronic communications markets. The econometric estimation techniques explicitly account for the endogeneity bias arising from the dynamic investment specification and from potential endogeneity due to omitted heterogeneity or reverse causality. Furthermore, this paper considers all relevant regulatory and competition variables that only have been used separately in the empirical literature so far. In particular, the paper measures regulation (i) in terms of the so-called "unbundling" charge which is the most relevant wholesale access charge in terms of migration incentives to NGNs as well as (ii) by the extent of service-based competition that expresses the market relevance of all forms of broadband access obligations imposed under the EU regulatory framework. In addition, the paper uses (iii) a formal regulatory density index as a robustness variable. In a similar vein, it simultaneously takes account of the relevant forms of infrastructure-based competition stemming from (i) mobile (wireless) networks ("intermodal") and (ii) wireline first-generation broadband networks ("intramodal"). A multiplicity of methods in conjunction with a broad set of control variables ensures the robustness of the results.

Section 2 reviews the recent and related empirical literature. Section 3 then outlines testable hypotheses concerning the role of access regulation and regulatory induced

[1] Although conclusive empirical evidence referring to the impact of NGN infrastructure is missing so far, numerous studies exist for telecommunications infrastructure in general (e.g. Röller and Waverman 2001) and broadband infrastructure (e.g. Czernich et al. 2011).

[2] Whereas the term "incumbent" refers to former—mostly state-owned—telecommunications monopolists of "legacy" infrastructure, the "entrant" firm refers to alternative operators either with own access infrastructure—such as cable TV networks—or without ("service-based" operators).

service-based competition as well as infrastructure-based competition. Section 4 describes the panel data set. Section 5 presents the empirical baseline specification and the identification strategy. Section 6 discusses the main empirical results. Finally, Sect. 7 summarizes and compiles relevant recommendations for future regulatory policies.

2 Empirical evidence

Empirical literature related to the impact of broadband access regulation can be divided into two broad categories: (i) quantitative analysis focusing on the impact on first-generation broadband investment and adoption, and (ii) quantitative analysis focusing on the impact on NGN investment and NGN adoption. The review starts with the older broadband related literature where numerous empirical studies exist. Both categories also consider empirical studies that employ measures of adoption which is sometimes used as a proxy for investment, and because, as explicitly argued by some authors, output-related adoption represents a better welfare measure in efficiently functioning markets (e.g. Crandall et al. 2013).

(i) The older broadband related empirical literature is comprehensively surveyed in Cambini and Jiang (2009, p. 571) who summarize the empirical analysis as regards the role of the unbundling access charge as follows: "The majority concludes that local loop unbundling based on forward-looking cost methodology discourages both ILECs [=incumbent local exchange carriers] and CLECs [=competitive local exchange carriers] from investing in networks." The subsequent empirical analysis on regulation and broadband investment largely reemphasizes the results in Cambini and Jiang: Bouckaert et al. (2010) examine the determinants of broadband adoption based on a sample of OECD countries for the years from 2003 to 2008. They find that infrastructure-based competition has a positive impact on broadband adoption, whereas service-based competition based on access regulation is an impediment to adoption. Lee et al. (2011) analyze the determinants of broadband adoption for the years from 2000 to 2008. The authors find a positive and significant effect of access obligations on the speed of adoption. Grajek and Röller (2011) use data from EU countries and investigate the relationship between regulation and total investment in the telecommunications industry. The authors find that access regulation negatively affects both total industry and individual firm investment. Crandall et al. (2013) utilize OECD data for the period 2001 to 2010. The authors find that unbundling access obligations have almost no significant impact on broadband adoption in the short run but a significantly negative impact on adoption in the long run.

(ii) Briglauer et al. (2013) are the first to investigate the determinants of NGN investment using data for the years from 2005 to 2011. Their empirical specification incorporates EU27 country-level data based on a small number of observations. The authors find that the more effective service-based competition is, the more negative is the impact on NGN investment. Infrastructure competition from cable and mobile networks affects NGN investment in a non-linear manner in terms of an inverted U-shape. Bacache et al. (2014) examine the impact of multi-layer access regulation on migration from old to new access infrastructures, most notably NGNs, using investment data from 15 European member states from July 2002 to July 2010. The authors find that the presence of multi-layer access regulation does not foster entrants to self-deploy NGNs. Wallsten and Hausladen (2009) examine the effects of broadband access regulation on NGN adoption with data from EU27 countries for the years from 2002 to 2007. The authors find that countries where unbundling is more effective experience lower adoption of NGN services. In turn, infrastructure-based competition exerts a positive impact on NGN adoption. Finally, Briglauer (2014) examines the determinants of NGN adoption for EU27 member states for the years from 2004 to 2013. The author finds that stricter previous broadband access regulation has a negative impact, while competitive pressure from first-generation broadband and mobile networks affects NGN adoption according to an inverted U-shape.

Summarizing, the evidence regarding the older broadband related literature indicates that broadband access regulation is negatively related to investment activities, while the impact on broadband adoption seems to be less clear. Regarding the NGN related empirical literature, all studies that employ NGN specific data from European countries find a negative impact of sector-specific access regulation and related service-based competition on NGN deployment in terms of aggregate investment or adoption. It appears that the results in the first-generation broadband literature carry over even more strongly to NGN investment and adoption. Furthermore, the literature review also indicates that there are still very few contributions that utilize NGN specific investment data. Moreover, these studies are based on a rather small sample of country-level observations or capture only the first phase of NGN deployment, whereas the data set available for this work accommodates a much larger number of observations on recent firm-level NGN data.

3 Hypotheses

The testable hypotheses on the main variables of interest are deduced from the theoretical literature as outlined in Sects. 3.1 and 3.2. Section 3.3 describes relevant NGN investment determinants and hypotheses on the demand and cost factors as well as the investment dynamics.

3.1 Sector-specific regulation and service-based competition

First, this section discusses the market effects related to service-based competition which is directly conducive to the intensity of the “treatment” of the individual regulatory access obligations (Bacache et al. 2014). To begin with, one has to consider expectations that are shaped on the basis of access regulation of the first-generation broadband infrastructure. In the particular case of NGN deployment, potential investors will ceteris paribus expect stricter future access regulation of NGNs, the stricter the first-generation broadband infrastructure is regulated.[3] However, rents

[3] Apparently, strict regulation of first-generation broadband access does not necessarily imply strict regulation of NGN access infrastructure. However, previous NGN related EC recommendations as well as court decisions provide reasonable evidence for the relevance of expectation effects (Briglauer 2014, p. 56).

earned from wholesale access at cost-oriented charges are lower than monopoly rents from selling (unregulated) broadband access services to retail customers. Expectation effects thus lower net present values and hence the incentive to invest for those operators who will most likely be subject to future fiber access regulation. Infrastructure investors might also foresee that they will be subject to a regulatory commitment problem and to regulatory opportunism meaning that national regulatory authorities (NRAs) have an incentive to enforce cheap wholesale access once the new infrastructure is established on a large scale irrespective of former decisions and announcements. In turn, regulatory-induced service-based competition would lead to higher NGN investment incentives only if service-based broadband competition leads to increases in variety and innovation and, hence, total broadband demand. This demand increasing effect might also increase investment incentives by incumbents if they can appropriate profits through sufficiently high access charges (Foros 2004; Kotakorpi 2006).

Second, regarding the role of the regulated unbundling access charge imposed by NRAs, the theoretical literature (Inderst and Peitz 2012; Bourreau et al. 2012) suggests that a lower access charge for the old technology is diminishing NGN investment by the entrant as the availability of a cheap access increases opportunity costs of the entrant's investment in new infrastructure. However, the literature finds countervailing effects for the incumbent (Bourreau et al. 2012): On the one hand, the "business migration effect" suggests that a lower access charge would indirectly lead to lower retail prices for NGN services, implying negative implications for investment incentives. On the other hand, there is the "wholesale revenue effect", which assumes that high investment by the incumbent triggers high investment by the entrant, resulting in a loss of wholesale revenues, but this loss is smaller with lower access charges. Overall, at the firm level there is some ambiguity concerning the question whether a higher or lower access charge is more likely to induce NGN investment by the incumbent and hence also with respect to aggregate NGN investment.

Summarizing, the theoretical literature suggests that service-based competition and related access regulation exert a negative impact on entrants' investment incentives. With respect to the investment incentives of the incumbent the overall effect is indeterminate to the extent that service-based competition also captures the effect of the height of regulated access charges and induces total demand increases. Similarly, entrants' investment incentives are positively related to the height of the unbundling access charge, whereas the impact on NGN investment incentives of the incumbent is indeterminate. Note that although different investment incentives can be identified at the firm level between regulated incumbent operators and unregulated entrants, aggregate industry investment represents the main point of reference for policy makers and the main subject of the empirical investigation.

3.2 Infrastructure-based competition

Mobile networks have become the main intermodal competitor for wireline providers both with respect to narrowband as well as broadband services. This phenomenon has been referred to as fixed-mobile substitution (FMS) which now exerts a crucial impact on existing and future market structures and thus also on NGN investment incentives. Some of the empirical studies reviewed in Sect. 2 found a significant and non-linear relationship between the extent of FMS and NGN investment. However, as shown in Sacco and Schmutzler (2011), there is generally no clear prediction, since the relationship depends on the definition of competitive intensity and the oligopoly framework and, consequently, investments can be increasing or decreasing functions of competition. Also, an inverted U-shaped relation, as found in Aghion et al. (2005) in a general equilibrium framework, is not necessarily more likely than a U-shaped relation in a partial equilibrium analysis.

In view of the first-generation (intramodal) broadband infrastructure that is mostly based on copper-lines and "digital subscriber line" (DSL) technology of the incumbents (legacy) as well as coaxial-cable infrastructure and hybrid-fiber technology of cable-TV network operators, one also has to consider the well-known "replacement effect" (Arrow 1962). Accordingly, NGN investment would cannibalize quasi-monopolistic rents on first-generation broadband services which thus represent an opportunity cost of NGN investment. Especially, in case of a well-established first-generation broadband infrastructure stock that enables high-quality broadband services, the replacement effect might be substantial and thus hinder or delay NGN investment.

Summarizing, there is no clear prediction regarding the impact of intermodal competition from mobile networks on NGN investment incentives. The replacement effect makes incumbent and entrant (cable) operators reluctant to network upgrades and gets more pronounced the lower the (perceived) quality and profit differential between the first-generation and next-generation broadband infrastructure is.

3.3 Demand and cost controls and investment dynamics

In addition to regulation and competition, the level and the speed of NGN investment will also be influenced by variables related to consumer demand and (adjustment) costs.

On the one hand, costs depend on population or household density and other demographic characteristics. Urbanization is perhaps a better measure of deployment costs than household or population density at an aggregate (country) level, because a hypothetical move of all households to one city would not change average household density but would have a massive impact on average NGN deployment costs (Vogelsang 2014, p. 3). Also, the housing structure, in particular, the number of multi-dwelling units determines average deployment costs. On the other hand, civil engineering and construction costs (including in-house wiring) represent by far the most relevant cost drivers which will also depend on topographic region or country-specific characteristics (FTTH Council Europe 2012). Finally, one has to be aware that NGN deployment is subject to complex technical network planning and standardization, and legal issues such as coordination with NRAs and potential access seekers, rights of way or other allowances such as contractual obligations with house owners have to be resolved beforehand. As a consequence, operators cannot immediately adjust their infrastructure stock to changing market conditions and it is likely that adjustment to optimal infrastructure stocks will take place only gradually over time (Briglauer et al. 2013).

Partial adjustment towards a long-run optimum also captures the feature of increasing marginal costs of NGN investment which reaps "low-hanging fruits" first and leaves "white areas" uncovered.

Demand and the willingness to pay for NGN services first depend on the overall size of the broadband market. Whereas traditional broadband services exhibit fairly stable demand, NGN products still represent a premium service for most consumers and hence aggregate demand will also depend on consumer wealth. Moreover, demand for NGN services is driven by consumer preferences referring to ICT affinity and Internet usage patterns on side of residential or business customers. Consumers' needs are also determined by their average education levels, since higher levels of education improve e-literacy skills, which considerably increases the utility derived from NGNs (Kiiski and Pohjola 2002, p. 302; Briglauer 2014). Whereas the above-mentioned demand determinants drive NGN investment, consumer demand might also be subject to switching costs. In case first-generation broadband services enjoy broad consumer acceptance in terms of high market saturation or incremental benefits of moving to NGN services are not large and transparent enough, switching costs might be substantial and hinder consumer migration and thus reduce NGN investment incentives (Briglauer 2014). The higher market saturation in terms of per household or per capita adoption of first-generation broadband services is, the lower is the remaining segment of consumers that can be directly migrated to NGN services without having to overcome switching costs. The latter reduce the profitability of NGN investment, since operators have to convince largely satisfied consumers to switch via offering costly price discounts or the like.

Summarizing, the higher deployment costs or the more unfavorable country-specific deployment characteristics are, the lower will be NGN investment activities. The nature of cost factors and institutional rigidities imply a gradual (partial) adjustment process. With respect to the demand determinants, overall willingness to pay for broadband services, the ICT affinity of consumers and the e-literacy and internet usage level are positively related to NGN investment. Controlling for these variables, broadband market saturation primarily captures switching costs which hinder migration to NGN services and thus lower NGN investment incentives.

4 Data

The EC's "Digital Agenda Scoreboard"[4] provides yearly data on wholesale broadband access regulation as well as cable and DSL-related data for the wireline competition variables. In addition, a regulatory density index is provided by the Swiss consulting firm "Polynomics".[5] The second main source is the database of FTTH Council Europe,[6] which includes annual numbers of deployed NGN lines for incumbent oper-

[4] The "Digital Agenda Scoreboard" database is available at: http://ec.europa.eu/digital-agenda/en/digital-agenda-scoreboard.

[5] Data are freely available upon request at: http://www.polynomics.ch/rdi.php. Data, however, are available only for the years from 1997 to 2010.

[6] Data are available to FTTH Council Europe members at: http://www.ftthcouncil.eu/resources?category_id=6.

ators and the group of entrants for the EU27 member states. EUROSTAT provides data on population, education, housing structure and construction costs. Furthermore, the empirical analysis uses data from “MarketLine”[7] on intermodal mobile competition and urbanization, International Telecommunications Union’s (ITU) “World Telecommunication/ICT Indicators” on fixed-legacy infrastructure, and data from “Euromonitor”[8] on internet usage and ICT affinity. Finally, the World Bank’s “World Development Indicators” provide data on GDP per capita. The empirical analysis employs a slightly unbalanced panel data set of EU27 countries for the time range from 2004 to 2012 for yearly data on the independent variables and from 2005 to 2013 for yearly data on the dependent variable.[9]

All sources and variable definitions are listed and described in detail in Table 3, while descriptive statistics are provided in Table 4 in the Appendix. Section 4.1 and Sect. 4.2 below describe the dependent and independent variables, respectively.

4.1 Dependent variable

The dependent variable measures the total number of NGN connections expressed in logs, *ln(NGN_total)*.[10] The dependent variable represents real NGN investment in physical units deployed by the group of alternative European infrastructure operators and European incumbent operators. NGN adoption represents the number of consumers who also show a sufficient willingness to pay for at least one of the NGN based services. The empirical analysis employs the total number of NGN adopters expressed in logs, *ln(NGN_adop)*, as well as the total number of deployed connections per household expressed in logs, *ln(NGN_total_w)*, as robustness variables.

4.2 Independent variables

Broadband access *regulation* is measured first by the extent of service-based competition, *sbc_bb*, which is the ratio of regulated and actually used wholesale broadband lines (based on “unbundling”, “bitstream” and “resale” access obligations) to the total number of retail broadband lines. The variable *sbc_bb* is thus a measure of the effect regulation has on the market by linking broadband access regulation to the corresponding market outcomes (Bacache et al. 2014; Briglauer et al. 2013). Second, the unbundling access charge, *price_ull*, stands for the access regulation that is most relevant in view of the migration from old to new broadband networks and directly set by NRAs. Third, a sub-index of the “Polynomics Regulation Index”, *rdi_bb*, provides a

[7] Data are commercially available at: http://advantage.marketline.com.

[8] The Euromonitor International database is commercially available at: http://www.euromonitor.com/.

[9] Data availability varies randomly by country, in particular, the EC does not provide market data for Bulgaria and Romania until 2005, which creates four missing values. Apparently, this cannot be attributed to NGN investment activities in these countries.

[10] For a definition of relevant NGN technologies the reader is referred to Briglauer et al. (2013, p. 144).

formal measure of relevant EU broadband access obligations and is used as a regulatory robustness variable.[11]

Infrastructure-based *competition* is measured in two ways: First, intermodal wireless competition from mobile networks is measured by the extent of FMS. The variable *fms* relates the total number of mobile lines to the total number of fixed lines. Second, the variables *cable* and *legacy* measure the first-generation infrastructure stock of cable and incumbent operators, respectively, and thus the replacement effect that is related to the existing first-generation broadband infrastructure (intramodal wireline competition).

Demand and cost shifters are included as *control variables*. GDP per capita, *gdp_pc_ppp*, captures income effects. The network readiness index, *nri*, the number of internet users per capita, *int_user*, and the share of businesses using local area networks, *bus_use_lan*, as well as the population with higher education level, *edu*, capture the affinity with ICT and broadband services. The stock of existing broadband lines (in logs), *ln(bb_lines)*, acts as a proxy for the market size and thus for the overall willingness to pay for broadband services. Broadband lines per household, *bb_lines_w*, measures market saturation in terms of household adoption with first-generation broadband services.

Regarding deployment and adjustment costs the variables *wage* and *labcost_con* serve as cost proxies for the NGN construction costs. In addition, the empirical analysis employs the percentage of a country's urban population, *urban*, and the number of building permits for multiple dwelling units, *mdwell_perm*, which reflect different costs due to varying degrees of densely populated areas and housing structures, respectively.

Finally, the empirical analysis includes period-, λ_t, and country-specific *fixed-effects*, θ_i, with the latter controlling for time-invariant and unobserved heterogeneity. Most notably, country-specific fixed-effects might be related to some of the main cost conditions, such as topographic and demographic characteristics, regulations on digging or different levels of (regulated) capital costs. Furthermore, demand and supply will be influenced by public subsidies, which also show only limited variation as regards the analysis period. Conversely, the costs of fiber equipment and other material costs are determined by global markets implying common trends in input prices which can be captured by period effects.

5 Econometric specification

Section 5.1 first presents the empirical baseline specification, which excludes the robustness variables and considers a market which is not in equilibrium but explicitly accounts for an endogenous adjustment process. Section 5.2 then describes the estimation and identification strategy.

[11] Contrary to the variable *sbc_bb*, the variable *rdi_bb* captures only the formal aspects of regulation and not the actual effect it exerts on market outcomes. This distinction is of relevance since a certain access regulation imposed by NRAs might exist on paper for years without any real effect on the relevant markets. The variable *rdi_bb* is used as a robustness variable also because it is available only up to 2010.

5.1 Aggregate estimation model

The dependent variable comprises NGN investment of incumbent operators and the group of alternative infrastructure operators which allows stacking these data by country in order to fully employ the available information on the dependent variable. The dynamic reduced-form model in which total NGN investment is expressed in logs,[12] $ln(NGN\_total_{jit})$, for incumbents and the groups of entrants j, for EU member state i and year t, reads as follows:

$$\begin{aligned} \ln(NGN\_total_{jit}) = \alpha_0^{total} &+ \beta_1 sbc\_bb_{i(t-1)} + \beta_2 price\_ull_{i(t-1)} \\ &+ \beta_3 fms_{i(t-1)} + \beta_4 fms^2_{i(t-1)} \\ &+ \beta_5 cable_{i(t-1)} + \beta_6 cable^2_{i(t-1)} + \beta_7 legacy_{i(t-1)} \\ &+ \beta_8 bb\_lines\_w_{i(t-1)} \\ &+ \beta_9 \ln(bb\_lines)_{i(t-1)} + \gamma' \mathbf{Z}_{i(t-1)} \\ &+ \theta_i + \lambda_t + \alpha_1 \ln(NGN\_total_{ji(t-1)}) + \varepsilon_{jit}. \end{aligned} \tag{1}$$

The dynamic investment adjustment process is captured by including the lagged dependent variable as a right-hand side regressor. If the dynamic specification is correct, then α_1 is in the interval (0; 1). Equation (1) depends on the main variables of interest, i.e., regulation in terms of the variables $sbc\_bb_{i(t-1)}$ and $price\_ull_{i(t-1)}$, and competition in terms of the variables $fms_{i(t-1)}$, $cable_{i(t-1)}$ and $legacy_{i(t-1)}$. In order to estimate non-linear relations as regards competition variables, as seen in the empirical literature, squared terms are also included in the baseline specification. Furthermore, Eq. (1) incorporates market size and market saturation effects related to the first-generation broadband market as captured by the variables $ln(bb\_lines)_{i(t-1)}$ and $bb\_lines\_w_{i(t-1)}$, respectively. Finally, Eq. (1) includes a vector of further demand and cost controls, $\mathbf{Z}_{i(t-1)}$, an additive error term, ε_{jit}, country-specific effects, θ_i and period effects, λ_t. Note that Eq. (1) includes lagged values of all the explanatory variables due to data availability (Sect. 4).

5.2 Estimation and identification strategy

Using dynamic generalized-method-of-moments (GMM) panel data estimation techniques allows to take into account endogeneity due to unobserved heterogeneity and the presence of the lagged dependent variable as a right-hand side variable (Nickell 1981) in Eq. (1). Moreover, the related literature suggests that there might be reverse causality patterns between investment decisions on the one hand and regulation or competition variables on the other hand. GMM estimators provide internal instruments which appears to be a superior strategy to using external instruments in view of a sufficient number of time periods ($t = 9$) and since several independent variables

[12] A log transformation helps to stabilize and regularize the series of the dependent variable.

are (potentially) endogenous.[13] Whereas the difference-GMM estimator (Arellano and Bond 1991) makes use of suitable lags of all endogenous and exogenous regressors as instruments, the system-GMM estimator (Arellano and Bover 1995) uses additional instruments. The empirical analysis uses the former to keep the number of instruments as small as possible and because the regression models show only limited persistence. Furthermore, the system-GMM estimator requires imposing an additional assumption on initial conditions of the process generating the dependent variable and thus works only under special circumstances (Roodman 2006).

The empirical analysis also employs a bias-corrected least-squares-dummy-variables estimator (LSDVC) developed by Bruno (2005a, b) for dynamic unbalanced panel data and a small number of cross-sectional units as is typically the case in small macro panels ($n = 27$). Since all explanatory variables in the specifications in Eq. (1) are lagged once, these variables can thus be considered as pre-determined which mitigates endogeneity problems, if there is no serial correlation. In fact, pre-determinedness is reasonable for dynamic autoregressive models such as in Eq. (1) (Wooldridge 2002, pp. 299–300). Further endogeneity problems due to time-variant heterogeneity should be limited in view of the large number of control variables. However, as the LSDVC estimator requires strict exogeneity of all regressors, it is considered to test the robustness of GMM estimation results. GMM is considered as the main estimator, since it is specifically designed for models where right-hand side variables are not strictly exogenous.[14] Yet, against the background of the different strengths and weaknesses of GMM and LSDVC estimators, it makes sense to employ both in order to ensure the robustness of the results.

6 Empirical results

Tables 1 and 2 below show the main estimation results based on the model specification in Eq. (1). All standard errors reported are robust and permit arbitrary forms of heteroscedasticity and autocorrelation in the ε's for GMM and are bootstrapped for LSDVC models.[15] As regards the GMM estimator, all regulatory and competition variables as well as the lagged dependent variable are treated as endogenous. The Arellano-Bond one-step estimator is the more efficient alternative in case of estimation in small samples and even in the presence of heteroscedasticity (Bond 2002). Since GMM estimators incorporate the assumption that the idiosyncratic errors of the untransformed specification are uncorrelated across units, the estimations include period effects in all GMM estimations reported in Tables 1 and 2 to prevent the most likely source of cross-correlation, i.e., contemporaneous correlation (Roodman 2006, pp. 26–36). The key identifying assumption underlying the GMM estimator is that the error terms in the original specification are serially uncorrelated and hence the speci-

[13] All main explanatory variables as listed in Table 3 in the appendix as well as the demand control variable *bus_use_lan* are specified as endogenous in the GMM regressions.

[14] Another advantage of the GMM-difference estimator is that non-stationarity in aggregate time series can be typically removed by first differencing the series. This is an important feature, since panel unit root tests assume large t.

[15] Stata 12.1 is used to estimate the regressions.

Table 1 GMM estimation results (Dep.var.: $ln(NGN\_total_{jit})$ in regr. (1) to (5); $ln(NGN\_total\_w_{jit})$ in regr. (6))

Regression nr.	(1) Full_total	(2) Full_total_r	(3) Final_total	(4) Full_ i_ull_price	(5) Final_i_ull_price	(6) Final_total_w
$Dep.var._{ji(t-1)}$	0.3751***	0.4025***	0.4142***	0.3801***	0.2234***	0.3299***
	(8.27)	(9.52)	(9.80)	(8.20)	(4.37)	(8.14)
$sbc\_bb_{i(t-1)}$	−1.5719**		−1.5665*	−3.5791***	−5.3002***	−3.0296**
	(−2.03)		(−1.94)	(−3.84)	(−3.92)	(−2.56)
$price\_ull_{i(t-1)}$	0.0054	0.0014	−0.0489	−0.0235	−0.0910	−0.0056
	(0.09)	(0.02)	(−0.87)	(−0.35)	(−1.16)	(−0.08)
$i\_ull\_price\_sh_{i(t-1)}$				0.2962**	0.6463**	
				(1.96)	(2.40)	
$rdi\_bb_{i(t-3)}$		−1.9096***				
		(−2.86)				
$fms_{i(t-1)}$	−1.3152*	−1.1435	−1.4573*	−0.8434	−1.2543	−1.3004
	(−1.71)	(−1.57)	(−1.93)	(−1.09)	(−1.22)	(−1.18)
$fms^2_{i(t-1)}$	0.0666	0.0632	0.0794	0.0380	0.0844	0.0871
	(1.36)	(1.35)	(1.57)	(0.75)	(1.29)	(1.28)
$cable_{i(t-1)}$	−6.4695	−7.2950*	2.7985*	−5.9891		1.3004
	(−1.40)	(−1.67)	(1.72)	(−1.47)		(0.60)
$cable^2_{i(t-1)}$	8.5428***	8.3089***		7.5080***		
	(3.15)	(3.16)		(3.11)		
$legacy_{i(t-1)}$	−0.1399**	−0.1013*	−0.1491***	−0.1291**		−0.1590**
	(−2.26)	(−1.89)	(−3.08)	(−2.21)		(−2.12)

Table 1 continued

Regression nr.	(1) Full_total	(2) Full_total_r	(3) Final_total	(4) Full_ i_ull_price	(5) Final_i_ull_price	(6) Final_total_w
$bb\_lines\_w_{i(t-1)}$	−21.09***	−18.116***	−19.553***	−23.4043***	−29.380***	−17.5572***
	(−3.89)	(−4.27)	(−3.46)	(−3.81)	(−3.91)	(−3.34)
$ln(bb\_lines)_{i(t-1)}$	1.2984***	1.2870***	0.8152**	1.1001***	0.8943*	0.7881*
	(5.60)	(5.78)	(2.40)	(5.05)	(1.77)	(1.95)
$bus\_lan_{i(t-1)}$	−1.3639	−1.4796		−0.9362	−1.5589	
	(−0.50)	(−0.65)		(−0.35)	(−0.52)	
$gdp\_pc\_ppp_{i(t-1)}$	0.0002*	0.0002	0.0001	0.0002**	0.0002*	0.0002
	(1.75)	(1.62)	(1.20)	(2.12)	(1.66)	(1.42)
$int\_user_{i(t-1)}$	2.9754	3.4243	3.4736	4.3653*	5.6578**	1.3126
	(1.52)	(1.33)	(1.41)	(1.93)	(2.15)	(0.71)
$nri_{i(t-1)}$	−0.1974	0.1317		0.3843		1.0114
	(−0.28)	(0.18)		(0.49)		(1.10)
$edu_{i(t-1)}$	−0.0197	0.0131		−0.0175		0.0129
	(−0.29)	(0.19)		(−0.26)		(0.15)
$labcost\_con_{i(t-1)}$	0.0244					0.0284
	(1.27)					(1.33)
$mdwell\_perm_{i(t-1)}$	−0.0011	−0.0009		−0.0015		−0.0006
	(−1.08)	(−1.00)		(−1.64)		(−0.42)
$wage_{i(t-1)}$	−0.4358**	−0.5459**	−0.3190**	−0.4219***	−0.6248**	−0.657***
	(−2.48)	(−2.92)	(−2.03)	(−2.74)	(−2.50)	(−2.64)

Table 1 continued

Regression nr.	(1) Full_total	(2) Full_total_r	(3) Final_total	(4) Full_ i_ull_price	(5) Final_i_ull_price	(6) Final_total_w
$urban_{i(t-1)}$	0.8373***	0.4943**	0.6519***	0.7507***	0.7959***	0.6747***
	(4.04)	(2.18)	(3.80)	(4.06)	(3.33)	(2.83)
Year dummies	YES	YES	YES	YES	YES	YES
Constant	−58.9559***	−33.3090*	−39.0156***	−52.7229***	−58.2865***	−47.2432*
	(−3.55)	(−1.71)	(−2.78)	(−3.30)	(−2.94)	(−1.90)
chi^2	2.637e+10	7.09e+09	8495.8089	3.884e+09	1896.1466	813389.1
AR(1) test	−3.8475	−3.8177	−3.8319	−3.6708	−3.6144	−3.3066
AR(2) test	−0.9840	0.0485	−1.1719	−0.7824	−1.2130	−1.2540
Hansen test (p-value)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)	(1.000)
Observations	428	428	428	428	428	428

t-statistics reported in parentheses are robust to heteroscedasticity and autocorrelation within panels in GMM estimates. All endogenous variables in first differences are instrumented with their own lagged levels with a maximum lag number of four. All regressions include period effects and country-specific fixed effects which are not reported for brevity. For the Arellano-Bond tests for autocorrelation (AR(1) and AR(2)) and the Hansen test of over-identifying restrictions, test statistics and p-values, respectively, are reported.

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2 LSDVC and GMM Regression results (Dep.var.: $ln(NGN\_total_{jit})$ in regr. (1) to (3); $ln(NGN\_adop_{jit})$ in regr. (4) to (5))

Regression nr.	(1) Full_ LSDVC	(2) Full_i LSDVC	(3) Final_ LSDVC	(4) Full_adop_ GMM	(5) Full_adop_ r_GMM
$Dep.var_{ji(t-1)}$	0.5593***	0.5513***	0.5752***	0.3378***	0.3632***
	(13.03)	(12.86)	(14.12)	(4.33)	(3.94)
$Dep.var_{ji(t-2)}$				−0.0239	−0.0543
				(−0.64)	(−1.44)
$sbc\_bb_{i(t-1)}$	−2.3861*	−3.8625**	−2.3495*	−2.3110**	−2.4204**
	(−1.93)	(−2.51)	(−1.88)	(−2.27)	(−2.06)
$price\_ull_{i(t-1)}$	−0.0182	−0.0502	−0.0207		0.0153
	(−0.40)	(−1.06)	(−0.48)		(0.34)
$i\_ull\_price\_sh_{i(t-1)}$		0.3112*			
		(1.77)			
$rdi\_bb_{i(t-3)}$					−0.0007
					(−0.00)
$fms_{i(t-1)}$	−0.4770	−0.3395	−0.5590	−1.4494***	−0.8625
	(−0.64)	(−0.44)	(−0.78)	(−2.66)	(−1.38)
$fms^2_{i(t-1)}$	0.0048	0.0006	0.0136	0.0629**	0.0258
	(0.09)	(0.01)	(0.26)	(2.10)	(0.71)
$cable_{i(t-1)}$	-6.3010**	−4.9659	-6.5407**	1.9997	−2.4592
	(−2.06)	(−1.59)	(−2.46)	(1.06)	(−0.60)
$cable^2_{i(t-1)}$	8.6867***	7.5363***	9.3140***		4.9203*
	(3.44)	(2.95)	(3.92)		(1.65)
$legacy_{i(t-1)}$	−0.1629***	−0.1523***	−0.1590***	−0.0694	−0.0444
	(−2.83)	(−2.60)	(−2.93)	(−1.42)	(−0.83)
$bb\_lines\_w_{i(t-1)}$	−14.1515**	−15.0065**	−11.5538**	−10.3747*	−14.6078***
	(−2.45)	(−2.56)	(−2.46)	(−1.94)	(−2.65)
$ln(bb\_lines)_{i(t-1)}$	1.6169***	1.1272*	1.5364***	0.4257	0.7765*
	(2.96)	(1.92)	(4.55)	(1.14)	(1.67)
$bus\_lan_{i(t-1)}$	0.1819	0.3788			
	(0.09)	(0.19)			
$gdp\_pc\_ppp_{i(t-1)}$	0.0002***	0.0002***	0.0002***	0.0001***	0.0001***
	(2.82)	(3.11)	(3.34)	(3.72)	(3.72)
$int\_user_{i(t-1)}$	1.3606	1.7563		4.1802**	2.9389*
	(0.43)	(0.56)		(2.28)	(1.92)
$nri_{i(t-1)}$	0.4124	0.4214			
	(0.64)	(0.65)			
$edu_{i(t-1)}$	−0.0049	−0.0049		0.0069**	0.0109***
	(−1.05)	(−1.05)		(2.37)	(3.25)

Table 2 continued

Regression nr.	(1) Full_ LSDVC	(2) Full_i LSDVC	(3) Final_ LSDVC	(4) Full_adop_ GMM	(5) Full_adop_ r_GMM
$mdwell\_perm_{i(t-1)}$	−0.0005	−0.0007			
	(−0.48)	(−0.63)			
$wage_{i(t-1)}$	−0.3308**	−0.3678**	−0.3741**	−0.2395*	−0.2098
	(−1.99)	(−2.21)	(−2.24)	(−1.67)	(−1.56)
$urban_{i(t-1)}$	0.9511***	0.8840***	0.9929***	0.7146***	0.9322***
	(3.78)	(3.40)	(4.95)	(3.48)	(3.60)
Year dummies	NO	NO	NO	YES	YES
Constant				−48.3668***	−70.4924***
				(−3.04)	(−3.40)
chi^2				799.5048	729.7756
AR(1) test				−1.6815	−1.8673
AR(2) test				−1.4311	−1.2170
Hansen test (p-value)				(1.000)	(1.000)
Observations	480	480	480	422	422

t-statistics reported in parentheses are robust to heteroscedasticity and autocorrelation within panels in GMM estimates. In regr. (4) to (5) endogenous variables in first differences are instrumented with their own lagged levels. Note that using $ln(NGN\_adop_{jit})$ as the dependent variable involves six additional missing observations (compared to GMM regr. using the dependent variable $ln(NGN\_total_{jit})$. All regressions include country-specific fixed effects. GMM estimations in regr. (4) to (5) also include period effects, which are not included for LSDVC estimations, because they were jointly insignificant. For the Arellano-Bond tests for autocorrelation (AR(1) and AR(2)) and the Hansen test of over-identifying restrictions, test statistics and p-values, respectively, are reported. The LSDVC standard errors in regr. (1) to (3) are bootstrapped with bias correction initialized by the Arellano and Bond estimator. Note that there are no standard post-estimation tests available in STATA for the user written "xtlsdvc" command (Bruno 2005b).

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

fication in Eq. (1) is dynamically complete. For all GMM models reported in Tables 1 and 2 the Arellano-Bond (AR(1) and AR(2)) tests for zero autocorrelation in the first-differenced errors reject at order 1 but not at order 2 at conventional levels. This implies, most importantly, that there is no evidence for serial correlation in the original error. Finally, the Hansen tests do not suggest rejection of the over-identifying restrictions in all GMM models and the Wald tests (chi^2 statistics) indicate a high significance of all model regressors in all specifications.

6.1 Main results

Table 1 shows the main regression results for alternative specifications as regards regulatory variables, normalization of the dependent variable—$ln(NGN\_total\_w_{jit})$ is used in regr. (6) instead of $ln(NGN\_total_{jit})$—and selection of control variables (regr. labeled "Full" and "Final"). Whereas "Full" indicates the inclusion of all available control variables, insignificant or the least significant demand and cost controls are excluded in "Final" regressions. The regression estimates discussed below are robust in light of these differences in model specifications.

To begin with, Table 1 shows that the coefficient of the *lagged dependent variable*, α_1, is highly significant and substantial in all regressions (including those in Table 2) showing that the dynamic specification is adequate. The coefficient estimates range from 0.2234 to 0.4142 across the different GMM regressions in Tables 1 and 2 which is in line with the hypothesis outlined in Sect. 3.3. Coefficient values between 0 and 1 indicate that there are adjustment costs underlying the NGN deployment process but deployment towards the long-run desired infrastructure stock takes place. The coefficients for the long-run (static) relationships can be derived from the dynamic model as $\beta_k/(1-\alpha_1)$ and $\gamma_l/(1-\alpha_1)$. Hence, ignoring costs of adjustment, the long-run coefficients of the static representation show substantially higher absolute values.[16]

Regarding the group of *regulatory variables*, one first infers from Table 1 that the negative impact of service-based competition dominates at the aggregate investment level. The coefficient of the variable $sbc\_bb_{i(t-1)}$ is significantly negative in all model specifications (including those in Table 2). Furthermore, the economic impact is substantial, as the estimates indicate that an increase in the intensity of service-based competition by 1 percentage point, decreases total NGN investment at least by ~1.58 % and up to a maximum of ~5.30 %. This strongly supports the hypothesis outlined in Sect. 3.1, according to which stricter access obligations diminish aggregate NGN investment incentives as the specifications explicitly control for a potential demand expanding effect via the market size variable $ln(bb\_lines)_{i(t-1)}$ in regr. (1) to (6). In regr. (2) the regulatory robustness variable, $rdi\_bb_{i(t-3)}$, is used, and the variable $sbc\_bb_{i(t-1)}$ is dropped. It appears that the formal regulation index picks-up well the effect of service-based competition, suggesting also that the latter captures access regulation adequately. The access charge in terms of the unbundling variable, $price\_ull_{i(t-1)}$, however, is insignificant in all specifications (including those in Table 2). This might be due to the opposing firm-level investment incentives as identified in the theoretical literature (Bourreau et al. 2012) but is likely also due to the low degree of variation in the variable $price\_ull_{i(t-1)}$. In particular, as Bacache et al. (2014, pp. 205–206) point out, there are only a very few unbundling access charge increases imposed by NRAs in the past which makes identification of the overall effect difficult. In order to circumvent this problem, additional variation can be introduced by referring to a measure that captures the extent of the unbundling regime. Accordingly, the interaction term, $i\_ull\_price\_sh_{i(t-1)}$, combines the unbundling charge, $price\_ull_{i(t-1)}$, with the respective unbundling market share, $ms\_ull_{i(t-1)}$. The latter is bound between 0 and 1 where the upper limit indicates that all retail broadband connections are offered via unbundling. From regr. (4) and (5) one infers that the coefficient estimate of the main term $price\_ull_{i(t-1)}$ is still insignificant, but the interaction term now shows a significantly positive impact that increases with a higher unbundling market share. Evaluated at the grand mean, $ms\_ull_{(average)} \sim 0.1$ (Table 4), this implies that an increase in the unbundling price by one unit (1€)

[16] Subsequently, the discussion of the estimates focuses only on their short-run impacts.

increases NGN investment in the range between 2.9 % (regr. (4)) and 6.4 % (regr. (5)).

Regarding infrastructure-based *competition* from cable ($cable_{i(t-1)}$) and mobile ($fms_{i(t-1)}$) operators, one only finds weak evidence for a non-linear relation as found in the previous literature. It appears that intermodal competition exerts a negative net impact for all values of the variable $fms_{i(t-1)}$, whereas the net effect of intramodal cable competition on NGN investment is more ambiguous. This is opposed to the impact of the first-generation broadband infrastructure stock of the incumbent operator, $legacy_{i(t-1)}$, which shows a significantly negative impact on NGN investment throughout. The different effects might be due to the substantial cost differences in upgrading first-generation broadband technologies. In particular, migration from old to new infrastructure is much more costly for incumbent than for cable operators. For the latter low upgrading costs open-up the potential of migrating the existing customer base to NGN services with higher average revenues resulting in a more favorable profit differential. Furthermore, the variable $legacy_{i(t-1)}$ presumably also captures the incumbent's opportunity costs related to the wholesale revenue effect (Bourreau et al. 2012) which does not exist on side of the unregulated cable operators. This interpretation is also consistent with the finding of a positive net impact of the unbundling charge on NGN investment in regr. (4) and (5).

Regarding the impact of the *controls*, there are strongly countervailing and significant effects related to the variables $bb\_lines\_w_{i(t-1)}$ and $ln(bb\_lines)_{i(t-1)}$. As outlined in Sect. 3.3, the former is supposed to capture switching costs, since other demand variables already control for ICT affinity, e-literacy and Internet usage of business and residential customers ($bus\_lan_{i(t-1)}$; $int\_user_{i(t-1)}$; $nri_{i(t-1)}$; $edu_{i(t-1)}$) and hence the negative coefficient of $bb\_lines\_w_{i(t-1)}$ is expected. Likewise, the positive coefficient estimate of the variable $ln(bb\_lines)_{i(t-1)}$ is expected, as it captures the overall broadband market size and thus willingness to pay for broadband services in general. Please note that the variables $bb\_lines\_w_{i(t-1)}$ *and* $ln(bb\_lines)_{i(t-1)}$ are correlated with the variables $legacy_{i(t-1)}$ and $cable_{i(t-1)}$ to some extent, however, dropping the latter does not change the impact of the former as shown in regr. (5). With respect to cost controls, the variables $wage_{i(t-1)}$ and $urban_{i(t-1)}$ show expected signs and significant coefficient estimates and apparently capture best deployment costs and topographic deployment conditions.

6.2 Further robustness specifications

This section presents additional estimations to examine the robustness of the main estimations results depicted in Table 1. The robustness tests refer to (i) an alternative estimation technique (LSDVC instead of GMM) and (ii) an alternative specification of the dependent variable ($ln(NGN\_adop_{jit})$ instead of $ln(NGN\_total_{jit})$).[17]

[17] The Hansen tests reported in Table 1 imply a perfect p-value of 1, which indicates that instrument proliferation might reduce the ability of the test. Therefore, the number of instruments is further restricted by reducing the maximum number of lags to two and by using the "collapse" option in STATA's "xtabond2" command. The results (available upon request) show that the results are also robust towards the choice of the lag specification and the number of moment conditions.

Table 2 reports the results for LSDVC estimations in regr. (1) to (3). It appears that the findings with respect to the lagged dependent variable and different specifications of the regulatory and competition variables are robust. Using NGN adoption as an output related dependent variable in GMM estimations in regr. (4) and (5) shows that the basic structure of coefficient estimates remains the same.[18] Hence, the negative impact of access regulation on NGN investment also transfers to NGN adoption as evidenced by the previous literature. This suggests that the negative impact on investment dominates the positive impact of regulation on adoption via lowering retail prices (Briglauer 2014). Also in line with the previous literature is the finding that some of the demand side variables, such as $int\_user_{i(t-1)}$ and $edu_{i(t-1)}$, appear to be of particular importance for NGN adoption.

7 Summary and conclusions

This work identifies the impact of EU access regulation and competition on NGN investment using a recent and comprehensive panel data set for EU27 member states and multiple estimation methods that enable robust inference in order to truly inform the ongoing policy debate in Europe (and elsewhere). The paper finds strong evidence that previous broadband access regulation imposed on first-generation (legacy) infrastructure exerts a significant and negative impact on aggregate NGN investment. This effect can be found for the height of the relevant access charge (unbundling) as well as for regulatory-induced service-based competition that is directly contingent on wholesale access regulation. These findings correspond well with the previous empirical and theoretical literature.

As regards the impact of infrastructure-based competition from mobile and cable networks the results are inconclusive and do not exhibit a clear non-linear impact as found in the related empirical literature. The latter might result from the fact that polynomial terms show good in-sample fit but lower out-of sample validity. However, the paper finds strong evidence that the incumbent's legacy infrastructure is subject to a replacement effect which is not the case to the same extent for the first-generation infrastructure of cable operators.

Regarding the impact of demand and cost-side factors, the results show that the size of the first-generation broadband market has a very strong and positive impact on NGN investment incentives, whereas a highly saturated broadband market involves strong switching costs that hinder migration to NGN services. Regarding the cost side, the paper finds that the level of urbanization appears to be a highly important determinant of NGN investment which is also subject to significant adjustment cost.

Whereas most of the explanatory variables represent market driven outcomes or country-specific conditions, regulatory variables represent discretionary policy decisions of the EC and NRAs. As the results indicate, strict access regulation not only exerts a significantly negative but also a highly substantial impact on aggregate NGN

[18] Regressions (4) and (5) also include the twice-lagged dependent variable because the AR(2) tests indicated model misspecification in the original estimation. As the coefficient of the twice-lagged dependent variable is insignificant, the condition for dynamic stability is fulfilled.

investment, which should be taken under careful consideration in future regulatory decision making. According to the results and in line with the vast majority of the related literature, deregulatory approaches imposed on first-generation infrastructure lead to an increase in NGN investment. Only if the relevant counterfactual to deregulation results in monopolistic NGN market structures in countries without substantial intermodal or intramodal competition, NGN access regulation remains appropriate. US experience indicates that an almost nation-wide infrastructure duopoly can be sufficient to ensure competition and trigger investment (Cave 2014).

The empirical results also point to the classical trade-off between static and dynamic efficiency: While regulation and competition in first-generation broadband markets benefit the consumers of those services in terms of lower prices, they also hinder NGN investment. As a consequence, policy makers should focus on dynamic efficiency and incentivize NGN investment in case positive externalities of first-generation broadband infrastructure will carry over to NGN infrastructure sufficiently, such that societal benefits exceed total NGN deployment costs. As indicated in the introductory section, there is no related econometric evidence on the welfare implications of NGN deployment available so far. Moreover, future empirical research should also provide more direct tests of the differential investment incentives and strategic effects at the firm level as predicted by the theoretical literature.

Acknowledgments The author is grateful to two anonymous referees for highly valuable and insightful comments as well as Deutsche Telekom AG for co-funding a previous and related research project and to Tim Radtke for research assistance. Furthermore, the author is grateful for helpful comments and suggestions provided by Carlo Cambini and Klaus Gugler and the participants at the 25th European Regional ITS Conference in Brussels, the HFM-Workshop "Wettbewerb und Regulierung im Internet" in Hamburg and at the 7th Annual CRNI Conference in Brussels.

8 Appendix

See Tables 3 and 4.

Table 3 Variable description and sources

Variable	Description	Source
Dependent variable(s)		
Log of NGN lines, *ln(NGN_total) (ln(NGN_total_w))*	Log of total number of lines deployed by NGN technologies to a home or place of business (normalized to a country's total number of households)	FTTH Council Europe Euromonitor (households)
Log of NGN adoption, ln(NGN_adop)	Log of total number of NGN connections adopted by consumers who use at least one service on this connection under a commercial contract	FTTH Council Europe
Main explanatory variables		
Broadband lines, *bb_lines (bb_lines_w)*	Number of total retail broadband connections based on DSL and coax cable enabling higher than 144 Kbit/s download speed but excluding NGN lines (normalized to total number of households)	EU Digital Agenda Scoreboard
Cable lines, *cable*	Number of total retail broadband coax lines run by entrants by means of cable TV networks normalized to total retail broadband lines	EU Digital Agenda Scoreboard
Extent of broadband access regulation, *sbc_bb*	Ratio of regulated and actually used wholesale broadband lines (based on "unbundling", "bitstream" and "resale" access obligations) to the total number of retail broadband lines (excluding cable entrant lines)	EU Digital Agenda Scoreboard
Average total cost for full unbundling, *price_ull*	Monthly average total cost for full unbundling (ULL) in € which is calculated as the monthly fee plus the connection fee distributed over three years	EU Digital Agenda Scoreboard
Share of ULL lines, *ms_ull*	Share of unbundled local loop lines to total retail broadband lines	EU Digital Agenda Scoreboard

Table 3 continued

Variable	Description	Source
Fixed legacy, *legacy*	Total number of active fixed landlines per 100 inhabitants. An active line is connecting the customer's equipment to the public telephone network	ITU
Mobile-to-fixed ratio, *fms*	Ratio of the total number of mobile lines to the total number of fixed lines	MarketLine
RDI24-broadband index, *rdi_bb*	The Polynomics Regulation Density Index measures the intensity of regulations in telecommunications. The RDI24-Broadband Index is a sub-index, measuring only regulation related to broadband infrastructure	Polynomics
Demand control variables		
Businesses with LAN, *bus_use_lan*	Share of a country's businesses that have a local area network (LAN)	Euromonitor
Internet users, *int_user*	Share of a country's population that is using the internet	Euromonitor
Network readiness, *nri*	Networked readiness index in points	Euromonitor
Education, *edu*	Total number of graduates in all programs in '000 persons	Euromonitor
GDP per capita, *gdp_pc_ppp*	GDP per capita and PPP adjusted in current US$	World Bank
Cost control variables		
Building permits, *mdwell_perm*	Building permits for two and more dwellings as annual index normalized to 100 in 2010	Eurostat
Hourly wage, *wage*	The manufacturing wage per hour in € and current prices with fixed 2012 exchange rates	Euromonitor
Labor cost, *labcost_con*	Annual labor cost index for the construction branch by NACE Rev. 2 normalized to 100 in 2008	Eurostat
Urban population, *urban*	Population of a country that lives in an urban environment as percentage of the total population	MarketLine

Table 4 Summary statistics

Variable	Obs	Mean	SD	Min	Max
NGN_total	270	2,072,843	4,706,856	1	3.75e+07
ln(NGN_total)	270	10.63032	5.608084	0	17.43946
NGN_total_w	270	.1315215	.1648317	1.21e−08	.7351943
ln(NGN_total_w)	247	−5.789674	5.302496	−18.22869	−.4238326
NGN_adop	270	316,400.6	668,623.5	1	5,144,100
ln(NGN_adop)	270	9.32781	4.685692	0	15.45336
bb_lines	267	3,723,236	5,769,546	13,738	2.80e+07
bb_lines_w	267	.1904645	.0973223	.0023487	.4044925
cable	254	.2157732	.1649066	0	1
sbc_bb	239	.194315	.197063	0	.9705678
price_ull	239	11.72037	4.383839	5.34	42
ms_ull	239	.1014437	.1406279	0	.6772212
i_ull_price_sh	254	1.112611	1.496397	0	7.07019
legacy	243	40.88424	12.98943	15.98503	66.38055
fms	269	3.375306	1.669958	1.2819	10.9396
rdi_bb	243	.6995885	.322663	0	1
bus_use_lan	270	.7118741	.1566787	.231	.996
int_user	270	.6368203	.1846024	.1500006	.951
edu	243	68.96461	13.13021	26	86.6
gdp_pc_ppp	243	29,783.69	13,548.51	8730.803	89055.8
mdwell_perm	243	161.4842	134.003	12.54	913.39
wage	269	11.06208	7.875111	.8	38.7
labcost_con	243	95.7	14.85244	39.8	134.7
urban	270	72.43043	11.89043	49.4118	97.4945

References

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and innovation: An inverted-U relationship. *Quarterly Journal of Economics*, *120*, 701–728.

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte carlo evidence and an application to employment equations. *Review of Economic Studies*, *58*, 277–297.

Arellano, M., & Bover, O. (1995). Another look at the instrumental-variable estimation of error-components models. *Journal of Econometrics*, *68*, 29–51.

Arrow, K. J. (1962). Economic welfare and the allocation of resources to invention. In R. R. Nelson (Ed.), *The rate and direction of economic activity* (pp. 609–626). New York: Princeton University Press.

Bacache, M., Bourreau, M., & Gaudin, G. (2014). Dynamic entry and investment in new infrastructures: Empirical evidence from the telecoms industry. *Review of Industrial Organization*, *44*, 179–209.

Bond, S. (2002). *Dynamic panel data models: A guide to micro data methods and practice*. Working Paper, Centre for Microdata Methods and Practice, CWP09/02.

Bourreau, M., Cambini, C., & Dogan, P. (2012). Access pricing, competition, and incentives to migrate from "Old" to "New" technology. *International Journal of Industrial Organization*, *30*, 713–723.

Bresnahan, T., & Trajtenberg, M. (1995). General purpose technologies: 'Engines of Growth'? *Journal of Econometrics*, *65*, 83–108.

Bouckaert, J., van Dijk, T., & Verboven, F. (2010). Access regulation, competition, and broadband adoption: An international study. *Telecommunications Policy*, *34*, 661–671.

Briglauer, W. (2014). The impact of regulation and competition on the adoption of fibre-based broadband services: Recent evidence from the European member states. *Journal of Regulatory Economics*, *46*, 51–79.

Briglauer, W., Ecker, G., & Gugler, K. (2013). The impact of infrastructure- and service-based competition on the deployment of next generation access networks: Recent evidence from the European member states. *Information Economics and Policy*, *25*, 142–153.

Briglauer, W., & Gugler, K. (2013). The deployment and penetration of high-speed fiber networks and services: Why are European member states lagging behind? *Telecommunications Policy*, *37*, 819–835.

Bruno, G. (2005a). Approximating the bias of the LSDV estimator for dynamic unbalanced panel data models. *Economics Letters*, *87*, 361–366.

Bruno, G. (2005b). Estimation and inference in dynamic unbalanced panel-data models with a small number of individuals. *The Stata Journal*, *5*, 473–500.

Cambini, C., & Jiang, Y. (2009). Broadband investment and regulation: A literature review. *Telecommunications Policy*, *33*, 559–574.

Cave, M. (2014). The ladder of investment in Europe, in retrospect and prospect. *Telecommunications Policy*, *38*, 674–683.

Crandall, R. W., Jeffrey, A., & Ingraham, A. (2013). The long-run effects of copper-loop unbundling and the implications for fibre. *Telecommunications Policy*, *37*, 262–281.

Czernich, N., Falck, O., Kretschmer, T., & Wößmann, L. (2011). Broadband infrastructure and economic growth. *The Economic Journal*, *121*, 505–532.

European Commission (2010a). A Digital Agenda for Europe. Brussels: COM.

European Commission (2010b). Commission Recommendation of 20 September 2010 on Regulated Access to Next Generation Access Networks (NGA). Brussels: 2010/572/EU.

Foros, Ø. (2004). Strategic investments with spillovers, vertical integration and foreclosure in the broadband access market. *International Journal of Industrial Organization*, *22*, 1–24.

FTTH Council Europe (2012). The Cost of Meeting Europe's Network Needs: The cost of putting in place an infrastructure now, that will meet the Digital Agenda targets for 2020, 2030, 2040 and beyond. Final report. http://www.ftthcouncil.eu/documents/Reports/2012/Cost_Model_Report_Full_Version.pdf. Accessed 31 March 2015.

Grajek, M., & Röller, L. H. (2011). Regulation and investment in network industries: Evidence from European telecoms. *Journal of Law and Economics*, *55*, 189–216.

Inderst, R., & Peitz, M. (2012). Market asymmetries and investments in next generation access networks. *Review of Network Economics*, *11*, 1–25.

Kiiski, S., & Pohjola, M. (2002). Cross-country diffusion of the internet. *Information Economics and Policy*, *14*, 297–310.

Kotakorpi, K. (2006). Access price regulation, investment and entry in telecommunications. *International Journal of Industrial Organization*, *24*, 1013–1020.

Lee, S., Marcu, M., & Lee, S. (2011). An empirical analysis of fixed and mobile broadband diffusion. *Information Economics and Policy*, *23*, 227–233.

Nickell, S. (1981). Biases in dynamic models with fixed effects. *Econometrica*, *49*, 1417–1426.

Pindyck, R. S. (2007). Mandatory unbundling and irreversible investment in telecom networks. *Review of Network Economics*, *6*, 274–298.

Roodman, D. (2006). *How to do xtabond2: An introduction to "Difference" and "System" GMM in stata*. Working paper No. 103, Center for Global Development.

Röller, L. H., & Waverman, L. (2001). Telecommunications infrastructure and economic development: A simultaneous approach. *American Economic Review*, *91*, 909–923.

Sacco, D., & Schmutzler, A. (2011). Is there a U-shaped relation between competition and investment? *International Journal of Industrial Organization*, *29*, 65–73.

Valletti, T. (2003). The theory of access pricing and its linkage with investment incentives. *Telecommunications Policy*, *27*, 659–675.

Vogelsang, I. (2014). *Will the U.S. and EU telecommunications policies converge? A survey*. CESifo Working Paper No. 4843.

Wallsten, S., & Hausladen, S. (2009). Net neutrality, unbundling, and their effects on international investment in next-generation networks. *Review of Network Economics*, *8*(1), 90–112.

Wooldridge, J. (2002). *Econometric analysis of cross section and panel dat*. Cambridge: MIT Press.