Promoting Consumer Migration to New Communications Technology: Does Regulation Affect the Digital Gap?

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Abstract

This paper provides evidence on the migration of consumers from an “old” (copper-based) to a “new” (fiber-based) communications technology, taking specifically into account the impact of regulatory interventions imposed on the old technology. The analysis has been applied to a sample of EU25 countries using panel data from 2003 to 2014 on the adoption (i.e. the demand of subscriptions by households and firms), and take-up rate of ultra-fast broadband technology (i.e. the ratio between fiber subscribers - “homes connected” - to population covered with fiber connections - “homes passed”). Results show that an increase in the regulated price for accessing the existing old network favours consumer migration to the new technology. However, the access price to old technology negatively affects the take-up rate of the new technology. This implies that access regulation also positively affects broadband coverage but more than demand adoption. Hence, in order to raise broadband take-up rate, other instruments are needed to support ultra-fast broadband subscriptions.

1 Introduction

In a time of increasing digitalization, operators of “old” 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. Broadband networks based on optical fiber technology (so called “Next Generation Networks” – NGN) enable a massive increase in bandwidth capacity. These broadband networks 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 on a massive scale as a result of complementarities in product and process applications. Majumdar et al. (2010), for instance, estimate the economic benefits related to broadband as a general purpose technology and find a significant positive impact on consumers and firm productivity. These effects can be enhanced as broadband networks and services are typically part of multi-sided markets and in view of substantial network effects. [1] However, such potential welfare gains can only be achieved if business users and consumers are not only physically connected to such networks but also show sufficient willingness to pay and adopt the new fiber based services.

In view of the expected benefits from NGN, the European Commission (EC) has decided to strengthen the competitiveness of Europe’s economy in its Digital Agenda for Europe (DAE) which has specified goals in terms of network coverage and service adoption already in 2010:

[1] Numerous other studies support the view that investment in old broadband infrastructures, and based on that adoption of broadband services, creates positive effects on the economic system and leads to an increase in GDP growth. 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. However, note that there is no clear evidence available so far that these externalities and spill-over effects beyond those associated with current broadband networks will emerge for NGNs.

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). While target (i) refers to fast broadband network coverage of 100 per cent of the population, target (ii) refers to a minimum level of household adoption of ultra-fast broadband services.

Whereas there has been some considerable progress across Europe in terms of ultra-fast broadband coverage, it is quite unlikely that target (ii) will be met in the coming years. Indeed, adoption, i.e. the demand for fiber-based broadband subscriptions by households and firms, and take-up rates, i.e. the ratio between fiber subscribers to population covered with fiber connections, are lagging far behind (see European Commission, 2014, and Figure A.1). In particular, the take-up rate is a useful indicator of the willingness of consumers to subscribe and therefore migrate to the new broadband services. The more consumers are satisfied with conventional broadband services, or the more consumers are reluctant to adopt new technologies (Fontana, 2008), the greater the gap will be with the newly installed network capacity. The latter induces social costs due to over-capacities. Only if consumers consider ultra-fast broadband services attractive enough, in terms of innovations or quality improvements compared with old broadband services, will they migrate to fiber connections and adopt the new technology.

What are the main drivers of fiber-based adoption and take-up in Europe? What is the role that the existing regulation can play on the old "legacy" ("copper-wire") network based on the standard xDSL technology to foster fiber adoption and take-up? Although the underlying regulation induced trade-offs between innovation and competition are well-known in theory for some time now (Woroch, 1998; Vogelsang, 2012), this paper makes a first attempt to answer these questions as regards fiber adoption and take-up. Using recent panel data of 25 European Union members states (EU25) for the years 2003 to 2014, the present analysis is the first that simultaneously examines the determinants of NGN (output-related) adoption and the (input- and output-related) NGN take-up rate. The role of the EU regulatory policies, as embedded in the sector-specific framework of electronic communication markets, is examined, controlling for the related competitive conditions, within fixed broadband markets ("intramodal") and from mobile networks ("intermodal"), expansion costs and demand characteristics. Competition from mobile describes the so-called "fixed-mobile substitution" phenomenon (Vogelsang, 2010) which was driven by massive technological progress in the mobile industry in the last decade. The focus of this paper is to examine regulatory policies more closely, in particular, the so-called "unbundling" price (local loop unbundling, LLU). The latter represents a mandatory wholesale access provision and is the most relevant policy instrument in terms of incentivizing migration to NGNs pertaining to investment and adoption. On the one hand, an increase of the unbundling price is expected to impact on the incentives to invest in fiber networks; on the other hand, it is also expected to affect the retail prices of the old technology based services and favour consumer migration to faster connections, by reducing the gap with the retail prices of the fiber-based services. As stated by Bourreau et al. (2012) and Crandall et al. (2013), a lower access price to the copper network would encourage customers to remain on copper, which would in turn discourage investments in NGNs. 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). The potential impact of access policies in the transition from copper to fiber networks is also acknowledged by recent recommendations of the EC.[2]

[2] See the recommendation on "Regulated Access to NGANs" (C(2010) 6223) and the recommendation on "Consistent non-discrimination on obligations and costing methodologies to promote competition and enhance the broadband investment environment" (C(2013) 5761). The latter states that the access prices of the traditional copper networks should remain stable over the coming years in order to sustain investment in next-generation networks and favor migration at retail level (paragraphs 44 and 45). Some NRAs (in Germany, Italy and Spain

In this perspective, this paper is a first attempt to empirically assess the complex interplay between regulation on an old technology and demand side adoption and take-up of a new fiber-based technology. In particular, our purpose is to provide empirical support for the presence of the so called "business migration affect" found in the theoretical model by Bourreau, Cambini and Dogan (2012; 2014): this effect implies that consumers might be incentivized to migrate from the old-low quality connections to the new-high quality ones as long as the retail price of the two services are close enough. Since the retail price of the old copper-based services is highly influenced by the level of the regulated access price especially when the unbundling regime is largely diffused, we empirically test whether a change in the wholesale price, by increasing the retail price to copper-based connections, influences the migration to the new technology-based connections in Europe.

Results show that, in countries where the unbundling regime is highly diffused, the unbundling access price imposed on the old legacy-based technology exerts a positive and significant impact on fiber adoption. This implies that a policy measure that increases the cost of accessing the old broadband network, though affecting competition, could exert a positive effect on favouring the adoption of the new technology. 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 network and so by a minor role of the unbundling regime: when controlling for this heterogeneity across countries, we find that the role of the unbundling regime is largely offset in Eastern European countries. This result casts doubts on the EC´s current policy of creating uniform regulatory framework to be applied in all EU countries. Clearly, the possible changes in the unbundling prices are only relevant in certain EU countries (mostly old EU15), but not over the entire continent.

for example) have followed the EU recommendation implementing stable unbundling prices (in nominal terms), while others (such as the French NRA) have decided to raise the unbundling price above the (long run) incremental cost to better stimulate investment and migration at retail level.

Finally, the take-up rate estimations results have shown that increasing the access price decreases the take-up rate. This implies that adoption increases but less than proportionally to coverage leading the ratio between the two to decrease. From a policy perspective, this implies that using a single instrument (i.e. the unbundling price) to influence both ultra-fast broadband adoption and coverage is not enough because the impact of an unbundling price increase differs on coverage and demand in terms of magnitude; accordingly, 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 related literature and Section 3 describes the basic hypotheses concerning the relationship between regulation and NGN adoption and take-up. Section 4 presents the empirical baseline specifications derived from the existing literature and the related econometric issues. Section 5 outlines the panel dataset that underlies the empirical examination. Section 6 presents the main results. Section 7 summarises and concludes.

2 Literature review

Fibre networks do not immediately replace copper or cable legacy networks, suggesting that the transition from services based on the old technology to new ones will go slowly. This implies that, during a transition phase, two different technologies will operate in parallel, and the incentives to invest in fibre networks 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 old network technology affect investments in new network technology and favour the migration, at a retail level, from the old to the new broadband technology.

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

In particular, the first systematic theoretical analysis on this issue was provided by Bourreau et al. (2012, 2014). The authors consider a model in which access to the legacy copper network is available throughout an entire country and an incumbent and an entrant compete for the provision of retail broadband services to consumers by investing in a new ultra-fast broadband technology. The entrant operator could also ask for mandatory access to the legacy network in the form of unbundling. In their setting, the country is composed of a continuum of areas, for which the fixed cost of rolling out the NGN varies (higher investment costs in rural areas *vis a vis* urban ones). Firms decide sequentially on their investments in fiber technology in the different regional markets, with the incumbent firm as the first mover, due to its control over the legacy network and other facilities. Under the assumption that the unbundling regime is available everywhere in a country, their main results show that investment in ultra-fast broadband networks varies non-monotonically with the access price. This result is due to the coexistence of three different effects: (i) the "replacement effect", which hinders 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; (iii) the "business migration effect" which exerts a direct impact on ultra-fast broadband adoption: when the (unbundling) 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 old to fiber-based services, operators should also offer low prices for those services. This effect ultimately also reduces the profitability of the fiber subscriptions, and hence, the incentives to invest in it.

While the first two effects are directly related to the incentives to deploy the new technology, the third one introduces a *demand side* effect and points out the interplay between retail prices of the two (old and new) technologies and the role that the access price to the old copper-based technology may play in favouring the adoption of those services. The goal of our analysis is not to provide further theoretical analysis on this point; instead, building on the existing theoretical investigations, our aim is to provide empirical support for the presence of this business migration effect in Europe.

The empirical evidence on ultra-fast broadband adoption is limited. Some papers, such as Denni and Gruber (2007), Bouckaert, van Dijk and Verboven (2010) and Nardotto, Valletti and Verboven (2015), have focused on the interplay between adoption of standard (but not fiber-based) broadband services and the existence of access regulation and local loop unbundling in particular, without considering the impact of the level of the unbundling price on broadband adoption as we do in this paper. More specifically on ultra-fast broadband adoption, Wallsten and Hausladen (2009) estimate the effects of broadband regulations on NGN adoption with data from EU27 countries from 2002 to 2007. They find that countries where unbundling is more effective experience lower NGN adoption. Differently from our analysis, however, the authors only examine the presence of unbundling regulation, but they do not provide any evidence on the possible impact of the price of unbundling access on NGN adoption. Similarly, Briglauer (2014) investigates the determinants of NGN adoption for EU member states from 2004 to 2013 and finds that the more effective regulatory-induced service-based competition is, the more negative the impact on adoption. Whereas this regulatory variable includes all wholesale broadband access regulations, it does not allow quantifying the effect of the unbundling regime as we do in this paper.

Summarizing, none of the above empirical papers analyses the indirect cross-price effect of the wholesale price imposed on the old legacy-based network technology on ultra-fast broadband adoption testing the existence of the business migration effect at the retail level as derived from the theoretical literature (Bourreau et al., 2012 and 2014). Furthermore, none of the existing empirical studies has analysed the determinants of the ultra-fast broadband take-up rate. The present paper has the aim of examining the role of regulation on stimulating the

European digital policy goals, regarding NGN adoption (goal (ii)) and NGN take-up (relating goal (i) and (ii)).

3 Testable hypotheses

Our key policy variable of interest is the regulated wholesale access price to the old (copper-wire based) network, 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 NGN coverage and adoption by end users. The present analysis thus focuses on this key variable examining the direct effects on NGN adoption as well as on take-up.

From the theoretical literature previously described, two different testable hypotheses can be drawn. First, our purpose is to provide evidence on the business migration effect. This effect implies that, in a country where the unbundling regime is largely diffused, the access price on copper networks (i.e. the unbundling price) may have a considerable effect on ultra-fast broadband adoption: assuming that the retail market for broadband services is substantially competitive, any increase in the unbundling prices would be translated into a higher cost of the basic broadband services, thus making it less attractive than the NGN-based services. In this case, consumers will then migrate to the new and faster broadband technologies to enjoy higher quality services. The following can therefore be tested:

> *Hypothesis 1: An increase in the regulated access prices to the old technology would make old broadband connections similar – in terms of retail prices – to the new technology based connections, and as a result the adoption of the latter would increase.*

The above hypothesis holds for countries in which the old legacy technology is well established on a nation-wide scale and unbundling regime is available everywhere in a country. In those countries, the access price to this technology plays a relevant role. However, in Europe the level of infrastructure development of the legacy (copper based) technology, especially in Eastern European countries, is very different from Western countries. In those countries, copper based networks exist mostly in urban areas and mobile connections are much more developed rather than fixed ones. Hence, 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 adoption should be weaker. The following hypothesis emerges:

> *Hypothesis 2: 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 adoption of the new technology.*

Our analysis aims also at providing first evidence on the determinants of take-up rate, i.e. the ratio between ultra-fast broadband adoption and coverage in Europe as well as on the role of access regulation in fostering ultra-fast broadband take up rate. An analysis of the take-up rate is more complicated due to the coexistence of multiple effects: an effect through NGN adoption and one through the channel of NGN coverage. Since, as shown by the theoretical literature, it is not possible to derive clear predictions on the impact of access regulation on ultra-fast broadband coverage, forming hypotheses on the take-up rate is difficult. We thus decide to rely on the data to understand which effect, on adoption or on coverage, tends to prevail in European member states.

4 Empirical specifications

The empirical specifications inherently depend on the pattern of diffusion of the variables we are considering. Data reported in Figure A.1 shows that NGN adoption follows a classical adjustment and diffusion process, both when considering the EU25 countries as a whole, as well as when we consider the two sub-groups of EU15 and Eastern European countries. This diffusion process, typically due to network effects or consumer inertia, is standard when considering ICT related technologies (Kiiski & Pohjola, 2002; Grajek & Kretschmer, 2009; Grajek & Röller, 2011; Briglauer, 2014). Differently, Figure A.1 shows 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.

In view of these different diffusion patterns and the interdependencies underlying the dependent variables, a two-fold research strategy has been employed: while the NGN adoption process is inherently dynamic, the development of the NGN take-up rates points to a static baseline specification. In what follows, we first outline the different models we estimate while we describe the estimation and identification strategy in Section 4.1.

In view of the testable hypotheses presented in Section 3, the dynamic reduced-form model, in which NGN adoption (superscript *a* denotes adoption in equation (1)) is expressed in logs[4] for EU member state *i* and year *t*, reads as follows:

$$\begin{aligned} \ln(NGN\_adop_{it}) = \alpha_0^a + \beta_j^a(access\_regulation_{i(t-1)}) + \\ \alpha_1^a \ln(NGN\_adop_{i(t-1)}) + \gamma^{a\prime}\mathbf{C}_{i(t-1)} + \delta^{a\prime}\mathbf{Z}_{i(t-1)} + \theta_i^a + \lambda_t^a + \varphi_{it} \end{aligned} \tag{1}$$

Following the theory (Bourreau et al., 2012 and 2014), the main independent variable in Equation (1) is *access_regulation*, i.e. the extent of regulation on wholesale obligations in country *i* in time *t*-1; *access_regulation* is measured using two (j = 1,2) different variables, as described in Section 5.2. Moreover, according to the ICT related empirical literature (Kiiski & Pohjola, 2002; Grajek & Kretschmer, 2009), the dynamics of the adoption process can be captured by including the lagged dependent variable as an additional right-hand side explanatory variable. The specification in equation (1) gives rise to an endogenous growth process if $0 < \alpha_1^a < 1$. $1 - \alpha_1^a$ measures the constant speed of diffusion. To this basic equation

[4] Taking logs of the (lagged) dependent variables yields an S-type Gompertz functional diffusion process which is commonly assumed in the empirical ICT literature. A log transformation also helps to stabilize and normalize the series of the (lagged) dependent variables which is positive and skewed.

we then add a series of controls. A first set of control variables (denoted by $\boldsymbol{C}_{i(t-1)}$) are related to the degree of (inter- or intramodal) competition, thus considering the potential impact on the demand of alternative communications technologies (such as basic xDSL/cable or mobile broadband access). $\boldsymbol{Z}_{i(t-1)}$ represents a second set of additional demand and cost controls that may affect ultra-fast broadband adoption (Bouckaert et al., 2010; Grajeck & Roller, 2011; Briglauer, 2014). Finally, φ_{it} represents an additive error term, and θ_i and λ_t country-specific and time effects, respectively.

As the take-up rate does not exhibit a similar endogenous adjustment process, modeling a static specification appears to be a reasonable choice. The empirical baseline specification for the static reduced form NGN take-up rate model (superscript *tur* denotes take-up rate in equation (2)), NGN_tur_{it}, for EU member state i and year t, reads as follows:

$$\text{NGN\_tur}_{it} = \alpha_0^{tur} + \beta_j^a (access\_regulation_{i(t-1)}) + \gamma^{a\prime}\mathbf{C}_{i(t-1)} + \delta^{a\prime}\mathbf{Z}_{i(t-1)} + \theta_i^{tur} + \lambda_t^{tur} + \nu_{it} \quad (2)$$

Equation (2) contains the same list of explanatory variables as in the dynamic specification, and in particular *access_regulation* as main independent variable, except for the lagged-dependent variable ($\alpha_1^{tur} = 0$).[5]

It should be noted that equations (1)-(2) include lagged values of all the explanatory variables in order to employ the entire available data set (as described in Section 5).[6]

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[5] Note that estimating a dynamic version of equation (2) yields insignificant coefficient estimates of the lagged dependent variable confirming the absence of a dynamic trend (results are available upon request from the authors).

[6] Moreover, it also makes sense to assume that adoption decisions at a particular point in time depend on the conditions of the latter period, in view of switching costs on the side of consumers of broadband services who are usually subjected to long term contracts up to two years (according to EU consumer protection policy

4.1 Estimation and identification strategy

In order to identify causal effects of regulatory policies, as devised by the EC and imposed by NRAs, 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 time 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 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; 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)-(2) 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-determinedness, or sequential exogeneity, is in fact reasonable for dynamic autoregressive models, such as those in equation (1) (Wooldridge, 2002: 299-300), serial correlation in the static specification (equation (2)) 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 the Cochrane-Orcutt method. Third, a large number of controls have been employed in order to further reduce any remaining omitted variable bias that might be due to time-variant heterogeneity.

(https://ec.europa.eu/digital-single-market/en/users-rights) the maximum initial duration of telecoms` services contracts shall be no longer than 24 months).

Finally, as parts of the robustness specifications, we also provide some instrumental variable (IV) estimations where the main regulatory variables related to the access price have been instrumented as described in Section 5.3.

5 Data

In the empirical analysis, country level panel data for EU member states from 2003 to 2014 have been employed. The data have been gathered from several different sources: FTTH Council Europe provides annual ultra-fast broadband adoption and coverage data from 2004 to 2014, thus covering almost the entire period of NGN expansion in EU27 member states. Ultra-fast broadband adoption and coverage data also form the basis of the NGN take-up rate, as discussed in Section 1. Owing to the fact that some values are missing, there are fewer observations than the maximum number of 297 (27×11). There is basically no NGN data for Malta and Cyprus for the entire period of interest and these countries have therefore been excluded. Moreover, NGN coverage and adoption exhibits missing values in some individual member states in the first two years of our period of analysis, i.e. 2004 to 2005, resulting in a total number of 239 observations for NGN adoption (and NGN coverage) for EU25 member states.[7]

As regards NGN take-up rates one can infer from Figure A.1 that these are significantly higher at the very beginning of NGN coverage, i.e. in the years from 2004 to 2007. One obvious explanation might be that NGN were initially deployed in areas in which consumers with a very high willingness to pay live, resulting in a high adoption of installed connections and hence in high take-up rates. Furthermore, during the first years of ultra-fast broadband expansion, many field experiments were conducted by operators in which the consumers were

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

either volunteers or they obtained special offers (in some cases without having to pay any extra price). We dropped ”unrealistically” high values of the take-up rate (> 0.75) in case of Spain, Poland, Slovenia, United Kingdom and Greece from 2004 up to 2006 resulting in a total number of 225 observations.[8]

All the independent variables (discussed in Section 5.2) are available for the years from 2003 to 2013. All variable descriptions together with data sources are listed in the Annex in Table A.1. Table A.2 provides the summary statistics.

5.1 Dependent variables

Adoption of ultra-fast broadband connections, denoted with *NGN_adop*, is measured by 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”).

To define the NGN take up rate we also need to determine the coverage of the service. Coverage is measured by the total number of deployed lines normalized to the total number of households (“homes passed”). Network coverage represents the installed capacity, in physical units, which provides consumers with potential access to NGN and functions as a pre-condition for NGN adoption.[9]

[8] Unrealistic means that the high take-up rate values are likely to represent an artifact of field experiments and small denominators in early years as motivated above. As part of our robustness checks, we show that NGN take-up rate estimation results prove to be very robust even if we do not restrict the data at all (see Table 3 (regression (4)) in Section 6.1).

[9] Values are missing for Bulgaria for the years from 2003 to 2006, for Romania from 2003 to 2004, for Estonia for 2003, as well as for Latvia, Lithuania, Hungary, Poland, Slovenia and Slovakia for 2003. Apparently, these missing values cannot be attributed to NGN coverage or adoption in these countries but rather to the fact that they joined the EU at later stages and hence were not obliged to report market data to the EC before.

The NGN take-up rate, *NGN_tur*, is the ratio between NGN adoption and NGN coverage and 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.

As already said, Figure A.1 points out that NGN adoption follows an adjustment and diffusion process, pertaining to EU25 countries, and the two sub-groups of EU15 and Eastern European countries,[10] while this is not the case for NGN take-up rate. The graphical evidence also suggests that, while NGN coverage shows substantial growth across EU countries, adoption and the take-up of NGN services are at much lower levels on average but comparatively larger in Eastern European countries where the presence of the old fixed broadband technology (xDSL and coax cable TV) is limited or even absent.

5.2 Independent variables

As pointed out in Section 3, our main purpose is to test the presence of the business migration effect which relates the demand of ultra-fast broadband subscriptions to the level of the regulated access price to the legacy network, approximating the retail price of standard (below (ultra-)fast) broadband services. Theory also shows that the business migration effect is expected to exist in countries where the access regime is diffused everywhere, i.e. entrants can potentially ask access to any available lines. To this aim, our main independent variable, *access_regulation*, in equations (1) and (2) is proxied by using two approaches.

The first approach is to measure the access regime with the monthly unbundling access price, measured in €, denoted with *llu_price*; this price is by far the most relevant form of

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

(wholesale) broadband xDSL regulations when considering migration from old to new broadband technologies ("LLU access" in Figure 1), and which is set directly by NRAs.[11]

However, the unbundling price only provides a limited representation of the overall complexity of real world unbundling regimes, which include several other institutional and technical annex regulations besides the monthly access price. In fact, a sufficiently well-established unbundling regime is a pre-requisite for the business migration effect, which implies that the impact of the unbundling price can be expected to depend on the extent of the unbundling regime. As a consequence, we introduce an additional unbundling variable by referring to a measure that also captures the extent of the unbundling regime. This variable, denoted with *i_price_llu_sh*, interacts the unbundling price, *llu_price*, with the respective unbundling market share (*ms_llu*), i.e. the share of actually unbundled lines to total xDSL broadband lines. The latter is bound between 0 and 1, where the upper limit indicates that all the xDSL broadband services are offered via unbundling. Both variables, *llu_price* and *i_price_llu_sh*, are considered as our main independent variables.

5.3 Instrumental variables

In countries where NGN adoption is particularly low, NRAs might decide to change the level of the access price to the old network to stimulate migration. Therefore, the wholesale price decision might be affected by the level of fiber adoption. To deal with this circularity and therefore with the potential endogeneity of our main regulatory variables, these variables are instrumented using two different exogenous sources of variation.

First, we use an alternative regulatory access policy, i.e. the price of the so-called "shared access" product (*sa_price*), as an instrument. This variable represents the monthly cost of

[11] This access instrument has become the mostly used entry mode by alternative operators in the last decades and it has replaced the interconnection charges used at the beginning of the liberalization process in the period 1998-2004. For more details, see Cambini and Rondi (2012).

"shared access", measured in €. Whereas unbundling provides full access to the incumbent´s local loop access lines, shared access only provides limited access to the upper line bandwidth. In practice, the regulated price of shared access products represents approximately one half of the unbundling price (see mean values reported in Table A.2). Hence, a change in shared access prices should not induce entrants to switch to much more cost intense self-provision of fiber-based NGN, whereas the unbundling price might have an impact on the entrant´s decision to buy access or self-deploy NGN according to the entrants´ replacement effect. Moreover, as one can infer from Figure 1, shared access regulation played a rather limited role with declining importance as a means of xDSL broadband access in our period of analysis. Accordingly, the relevance of shared access should have been even much lower with respect to emerging NGN markets. At the same time, shared access and unbundling prices are closely related, since both are determined by NRAs on the basis of (common) network costs.[12] As the latter represent about 60-80% of the total costs (ERG, 2007), the here adopted regulatory variables, in particular the unbundling price, also represent a valid proxy of the average retail broadband price level.

[12] Apparently, the same NRA sets both shared access and unbundling access prices. Hence, in order to also rule out potential endogeneity due to reverse causality, we performed Granger causality tests which show that neither NGN adoption causes shared access nor shared access Granger causes NGN adoption (results are available upon request from the authors).

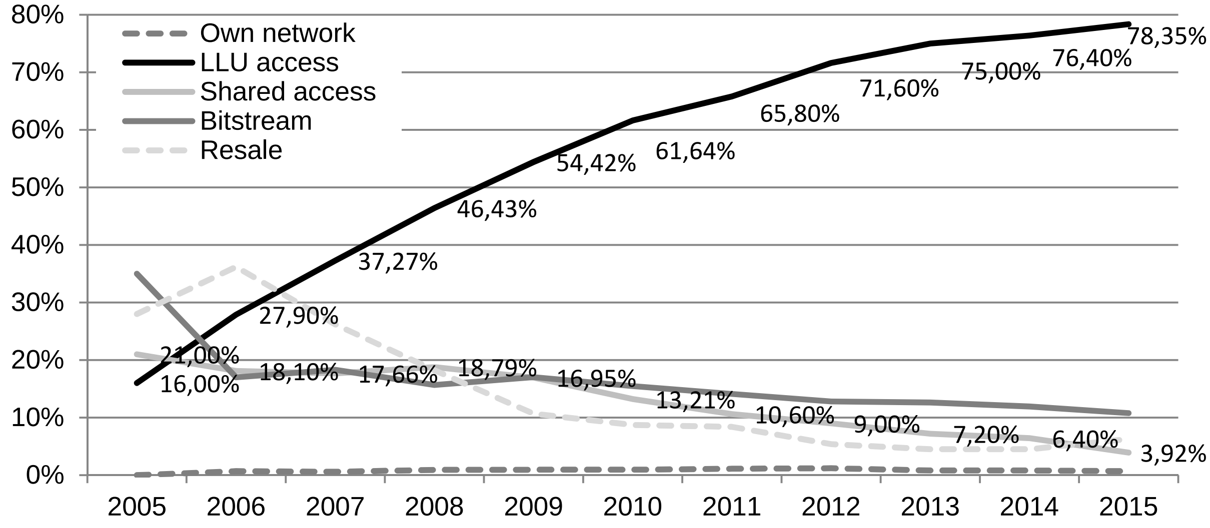

Figure 1: Relevance (%) of wholesale xDSL broadband access types in the EU[13]

Second, we consider the yearly average unbundling price in the EU countries (other than the focal country), denoted *llu_euprice*, as a "geographic" instrument (Grajek & Röller, 2011). Clearly, the NRA of country *i* sets its own access price but cannot influence the price set by other NRAs in other countries *l≠i*. The rationale behind this is the harmonization process within the EU, which makes it difficult for a single member state to radically deviate from the regulatory measures undertaken in the rest of EU. In essence, the eCommunications framework contains some explicit and implicit rules to incentivize harmonization and "punish" deviating NRAs by requiring stronger proof of evidence in the course of consultation and notifications procedures with the EC.

5.4 Further control variables

Apart from our main independent variable which is derived from the theoretical literature, we also introduce several controls in our reduced-form model specifications to further mitigate the omitted variables problem.

A first set of variables are related to *competition* in retail broadband markets: the first one stems from mobile networks ("intermodal" wireless competition). In order to account for

[13] Data represents EU averages and is gathered from the EC´s Digital Agenda Scoreboard (Table A.1).

mobile network competition, we introduce a variable to account for fixed-mobile substitution; this variable, denoted with *fms*, relates the total number of mobile subscriptions to the total number of fixed landlines. The second competition variable, denoted with *bb_ne,* represents the entrants´ retail market share in fixed broadband lines, and thus the impact of wireline ("intramodal") competition on old broadband markets on emerging NGN markets. In particular, this variable captures retail competition stemming from unbundling (Figure 1) and coaxial cable TV operators. In order to estimate the potential non-linear relations as regards competition variables (Schmutzler & Sacco, 2011), squared terms of the variables, related to intermodal (*fms*) and intramodal (*bb_ne*) competition, have also been included in our baseline specifications. Third, as shown in the theoretical literature (Bourreau et al., 2012), telecom companies might not be willing to migrate to a new technology if the returns they collect on the old one is important. In other words, all wholesale and retail revenues generated from the incumbent´s old network may represent an outside option for the incumbent that may prevent those companies to push for migration. We thus include a variable, labelled *legacy*, which measures a country's total stock of traditional fixed-linked connections and largely represents the incumbent operators´ infrastructure stock. This variable captures, though indirectly, the wholesale revenue effect pointed out in Section 2.

A second comprehensive set of *demand* and *cost controls* as well as *macroeconomic controls*, ***Z***, have also been included, in line with standard controls employed in the previous literature. A detailed description of all the controls can be found in Table A.1 in the Annex.

Finally, *time effects*, λ, and *country fixed-effects*, θ, have been considered. Including time effects makes it possible to control for relevant industry developments that are common to all EU 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 characteristics or NGN subsidies which, once having been determined by governments, generally stay in place for a longer period of time.

6 Empirical Results

According to our two-fold research strategy, the results of the dynamic adoption model 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 adoption in combination with the results on NGN coverage from the previous literature also provide important information for the interpretation of the estimation results pertaining to the NGN take-up rate model.

6.1 Dynamic NGN adoption model

Table 1 reports the results of the LSDVC estimations of various NGN adoption models. Regression (1) presents the estimates of the basic specification in equation (1), while regressions (2)-(5) present further specifications in terms of different selections of competition and unbundling variables as well as a control on Eastern European countries.

The coefficient of the *lagged dependent variable*, α_1^a, is highly significant and substantial in all the regressions, indicating that the dynamic specification is appropriate. The coefficients have been estimated quite precisely and narrowly with values ranging from 0.684 to 0.744 which are larger than those of comparable LSDVC estimates from NGN coverage models found in the previous literature. In particular, Briglauer (2015, Table 2) identifies estimates in the interval from 0.551 to 0.575. This suggests that consumer inertia and switching costs are even more pronounced than investment adjustment costs implying that the speed of diffusion $(1-\alpha_1^a)$ is lower than the speed of adjustment underlying NGN coverage (explaining also the increasing gap between coverage and adoption levels as evidenced in Figure A.1). The coefficients for the long-run relationships can be derived from the dynamic model by dividing the short-run coefficients by $(1-\alpha_1^a)$. Therefore, the long-run coefficients of the static representation show substantially higher absolute values.

As far as the *unbundling price* is concerned, the coefficient estimates of the main term, *llu_price*, are insignificant in all the regressions in Table 1. However, the coefficient of the interaction term *i_price_llu_sh* is significant and positive in all specifications. Wald-type tests show that both unbundling related variables are jointly significant at the 10% level (not reported). This implies that the marginal effect of the unbundling price on NGN adoption is non-zero. The lower part of Table 1 reports the coefficient of the combined marginal effect which is positive and significant at the 10% level in all specifications in case of a fully effective unbundling regime (*ms_llu* = 1). According to our data, the combined marginal effect is significant only for high levels of the unbundling market share (*ms_llu* > 0.7). Although this appears exceedingly high in view of the grand mean value of *ms_llu*, a high unbundling market share is in fact required for the business migration effect to become effective, as the theory shows. Furthermore, comparing regressions (1) and (2) as well as (4) and (5) shows that the omitted variable bias is low if we drop the insignificant main term *llu_price*. This is in fact expected in our case, since the coefficient of the main term *llu_price* measures the marginal effect of the unbundling price when the unbundling market share is zero (i.e., $\vartheta ln(NGN\_adop)/\vartheta llu\_price$ given *ms_llu* = 0 is β_1).[14] Obviously, when unbundling is not implemented in the market, the effect of the unbundling price must be zero on a priori grounds for all levels of the access price. Accordingly, in interpreting the overall marginal effect of the unbundling price it is legitimate to focus on the specifications in regressions (2) and (5) which exclude the main term without incurring omitted variable bias (Balli and Sorensen, 2013). In regression (2) the marginal effect of *llu_price* on NGN adoption is

[14] Note that the variable *ms_ull* measures a market share and thus has a natural zero which justifies the theoretical prediction on the coefficient of the unbundling price.

positive and significant for each given level of the unbundling market share and extraneous information makes regression (2) slightly more efficient than regression (1). These results are in line with our expectations (*Hypothesis 1*).[15]

In regressions (4)-(5), it is also examined whether the Eastern European countries (*East* = 1) [16] that exhibit a lack of well-developed legacy networks and technologies prior to NGN expansion experience a less pronounced effect of the unbundling regime. As expected (Hypothesis 2), from the coefficients of the interaction term *i_price_llu_sh_East*, it can be inferred that the effect of the unbundling price is largely offset in Eastern European countries. While the combined marginal effects that do not explicitly take into account the Eastern European countries (East = 0) are positive and significant (p-values = 0.058 in regr. (4) and 0.042 in regr. (5)), the test of the combined marginal effect for Eastern European countries (H_0: $\beta_1 1llu\_price + \beta_2 i\_price\_llu\_sh + i\_price\_llu\_sh\_East = 0$) produces negative but insignificant coefficient estimates (p-value = 0.147 in regr. (4) and 0.162 in regr. (5)). From these results we conclude that there is substantial heterogeneity among EU member states.

[15] Note that in interpreting the total marginal effect of the unbundling price, *llu_price*, we hold *ms_ull* constant as this is part of the control variable *bb_ne* which captures all modes of broadband wireline competition from alternative operators.

[16] The indicator variable *East* takes on the value one for Eastern European countries as listed in footnote 10 and zero otherwise.

Table 1: Dynamic NGN adoption model (Dep. var.: *ln(NGN_adop)*)

Regr. nr.:	(1) adop _base	(2) adop _llu_price	(3) adop _comp	(4) adop _East	(5) adop_llu _East
Lag: ln(NGN_adop)	0.728***	0.731***	0.684***	0.741***	0.744***
	(12.74)	(14.20)	(12.25)	(13.02)	(13.21)
Lag: llu_price	-0.027		-0.025	-0.029	
	(-0.77)		(-0.76)	(-0.85)	
Lag: i_price_llu_sh	0.157**	0.147**	0.146**	0.172**	0.161**
	(1.97)	(2.00)	(1.99)	(2.19)	(2.04)
Lag: i_price_llu_sh_East				-1.039*	-1.019*
				(-1.68)	(-1.65)
Lag: fms	-0.107	-0.086	-0.183*	-0.186*	-0.178
	(-0.26)	(-0.21)	(-1.74)	(-1.67)	(-1.60)
Lag: fms^2	-0.004	-0.005			
	(-0.16)	(-0.20)			
Lag: bb_ne	0.076	-0.139	-2.154*	-1.507	-1.491
	(0.01)	(-0.03)	(-1.81)	(-1.16)	(-1.15)
Lag: bb_ne^2	-1.893	-1.658			
	(-0.37)	(-0.33)			
Lag: legacy	-0.054*	-0.054*	-0.053**	-0.059**	-0.060**
	(-1.71)	(-1.74)	(-2.06)	(-2.15)	(-2.20)
Lag: ln(bb_lines)	1.252**	1.366***	1.275**	1.200**	1.322***
	(2.25)	(2.62)	(2.52)	(2.25)	(2.66)
Lag: adop_bb_lines	-3.236**	-3.032*	-2.804*	-2.981*	-2.756*
	(-2.03)	(-1.90)	(-1.95)	(-1.91)	(-1.77)
Lag: edu	0.037	0.033	0.044	0.038	0.033
	(1.14)	(1.01)	(1.38)	(1.17)	(1.04)
Lag: nri	0.336	0.357	0.311	0.420	0.443
	(1.08)	(1.14)	(1.08)	(1.35)	(1.41)
Lag: gdp	-0.000	-0.000	-0.000	-0.000	-0.000
	(-0.94)	(-1.12)	(-0.59)	(-1.03)	(-1.23)
Lag: lt_ir	0.005	-0.002	0.001	0.007	-0.001
	(0.16)	(-0.08)	(0.04)	(0.23)	(-0.03)
Lag: labcost_con	-0.007	-0.007	-0.005	-0.005	-0.006
	(-0.81)	(-0.89)	(-0.68)	(-0.58)	(-0.69)
Lag: urban_pop	0.269**	0.264**	0.234**	0.238*	0.232*
	(2.20)	(2.41)	(2.17)	(1.94)	(1.90)
Lag: wage	-0.027	-0.043	-0.018	-0.050	-0.065
	(-0.30)	(-0.48)	(-0.22)	(-0.56)	(-0.74)
p-value (H_0: β_1*llu_price*+β_2*i_price_llu_sh (+i_price_llu_sh_East)*= 0)					
	0.093		0.091	0.058	
R^2(*within*)	0.862	0.863	0.862	0.864	0.863
F	63.203	67.112	72.408	85.852	73.14
F ($\theta_i = 0$)	2.673	2.667	2.906	3.315	3.03
RMSE	0.634	0.591	0.630	0.622	0.627
#Obs	214	214	214	214	214

Note that including the lagged dep. var. decreases the number of maximum observations by the number of available groups (N = 25) from 239 to 214. The LSDVC standard errors in regressions (1)-(5) have been bootstrapped based on 300 iterations with bias correction up to order O(1/T) initialized by the Arellano and Bond estimator (Arellano & Bond, 1991). There are no standard post-estimation routines available in STATA for the user written "xtlsdvc" command (Bruno, 2005b). Therefore, the R^2 within, the *F*-statistics and *RMSE* have been provided on the basis of corresponding LSDV regressions with a lagged dependent variable. We do not include time effects which are jointly insignificant in all regressions and we do not include a constant which is eliminated by the within transformation. *t*-statistics in parentheses.

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

Figure 2 reports the marginal effects of the unbundling price for various levels of the unbundling market share and two groups of European countries on the basis of the estimates in regression (2) (left panel with EU25) and regression (5) (right panel with EU10). Whereas the marginal effect of the unbundling price is positive and significant at the 5% level for all values of the unbundling market share (ms_llu_{max} = 0.677) for the group of the EU25, it is insignificant in the group of Eastern European countries throughout (see horizontal reference line at 0). The vertical lines indicate the respective group means ("long dash" for EU10 at *ms_llu* = 0.016 and EU15 at *ms_llu* = 0.157) and the grand mean ("short dash" for EU25 at *ms_llu* = 0.106). From the left panel we infer that an increase of the unbundling price by 1€ (i.e., about 10%) increases NGN adoption by about 1.5% and about 2.3% when evaluated at the grand mean and old EU15 group mean, respectively.

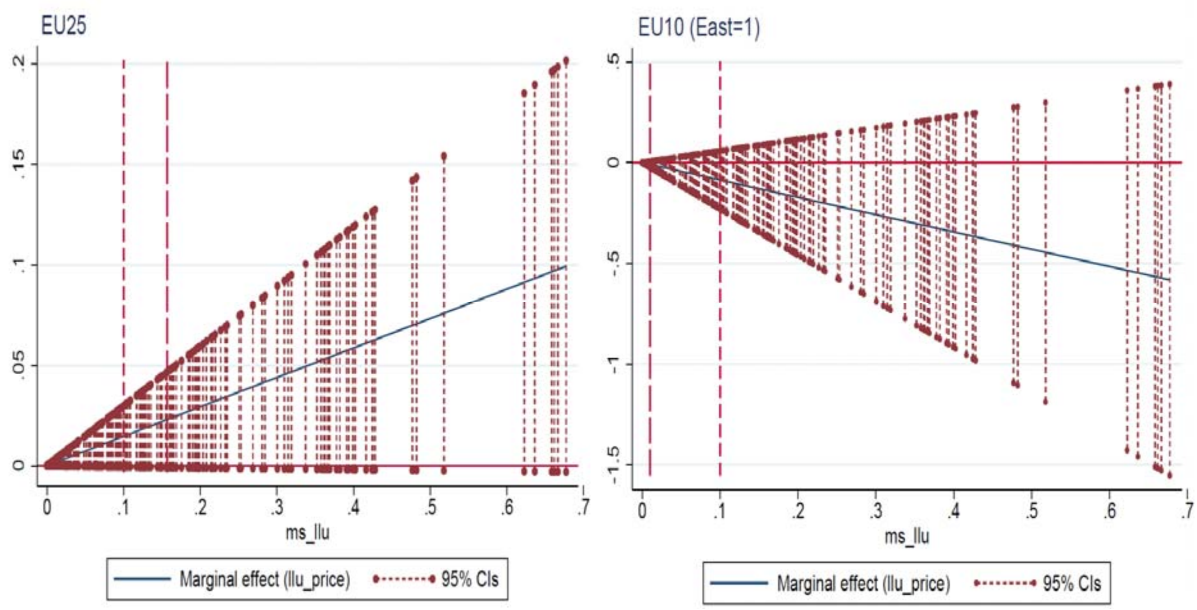

Figure 2: Marginal effects of the unbundling price (EU25 left panel, EU10 right panel)

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. Only a very few studies employ retail tariff data to estimate various own-price and cross-price elasticities of demand. Srinuan, Srinuan and Bohlin (2012) have developed an empirical investigation to analyze direct and cross-price elasticities among different types of broadband access technologies (xDSL, cable, fibre, mobile broadband). Data was obtained from a random nationwide 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 retail DSL price, is 3.289. A recent study by Grzybowski, Nitsche, Verboven and Wiethaus (2014) 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 retail 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. Our coefficient estimates which are based on a more extensive EU sample point to a lower cross price effect (0.15-0.23%), but they are in line with previous studies as they also point out the presence of a business migration effect from the access price of the old technology to the adoption of the new NGN services. The lower magnitudes of our estimates are plausible as well, as we estimate the indirect cross-price effect derived from wholesale access prices.

As far as the *competition variables* are concerned, there is no evidence for a non-linear U-shape type relationship according to regressions (1)-(2). The linear terms in regressions (3)-(4), however, point to a negative impact of intramodal and intermodal competition on NGN adoption. To the extent that these competition variables capture market outcomes in terms of retail prices, the negative relationships can be seen as further direct evidence of the business migration effect. However, the results could also be driven by the indirect impact of competition on investment (NGN coverage), suggesting that the Schumpeterian effect dominates the escape competition effect (Schmutzler and Sacco, 2011). Similarly, competition stemming from the old network (*legacy*) exerts a significantly negative impact on

NGN adoption in all regression specifications. This indicates that a well-established network and technology exerts a substantial replacement effect on the side of network operators.

As regards our *further controls*, 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. In contrast, it can be inferred that adoption of old broadband services, *bb_lines_adop*, counteracts this effect. Indeed, in the case in which old broadband services enjoy broad consumer acceptance, the switching costs might be substantial and hinder consumer migration to NGN services.[17]

Table 2 shows additional estimations in order to examine the robustness of our previous estimation results of the NGN adoption model. In regression (1) we first show that the results are robust if we drop insignificant cost controls which only exert an indirect impact on NGN adoption. In regressions (2)-(3) we re-estimate regression (1) using different specifications of the dependent variable. In regression (2) we normalize NGN adoption with respect to the total population (instead of households) of a member state (*ln(NGN_adop_pw)*), whereas in regression (3) we define the dependent variable as the log of adopted NGN lines (*ln(NGN_adop)*) without any population or household weighting (*ln(NGN_adop_uw)*). Apparently, the main estimation results remain robust as regards a reduced set of controls and different measurements of our dependent variable. Regressions (2)-(3) also support our finding of countervailing effects of the unbundling price once we control for Eastern European countries (*East* = 1).

Regressions (4)-(5) in Table 2 show the two-stage least squares (2SLS) fixed effects estimation results for the specification in regression (1) except for the insignificant main term *llu_price* which is omitted for the reasons explained above. As described in section 5.2, the

[17] The reader is referred to Briglauer (2014) for NGN related empirical evidence and to Fontana (2008) for a more general discussion of switching costs related to an incumbent technology and a new one.

unbundling price variables, *llu_price* and *i_price_llu_sh*, can be instrumented with the price of shared access products, *sa_price*, and the corresponding interaction term, denoted *i_sa_price_sh*, respectively. In order to be able to examine the validity of instruments we first add the squared term of the shared access price, *i_sa_price_sq_sh* in regression (4). In regression (5) we further add our second source of exogenous variation that comes from the average EU level unbundling price in non-focal member states, *llu_euprice*. *F*-tests of excluded instruments from the respective first stage regressions confirm that the instruments are jointly highly significant. Furthermore, the Cragg-Donald Wald (*CDW*) *F* statistic shows that there is no evidence for weak identification. Similarly, the Kleibergen-Paap (*KP*) LM statistic clearly rejects the null hypothesis that the equation is underidentified. We also examine the validity of our instruments. Whereas the *p*-values related to Hansen´s *J* statistic suggest that all instruments are jointly valid, the *p*-values of difference-in-Sargan tests (*C*-statistic) also indicate that the additional instruments, *i_sa_price_sq_sh* and *llu_euprice*, are valid as subsets of instruments.

In all specifications of Table 2 the main estimation results carry over quite well although some coefficients are estimated less precisely in IV estimations. A robust version of the Durbin-Wu-Hausman (*DWH*) test indicates that the point estimates are qualitatively unaffected by 2SLS estimation and hence unbundling prices can be appropriately treated as exogenous. In this case, LSDV/LSDVC estimates are consistent and more efficient. Finally, note also that the coefficients of the lagged dependent variable in regressions (4)-(5) are now – albeit highly significant and positive – substantially lower than the corresponding coefficient estimates in Table 1. This is expected as the estimator in regression (4)-(5) cannot employ the same LSDVC bias-correction and thus ignores the "dynamic bias" (Grajek & Röller, 2011) which necessarily yields a downward biased LSDV estimate of the coefficient of the lagged dependent variable (Bond, 2002).

Table 2: Robustness results for NGN adoption model (Dep. vars.: *ln(NGN_adop)* in (1) and (4)-(5)); *ln(NGN_adop_pw)* in (2); *ln(NGN_adop_uw)* in (3))

Regr. nr.:	**(1) adop_controls**	**(2) adop_pw**	**(3) adop_uw**	**(4) adop_IV_1**	**(5) adop_IV_2**
Lag: ln(NGN_adop)	0.676***	0.732***	0.728***	0.593***	0.593***
	(12.80)	(12.64)	(12.03)	(8.97)	(8.96)
Lag: llu_price	-0.028	-0.033	-0.032		
	(-0.90)	(-1.08)	(-1.06)		
Lag: i_price_llu_sh	0.143**	0.165**	0.165**	0.141*	0.140*
	(2.03)	(2.11)	(2.14)	(1.93)	(1.92)
Lag: i_price_llu_sh_East		-1.022*	-1.023*		
		(-1.85)	(-1.86)		
Lag: fms	-0.185*	-0.185*	-0.186*	-0.151**	-0.151**
	(-1.88)	(-1.92)	(-1.94)	(-2.09)	(-2.10)
Lag: bb_ne	-1.941*	-1.259	-1.266	-2.180**	-2.177**
	(-1.69)	(-1.07)	(-1.08)	(-2.16)	(-2.16)
Lag: legacy	-0.049**	-0.049**	-0.050**	-0.049***	-0.049***
	(-2.32)	(-2.47)	(-2.52)	(-3.20)	(-3.21)
Lag: ln(bb_lines)	1.179**	1.129**	1.120**	1.256***	1.255***
	(2.53)	(2.41)	(2.42)	(4.39)	(4.38)
Lag: adop_bb_lines	-2.886**	-3.133**	-3.116**	-2.304**	-2.301**
	(-2.17)	(-2.20)	(-2.20)	(-2.15)	(-2.15)
Lag: edu	0.047	0.044	0.044	0.064**	0.063**
	(1.52)	(1.20)	(1.22)	(2.20)	(2.20)
Lag: nri	0.282	0.347	0.358	0.337	0.337
	(1.01)	(1.06)	(1.10)	(1.32)	(1.32)
Lag: gdp	-0.000	-0.000	-0.000	-0.000	-0.000
	(-0.61)	(-1.20)	(-1.13)	(-0.38)	(-0.38)
Lag: urban_pop	0.235**	0.228**	0.231**	0.228**	0.228**
	(2.18)	(2.10)	(2.15)	(2.44)	(2.44)
	p-value (H_0: $\beta_1 llu\_price+\beta_2 i\_price\_llu\_sh = 0$)				
	0.096	0.096	0.089		
R^2(*within*)	0.714	0.718	0.720	0.861	0.861
F	46.107	43.103	43.397	68.198	68.220
F ($\theta_i = 0$)	11.037	11.565	11.366	2.481	3.14
F(excl. instruments)				206.05	157.42
DWH (p-value)				0.453	0.5676
CDW				272.146	204.058
KP				14.093	14.304
Hansen J statistic (p-value)				0.3127	0.4602
C statistic (p-value) (i_sa_price_sq_sh)				0.1431	
C statistic (p-value) (llu_euprice)					0.248
#Obs	214	214	214	214	214

The LSDVC standard errors in regressions (1)-(3) have been bootstrapped based on 300 iterations with bias correction up to order O(1/T) initialized by the Arellano and Bond estimator (Arellano & Bond, 1991). Note that there are no standard post-estimation routines available in STATA for the user written "xtlsdvc" command (Bruno, 2005b). Therefore, the R^2 within and the *F*-statistics have been provided on the basis of corresponding LSDV regressions with a lagged dependent variable. Estimates in regressions (4)-(5) are based on the 2SLS estimator and robust to arbitrary forms of heteroscedasticity and serial correlation. All regressions include country fixed effects but we exclude time effects which are jointly insignificant. *t*-statistics in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6.2 The NGN take-up rate model

As described in Section 5, the NGN take-up rate relates NGN adoption to NGN coverage. This index is important for three reasons: first, it is a relevant indicator of the willingness of consumers to migrate to a new technology; second, it is a measure of capacity utilization; third, it is a key policy variable implicitly defined by the DAE targets of the EC (as well as in other jurisdictions outside the EU).

The main results of the static NGN take-up rate model are reported in Table 3 and are robust towards different specifications of the regulatory variable, selections of controls and the sample size. The F-test ($F(\theta_i = 0)$, 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.[18] 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); not reported in Table 3). This test is robust to conditional heteroscedasticity, which is present in the take-up rate model specifications. Utilizing the Cochrane-Orcutt method, two-way fixed-effects regressions that are consistent in the presence of AR(1) disturbances have been employed in regressions (1)-(5).

The results reported in Section 6.1 showed that NGN adoption is positively affected by an increase in the access price to the old networks. From the previous empirical literature we know that this also holds for NGN coverage. In particular, the coefficient estimate of the unbundling interaction term (0.3112) in Briglauer (2015) based on a comparable LSDVC regression clearly exceeds the respective point estimates of our NGN adoption models. Putting these results together, the comparatively stronger effect on NGN coverage suggests a

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

negative impact of the unbundling price on the take-up rate. Indeed, our estimation results show that an increase in the local loop unbundling price, *llu_price*, has a significantly negative impact on the NGN take-up rate in regressions (1)-(5). As the effect is now captured by the main term, we can ignore the insignificant interaction terms which we drop in regressions (2)-(5). The effect, though weak, is significant and constant across all specifications. Accordingly, an increase in the unbundling price by 1€, decreases the NGN take-up rate by around 1 percentage point. In turn, decreasing *llu price* would positively affect the take-up rate but at the expense of lowering both adoption and coverage. Hence, in order to increase adoption and coverage as well as take-up, it appears that additional policies – next to increasing the unbundling price – are needed to promote demand expansion and take-up.

In line with our previous results, when controlling for the presence of Eastern countries (*East* = 1 in regression (5)) the combined marginal effect (H_0: $\beta_1^a llu\_price + \beta_3^a i\_llu\_price\_East = 0$) is negative and insignificant (*p*-value = 0.188), which suggests 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 competition does. The more intense the intermodal competition is, the lower the NGN take-up rate; this effect is also non-linear, as suggested by all model specifications in regressions (1)-(5). The corresponding coefficients on the *fms* and fms^2 variables, however, show that the combined marginal effect on NGN adoption is positive and significant (*p*-value = 0.08 in regression (1)). Moreover, the optimal level of competition intensity (*fms** about 6.1) is well above the grand mean value (Table A.2: fms_{gm} about 3.37). Whereas the impact of *fms* on NGN adoption was negative, it exerts a positive impact on NGN take-up on average. This suggests that the investment diminishing Schumpeterian effect dominates the business migration effect, the latter being also captured by the unbundling price.

Table 3: Results for NGN take-up rate equation (Dep. var.: *NGN_tur*)

Regr. nr.:	**(1)** **tur_base**	**(2)** **tur_ull**	**(3)** **tur_controls**	**(4)** **tur_base_full**	**(5)** **tur_East**
Lag: llu_price	-0.011*	-0.011**	-0.012**	-0.017***	-0.011*
	(-1.93)	(-1.99)	(-2.16)	(-3.19)	(-1.80)
Lag: i_price_llu_sh	-0.005				
	(-0.46)				
Lag: i_llu_price_East					0.000
					(0.04)
Lag: fms	0.122*	0.121*	0.121*	0.152**	0.152**
	(1.80)	(1.78)	(1.80)	(2.06)	(2.06)
Lag: fms^2	-0.010**	-0.010**	-0.010**	-0.011**	-0.011**
	(-2.24)	(-2.21)	(-2.23)	(-2.28)	(-2.28)
Lag: bb_ne	-0.992	-1.010	-0.868	-0.310	-0.310
	(-1.27)	(-1.31)	(-1.16)	(-0.49)	(-0.49)
Lag: bb_ne^2	1.270	1.272	1.086	0.356	0.356
	(1.59)	(1.60)	(1.41)	(0.53)	(0.53)
Lag: legacy	0.006	0.006	0.004	0.004	0.004
	(1.21)	(1.17)	(0.90)	(0.74)	(0.74)
Lag: gdp	0.000	0.000	-0.000	-0.000	-0.000
	(0.60)	(0.56)	(-0.05)	(-0.03)	(-0.03)
Lag: lt_ir	-0.000	-0.000			
	(-0.06)	(-0.04)			
Lag: ln(bb_lines)	0.157	0.154	0.097	-0.051	0.101
	(1.20)	(1.18)	(0.93)	(-0.49)	(0.94)
Lag: adop_bb_lines	-0.217	-0.202			
	(-0.70)	(-0.65)			
Lag: edu	-0.000	-0.000			
	(-1.11)	(-1.07)			
Lag: nri	0.103	0.104	0.096	0.039	0.097
	(1.49)	(1.51)	(1.40)	(0.52)	(1.42)
Lag: labcost_con	0.000	0.000			
	(0.20)	(0.23)			
Lag: urban_pop	0.034	0.033	0.042*	0.006	0.042*
	(1.28)	(1.25)	(1.69)	(0.19)	(1.67)
Lag: wage	0.036**	0.034**	0.027*	0.028	0.027*
	(2.16)	(2.09)	(1.79)	(1.53)	(1.82)
Constant	-1.170***	-1.138***	-1.041***	-0.358	-1.044***
	(-3.47)	(-3.42)	(-3.28)	(-0.28)	(-3.04)
Year dummies	YES	YES	YES	YES	YES
R^2 *(within)*	0.251	0.248	0.236	0.181	0.241
F	1.919	1.974	2.265	1.834	2.208
$F\ (\theta_i = 0)$	2.595	2.542	2.671	1.487	2.753
RMSE	0.073	0.073	0.073	0.084	0.073
#Obs.	200	200	200	214	200

Note that panel-by-panel Cochrane-Orcutt method decreases the number of maximum observations by the number of available groups ($N = 25$) from 225 to 200. In addition, values of the NGN take-up rate ≥ 0.75 have been dropped, as pointed out in section 5 in regressions (1)-(3) and (5). Regression (4) contains results for the unrestricted "full" sample. All regressions include country fixed effects and time effects which are highly significant in regressions (1)-(5). Standard errors in regressions (1)-(5) are robust to arbitrary forms of heteroscedasticity and serial correlation. *t*-statistics in parentheses.
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

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 take-up rate in next generation broadband technology. In particular, the focus of the paper has been on the potential role of the unbundling access price which is imposed directly by NRAs on the old broadband networks and acts as a key policy variable to speed up investment and the adoption of new fiber-based broadband connections.

Our analysis exhibits several policy relevant implications: Results first show that NGN adoption is 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 unbundling access price regulation could affect NGN adoption via a business migration effect. The data show that, in countries where the extent unbundling regime is relevant, relaxing the unbundling regulation, i.e. allowing an increase in access prices for the old legacy networks, could help to support a demand expansion by reducing 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 networks are much less developed. Furthermore, the effect of an increase in the unbundling 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, an increase in unbundling prices could also generate extra-capacity without enhancing sufficient demand for new fiber-based services, 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.

It is important to stress that, in order to achieve the mid-term adoption DAE goal, 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 in the mid-term development of content and applications will automatically evolve after the necessary network technology 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. In this context, future research should provide further theoretical and empirical assessments of the welfare implications of defining public policy targets related to NGN such as those embedded in the Commission´s DAE.

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Annex

Tables A.1, A.2 and Figure A.1.

Table A.1: Description of the variables and sources

Variable	Description	Source
	Dependent variables	
NGN adoption *NGN_adop* (household weighted) *NGN_adop_pw* (population weighted) *NGN_adop_uw* (unweighted)	Total number of subscribers in terms of "homes connected" by FTTx technologies (*Fibre-to-the-home; Fibre-to-the-building; Fibre-to-the-curb; Fibre-to-the-last amplifier/DOCSIS 3.0*) normalized to each country's total number of households/population ("_pw") or unweighted ("_uw"). "Subscribers" refers to premises under a commercial contract. "Premises" is a home or place of business.	FTTH Council Europe[a)]
NGN take-up rate *NGN_tur*	Ratio between NGN adoption and NGN coverage. NGN coverage is defined as the total number of homes passed by FTTx technologies. "Homes passed" refers to the total number of premises.	FTTH Council Europe
	Main independent variables and instruments	
Average total cost of the full LLU *llu_price*	Monthly average total price for the full local loop unbundling (LLU) access in €.	EU DAE Score-board[b)]
LLU interaction *i_price_llu_sh*	Unbundling price (*llu_price)* multiplied by the share of unbundled local loop lines (*ms_llu*) to total retail broadband lines.	EU DAE Scoreboard
Average cost of shared access, *sa_price* (instrument)	Monthly average total cost of shared access (*sa_price*) in €.	EU DAE Scoreboard
sa interaction *i_price_sa_sh* (instrument)	Shared access price (*sa_price)* multiplied by the share of shared access lines to total retail broadband lines.	EU DAE Scoreboard
Average EU LLU price *llu_euprice* (instrument)	Average yearly unbundling price in non-focal EU member states calculated as: (EU aggregate unbundling price – unbundling price in member state *i*) /(*n* - 1)).	EU DAE Scoreboard
	Competition control variables	
Entrant's market share *bb_ne*	New entrant's retail market share in fixed broadband lines based on wholesale access regulations (incl. unbundling operators) and own networks (incl. cable TV operators).	EU DAE Scoreboard
Mobile-to-fixed ratio *fms*	Ratio of Mobile Lines to Fixed Lines (Absolute).	Market-Line[c)]
Fixed legacy *legacy*	Total number of active fixed telecommunications landlines per 100 inhabitants. An active line connects the subscriber's terminal equipment to the public switched telephone network lines (analogue and ISDN channels).	ITU[d)]

Table A.1 ctd.

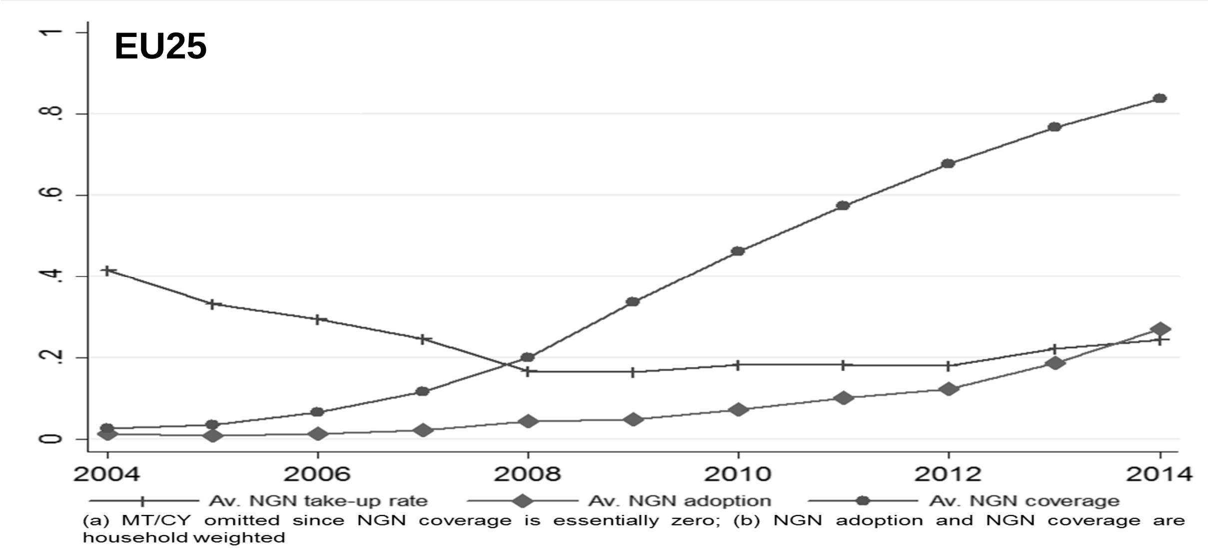
	Demand control variables	
broadband lines *bb_lines*	Number of total retail broadband connections based on DSL and coax cable that enable a higher than 144 Kbit/s download speed but exclude FTTx technologies.	EU DAE Scoreboard
Broadband adoption *adop_bb_lines*	Number of total broadband connections adopted by consumers divided by total population.	EU DAE Scoreboard
Networked Readiness Index *nri*	Propensity of a country to exploit the opportunities offered by information and communication technology (ICT).	Euro-monitor[e)]
Education *edu*	Percentage of population having attained secondary or higher education, for the population aged 25 to 64 years.	Eurostat[f)]
	Macroeconomic control variables	
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[g)]
GDP per capita *gdp*	GDP per capita (total) and PPP adjusted to same-year US$.	World Bank[h)] Euromonitor (population)
	Cost control variables	
Hourly wage *wage*	Manufacturing wage per hour in € and same-year prices with fixed 2012 exchange rates.	Euromonitor
Labour cost construct *labcost_con*	Annual labour cost index for the Construction branch by NACE Rev. 2 normalized to 100 in 2008. The index measures the development of the total cost, on an hourly basis, for employing the labor force, including wages and salaries, social security contributions, taxes, excluding subsidies.	Eurostat
Urban population *urban_pop*	Population of a country that lives in an urban environment as a share of the total population.	MarketLine

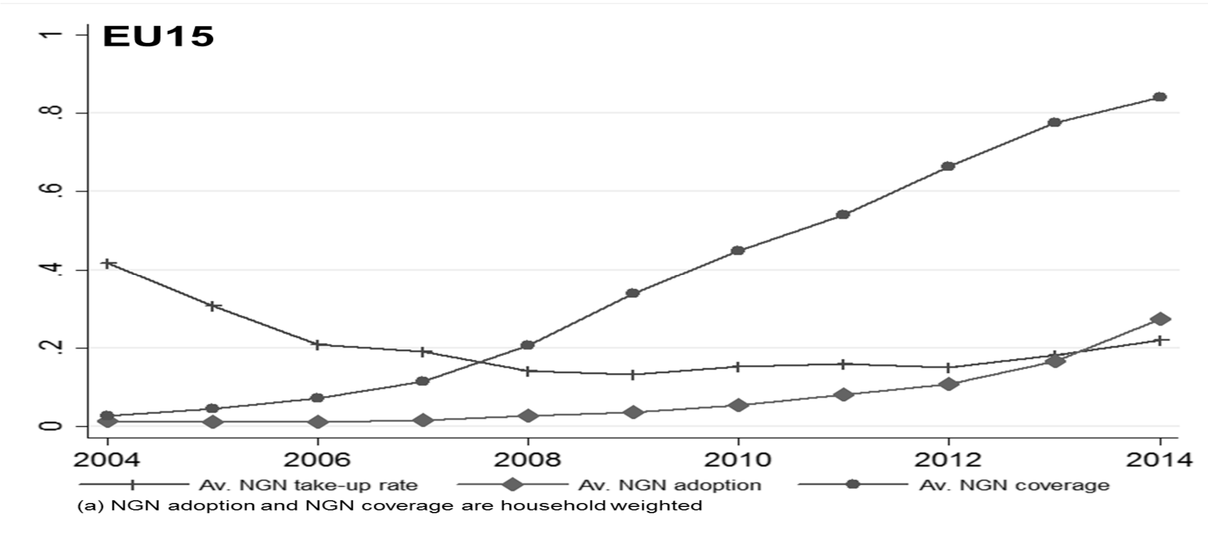
Notes: [a)]These data are available to FTTH Council Europe members at: http://www.ftthcouncil.eu/resources?category_id=6 [b)]Data is publicly available at: http://ec.europa.eu/information_society/policy/ecomm/library/communications_reports/index_en.ht. [c)]Data are commercially available at: http://advantage.marketline.com/PageForbidden?returnUrl=%2F. [d)]Data are publically available at: http://www.itu.int/ITU-D/ict/statistics/. [e)]Data are commercially available at: http://www.euromonitor.com/. [f)]Data are publically available at: http://ec.europa.eu/eurostat/de/data/database. [g)]Data are publically available at: https://www.ecb.europa.eu/stats/html/index.en.html. [h)]Data are publically available at: http://data.worldbank.org.

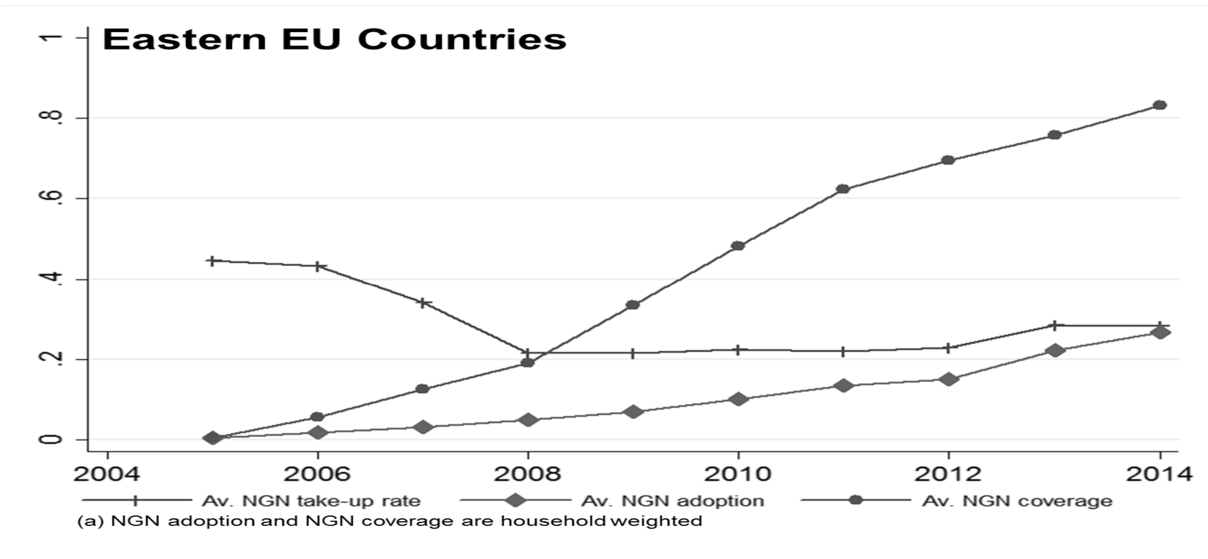
Table A.2: Summary statistics

Variable	Obs	Mean	Std. Dev.	Min	Max
NGN_cov	296	.3830631	.4678066	0	2.306572
NGN_adop	296	.0730204	.1090571	0	.5471706
NGN_adop_pw	296	.0314706	.0471296	0	.2401171
NGN_adop_uw	296	431186.6	946565.3	0	7687000
ln(NGN_adop)	240	-3.705415	2.194935	-12.47299	-.6029947
NGN_tur	226	.2199841	.1641123	.0000517	.7222222
llu_price	266	11.45305	4.303125	5.28	42
i_price_llu_sh	266	1.137547	1.5134	0	7.070189
i_price_llu_sh_East	266	.0550533	.2040729	0	1.379083
i_llu_price_East	266	3.93312	6.134875	0	42
sa_price	266	5.397406	3.431645	.74	23.89
i_sa_price_sh	266	.4916556	.7002106	0	3.785667
i_sa_price_sq_sh	266	2.718223	5.468133	0	53.52725
ms_llu	266	.1064223	.1461762	0	.6772212
llu_euprice	266	11.45305	2.783358	8.828846	19.59542
fms	270	3.371881	1.667801	1.2819	10.9396
bb_ne	267	.501393	.1558175	0	1
legacy	270	40.41304	13.08719	13.86	66.38055
ln(bb_lines)	267	14.00171	1.680992	9.527921	17.1463
bb_lines_adop	267	.4564225	.220693	.0069897	.9247583
edu	270	73.53926	16.01936	23.6	93.4
nri	270	4.578519	.6294371	3.2	6
gdp	270	30200.01	13641.82	8730.8	90789.65
lt_ir	296	4.50125	2.227483	.22	22.5
labcost_con	270	97.18	15.21722	39.8	140.6
urban_pop	270	.7243043	.1189043	.494118	.974945
wage	270	11.05556	7.861194	.8	38.7

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







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