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Abstract

This paper provides evidence on the migration from an “old” technology to a “new” technology, taking into account the impact that regulatory interventions on the old one might have on the incentives to invest and adopt the new one. This analysis has been applied to a sample of EU27 countries using panel data from 2004 to 2014 on the adoption, coverage and take-up rate of ultra-fast broadband infrastructures, whose development is one of the flagship initiatives of the Europe 2020 programmes. Results show that a 1% increase in the regulated price to access the old technology increases the adoption and the investment on the new broadband technology by ~0.45% and ~0.47%. These effects are not homogeneous across countries and are weakened in Eastern European countries, where the existing old broadband infrastructures are less developed than in the rest of Europe. It has also been shown that the access price to old networks negatively affects the take-up rate of the new technology-based services, thus calling for the need of more specific and complementary demand side policy incentives to enhance service adoption.

1 Introduction

In a time of increasing digitalization, such as the one we are currently observing, operators of “old” (copper-wire and coaxial cable based) broadband networks are facing a huge increase in demand for bandwidth and real time criteria, due to the presence of interactive multimedia services such as streamed video on demand, file sharing, online gaming, and high definition television, as well as specific business applications, such as cloud computing services or video conferencing. As a consequence, the fibre-based deployment of ultra-fast broadband networks (”new” or “Next Generation Networks” – NGNs) that enable a massive increase in bandwidth capacity has become a major issue for regulators and telecom companies. The latter, however, have to sustain costly investments to upgrade the infrastructure, which is also fraught with high uncertainties as regards the future demand and regulatory policies. At the same time, NGNs can be considered as a general purpose technology (Bresnahan & Trajtenberg, 1995), which has the potential to trigger productivity gains and growth across major economic sectors, such as health, electricity and transport, on a massive scale.[1]

In view of the expected externalities that are involved, the European Commission (EC) has decided to strengthen the competitiveness of Europe’s economy by explicitly focusing on digital infrastructure and communication technologies. In order to reach the related growth and productivity potential of NGNs, the Digital Agenda for Europe (DAE) has specified goals in terms of network coverage and service adoption: The DAE “seeks to ensure that, by 2020, (i) all Europeans will have access to much higher internet speeds of above 30 Mbps and (ii) 50% or more of European households will subscribe to internet connections above 100 Mbps” (European Commission, 2010:19).[2] While target (i) refers to a coverage level of 100 per cent of the population, target (ii) refers to a minimum household adoption level. However, recent market data (European Commission, 2014) have shown that both targets are unlikely to be met, unless substantial infrastructure investments are introduced in the coming years. Similar targets can be found in other jurisdictions outside the EU, such as the “National Broadband Network” and the “Ultra-Fast Broadband Initiative“ in Australia and New Zealand, respectively, the “Digital Divide Closing Plan” in South-Korea or the “Connecting America: The National Broadband Plan” in the US.

What are the main drivers of ultra-fast broadband adoption and coverage in Europe? What is the role that the existing regulation can play on the old “legacy” (“copper-wire”) network to foster NGN adoption and coverage? In this paper, an attempt has

[1] Numerous studies support the view that investment in (old) broadband infrastructures creates positive effects on the economic system and leads to an increase in GDP growth (e.g. Röller & Waverman, 2001; Czernich, Falck, Kretschmer & Wößmann, 2011). In particular, Czernich et al. (2011) have shown that a 10% increase in the broadband adoption rate in OECD countries results in a 1-1.5% increase in the annual GDP per-capita.

[2] The DAE is one of the seven flagship initiatives under Europe 2020. For further details about the DAE, the reader can refer to the European Commission’s website: http://ec.europa.eu/digital-agenda/digital-agenda-europe.

been made to answer these questions. Using a recent EU27 panel data set for the years 2004 to 2014, and static and dynamic model specifications, the present work is the first that has simultaneously examines the determinants of NGN coverage, NGN adoption and the NGN take-up rate. The latter measure relates NGN adoption to NGN coverage. The role of the EU regulatory policies, as embedded in the sector-specific framework of electronic communication markets, is examined, as well as the related market conditions, including relevant forms of competition within fixed broadband markets ("intramodal") and from mobile networks ("intermodal"), deployment costs and demand characteristics. The market conditions in most of the European countries so far appear to be insufficient to trigger the broad-scale deployment of NGN. Accordingly, the focus of this work has been on examining regulatory policies more closely, in particular, the so-called "unbundling" price, which is the most relevant policy instrument in terms of incentivizing migration to NGNs pertaining to investment and adoption. Unbundling prices are set directly by national regulatory authorities (NRAs) in individual member states subject to framework directives at the EU level (European Commission, 2000; European Commission, 2002a; European Commission, 2002b). In view of the dual DAE policy goals, and in order to avoid inefficient NGN deployment, it is essential to identify the right regulatory policies. Therefore, the present paper examines how relevant broadband market regulations have an impact on both input-related NGN investment and output-related NGN adoption, as well as their simultaneous impact on NGN take-up.

The European policy goals are closely interrelated, since investment in NGN, i.e. network coverage, also depends on the (expected) adoption, i.e. (future) demand, which in turn is determined by the attractiveness of specific NGN services and applications. Only if consumers consider NGN services attractive enough, in terms of innovations or quality improvements compared with old broadband services, will they migrate to NGN. In this perspective, the take-up rate, is a useful indicator of the willingness of consumers to migrate to the new infrastructure. The more consumers are satisfied with conventional broadband services, or the more consumers are reluctant to adopt new technologies, the greater the gap will be with the newly installed network capacity. A high take-up rate, with adoption being close to capacity in terms of NGN coverage, avoids social costs due to over-capacities. For these reasons, the analysis also focuses on the NGN take-up rate, because of its primary role in the EU scenario, by empirically assessing its main determinants. In this perspective, this paper is the first to attempt to empirically assess the complex interplay between regulation on an old technology and investment and adoption of a new technology, as recently proposed in a theoretical framework by Bourreau, Cambini and Dogan (2012) and Bourreau, Cambini and Dogan (2014).

Results show that the access price imposed on the old legacy infrastructure significantly affects both NGN adoption and coverage. In particular, results show that a 1% increase in the unbundling price increases NGN adoption and NGN investment by ~0.45% and ~0.47%, respectively. This implies that a policy measure that increases the cost of accessing the old broadband infrastructure, though affecting competition, could exert a positive effect on incentivizing the deployment of a new fibre infrastructure (hence, expanding NGN coverage), but also on the adoption of the new connections, by reducing the gap between the retail prices between old and new technology based broadband services. However, and interestingly from a policy perspective, these effects are greatly reduced in Eastern European countries that are characterized by a lack of a well-developed legacy infrastructure: when controlling for this heterogeneity across countries, it has been found that the role of the unbundling regime is offset in Eastern European countries. This result casts doubts on the EC´s current policy of creating a single market in Europe with uniform regulatory rules to be applied in all countries. Clearly, the possible changes in the unbundling prices are only relevant in certain EU countries (mostly EU15), but not over the entire continent. Finally, the take-up rate estimations results have shown that increasing the price of the access price decreases the take-up rate, since adoption increases but less than proportionally to coverage. From a policy perspective, this implies that using a single instrument (i.e. the price for local loop unbundling, LLU) to influence both demand adoption and coverage is not enough, and other instruments are needed to support demand adoption, such as vouchers or tax deductions.

The remainder of the paper is organised as follows: Section 2 reviews the NGN related literature, focusing in particular on empirical literature. Section 3 describes the basic hypotheses concerning the relationship between regulation and competition on NGN coverage, adoption and take-up. Section 4 outlines the panel dataset that underlies the empirical examination. Section 5 presents the empirical baseline specifications and the related econometric issues. Section 6 describes and interprets the main results. Section 7 summarises and compiles the most relevant trade-offs for policy makers.

2 Literature review

The economic literature on the migration from old to new broadband technology is relatively recent, and evidence on this phenomenon is relatively scant.

The deployment of fibre infrastructures does not immediately replace copper or cable legacy networks, suggesting that the transition from old infrastructures to new infrastructures will go slowly. This implies that, during a transition phase, two different infrastructures will operate in parallel, and presumably each type of network will be regulated with a different set of rules. The incentives to invest in fibre infrastructures will therefore also be influenced by the terms of access set for the legacy copper networks.[3] The recent theoretical literature (Bourreau et al., 2012; Bourreau et al., 2014; Inderst & Peitz, 2012) has focused on how access regulations on an existing old network affect infrastructure investments in new networks and favour the migration, at a retail level, from the old to the new broadband infrastructure.

[3] It should be noted that cable coax networks also constitute old broadband networks. However, only copper-wire based ("legacy") networks have been subjected to sector-specific regulations, such as unbundling, in the EU regulatory framework for electronic communications markets.

The related empirical literature on NGN investment (coverage) is relatively scant. Minamihashi (2012) has examined whether unbundling regulations imposed on the Japanese incumbent operator have prevented entrants from self-deploying new broadband infrastructures, using municipal level data from 2005 to 2009. The author has found that unbundling regulations hinder entrants from investing in their own NGN infrastructure. However, during the analysed years, the incumbent's NGN investments were not hindered by the unbundling regulations. Bacache, Bourreau and Gaudin (2014) have examined the incentives embedded in the EU regulatory framework on migration from old to new broadband infrastructures using biannual data from 15 European member states over a period from July 2002 to July 2010. The authors related the number of broadband lines based on new infrastructure to the number of unbundling lines and found that unbundling regulations did not foster entrants investing in NGN. Briglauer (2015) has examined the impact of broadband regulations, including the unbundling price, on NGN investment, utilizing EU27 panel data from 2004 to 2013. The author has found that, as the unbundling price increased, so did the average incentives for NGN investment.

As far as NGN adoption is concerned, the existing empirical literature presents (i) several contributions related to old broadband markets, but only (ii) a few NGN-related publications. Regarding point (i), several relatively old papers exist that have dealt with the determinants of broadband adoption in both the US and European countries. Bouckaert, van Dijk and Verboven (2010) have examined the determinants of broadband adoption from 2003 to 2008 in OECD countries and have found that infrastructure-based competition has a positive impact on broadband adoption. The first paper to use EU data was that of Distaso, Lupi and Maneti (2006), who found that infrastructure-based competition was the main driver of broadband adoption and that it played a more important role than service-based competition, especially in the longer term. More recently, Nardotto, Valletti and Verboven (2015) have employed disaggregated broadband data related to the old telecom infrastructure in the UK for the period December 2005 to December 2009. The authors have shown that unbundling in the UK has not resulted in an increase in broadband adoption but has positively affected service quality.

The above mentioned papers have shed some light on the impact of infrastructure-based competition and access regulation on standard broadband adoption. However, although they are interesting, they are of limited interest for a better understanding of NGN adoption, where the presence of a relatively good legacy infrastructure may represent a constraint to the development of NGN adoption. There are very few papers that deal with NGN demand adoption (point (ii)). Wallsten and Hausladen (2009) have estimated the effects of broadband regulations on NGN adoption with data from EU27 countries from 2002 to 2007, thus covering the very early market phase. They have found that countries where unbundling is more effective experience lower NGN adoption. In their paper, the authors only examined the presence of unbundling regulation, but did not provide any evidence on the possible impact of the price of unbundling access on NGN adoption. Samanta, Martin, Guild and Pan (2012) have examined the demand-side determinants of high-speed broadband deployment using International Telecommunication Union (ITU) and OECD data for 25 countries (for the years) from 1999 to 2009. The authors employed a dummy variable to capture the extent of unbundling regulation and found that this variable had no significant impact. More recently, Briglauer (2014) has investigated the determinants of NGN adoption for EU27 member states from 2004 to 2013. The author has found that the more effective the previous broadband access regulation was, the more negative the impact on adoption. He also found that competitive pressure from mobile networks affects adoption in a non-linear manner.

It should be pointed out that none of the above papers analysed the cross price effect of an old network, i.e. a change in the local loop unbundling price on NGN adoption. This type of analysis can be considered extremely important since, as the theoretical models show, the consumers' migration, at the retail level, from old broadband connections to fibre-based connections depends on the relative price difference between the NGN retail services and the standard broadband ones. In fact, when the access price of the legacy network is low, the retail prices for the services that rely on this network are also low. Hence, in order to encourage customers to switch from the legacy network, operators would need to introduce low-priced NGN services. Furthermore, none of the existing empirical studies has analyzed the determinants of the NGN take-up rate. As mentioned in the introduction, the latter is an important indicator of consumer willingness to adopt new services, of capacity utilization and of the extent to which policy targets are achieved.

Overall, the present paper has the aim of examining the potential role of regulation on stimulating both policy goals, i.e., coverage and adoption. In order to provide useful information to the policy debate, the impact on NGN coverage and NGN adoption is estimated as well as the impact on the NGN take-up rate in separate regressions.

3 Hypotheses

As outlined in the introduction, the key policy variable of interest is the regulated wholesale access price to the old (legacy) infrastructure, i.e. the local loop unbundling price. The current policy debate is focused on how to revise the regulation of this wholesale price in order to foster both ultra-fast broadband coverage and adoption by end users. In fact, the EC is currently modifying the regulatory framework in order to fulfill the EU targets defined within the DAE program.[4] The present analysis thus focuses on this key variable.

[4] The reader can refer to the relevant recommendations of the European Commission related to regulated access to Next Generation Access Networks (2010/572) and non-discrimination and costing methodologies (2013/466), as well as to the current public consultation on the review of the regulatory framework for electronic communication networks and services (information available at: http://ec.europa.eu/digital-agenda/en/news/public-consultation-evaluation-and-review-regulatory-framework-electronic-communications).

To this aim, it is important to derive sound testable hypotheses from the recent theoretical literature on the economics of technology migration. The first systematic theoretical analysis on this issue was provided by Bourreau et al. (2012) and Bourreau et al. (2014). The authors consider a model in which access to the legacy copper network is available throughout an entire country, and an incumbent that is subject to access regulation on the old network, and an (unregulated) entrant operator competes for the provision of retail broadband services to consumers by investing in a new ultra-fast broadband infrastructure. The entrant operator could also demand access in the form of LLU. Their main results show that NGN coverage varies non-monotonically with the LLU access price. This result is due to the coexistence of three different effects: (i) the "replacement effect", which hinders infrastructure investment by alternative operators when the access price is low; (ii) the "wholesale revenue effect", which discourages the incumbent from investing in a higher quality network when the access price is high (since the entrant may invest in reaction, and the incumbent will then lose some of its wholesale profits); and finally (iii) the "business migration effect": when the LLU access price is low, the retail prices of the services that rely on the copper network are also low. Therefore, in order to encourage customers to switch from an old to NGN services, operators should also offer low prices for the NGN services. This effect reduces the profitability of the NGN infrastructure, and hence, the incentives to invest in it.

From this analysis, four different testable hypotheses can be drawn. First, the effect of the access price on the investment in the new technology networks is in general ambiguous. As pointed out, three effects are at play and the aggregate NGN coverage generally varies non-monotonically with the access price of the copper network. This nonlinear effect emerges mainly from the so-called wholesale revenue effect (Bourreau et al., 2012), which discourages the incumbent from investing in a higher quality network when the access price is high in order not to jeopardize the extra-return they can obtain from providing access to their old infrastructures to third parties. In other words, while increasing access to old networks would incentivize not only the entrants but also the incumbents to invest in new infrastructures, and would favour the consumers to switch to adopting the new technology based services, the extra-return on the old legacy infrastructure would limit the incentives of the incumbents to invest. This implies that the effect of an increase in the access price is not clear a priori, unless it would be possible to control for the wholesale revenue effect; if this were possible, the following testable hypothesis would emerge:

> ***H1****: Assuming that it is possible to control the wholesale revenue effect, an increase in the regulated access price to the old technology would boost the new technology investment and expand its coverage.*

Second, regarding NGN adoption, an issue that is extremely important and that may affect consumer migration, at a retail level, from the standard copper infrastructures to NGN connections, is the relative price difference between the NGN retail services and the standard broadband ones. Indeed, when the access price on the legacy network is low, the prices of the services that rely on this network are also low. Hence, in order to encourage customers to move away from the legacy network, operators would need to introduce low-priced NGN offers. The latter effect, which is referred to as the business migration effect, implies that the access price on copper networks (i.e. the LLU price) may have a considerable effect on NGN adoption: assuming that the retail market for copper-based broadband services is substantially competitive, any increase in the cost of LLU prices would be translated into a higher cost of the basic broadband connections, thus making it less attractive than the NGN-based services. The following can therefore be tested:

> ***H2:*** *An increase in the regulated access prices to the old technology would make old broadband services similar to the new technology based services, and as a result the adoption of the latter would increase.*

An analysis of the take-up rate, which relates NGN adoption to NGN coverage seems less insightful because the adoption and coverage of the new infrastructures, as tested in the previous hypotheses, are simply being compared. However, as pointed out in the main Introduction, this index is not only a useful indicator of the willingness of consumers to migrate to a new infrastructure, but also the key policy variable used by the EC to define specific targets, in terms of NGN adoption and coverage, and implicitly also to define the take-up rate target. As shown in Hypotheses 1 and 2, it could be expected – after controlling for specific effects – that both adoption and coverage would be positively affected by an increase in the access price to the old networks and therefore the expected effect of this price on the take-up rate is ex ante indeterminate. The following can therefore be tested:

> ***H3:*** *The impact of an increase in the regulated access price to the old technology on the take-up rate of the new technology depends on the incremental effect of such a price increase on the new technology adoption rate and coverage.*

Finally, the above hypotheses hold for countries in which the old legacy infrastructure is well established on a nation-wide scale. In those countries, the access price to this infrastructure plays a relevant role. However, in countries where the legacy network is not very well developed, mostly for historical reasons, the role of the access price on the new technology coverage and adoption should be weaker. The following hypothesis emerges:

> ***H4:*** *In countries in which the presence of the old legacy technology is limited, an increase in the access price to the old technology should play a minor role in incentivizing the coverage and the adoption of the new technology.*

4 Data

In the empirical analysis, country level panel data for EU27 member states from 2004 to 2014 have been considered. The data have been gathered from several different sources: FTTH Council Europe[5] provides annual NGN coverage and adoption data from 2004 to 2014, thus covering almost the entire period of NGN deployment in EU member states. NGN coverage and adoption data also form the basis of the NGN take-up rate and the NGN gap measure, as discussed in section 4.1. Owing to the fact that some values are missing, there are fewer observations than the maximum number of 297 (27×11).[6] Furthermore, any unrealistically high take-up rates ≥ 0.75 which have occasionally been observed at the beginning of the NGN deployment in Spain, Poland, Slovenia and the United Kingdom from 2004 up to 2006, as well as in Greece from 2007 up to 2010 have been dropped. Generally, it is possible to observe, from Figures A.1 and A.2, that NGN take-up rates are significantly higher at the very beginning of NGN deployment, i.e. in the years from 2004 to 2007. One obvious explanation might be that NGN were initially deployed in areas in which there was a very high demand (e.g. universities, public administrations, large businesses, residential consumers with high willingness to pay), which resulted in a high adoption of installed NGN connections and hence in high take-up rates. Furthermore, during the first years of NGN deployment, many field experiments were conducted by operators in which the consumers were either volunteers or they obtained special offers (in some cases without having to pay any extra price). Hence, a very high take-up rate can be observed with respect to the selected and targeted consumers, which, at the same time constituted a substantial segment of the market.

As regards the independent variables, the EU Digital Agenda Scoreboard[7] provides yearly data on broadband regulations. As for the competition variables, the data on intermodal competition from mobiles ("wireless") and intramodal broadband competition ("wireline") have been provided by Euromonitor,[8] the International Telecommunications Union (ITU)[9] and the EU Digital Agenda Scoreboard. Euromonitor also provides data on the number of households and on the Networked

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

[6] There is basically no data for Malta and Cyprus on NGN deployment for the entire period of interest and these countries have therefore been excluded. Data on NGN coverage are also missing for the Czech Republic, Germany, Estonia, Poland, Slovenia and the United Kingdom in 2004, for Latvia, Lithuania, Portugal, Romania and Slovakia in 2004 and 2005, and for Greece, Luxembourg, Hungary and Bulgaria for a time span of up to five years starting from 2004.

[7] The EU "Digital Agenda Scoreboard" is available at: http://ec.europa.eu/information_society/policy/ecomm/library/communications_reports/index_en.ht. Values are missing for Bulgaria for the years from 2003 to 2006, for Romania from 2003 to 2004, for Estonia for 2003 and 2012, as well as for Cyprus, Latvia, Lithuania, Hungary, Malta, Poland, Slovenia and Slovakia for 2003.

[8] The Euromonitor International database is commercially available at: http://www.euromonitor.com/. Telecommunication revenue values are missing for the Netherlands for the year 2003, for Greece for 2013 and for Romania and Slovenia for both 2003 and 2004.

[9] The ITU World Telecommunication/ICT Indicator Database is available at: http://www.itu.int/ITU-D/ict/statistics/.

Readiness Index. Eurostat[10] provides data on education and ICT labour costs. Market Line[11] provides data on the percentage of urban population and population density. Finally, World Bank[12] and the International Monetary Fund[13] provide data on GDP, and the European Central Bank has provided data on the long-term interest rates.[14] All the independent variables (discussed in section 4.2) are available for the years from 2003 to 2013. As the data availability differs according to the variable, an unbalanced panel data set has been employed.[15]

The variable descriptions are listed in the Annex in Table A.1 and Table A.2, respectively, together with the data sources and summary statistics.

4.1 Dependent variables

NGN coverage, *NGN_cov*, measures the total number of deployed lines normalized to the total number of households ("homes passed"). Network coverage thus represents the installed capacity, in physical units, where the term "homes passed" refers to the number of consumers with potential access to NGN infrastructure. On the other hand, the variable NGN adoption, *NGN_adop*, measures the total number of consumers (normalized to households) who subscribe to at least one service offered via the NGN connection on a commercial basis ("homes connected").

The NGN take-up rate, *NGN_tur*, is the ratio between NGN adoption and NGN coverage, and thus ranges continuously in the [0;1] interval, as adoption cannot be higher than the installed capacity. In the case of optimal network utilization, the variable takes on the value of one. However, the denominator of *NGN_tur*, i.e., *NGN_cov*, is not in the [0;1] interval, as household coverage is already above 100% in some member states. This is due to a parallel coverage with the NGN infrastructure, in particular in urban areas, where homes are supplied with both cable and traditional telecommunication operators. However, the saturation level for NGN adoption is 100%, as households normally will not subscribe to multiple connections, considering the huge bandwidth capacity of a single NGN connection. In order to capture this asymmetry in maximum adoption and coverage levels, an alternative take-up measure has been defined as a robustness variable, that is, *NGN_gap*, which indicates the difference between NGN coverage and NGN adoption in absolute terms, where the upper bound of the variable *NGN_cov* is set equal to one.

[10] Data are available at: http://epp.eurostat.ec.europa.eu/portal/page/portal/information_society/-data/database. A few values are missing for the Austrian, Italian and Swedish dwelling permits,, as well as for the labour cost variables for Ireland and Greece. Networked Readiness Index values are also missing for Malta and Cyprus for 2003 and for Romania for 2006. Values pertaining to the number of internet users for Greece are missing (for the years) from 2011 to 2013.

[11] Data are commercially available at: http://advantage.marketline.com/PageForbidden?returnUrl=%2F.

[12] The World Bank's "World Development Indicators" are available at: http://data.worldbank.org.

[13] Data are available at: http://www.imf.org/external/data.htm.

[14] Values are missing for the long-term interest rate of Romania (for the years) from 2003 to 2005.

[15] In addition, there are some gaps in the raw data and the corresponding missing data had to be linearly interpolated. Overall, ~0.8% of all the raw data were calculated using linear interpolation or had to be extrapolated constantly for the future.

NGN coverage and adoption rates follow an investment adjustment and diffusion process, respectively, as evidenced by the related empirical literature, Figure A.1, pertaining to EU27 countries, and the two sub-groups of EU15 and Eastern European Countries[16] in Figure A.2, show that the NGN take-up rate does not follow a specific growth pattern but instead fluctuates around average mean values throughout most of the analysis period. It should also be noted that the mean of the NGN take-up rate is well below the target take-up rate implied by the DAE (i.e., 0.5). The graphical evidence suggests that, while coverage seems to present a rather similar trend across EU countries, adoption and the take-up rate of NGN services are larger in Eastern European countries where the presence of the old legacy infrastructure is limited or even absent, and where any regulatory policies towards a revision of the access prices to the legacy infrastructure appears to be less relevant.

4.2 Independent Variables

The independent variables can be divided into four categories: (i) regulation; (ii) competition; (iii) controls; and (iv) time period- and country fixed effects.

(i) The monthly unbundling access price, measured in €, *llu_price*, is the most relevant form of (wholesale) broadband regulation when considering migration from old to new broadband networks, and which is set directly by NRAs. However, as Bacache et al. (2014:205-206) pointed out, only a few unbundling price changes were imposed by NRAs in the past, which makes identification of the overall effect difficult. In order to circumvent this problem, an additional unbundling variable has been introduced by referring to a measure that captures the effectiveness of the unbundling regime (Briglauer, 2015). Accordingly, the variable, *i_price_llu_sh*, combines the unbundling price, *llu_price*, with the respective unbundling market share, *ms_llu*. The latter is bound between 0 and 1, where the upper limit indicates that all the retail broadband connections are offered via unbundling. This variable also provides a better representation of the overall complexity of unbundling regimes which include several other institutional and technical regulations besides the monthly access charge. Overall, both variables, *llu_price* and *i_price_llu_sh* have been used as our main **regulatory** variables.

Furthermore, the variable *sa_price* is used as an instrumenting variable; this variable represents the monthly cost of “shared access”, measured in €. Whereas unbundling provides full LLU access to the incumbent´s access lines, shared access only provides limited access to the upper line bandwidth. Accordingly, the regulated price of shared access products represents approximately one half of the unbundling price (see Table A.2). Hence, a change in shared access prices should not induce entrants to switch to much more cost intense self-provision of the NGN infrastructure, whereas the unbundling price – which represents the most investment intense business case for entrants – has an impact on the entrant´s investment decision at the margin. At

[16] Bulgaria, Czech Republic, Estonia, Latvia, Lithuania, Hungary, Poland, Romania, Slovenia and Slovakia have been included in the East European country group. Hence, the EU15 group includes all other EU27 member states, except Malta and Cyprus.

the same time, shared access and unbundling prices are closely related, since both are determined by NRAs on the basis of (common) network costs. As the latter represent about 60-80% of the total costs (ERG, 2007), our regulatory variables, in particular the unbundling price, also represent a valid proxy of the average retail broadband price.

(ii) Three variables are related to **competition** in retail broadband markets: the first one stems from mobile networks (“intermodal” wireless competition). In order to account for mobile network competition, the variable *fms*, which relates the total number of mobile subscriptions to the total number of fixed landlines, has been used. The second competition variable, *bb_ne,* represents the entrant's retail market share in fixed broadband lines, and thus the impact of wireline (“intramodal”) competition on old broadband markets on emerging NGN markets. Thirdly, the *legacy* variable measures a country’s total stock of fixed-linked copper-wire connections, and it is therefore able to directly capture the replacement effect for the incumbent that stems from all wholesale and retail services of the incumbent´s old network infrastructure. Accordingly, this variable also captures the wholesale revenue effect as defined in Section 3.

(iii) A broad set of **demand** and **cost controls**, ***Z***, have also been included, in line with the previous empirical literature, and on the basis of industry knowledge (e.g. FTTH Council Europe, 2013: 36-47). A detailed description of all the controls can be found in Table A.1 in the Annex.

(iv) Finally, **period effects**, *δ*, and **country fixed-effects**, *θ,* have also been considered. Including period effects makes it possible to control for relevant industry developments that are common to all EU27 member states throughout the entire period of analysis, such as different market phases or changes in equipment and material prices, which are determined by industry standards and global markets. The fixed effects are related to some of the main cost conditions, such as the topographic and demographic characteristics. Likewise, supply- and demand-oriented NGN subsidies, once having been determined by local or national governments, generally stay in place for a longer period of time.

5 Empirical specifications

In view of the different diffusion patterns and the interdependencies underlying the dependent variables, a two-fold research strategy has been employed: the empirical baseline specifications for the separate regressions of the NGN investment and the adoption models have been presented in section 5.1. Although any adoption and investment process is inherently dynamic, the development of the NGN take-up rates points to a static baseline specification, which has been outlined in Section 5.2. The adopted estimation and identification strategy has been described in Section 5.3.

5.1 Dynamic NGN investment and adoption models

According to the ICT related empirical literature, the dynamics of the adoption process, which is due to network effects or consumer inertia, as well as of the investment process, which is mainly determined by the extent of adjustment costs, can be captured by including the lagged dependent variable as an additional right-hand side explanatory variable (Kiiski & Pohjola, 2002; Grajek & Röller, 2011). In view of the discussion presented in sections 3 and 4, the dynamic reduced-form models, in which NGN investment (superscript *c* denotes coverage in equation 1) and NGN adoption (superscript *a* denotes adoption in equation 2) are expressed in logs[17] for EU member state *i* and year *t*, read as follows:

$$\begin{aligned}(1)\quad & \ln(NGN\_\mathrm{cov}_{it}) = \alpha_0^c + \beta_1^c \ln(llu\_price_{i(t-1)}) + \beta_2^c \ln(i\_price\_llu\_sh_{i(t-1)}) \\ & + \beta_3^c\, fms_{i(t-1)} + \beta_4^c\, fms^2{}_{i(t-1)} + \beta_5^c bb\_ne_{i(t-1)} + \beta_6^c bb\_ne^2{}_{i(t-1)} + \beta_7^c legacy_{i(t-1)} \\ & + \gamma^{c\prime}\mathbf{Z}_{i(t-1)}^c + \theta_i^c + \lambda_t^c + \alpha_1^c \ln(NGN\_\mathrm{cov}_{i(t-1)}) + \varepsilon_{it}\end{aligned}$$

$$\begin{aligned}(2)\quad & \ln(NGN\_adop_{it}) = \alpha_0^a + \beta_1^a \ln(llu\_price_{i(t-1)}) + \beta_2^a \ln(i\_price\_llu\_sh_{i(t-1)}) \\ & + \beta_3^a\, fms_{i(t-1)} + \beta_4^a\, fms^2{}_{i(t-1)} + \beta_5^a bb\_ne_{i(t-1)} + \beta_6^a bb\_ne^2{}_{i(t-1)} + \beta_7^a legacy_{i(t-1)} \\ & + \gamma^{a\prime}\mathbf{Z}_{i(t-1)}^a + \theta_i^a + \lambda_t^a + \alpha_1^a \ln(NGN\_adop_{i(t-1)}) + \varphi_{it}\end{aligned}$$

The coefficients of the lagged dependent variables measure the constant speed of diffusion $(1-\alpha_1^a)$ and the speed of adjustment $(1-\alpha_1^c)$ in the NGN adoption and NGN investment specifications, respectively. The dynamic specifications are correct, and give rise to an endogenous growth process if $0 < \alpha_1 < 1$. Equation (1) and equation (2) also depend on the main variables of interest, i.e., regulation, in terms of the variables $ln(llu\_price_{i(t-1)})$ and $ln(i\_price\_llu\_sh_{i(t-1)})$, and competition, in terms of the variables $fms_{i(t-1)}$, $bb\_ne_{i(t-1)}$ and $legacy_{i(t-1)}$. In order to estimate the potential non-linear relations as regards competition variables, squared terms of the variables, related to intermodal ($fms_{i(t-1)}$) and intramodal ($bb\_ne_{i(t-1)}$) competition, have also been included in our baseline specifications (Schmutzler & Sacco, 2011). Furthermore, a vector of controls, $\mathbf{Z}_{i(t-1)}$, with demand controls and cost controls has been included in the adoption and coverage baseline equations, respectively. Finally, ε_{it} and φ_{it} represent additive error terms, θ_i´s country-specific effects and λ_t´s period effects.

[17] A log transformation helps to stabilize the series of dependent variables and is also necessary to capture the dynamics of the data generating diffusion and adjustment processes adequately. In order to be able to interpret the main variables of interest in terms of elasticities, the variables related to the unbundling price have also been expressed as a logarithm in the dynamic specifications.

5.2 Static NGN Take-Up Rate model

As the take-up rate does not exhibit an endogenous adjustment process (Figure A.1), modelling a static specification appears to be a reasonable choice. The empirical baseline specification for the NGN take-up rate model, NGN_tur_{it}, for EU member state i and year t, reads as follows:

$$\begin{aligned} \text{NGN\_tur}_{it} &= \alpha_0^{tur} + \beta_1^{tur} llu\_price_{i(t-1)} + \beta_2^{tur} i\_price\_llu\_sh_{i(t-1)} + \\ (3) \quad & \beta_3^{tur} fms_{i(t-1)} + \beta_4^{tur} fms^2{}_{i(t-1)} + \beta_5^{tur} bb\_ne_{i(t-1)} + \beta_6^{tur} bb\_ne^2{}_{i(t-1)} + \beta_7^{tur} legacy_{i(t-1)} \\ & + \gamma^{tur\prime} \mathbf{Z}^a_{i(t-1)} + \gamma' \mathbf{Z}^c_{i(t-1)} + \theta_i^{tur} + \lambda_t^{tur} + \nu_{it} \end{aligned}$$

Equation (3) contains the same list of explanatory variables as in the dynamic specifications, except for the lagged-dependent variable ($\alpha_1^{tur} = 0$) and the fact that equation (3) controls for both demand and cost shifters, $\mathbf{Z}^a_{i(t-1)}$ and $\mathbf{Z}^c_{i(t-1)}$. It should be noted that equations (1)-(3) include lagged values of all the explanatory variables in order to employ the entire available data set (as described in section 4).[18,19]

5.3 Estimation and identification strategy

In order to identify causal effects, two-way fixed-effect regressions have been employed to control for potential endogeneity due to unobserved and time-constant heterogeneity at the country level (θ) as well as period effects (λ) to control for any time specific shocks that are common to all cross-sectional units (member states). However, estimating equations (1) and (2) by means of an ordinary fixed-effect (least-squares-dummy-variable, LSDV) estimator, would yield inconsistent and biased results, since the lagged dependent variable and the error terms that include the fixed effects would be correlated (Nickell, 1981). In order to identify the parameters of the dynamic models, a bias-corrected fixed-effect estimator (LSDVC), developed by Bruno (2005a) and Bruno (2005b) specifically for dynamic unbalanced panel data, and a small number of cross-sectional units (N = 25), has been employed.

Second, by lagging all the explanatory variables, the dependent variables in equations (1)-(3) are related to the pre-determined values of the independent variables, which mitigates endogeneity due to time-variant heterogeneity if the model is dynamically complete, i.e. in the absence of serial correlations. Although pre-

[18] Moreover, it also makes sense to assume that adoption and investment decisions at a particular point in time do depend on the conditions of the latter period, in view of switching and adjustment costs on the side of consumers and operators, respectively. Investing firms are faced with rigidities related to the legal and institutional framework, as well as technical complexities of NGN deployment, and consumers of broadband services are usually subjected to long term contracts (up to two years) and non-transparent tariff structures.

[19] For the sake of clarity, the indices have been dropped in the remainder of the paper.

determinedness, or sequential exogeneity, is in fact reasonable for dynamic autoregressive models, such as those in equations (1) and (2) (Wooldridge, 2002: 299-300), serial correlation in the static specification (equation (3)) has to be addressed in a different way. The nature of a serial correlation is first examined and then the serial components are removed using a suitable data transformation.

Third, to rule out potential endogeneity due to reverse causality, Granger causality tests (Granger, 1969) have been also performed. The results, which are reported in Table A.3 in the Annex, indicate that there is no evidence of reverse causality.[20]

Fourth, a large number of demand and cost controls have been employed in order to further reduce any remaining omitted variable bias that might be due to time-variant heterogeneity.

Finally, as parts of the robustness specifications, the main regulatory variable, *llu_price*, has been instrumented with the *sa_price* variable as well as with some other exogenous cost shifters.

6 Empirical Results

According to the aforementioned two-fold research strategy, the results of the dynamic models are first discussed in Section 6.1 and those of the static take-up rate model are given in Section 6.2. The estimation results of the individual models on NGN coverage and adoption also provide important information for the interpretation of the estimation results pertaining to the take-up rate model. Finally, additional estimations are presented in Section 6.3 in order to examine the robustness of the main estimation results.[21]

6.1 Dynamic NGN investment and adoption models

Table 1 and Table 2 report the results of the LSDVC estimations of various NGN investment and adoption models. The models reported in regressions (2)-(4) represent deviations from the baseline specifications (regression (1)) as outlined in equations (1) and (2) in terms of different selections of controls and unbundling variables.

The coefficients of the **lagged dependent variables**, α_1^a and α_1^c, are highly significant and substantial in all the regressions in both the investment and adoption

[20] Granger causality tests require stationary time series. In order to formally test for stationarity, a "Fisher-type" (Augmented Dickey–Fuller) unit-root test, which has been designed for unbalanced panels, has been performed. This test rejects the null hypothesis that all panels contain unit roots for all the variables used in our model specifications (the results are available upon request from the authors; however, owing to the low number of observations (T = 11), the power of this test is limited).

[21] Stata/IC 13.0 has been used to estimate all the regressions. Before running the regressions, a check was made on the bivariate correlations between the explanatory variables. Since two variables with high bivariate correlation produce inefficient estimates, they were excluded in the case of a higher correlation coefficient than 0.85.

models, thus indicating that the dynamic specification is correct. The coefficients have been estimated quite precisely and are slightly larger in the adoption regressions. This is in line with the previous literature, and suggests that consumer inertia and switching costs are even more pronounced than adjustment costs.

As far as the **unbundling price**, *ln(llu_price)*, is concerned, the coefficient estimates are insignificant in all the regressions in Table 1 and Table 2. As indicated in section 4.2, this might be due to the low degree of variation in the unbundling price variable. However, the variable *ln(i_price_llu_sh)* shows a significantly positive impact on both NGN adoption and NGN investment. In particular, a 1% increase in the unbundling price increases NGN adoption and NGN investment by ~0.45% and ~0.47%, respectively.[22] These results are in line with the expectations (**Hypotheses 1** and **2**), as the wholesale revenue effect is explicitly controlled for by including the variable *legacy*. It has also been tested whether the Eastern European countries (*East* = 1) that lacked a well-developed legacy infrastructure prior to NGN deployment exhibit a less pronounced effect of the unbundling regime. As expected (**Hypothesis 4**), from the coefficient of the variable *ln(i_price_llu_sh_East)*, it can be inferred that this effect is offset in Eastern European countries. Accordingly, a 1% increase in the unbundling price in regressions (4) of the coverage and adoption specifications implies an almost null marginal increase in coverage (~ 0.1% percentage points) and adoption (0.13%). In fact, Wald-type tests indicate that the coefficients of both linear and interactions terms are jointly insignificant, indicating that the effect of the unbundling price is de facto neutralized in Eastern European countries.

Moreover, the cross-price effect of the unbundling price on NGN adoption is of particular interest, because of the lack of evidence within the existing economic literature. Srinuan, Srinuan and Bohlin (2012) have developed an empirical investigation to analyze direct and cross-price elasticity among different types of broadband access technologies (xDSL, cable, fibre, mobile broadband). Data was obtained from a random nationwide postal mail survey of Swedish households between August and September 2009, with 2038 respondents. The results show that the cross-price elasticity of demand for fibre, in relation to the DSL price, is 3.289. A recent study by Grzybowski, Nitsche, Verboven and Wiethaus (2015) has used a large database from a survey of 6446 households in Slovakia between April-July 2011 to estimate own- and cross- price elasticity of demand for different broadband technologies (DSL, fibre, cable, WiFi and mobile broadband access). The results show that a 1% increase in DSL price would increase the demand for fibre by between 0.66% (at a country level) and 0.96% (at a municipality level), thus indicating a cross-price elasticity of demand for fibre, in relation to DSL, of 0.66-0.96. The present results on an EU level sample, which is more extensive than that of the previous papers, are consistent with the aforementioned studies as they point out the presence of a business migration effect from the old to the new technology infrastructure.

[22] Note that totally differentiating with respect to the unbundling price yields the constant elasticity as captured by the coefficient β_2 which is independent of the unbundling market share.

As far as the **competition variables** are concerned, no significant pattern for intermodal (*fms*) or intramodal competition (*bb_ne*) has been found in either type of model. Regressions with significant estimates have indicated a negative impact of intramodal competition on NGN coverage (regression (1)) and NGN adoption in regression (4) and of intermodal competition with respect to NGN adoption (regressions (2) and (4)). To the extent that these competition variables capture market outcomes in terms of retail prices, the negative relationships can be seen as evidence of the business migration effect. Similarly, competition stemming from the old infrastructure (*legacy*) exerts a significantly negative impact on NGN investment and adoption in almost all regression specifications. This indicates that a well-established infrastructure also exerts a substantial replacement effect on the side of infrastructure operators (Table 1) and substantial switching costs on the side of consumers (Table 2). When the coefficient estimates are compared, it appears that the replacement effect is more severe on the supply side. However, the replacement effect is mitigated if the legacy infrastructure in Eastern European countries, as measured by the interaction term *i_legacy_East,* is considered explicitly, thus again confirming the expectations of **Hypothesis 4.**

As regards the cost and demand **controls**, the signs of all the significant coefficient estimates are in line with the basic economic theory. Moreover, the coefficient estimates of the main variables of interest also appear to be robust towards alternative selections of control variables in Table 1 and Table 2. Furthermore, if the demand and cost controls are added to the NGN coverage and NGN adoption baseline model ("base"), the main results do not change. Overall, regressions (4) in Table 1 and Table 2 can be considered as the final estimations as they also cover the heterogeneity of EU member states as regards the initial conditions for NGN deployment. Comparing these regressions, it emerges that the size of the old broadband market, *ln(bb_lines)*, which proxies total willingness to pay for ICT services, has a significantly positive impact on both NGN adoption and NGN investment. As regards the adoption model, it can also be inferred that adoption of old broadband services, *adop_bb_lines*, counteracts this effect. Indeed, in the case in which conventional broadband services enjoy broad consumer acceptance, in terms of quality characteristics and high market saturation, the switching costs might be substantial and hinder consumer migration to NGN services.

Table 1: Dynamic investment model (Dependent var.: *ln(NGN_cov)*)

Regr. nr.	(1) base	(2) full	(3) Eastern_1	(4) Eastern_2
Lag: ln(NGN_cov)	0.6415***	0.5960***	0.5647***	0.5752***
	(8.04)	(7.58)	(7.20)	(7.27)
Lag: ln(llu_price)	0.1703	0.5633	0.3322	0.0854
	(0.28)	(0.99)	(0.56)	(0.15)
Lag: ln(i_price_llu_sh)	0.2159**	0.2293**	0.4506***	0.4745***
	(2.05)	(2.12)	(2.62)	(2.75)
Lag: ln(i_price_llu_sh_East)			-0.3886*	-0.3732*
			(-1.71)	(-1.66)
Lag: fms	-0.5297	-1.1199	-0.8736	-0.6778
	(-0.77)	(-1.61)	(-1.22)	(-0.96)
Lag: fms^2	0.0404	0.0709	0.0570	0.0450
	(0.86)	(1.51)	(1.19)	(0.94)
Lag: bb_ne	12.2182	1.9307	0.0559	-3.1084
	(1.63)	(0.23)	(0.01)	(-0.36)
Lag: bb_ne^2	-18.0555**	-8.7270	-6.1103	-2.5497
	(-2.26)	(-1.01)	(-0.70)	(-0.29)
Lag: legacy	-0.0722*	-0.1079**	-0.1100**	-0.1214***
	(-1.67)	(-2.35)	(-2.40)	(-2.65)
Lag: i_legacy_East				0.1426**
				(2.19)
Lag: urban_pop	0.0659	0.1741	0.1783	0.0903
	(0.41)	(1.01)	(1.05)	(0.51)
Lag: wage	-0.1920	-0.3756***	-0.4137***	-0.4735***
	(-1.63)	(-2.95)	(-3.29)	(-3.70)
Lag: labcost_ict	-0.0358**	-0.0315**	-0.0309**	-0.0345**
	(-2.31)	(-2.08)	(-2.03)	(-2.30)
Lag: gdp		-0.0000	-0.0000	-0.0000
		(-1.03)	(-1.45)	(-1.27)
Lag: ln(bb_lines)		0.6641	0.8547*	1.2482**
		(1.40)	(1.85)	(2.32)
Lag: edu		0.0090***	0.0106***	0.0100***
		(2.62)	(3.10)	(2.95)
Lag: nri		-1.2984	-1.3285	-1.1536
		(-1.47)	(-1.50)	(-1.34)
Year dummies	YES	YES	YES	YES
R^2 (within)	0.8213	0.8364	0.8431	0.8478
AR(2) (*p*-value)	0.301	0.274	0.260	0.384
Observations	178	178	178	178

The LSDVC standard errors in regressions (1)-(4) have been bootstrapped with bias correction initialized by the Arellano and Bond estimator (Arellano & Bond, 1991) for estimates. Note that there are no standard post-estimation tests available in STATA for the user written "xtlsdvc" command (Bruno, 2005b). Therefore, the R^2 within has been provided on the basis of an LSDV regression with a lagged dependent variable. Moreover, a specification test, based on the Arellano-Bond test for autocorrelation in the residuals, has also been provided. If the assumption of serial independence in the original errors, ε´s and φ´s, is correct, the transformed residuals should not show any significant AR(2) test statistics. The *t*-statistics are reported in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 2: Dynamic adoption model (Dependent var.: *ln(NGN_adop)*)

Regr. nr.	(1) base	(2) fms	(3) full	(4) Eastern
Lag: ln(NGN_adop)	0.6533***	0.6464***	0.6431***	0.6270***
	(12.32)	(11.38)	(11.35)	(12.34)
Lag: ln(llu_price)	-0.4199	-0.3805	-0.6332	-0.6661
	(-0.97)	(-0.87)	(-1.46)	(-1.42)
Lag: ln(i_price_llu_sh)	0.2877***	0.2987***	0.2920***	0.4488***
	(3.85)	(4.17)	(4.15)	(4.26)
Lag: ln(i_price_llu_sh_East)				-0.3147**
				(-2.12)
Lag: fms	-0.4413	-0.2642**	-0.1513	-0.1824*
	(-1.10)	(-2.41)	(-1.31)	(-1.66)
Lag: fms^2	0.0122			
	(0.43)			
Lag: bb_ne	1.2408	-0.6535	4.7136	-3.7940***
	(0.21)	(-0.11)	(0.79)	(-2.78)
Lag: bb_ne^2	-5.4528	-3.3921	-9.0910	
	(-0.96)	(-0.61)	(-1.59)	
Lag: legacy	-0.0578**	-0.0421*	-0.0437*	-0.0337
	(-2.30)	(-1.87)	(-1.80)	(-1.35)
Lag: gdp	-0.0000	-0.0000	-0.0000	-0.0000
	(-0.95)	(-1.32)	(-1.56)	(-1.46)
Lag: ln(bb_lines)	0.5685*	0.3020	0.4584	1.1270**
	(1.73)	(0.68)	(1.06)	(2.46)
Lag: adop_bb_lines				-3.0634*
				(-1.76)
Lag: edu	0.0863***	0.0729**	0.0347	0.0011
	(2.91)	(2.26)	(0.98)	(0.43)
Lag: nri	0.0109	-0.6091	-0.1894	-0.2750
	(0.04)	(-1.20)	(-0.36)	(-0.53)
Lag: labcost_ict			-0.0233**	-0.0263***
			(-2.44)	(-2.95)
Lag: urban_pop			0.1770	0.2148*
			(1.59)	(1.95)
Year dummies	YES	YES	YES	YES
R^2 (within)	0.8625	0.8695	0.8770	0.8810
AR(2) (p-value)	0.376	0.714	0.692	0.631
Observations	196	196	196	196

The LSDVC standard errors in regressions (1)-(4) have been bootstrapped with bias correction initialized by the Arellano and Bond estimator (Arellano & Bond, 1991) for estimates. Note that there are no standard post-estimation tests available in STATA for the user written "xtlsdvc" command (Bruno, 2005b). Therefore, the R^2 within has been provided on the basis of an LSDV regression with a lagged dependent variable. Moreover, a specification test, based on the Arellano-Bond test for autocorrelation in the residuals, has also been provided. If the assumption of serial independence in the original errors, ε´s and φ´s, is correct, the transformed residuals should not show any significant AR(2) test statistics. The *t*-statistics are reported in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.2 The NGN take-up rate model

As described in Section 3, the take-up rate relates NGN adoption to NGN coverage. This index is extremely important for three reasons: first, it is a relevant indicator of the willingness of consumers to migrate to a new infrastructure; second, it is a measure of capacity utilization; third, and perhaps more important, it is a key policy variable defined by the EC in its DAE targets. The results reported in Section 6.1 on coverage and adoption show that both NGN coverage and adoption is positively affected by an increase in the access price to the old networks, thus implying that the expected effect of this price on the take-up rate is ex ante unclear. The main results of the static NGN take-up rate model are reported in Table 3. The *F*-test (*F_f*), at the bottom of Table 3, shows that country-level fixed-effects are highly significant, which in turn implies that pooled OLS would produce inconsistent estimates if the fixed-effects were correlated to the independent variables.[23] Wooldridge´s test for serial correlation in panel data (Wooldridge, 2002) clearly indicates the presence of a first-order serial correlation (e.g. $F(1, 24) = 34.074$ for the baseline model in regression (1)). This test is robust to conditional heteroscedasticity, which is present in the take-up rate model specifications. Accordingly, two-way fixed-effects regressions have been employed with an AR(1) disturbance in regressions (1)-(4). It should be noted that all the demand and cost side controls have been included in regressions (1)-(4), as outlined in Section 5.2.

The results show that an increase in the local loop unbundling price, *llu_price*, has a significantly negative impact on the take-up rate of NGN connections. Putting together the results from the previous Sections, the overall results show that both adoption and coverage do in fact increase with an increase in the regulated access price, but the effects on coverage slightly dominates the effect on the demand side and hence reduces the take-up rate (**Hypothesis 3**). This effect, though weakened by the simultaneous effects on adoption and coverage, is constant across the specifications. Accordingly, an increase in the unbundling price by 1€, increases the NGN take-up rate by ~ 1 percentage point. Similarly, and in line with our previous results, controlling for the presence of Eastern countries (regression 4) does not affect the results, which means that the role of the unbundling price is irrelevant in those countries to sustain NGN take-up.

Most cost and demand side controls do not seem to play any relevant role, while fixed-mobile substitution does. The more intense the intermodal competition is, the lower the NGN take-up rate; this effect is also non-linear, as suggested by the model specifications in regressions (3)-(4). The corresponding coefficients (regression (4)) on the *fms* and fms^2 variables point to an inverted U-shaped relationship, with an optimal level of competition intensity for *fms* ~ 6.18, which is well above the grand mean value (*fms* ~ 3.37 (Table A.2)). Hence, on average intermodal competition from mobile networks exerted a positive impact on the NGN take-up rate in the past.

[23] A robust Hausman test clearly rejects the random effect model assumption (the Sargan-Hansen test results are significant at the 1% level; not reported here, but available upon request). Clearly, the EU27 member states do not represent a random sample drawn from the population of all countries.

6.3 Further robustness tests

This section presents additional estimations that can be used to examine the robustness of the main results. The robustness tests refer to (i) an alternative estimator (fixed-effects instrumental variable (IV) estimation in regressions (1)-(3)) and (ii) an alternative specification of the dependent variable (*ln(NGN_gap)*[24] in regression (4)).

As described in section 4.2, the unbundling price has been instrumented with the price of shared access, *sa_price*, as well as with some other (excluded) exogenous cost shifters (population density, *pop_dens*, and the long-term interest rate, *lt_ir*). In line with the previous sections, we employ the bias-corrected LSDVC estimator for the dynamic NGN adoption and coverage specification in regressions (1)-(2) and the ordinary (LSDV) fixed-effect estimator for the static NGN take-up rate and NGN gap model in regressions (3)-(4).

A first stage regression shows that the instruments are jointly highly significant (F = 48.07). From regression (1)-(2) in Table 4, the main estimation results carry over quite well as regards the dynamic NGN coverage (regression (1)) and NGN adoption (regression (2)) models, where the "full" model specifications have been re-estimated, as reported in Table 1 and Table 2. The same results on the unbundling price also show up in the IV NGN take-up rate (regression (3)) model. Focusing on the role of the unbundling price we re-estimated the structure of the "ull" model, as reported in regression (2) of Table 3. Whereas the main term is now insignificant, the interaction term picks-up the negative relation which is significant at the 1% level.

As far as the *ln(NGN_gap)* model is concerned, supportive evidence has also been found on the impact of the unbundling price. The positive coefficient estimate can now be expected, in view of the construction of the variable *ln(NGN_gap)*. This also holds for the other explanatory variables, and, in particular, the market size now exerts a positive and significant effect.

[24] In order to normalize the series, logs of the dependent variable were considered.

Table 3: Static take-up rate model (Dependent var.: *NGN_tur*)

Regr. nr.	(1) base	(2) llu	(3) fms	(4) Eastern
Lag: llu_price	-0.0097*	-0.0096*	-0.0102*	-0.0116*
	(-1.77)	(-1.74)	(-1.88)	(-1.81)
Lag: i_price_llu_sh		-0.0013		
		(-0.11)		
Lag: i_llu_price_East				0.0036
				(0.35)
Lag: fms	-0.0280*	-0.0283*	0.1119*	0.1186*
	(-1.68)	(-1.69)	(1.68)	(1.76)
Lag: fms^2			-0.0094**	-0.0096**
			(-2.14)	(-2.17)
Lag: bb_ne	-0.9742	-0.9714	-0.9342	-1.0172
	(-1.22)	(-1.20)	(-1.19)	(-1.31)
Lag: bb_ne^2	1.2196	1.2210	1.1889	1.2858
	(1.49)	(1.48)	(1.48)	(1.61)
Lag: legacy	0.0021	0.0021	0.0051	0.0064
	(0.49)	(0.49)	(1.12)	(1.35)
Lag: gdp	0.0000	0.0000	-0.0000	0.0000
	(0.21)	(0.22)	(-0.04)	(0.57)
Lag: ln(bb_lines)	0.1502	0.1501	0.1667	0.1779
	(1.13)	(1.12)	(1.26)	(1.31)
Lag: adop_bb_lines	-0.3135	-0.3169	-0.2531	-0.2495
	(-1.00)	(-1.00)	(-0.81)	(-0.80)
Lag: edu	-0.0000	0.0000	-0.0003	-0.0005
	(-0.00)	(0.00)	(-0.05)	(-1.15)
Lag: nri	0.0799	0.0794	0.1069	0.1072
	(1.16)	(1.14)	(1.53)	(1.55)
Lag: labcost_ict	-0.0001	-0.0001	-0.0004	-0.0004
	(-0.10)	(-0.09)	(-0.24)	(-0.29)
Lag: urban_pop	0.0364	0.0366	0.0409	0.0282
	(1.47)	(1.47)	(1.62)	(1.04)
Lag: wage	0.0271*	0.0275*	0.0287*	0.0346**
	(1.83)	(1.82)	(1.92)	(2.18)
Constant	-1.0575***	-1.0650***	-1.0148***	-1.0273***
	(-2.91)	(-2.89)	(-2.89)	(-2.86)
Year dummies	YES	YES	YES	YES
R^2 (within)	0.2368	0.2378	0.2518	0.2547
F	2.0504	1.9629	2.1170	2.0501
F_f	2.6233	2.6220	2.4251	2.6249
Observations	200	200	200	200

Note that panel-by-panel Cochrane-Orcutt method decreases the number of maximum observations by the number of available groups. In addition, some values in our panel data set are missing, as pointed out in section 4. All regressions include country fixed effects and period effects. The *t*-statistics are reported in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 4: Robustness regressions (Dependent var.: (regr. (1): *ln(NGN_cov)*; regr. (2): *ln(NGN_adop)*; regr. (3): *NGN_tur*; regr. (4): *ln(NGN_gap)*

Regr. nr.	(1) cov_full_IV _LSDVC	(2) adop_full_IV _LSDVC	(3) tur_ull_IV _FE_robust	(4) ln(NGN_gap) _FE_AR(1)
Lag: Dependent var.	0.6362***	0.6534***		
	(8.50)	(11.37)		
Lag: ln(llu_price)	0.1620	-0.4045		
	(0.33)	(-0.92)		
Lag: llu_price			0.0083	0.1195***
			(1.33)	(2.97)
Lag:ln(i_price_llu_sh)	0.1538*	0.2995***	-0.0192***	
(reg (3): i_price_llu_sh)	(1.66)	(4.08)	(-3.22)	
Lag: fms	-1.0029*	-0.2125*	-0.0426*	-0.0562
	(-1.82)	(-1.82)	(-1.74)	(-0.29)
Lag: fms^2	0.0595			
	(1.58)			
Lag: bb_ne	3.8542	2.4236	-2.2000*	-1.5749
	(0.48)	(0.38)	(-1.96)	(-0.34)
Lag: bb_ne^2	-8.8926	-6.3057	2.7773**	2.5772
	(-1.04)	(-1.03)	(2.56)	(0.50)
Lag: legacy	-0.1090***	-0.0454*	0.0074	-0.0229
	(-3.02)	(-1.81)	(1.35)	(-0.58)
Lag: gdp	-0.0000	-0.0000	0.0000	-0.0000
	(-0.40)	(-1.43)	(0.89)	(-0.68)
Lag: ln(bb_lines)	0.5454	0.4030	-0.0029	1.4941**
	(1.12)	(0.86)	(-0.05)	(2.15)
Lag: adop_bb_lines			-0.5342*	-1.8500
			(-1.94)	(-0.80)
Lag: edu	0.0064*	0.0580	0.0086	-0.0498
	(1.88)	(1.61)	(1.01)	(-0.81)
Lag: nri	-1.0308	-0.4300	-0.0365	0.2883
	(-1.39)	(-0.78)	(-0.72)	(0.47)
Lag: urban_pop	0.1829	0.1562	0.0153	0.4764
	(1.28)	(1.27)	(0.63)	(1.24)
Lag: wage	-0.2973***		0.0297**	-0.3824**
	(-2.76)		(2.41)	(-2.26)
Lag: labcost_ict	-0.0149	-0.0096	0.0012	-0.0200
	(-1.21)	(-0.82)	(0.54)	(-1.41)
Constant			-1.6167	-29.5569***
			(-0.79)	(-3.23)
Year dummies	YES	YES	YES	YES
R^2 (within)	0.7795	0.7410	0.4032	0.1555
F_f	12.27	8.23	7.8381	1.12
AR(2) (p-value)	0.804	0.600		
Observations	200	196	218	216

Estimates in regressions (1)-(3) are based on the two-stage least squares IV estimator. Regression (4) is based on panel-by-panel Cochrane-Orcutt method to eliminate first-order serial correlation. All regressions include country fixed effects and period effects. The *t*-statistics are reported in parentheses and are bootstrapped in regressions (1)-(2) and robust to arbitrary forms of heteroscedasticity and serial correlation in regression (3); * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

7 Summary and Conclusions

The aim of this paper has been to provide evidence on a hotly debated issue, i.e. how to simultaneously incentivize the adoption and the investment in next generation broadband technology. In particular, the focus of the paper has been on the potential role of the access price on the old broadband infrastructure, which is set directly by NRAs and acts as a key policy variable to speed up investment and the adoption of new ultra-fast broadband connections.

Results show that NGN coverage and adoption are characterized by the presence of path dependency: this implies that policies aimed at fostering retail migration are important to sustain demand expansion. At the same time, the existing access price regulation, i.e. the LLU price, could affect NGN adoption indirectly, albeit considerably. The data show that relaxing the LLU regulation, i.e. allowing an increase in access prices for the old legacy infrastructures, could help to support a demand expansion and reduce the price differentials between the prices of standard broadband services and the NGN-based ones. However, we found that there is considerable heterogeneity among EU member states implying, in particular, that the impact of unbundling policies are strongly weakened in Eastern European countries, where the regulated old broadband infrastructures are much less developed. Furthermore, the effect of an increase in the LLU access price is greater for NGN coverage than for adoption, thus widening the gap between adoption and coverage and therefore reducing the take-up rate. In other words, although it positively affects NGN adoption and NGN coverage, an increase in LLU prices could also generate extra-capacity without enhancing sufficient ultra-fast broadband demand, thus implying that, on the demand side, additional policies are needed to sustain demand expansion. This result is reminiscent of Tinbergen´s maxim according to which the number of policy instruments must be equal to the number of policy targets.

Consequently, in order to achieve the mid-term dual DAE goals, both the demand and the supply sides of the European broadband markets need to be stimulated. Significant investments in telecom and/or cable infrastructure are needed on the supply side in order to enable much higher internet speeds. Instead, on the demand side, the consumers need to be persuaded about the potential benefits of new applications that make use of these higher speeds and need to be offered affordable prices in order to subscribe, e.g. via vouchers, tax deductions or other public demand stimuli. Only on the assumption that development of content and applications will autonomously evolve sufficient demand after the necessary infrastructure has already been put in place and the welfare loss due to slower migration is not too large, the negative impact of the access price on the take-up rate can be considered as a second-order effect.

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Annex

Tables A.1, A.2, A.3 and Figures A.1 and A.2.

Table A.1: Description of the variables and sources

Variable	Description	Source
	Dependent variables	
NGN coverage *NGN_cov* (household weighted)	Total number of homes passed by FTTx technologies (*Fibre-to-the-home; Fibre-to-the-building; Fibre-to-the-curb; Fibre-to-the-last amplifier/DOCSIS 3.0*). "Homes passed" refers to the total number of premises. "Premises" is a home or place of business, normalized to each country's total number of households.	FTTH Council Europe Euromonitor (households)
NGN adoption *NGN_adop* (household weighted)	Total number of subscribers in terms of "homes connected" by FTTx technologies. "Subscribers" refers to premises that uses at least one service in this connection under a commercial contract, normalized to each country's total number of households.	FTTH Council Europe
NGN take-up rate, *NGN_tur*	Ratio between NGN adoption and NGN coverage.	FTTH Council Europe
NGN gap *NGN_gap*	Difference between NGN coverage and NGN adoption.	FTTH Council Europe
	Main explanatory variables: Regulation	
Average total cost of the full LLU, *llu_price*	Monthly average total cost of the full LLU in €.	EU Digital Agenda Scoreboard
Average cost of shared access, *sa_price*	Monthly average total cost of shared access in €.	EU Digital Agenda Scoreboard
	Main explanatory variables: Competition	
Entrant's market share, *bb_ne*	New entrant's retail market share in fixed broadband lines.	Communication Committee (COCOM)
Mobile-to-fixed ratio, *fms*	Ratio of Mobile Lines to Fixed Lines (Absolute).	Market Line Extract
Fixed legacy, *legacy*	Total number of active fixed landlines per 100 inhabitants. An active line connects the subscriber's terminal equipment to the public switched telephone network PSTN lines.	ITU
Share of LLU lines, *ms_llu*	Share of unbundled local loop lines to the total retail broadband lines.	EU Digital Agenda Scoreboard

Table A.1 ctd.

	Demand control variables	
Broadband lines, *bb_lines*	Number of total retail broadband connections based on DSL and coax cable that enable a higher than 144 Kbit/s download speed but exclude FTTx lines.	EU Digital Agenda Scoreboard
Broadband adoption, *adop_bb_lines*	Number of total broadband connections adopted by consumers divided by total population.	EU Digital Agenda Scoreboard
Networked Readiness Index, *nri*	Propensity of a country to exploit the opportunities offered by information and communication technology (ICT).	Euromonitor
Education, *edu*	Percentage of population having attained secondary or higher education, for the population aged 25 to 64 years.	Eurostat
GDP per capita, *gdp*	GDP per capita (total) and PPP adjusted to current US$.	World Bank Euromonitor (population)
	Cost control variables	
Hourly wage, *wage*	The manufacturing wage per hour in € and current prices with fixed 2012 exchange rates.	Euromonitor
Labour cost, *labcost_ict*	Annual labour cost index for the Information and Communication branch by NACE Rev. 2 normalized to 100 in 2008. The index measures the development of the total cost, on an hourly basis, to employ the labour force, and it includes wages and salaries, social security contributions and taxes, but excludes subsidies.	Eurostat
Urban population, *urban_pop*	Population of a country that lives in an urban environment as a percentage of the total population.	MarketLine
Population density *pop_dens*	Population density in number of inhabitants per Square Kilometre.	Market Line Extract
Long-term interest rate, *lt_ir*	Long-term interest rate for debt security issued after 10 years of maturity at the local currency unit rate.	European Central Bank

Table A.2: Summary statistics

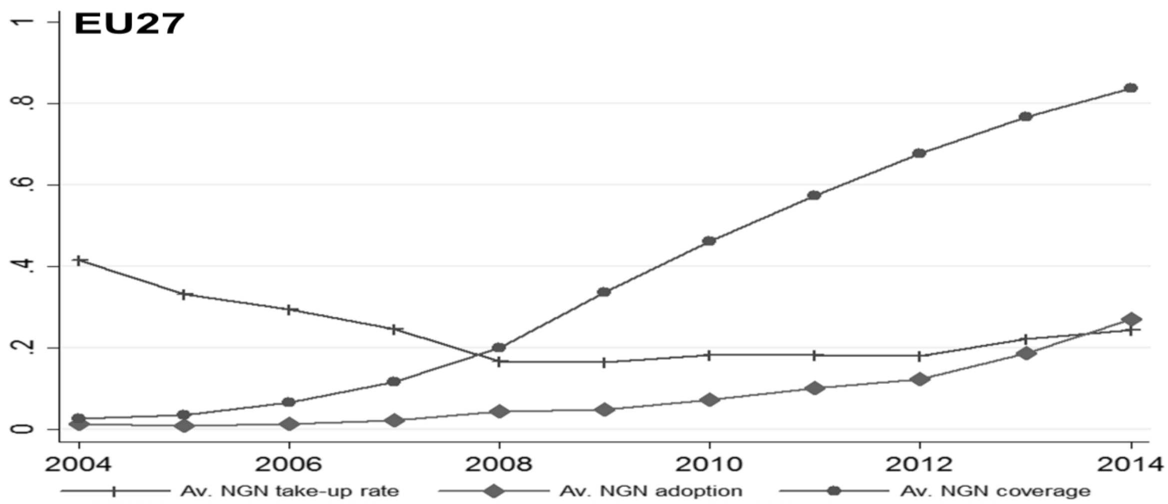
Variable	Obs	Mean	Std. Dev.	Min	Max
NGN_adop	296	0.0730204	0.1090571	0	0.5471706
NGN_cov	296	0.3830631	0.4678066	.4678066	2.306572
NGN_tur	226	0.2199841	0.1641123	0.0000517	0.7222222
NGN_gap	296	0.2651446	0.2945837	0	0.9983765
llu_price	266	11.45305	4.303125	5.28	42
sa_price	266	5.397406	3.431645	0.74	23.89
fms	270	3.371881	1.667801	1.2819	10.9396
bb_ne	267	0.501393	0.1558175	0	1
legacy	270	40.41304	13.08719	13.86	66.38055
bb_lines	267	3723236	5769546	13738	27960396
ms_llu	266	0.1064223	0.1461762	0	0.6772212
nri	270	4.578519	.6294371	3.2	6
gdp	270	30200.01	13641.82	8730.803	90789.65
edu	270	73.53926	16.01936	23.6	93.4
wage	270	11.05556	7.861194	0.8	38.7
urban_pop	270	72.43043	11.89043	49.4118	97.4945
labcost_ict	270	99.84741	15.33449	47.9	163.5
pop_dens	270	174.247	237.3405	17.1923	1285.241
lt_ir	296	4.50125	2.227483	0.22	22.5

Table A.3: Direct Granger-causality tests

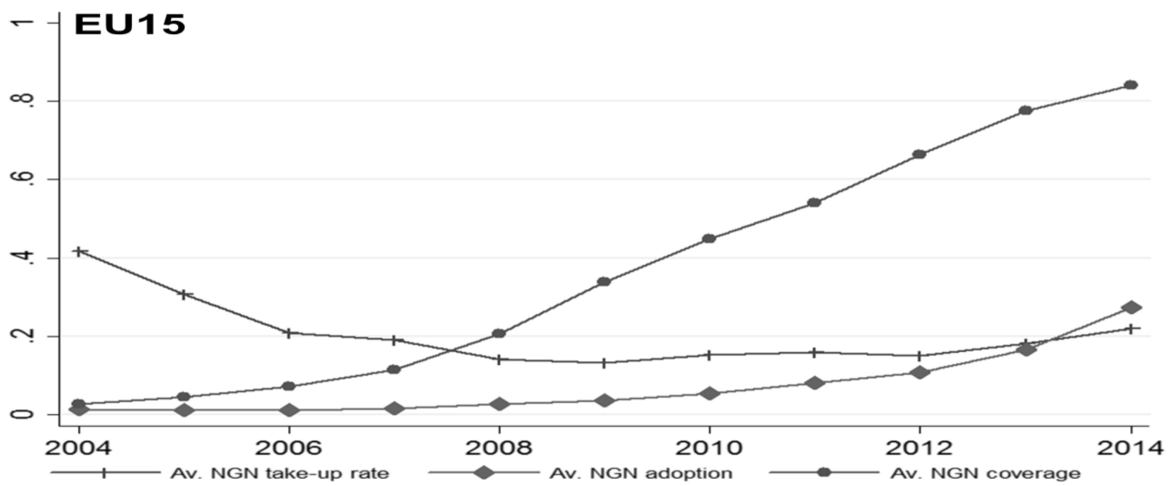
Since Granger-causality tests include several lags of the right-hand side variable, including the lagged dependent variable, the Arellano and Bond (1991) difference-in-difference GMM estimator has been employed with a maximum number of three lags of the right-hand side variables and internal instruments. Period effects have been included. Granger-causality tests are Wald tests of the joint significance of the respective coefficients which are χ^2 distributed. The standard errors have been adjusted for clustering within countries and are robust to heteroscedasticity; the *p*-values are reported.

GMM (NGN adoption)	***p*-value**	**H_0: β_1, β_2 = 0**	**Answer**
Does the LLU price cause NGN adoption? Does NGN adoption cause LLU price?	0.0077 0.2890	Rejected Not Rejected	Yes No
Do new BB entrants market share cause NGN adoption? Does NGN adoption cause new BB entrants market share?	0.2078 0.7779	Not Rejected Not Rejected	No No
Does fixed to mobile substitution rate cause NGN adoption? Does NGN adoption cause fixed to mobile substitution rate?	0.1365 0.7434	Not Rejected Not Rejected	No No
Does the no. of active fixed landlines cause NGN adoption? Does NGN adoption cause the no. of active fixed landlines?	0.0632 0.7600	Rejected Not Rejected	Yes No
GMM (NGN coverage)	***p*-value**	**H_0: β_1, β_2 = 0**	**Answer**
Does the LLU price cause NGN coverage? Does NGN coverage cause LLU price?	0.0316 0.7613	Rejected Not Rejected	Yes No
Do new BB entrants market share cause NGN coverage? Does NGN coverage cause new BB entrants market share?	0.3365 0.8522	Not Rejected Not Rejected	No No
Does fixed to mobile substitution rate cause NGN coverage? Does NGN coverage cause fixed mobile substitution rate?	0.0011 0.6111	Rejected Not Rejected	Yes No
Does the no. of active fixed landlines cause NGN coverage? Does NGN coverage cause the no. of active fixed landlines?	0.0066 0.5930	Rejected Not Rejected	Yes No
GMM (NGN take-up rate)	***p*-value**	**H_0: β_1, β_2 = 0**	**Answer**
Does the LLU price cause NGN take-up rate? Does the NGN take-up rate cause LLU price?	0.0865 0.7138	Rejected Not Rejected	Yes No
Do new BB entrants market share cause NGN take-up rate? Does the NGN take-up rate cause new BB entrants market share?	0.9207 0.9941	Not Rejected Not Rejected	No No
Does the FMS rate cause NGN take-up rate? Does the NGN take-up rate cause FMS rate?	0.9986 0.9967	Not Rejected Not Rejected	No No
Does the no. of active fixed landlines cause NGN take-up rate? Does the NGN take-up rate cause the no. of active fixed landlines?	0.8553 0.6951	Not Rejected Not Rejected	No No

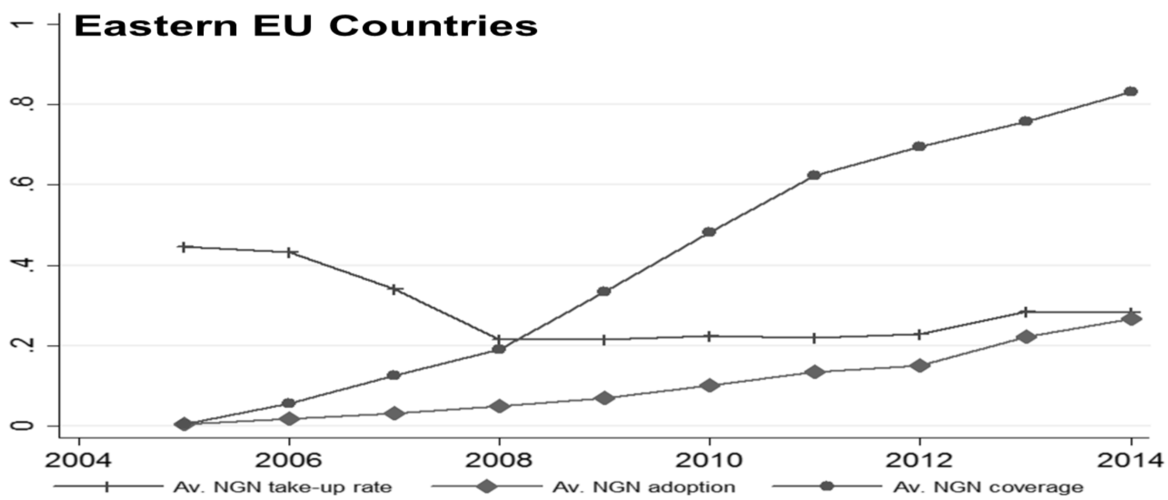
Figure A.1: NGN coverage, adoption and take-up rates in the average EU member state (Source: FTTH Council Europe)



(a) MT/CY omitted since NGN coverage is essentially zero; (b) NGN adoption and NGN coverage are household weighted

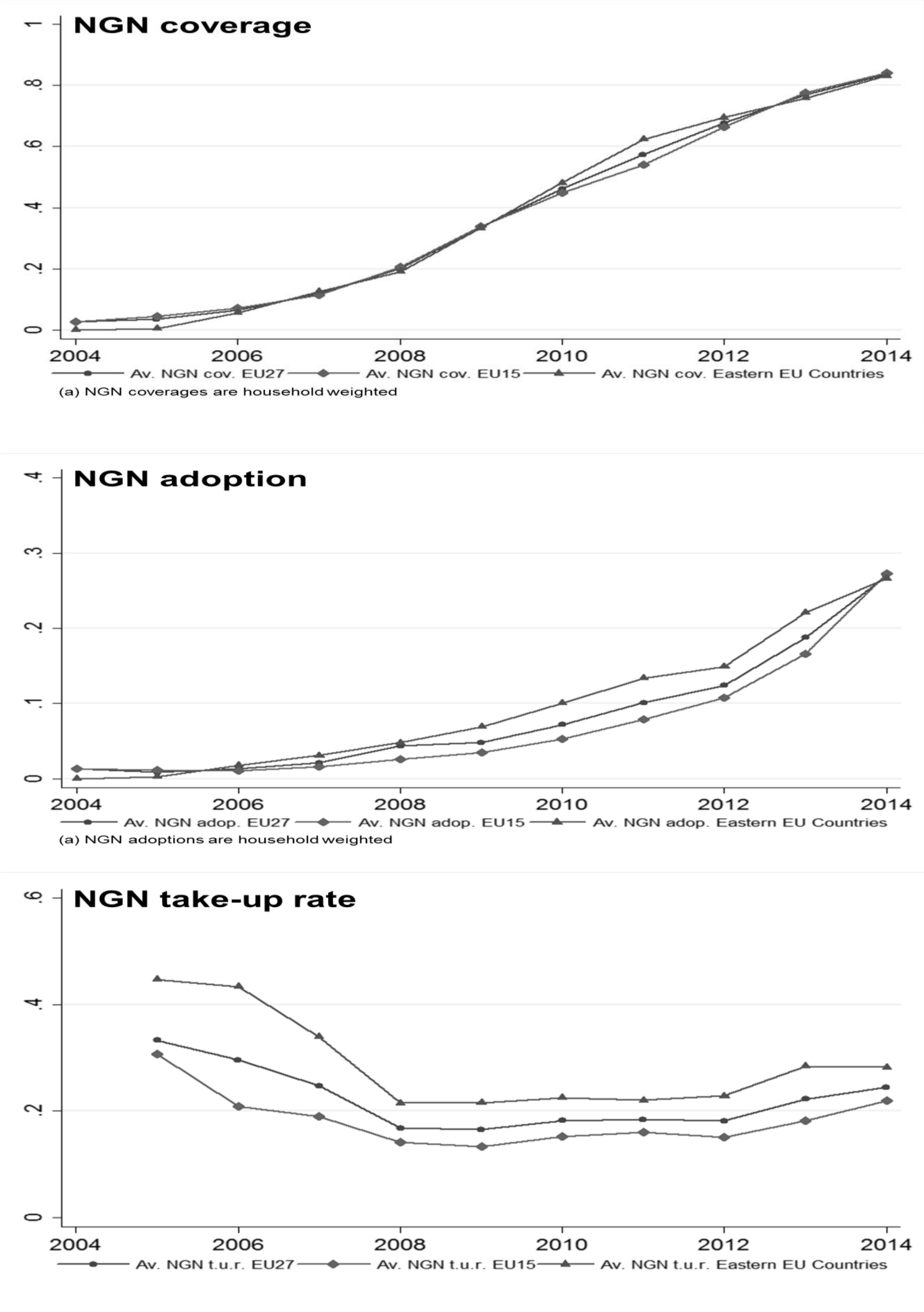


(a) NGN adoption and NGN coverage are household weighted



(a) NGN adoption and NGN coverage are household weighted

Figure A.2: NGN adoption, coverage and take-up: EU15 vs. Eastern European countries (Source: FTTH Council Europe)



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